Bose-Einstein condensate on a chip

After the creation of Bose-Einstein condensates (BECs) six years ago, scientists realized that all the components used to generate them could be miniaturized onto a single chip. A German team at Ludwig Maximilians University (Munich, Germany) has succeeded in doing just that. The work clears the way for practical applications of the condensates, such as extremely sensitive measurements of gravitational fields for geological purposes (*Nature* **2001**, *413*, 498).

Ludwig Maximilians University, Munich, Germany, Physics Department

In this computer graphic of a microchip upside down in an ultrahigh-vacuum glass cell, the BEC is produced on the left, transported to the right, and released into free-fall, showing the characteristic spherical cloud of atoms (blue) with a dense elliptic center (red and yellow).

BECs are the material equivalent of laser beams—a quantum-mechanical coherent state of many atoms (see *The Industrial Physicist*, December 2001/January **2002**, pp. 12–13). Like any quantum-mechanical phenomenon, the condensates tend to be easier to study on the microscopic scale, and the German team made use of this fact in creating the BEC-on-a-chip. For one thing, the strong magnetic gradients needed to trap the atoms could be generated with a current of 3 A carried through a 50-μm-wide conductor, which creates a magnetic gradient of 7,300 G/cm. The high gradient and high curvature of the magnetic field, about 4×10^7 G/cm^2, lead to a high natural oscillation frequency for the atoms in the trap. This, in turn, helps compress the atomic cloud and produce fast atomic collisions. When combined with a radio-frequency sweep that expels the highest-energy atoms from the cloud, the result is a rapid cooling, down to the nanokelvin temperatures required for a BEC. The BEC chip achieved the needed cooling in only 0.7 s, about one-third of the time required by macroscopic BEC devices.

The chip is mounted in a tiny vacuum chamber, which rapidly achieves a pressure of 10^{-12} atm, and receives rubidium atoms that are then laser-cooled before entering the magnet trap, where they are cooled further by evaporation. The elongated trap that is created, which contains just 3,000 atoms, has interesting properties of its own. Inside the trap, the wavefunctions of the atoms overlap with their immediate neighbors but do not extend over the whole length of the condensate, a situation of interest to many researchers for theoretical reasons.

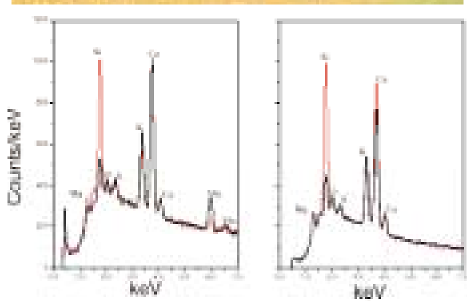
On a more practical level, the BEC-on-a-chip and its compact vacuum system bring technological applications much nearer. An interferometer made from such a device could measure tiny changes in gravitational fields, such as those created by subterranean ore or petroleum masses. Although a few months ago such an application seemed six or seven years off, "we think this is probably no more than a year away now," says J. Reichel, one of the researchers. "There are still two problems, however. Noise from the current sources may destroy the coherence of the condensate, and small stray magnetic fields can create spurious signals. So they both must be suppressed." The team is already working on an interferometer and developing a BEC-based detector of single atoms using the same interferometric approach. Ω

Pyroelectric-crystal X-rays

J. D. Brownridge, a physicist at the State University of New York at Binghamton, says "sometimes nature is trying to tell us something, but we are just not listening." Fortunately, Brownridge was listening several years ago when he noticed an unexplained background noise in an X-ray detector he was developing. His curiosity led him to the discovery that focused beams of electrons are produced by heating and cooling pyroelectric crystals in a vacuum (*Appl. Phys. Lett.* **2001**, *79*, 3364). The resulting compact and economical sources of electron beams and the X-rays they generate may find applications in instruments that until now required radioactive materials or expensive high-voltage equipment.

In earlier work, Brownridge had found that the source of the stray X-rays in his radiation detector was cesium nitrate crys-

State University of New York at Binghamton, Department of Physics



Leaves from adjacent sweet gum trees are irradiated with X-rays provided by a pyroelectric crystal, and the resulting spectra may be analyzed to determine and compare the presence of certain elements.

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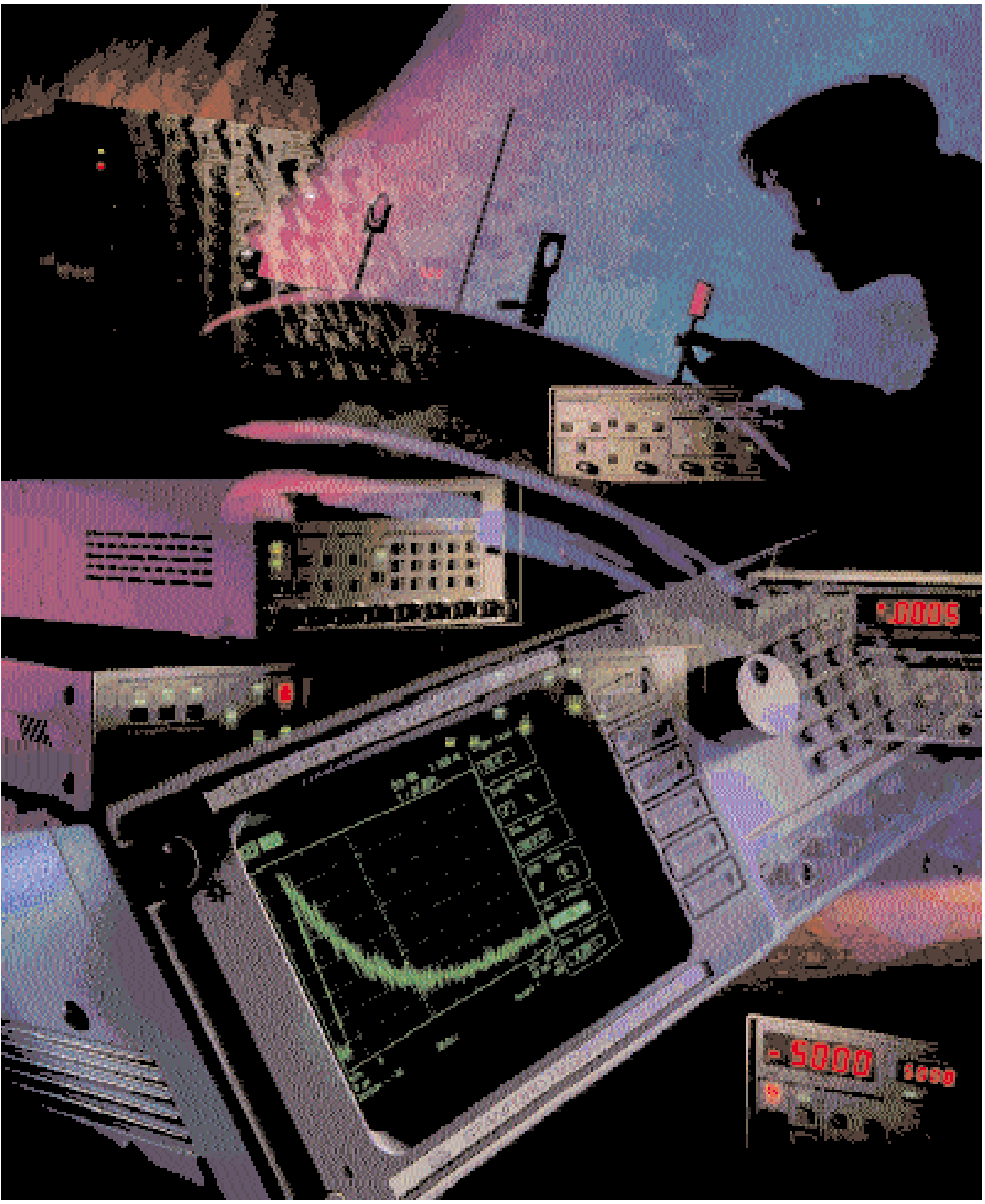

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tals. He determined that the X-rays came from electron beams accelerated from the surface of pyroelectric crystals, such as cesium nitrate, or in the current experiments, lithium niobate—pyroelectric crystals long known to generate an electric field as they are heated or cooled. Such crystals have an ion that is placed asymmetrically within a crystal lattice. As the crystal heats, the ions move into a more symmetrical position, and as it cools, the atoms assume a more asymmetrical form. If the crystal is cut perpendicular to the direction of asymmetry, a positive charge develops at one end of the crystal lattice and a negative charge at the other as the ions move in the crystal. The crystals' sensitivity to small amounts of heat has made them ideal infrared detectors, among their many applications.

Fields of up to a megavolt per centimeter near the ends of the crystals are sufficient to tear apart gas molecules that come close to the crystal. For example, on the negative end, ions from gases are attracted to the crystal while electrons are repelled. When the crystals cool in gas at atmospheric pressure, the charge on the crystals is rapidly neutralized by the charges of the gas ions. But Brownridge and his colleague, S. M. Shafroth of the University of North Carolina at Chapel Hill, showed that if the crystal is heated to 115 °C and then cooled to room temperature in a partial vacuum of a few millionths of an atmosphere, neutralization occurs much more slowly because of an inadequate number of gas ions. Instead, the electrons torn loose from the gas at the negative end are accelerated sharply away from the crystal, reaching energies of 170 keV. When such electrons strike a solid, they generate X-rays. At the positive end of the crystal, the gas ions are similarly accelerated to energies of 110 keV.

The beam contains a few millijoules of energy, and the greater the gas pressure, the more rapidly this energy is released and the higher the current. The better the vacuum, the lower the current and the longer the beam lasts.

Not only does the pyroelectric crystal accelerate the electrons, it also focuses them. "Because the electric field is stronger at the edges of the crystal, the field is somewhat tilted, creating a natural electric lens with a focal length in our experiments of about 2 cm,'' explains Brownridge.

The electron beams and X-rays produced by the pyroelectric crystal are sufficient for many instruments, especially those using X-ray fluorescence. "We are hoping that this can be developed as an economical alternative to the use of radioactive sources in schools and elsewhere," says Brownridge. Ω

Building enzymes, filters

As artificial structures get smaller, the methods of chemistry and physics are converging on the molecular scale. In an example of that process, a team of researchers at Northwestern University's department of chemistry has succeeded in building artificial enzymes and highly selective filters from square molecular building blocks (*Angew. Chem., Int. Ed.* 2001, *40*, 4239–4243). "We have created a way of building molecules designed for a specific task from the bottom up, starting from a molecular square matrix," explains Son Binh Nguyen, one of the researchers. Potentially, the process the team devised could lead to a modular-design approach—broadly similar to that already used in microcircuits—for building molecules to carry out specific chemical reactions.

Natural enzymes are proteins that are highly specific and potent catalysts. Each catalyzes only a single chemical reaction and can increase reaction rates millions of times. In contrast, most manmade catalysts accelerate many reactions but do not have anywhere near the effectiveness of enzymes. Often, catalysts wear out after catalyzing only a few dozen reactions rather than the millions of reactions an enzyme can catalyze in its lifetime.

Trying to modify existing enzymes for tasks such as industrial processing or med-

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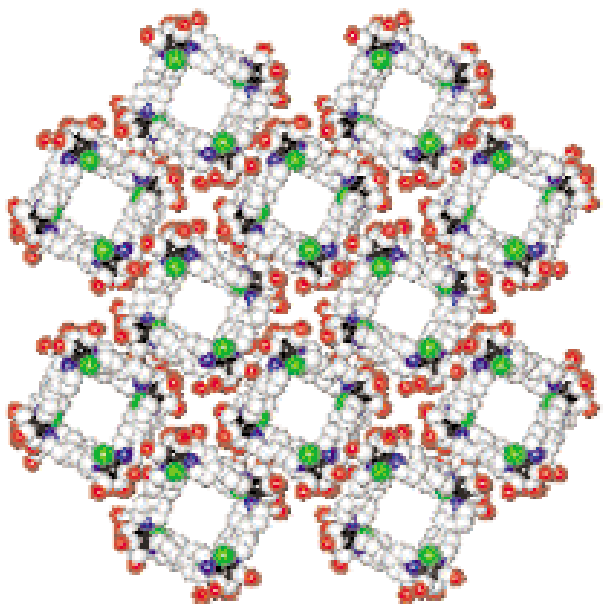

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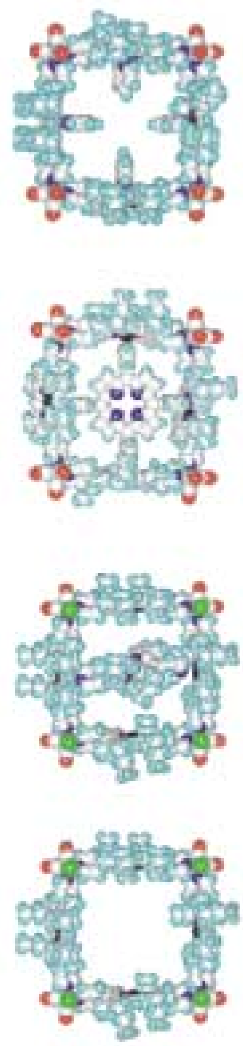

Crystal structure of an artificial enzyme with bipyridine edges and a square cavity (a); the size, shape, and chemical affinity of the cavities can be modified by axial binding to zinc or other metal sites embedded in the edges of the square (b).

Northwestern University, Department of Chemistry ical treatments is exceedingly difficult. Enzymes, being proteins, are generated as long strings of amino acids, which rapidly fold into the complex shapes needed for their function. This folding process is nearly impossible to predict accurately, and it takes huge chunks of supercomputer time to simulate the folding of simple enzymes. Instead, the Northwestern team—consisting of Melissa Merlau, Pilar Mejia, Nguyen, and Joseph Hupp—created a system of building artificial enzymes from various kinds of square molecules with cavities in their middle. The smallest squares have cavities of 3 Å on a side and edges of pyrazine; the largest have cavities of 18 Å on a side and porphyrin edges.

"We put the catalytic molecules inside these squares, just as a natural enzyme puts the catalytic center inside a much larger superstructure," explains Nguyen. The square structure acts as a filter, allowing only molecules of a specific size and shape to fit in and contact the center, thus greatly increasing the specificity of the catalysis. In addition, the superstructure protects the center, allowing it to react many times before degrading. By combining various catalytic centers with square superstructures of specific sizes, the team can build designer enzymes for specific reactions.

In addition, Hupp and Northwestern coworkers Randall Snurr and Ken Czaplewski (*Adv. Mat.* **2001**, *13*, 1895–1897) have found that when solutions of these structures are evaporated, the square molecules easily form thin crystalline films, molecular screens, or sieves, which can be used as selective filters. By inserting molecules into the square cavities, they are designing filters that, for example, can filter out left-handed or right-handed versions of a molecule, a necessity in drug manufacture. Combining the enzymes and the films, Northwestern scientists hope to eventually develop thin-film enzymes that can catalyze reactions at a high rate. Ω

Bird songs, human speech

Recognizing human speech and identifying people by their spoken words are not easy tasks for computers. There are no algorithms that can reliably recognize speech in a general context or identify a given speaker. Yet human infants and children not only learn these tasks, they also learn to reproduce speech at the same time. If science could understand how youngsters accomplish this learning process, that knowledge might supply the key to replicating the same capability in a computer.

Neither human infants and children nor dolphins and whales—the other mammals that learn complex vocal patterns—are ideal experimental subjects. So researchers have looked to songbirds, which also learn

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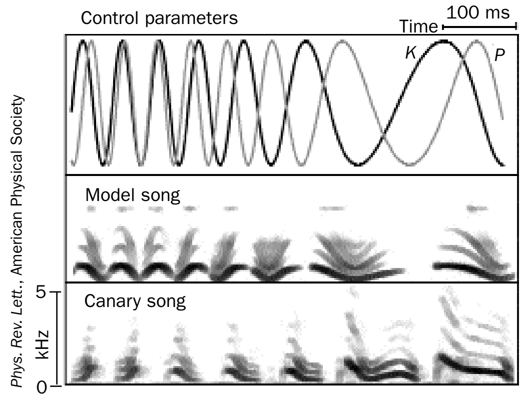


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Synthetic signals generated by slow modulation of only two variables—pressure *P* and tension *K*—were remarkably similar to complex natural canary song.

to recognize and reproduce vocal patterns, possibly by mechanisms similar to those used by humans. What may make this process possible, researchers have discovered, is the fact that bird songs can be described by a few physical parameters. Thus, it is possible that birds may have to learn to recognize and control only these few parameters.

Using physical models developed initially to understand the formation of human vowels, physicists at Rockefeller University (New York, NY) and the University of Buenos Aires in Argentina showed that the song syllables of canaries can be accurately described by coupled oscillations of just two parameters—the pressure supplied by the lungs and the elasticity of the lateral labia, the analogues of human vocal folds (*Phys. Rev. Lett.* **2001**, *87*, 208101-1). When the researchers applied these oscillations to the models in simulations, self-oscillations were set up that accurately reproduced canary songs. Each song syllable could be modeled by an elliptical path of change in pressure and elasticity, and just five numbers could describe each of these syllables.

"This implies that a bird's brain needs to exercise control only over these five parameters and recognize them in other songs," says G. Cecchi, one of the researchers, who is now at the IBM Thomas J. Watson Research Center (Yorktown Heights, NY).

"The fact that only simple neural patterns are needed to produce complex sounds could have implications for human speech production and recognition," points out Gabriel Mindlin, one of the University of Buenos Aires physicists. In related work, Mindlin and colleagues have shown that similar models with only a small number of parameters can model human vowels. "Fitting the parameters to speech waveforms is a very different approach from the spectral analysis currently used in speech-recognition algorithms," says Mindlin, and this process could be the key to understanding how human speech recognition and identification occur. Applying these fitting techniques might make computer speech recognition more accurate, although the researchers agree that far more work remains to be done. Ω

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