Laser and Magnetic Traps Create Bose-Einstein Condensate

Physicists at the University of Colorado—Boulder have achieved a temperature far lower than has been produced previously, creating a state of matter predicted decades ago by Albert Einstein and Satyendra Nath Bose.

Cooling rubidium atoms to less than 170 nanokelvins caused the individual atoms to condense into a "superatom" behaving as a single entity, said Eric Cornell and Carl Wieman of JILA, a joint program of the National Institute of Standards and Technology and the University of Colorado.

The team used laser and magnetic traps to create the Bose-Einstein condensate, a tiny ball of rubidium atoms which are as stationary as the laws of quantum mechanics permit. This ball is surrounded by a diffuse cloud of normal rubidium atoms. Made visible by a video camera, the condensate looks like the pit in a cherry except that it measures about 20 μm in diameter.

Beginning with a gas of room-temperature atoms, the JILA team first slowed the rubidium and captured it in a trap created by the light produced by diode lasers similar to ones used in compact disk players. The infrared lasers are aligned so that the atoms are bombarded by a steady stream of photons from all directions—front, back, left, right, up, and down. The wavelength of the photons is chosen so that they will interact only with atoms that are moving toward the photons.

This cools the atoms to about 10 microkelvins, still far too hot to produce Bose-Einstein condensation, and about 10 million of these cold atoms are captured in the light trap. Once the atoms are trapped, the lasers are turned off and the atoms are kept in place by a magnetic field. The atoms are further cooled in the magnetic trap by selecting the hottest atoms and kicking them out of the trap.

According to the team, the trickiest part was trapping a high enough density of atoms at a cold enough temperature. Cornell came up with an improvement to the standard magnetic trap—called a time-averaged orbiting potential trap—that was the final breakthrough which allowed them to reach the record-setting temperature.

Because the coldest atoms had a tendency to fall out of the center of the standard atom trap, Cornell designed a technique to move the funnel around. "It's like playing keep-away with the atoms because the hole kept circulating faster than the atoms could respond," Cornell said.

The 2,000 rubidium atoms in the condensate are in a strange condition, existing in a kind of smeared-out, overlapping stew, most of the properties of which are still a big unknown. The condensation is like an atomic counterpart to the laser because it puts a large number of atoms into the same quantum mechanical state, the scientists said. Lasers cause a large number of photons to have identical energy and direction.

The atoms within the condensate obey the laws of quantum physics and are fundamentally different from the normal atoms in the much less dense cloud surrounding it.

"I would expect a large number of people to replicate this work," Wieman said. "It will provide physicists with a new way of studying quantum effects on a large scale, similar to the threshold effects observed in superconductivity and superfluidity."

Results of the experiment were published in the July 14 issue of *Science*.

Metals Mined from Pond Sludge

Studies of pond sludge reveal that, if the material is heated and cooled, a variety of minerals in the mud can be mined with a magnet. The remaining material is crushed glass, which could be inexpensively disposed of in a landfill.

Alex Gabbard of Oak Ridge National Laboratory's (ORNL) Metals and Ceramics Division and Charles Malone of the Instrumentation and Controls Division conducted tests on surrogate sludge that contained a dozen nonradioactive metals and nonmetallic elements found in the actual sludge of ORNL's K-25 site. These elements include aluminum, copper, iron, nickel, silver, and sodium. The surrogate sludge did not contain uranium or other radioactive metals, which are present in the real material.

"Our tests showed that cooking the pond sludge in graphite containers in an electrical resistance furnace has several effects," Gabbard said. "The volume of the material is reduced by more than two-thirds. The material is transformed into glass, or vitrified, in the shape of the container. When the material is a heated liquid, some valuable metals—mainly, iron, nickel, and copper—migrate to outer surfaces as 'gold spots' that can be easily separated magnetically from the rest of the material once it has hardened."

The researchers do not yet understand why iron, nickel, copper, and sulfur in the sludge form golden globules that are not strongly attached to the rest of the material. Scanning electron micrographs show that the numerous iron-nickel-copper globules that make the black glass sparkle are surrounded by a sulfur skin. Gabbard thinks this skin may keep the spherical globules from bonding with the molten mud as it solidifies.

The formation and separation of the globules, Gabbard said, are likely due to the oxygen-free conditions created by the treatment method. To dry the sludge, an oxygen scavenger was used to remove oxygen, and the sludge was heated to 2100°F (1150°C) in a nonoxidizing, helium atmosphere in the furnace. By contrast, *in situ* vitrification processes for turning radioactively contaminated soil into glass in tests at ORNL waste burial grounds add oxygen to the vitrified material.

The researchers also found that the best containers for the sludge were made of graphite, not ceramics. The ceramic containers became brittle and fractured during the heating process, but the graphite crucibles were not visibly affected and were reusable.

Gabbard said the researchers would like to test actual pond sludge samples containing uranium to see if it also precipitates out of the mud as magnetic "gold spots" along with the iron, copper, and nickel. In Gabbard's vision, if this technique actually could mine uranium from the mud, the uranium could be stored for potential use as fuel for nuclear power plants.

SBIR Updates

Advanced Refractory Technologies, Inc. (ART) (Buffalo, New York) and **Westinghouse Electric Corporation** (Cleveland, Ohio) are to use Phase II SBIR funding of approximately $600,000 from the Department of Defense for a two-year technical effort to study component development for improved pulse power batteries.

Essential Research, Inc. (Cleveland, Ohio) has been awarded a grant from the Ballistic Missile Defense Organization for $65,000. This Phase I award will fund research and development of a solar-driven, themo-photovoltaic (TPV) electric power generation system.

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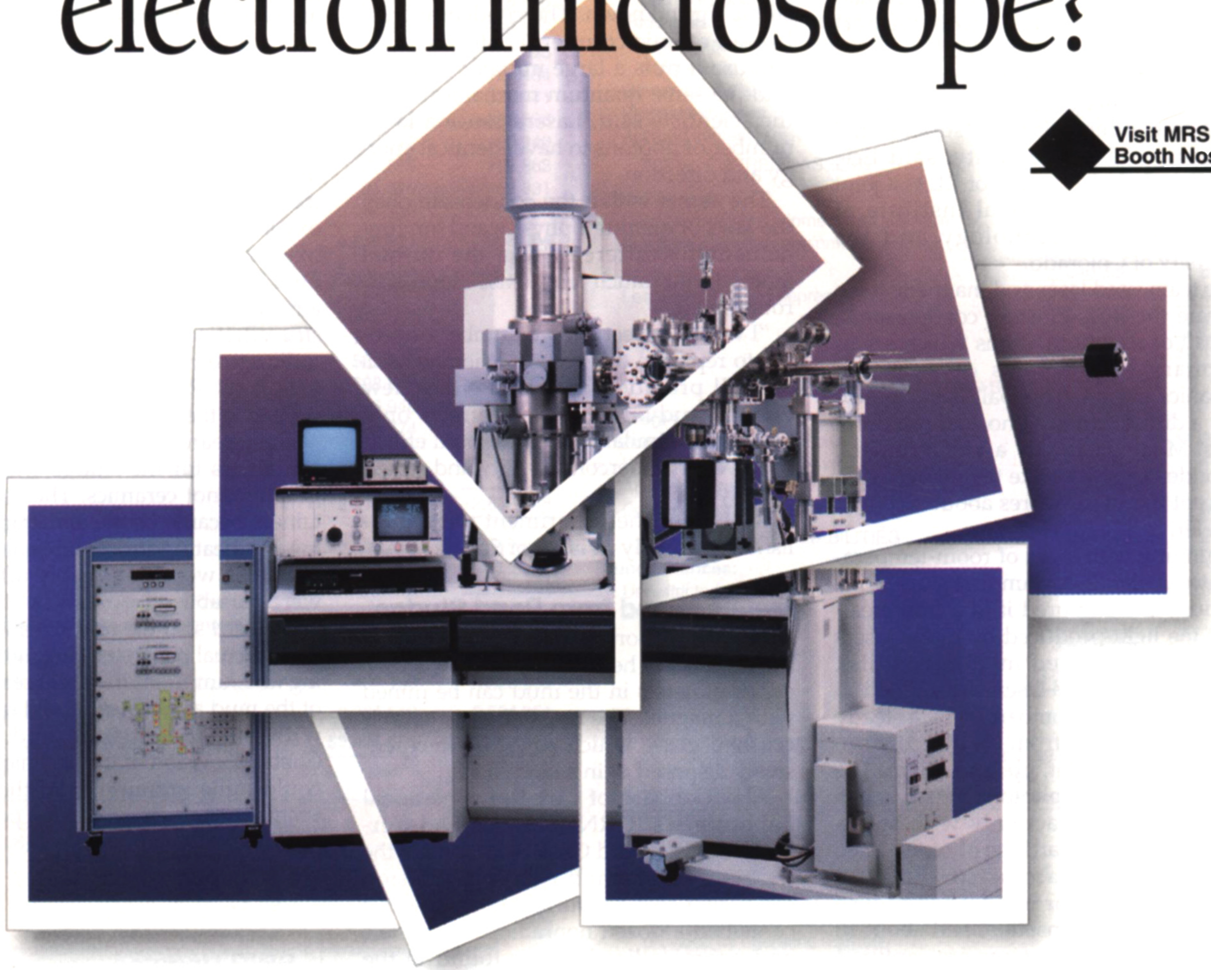

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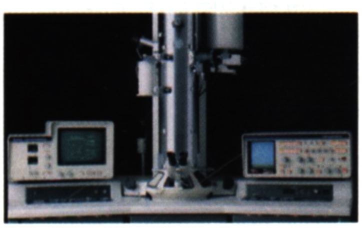

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Fuel Reformer Releases Hydrogen from Methanol

Researchers at Argonne National Laboratory have developed an on-board methanol reformer device that releases the hydrogen bound up in methanol. Because it is more compact than other reformers, it could enable fuel cells to power electric cars.

The reformer would combine methanol with oxygen from the air to produce a hydrogen-rich mixture of gases that would be injected into the fuel cell. The design consists of a cylinder packed with a common and inexpensive catalyst. A nozzle sprays liquid methanol into the cylinder, and an ignition source starts it.

In addition to hydrogen, the reformer produces carbon dioxide and carbon monoxide. A small on-board chemical reactor would convert the carbon monoxide into carbon dioxide.

According to Romesh Kumar of Argonne's chemical technology division, a major problem in using fuel cells to power electric cars is that they are fueled by hydrogen, a very light gas that is difficult to store. Currently available hydrogen-storage technologies are so heavy and bulky that they would limit the driving range of any car that used them.

"But an on-board reformer like ours," Kumar said, "could solve this problem by reforming methanol from the gas tank and feeding the hydrogen into a fuel cell."

The Argonne device takes up less volume than a seven-gallon container, Kumar said. This makes the fuel reformer small enough to fit under the hood of a compact car beside a 50-kilowatt polymer-electrolyte-membrane (PEM) fuel cell.

Electric Shock Technique Applied to Recycling

Scientists at the Karlsruhe Research Center in Germany and at the University of Tomsk in Russia are examining the use of electric shocks to separate materials and grind down concrete, glass, granite, or silicon. Initially, the waste is submerged in a liquid, which is subjected to a pulse from a 250-Kv impulse power system. Under this technique, approximately 100 kg of materials per hour are ground into fine powder. This process is less costly and less complicated than current recycling processes. The scientists expect to apply this process in the future to sterilize medical instruments and purify drinking water.

Modified from *The German Research Service* **11** (1995), p. 4.

12 Predoctoral Fellowships Named in Integrated Manufacturing

The National Research Council (NRC) has named 12 predoctoral fellows in integrated manufacturing following a nationwide competition sponsored by the Department of Energy (DOE).

The 1995 recipients and the institutions they will attend are **James Robert Bradley**, Stanford University; **Christopher Edward Couch**, Massachusetts Institute of Technology; **Stewart Lee Coulter**, Georgia

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Institute of Technology; **Ely Dahan**, Stanford University; **Jay Paul Daniel**, University of California—Berkeley; **Richard Joseph Jerz**, University of Iowa; **James Daniel Morrow**, Carnegie-Mellon University; **Edward Phillip Morse**, Cornell University; **Richard Joseph Russell II**, University of Southern California; **Glen M. Schmidt**, Stanford University; **Hooman Tajbakhsh**, University of Illinois at Urbana-Champaign; and **Richard Meredith Voyles**, Carnegie-Mellon University.

The program, initiated in 1993 with the advice and guidance of the National Academy of Engineering, emphasizes integrated systems of manufacturing—including, but not limited to, large-scale systems—and integration of product design with manufacturing processes.

Some of the 1995 award-winning research projects include investigating in-process sensors that can detect damage during fixed abrasive brittle materials machining; developing a practical method for assessing environmental impact to aid designers in comparison of feasible designs; understanding the errors and their propagation in machine tools and developing strategies for controlling them to an acceptable level; and using gesture-based programming, observation, and expertise encapsulation to create a robotic system that provides assembly feedback to designers, automatically assembles simple but interesting parts, and is programmed by demonstration.

Each award carries a stipend of $20,000 per year and an institutional cost-of-education allowance of up to $15,000 per year for three years of support.

A similar competition is planned for 1996. Further information can be obtained from the Fellowship Office at 2101 Constitution Avenue, N.W., Washington, D.C. 20418; (202) 334-2872 or e-mail infofell@nas.edu.Information and the application is also available on the World Wide Web at http://www.nas.edu/fo/index.html.

100-Trillion-Watt Laser Test Fired

A 100-terawatt high power, ultrashort pulse laser was successfully test fired inside Lawrence Livermore National Laboratory's Nova two-beam target area.

The laser produced 100 trillion watts of power in less than 0.5 picosecond, which is about 3,000 times shorter than a pulse from the Nova laser. In so doing, the 100 terawatt laser surpassed in power the combined total of Nova's 10 beams as well as the University of Rochester's 60-beam Omega laser.

The 100 terawatt laser will have applications in areas such as basic laser-plasma physics, x-ray lasers, and fast ignitor research while simultaneously serving as an engineering prototype for the petawatt.

The 100-terawatt laser is the result of the work of scientists to produce extremely short, high-power and high-intensity pulses. A desktop system today can produce pulses 1,000 times greater than was

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possible 10 years ago and achieve focused irradiance greater than 10^{18} W/cm^2.

"When you achieve focused irradiance on that scale, you cross a threshold in laser-matter physics," said Michael Perry, head of the Petawatt Laser Project. "That's because laser plasmas become relativistic at about 10^{18} W/cm^2 for 1 micron light." The 100-terawatt laser will be able to produce an irradiance in excess of 10^{20} W/cm^2.

The progress in high power short pulse lasers is attributable to several factors, including chirped pulse amplification, which permits a laser pulse to be stretched 10,000 times its length in time so that it can pass through laser optics without damaging them; broad bandwidth laser crystals that permit much shorter laser pulses than previously possible; the development of oscillators capable of producing pulses in the picosecond range; and diffraction gratings that can handle more laser power without sustaining damage as they compress the laser pulse to near its original duration following amplification.

The petawatt laser will produce 10–20 times the power of the 100 terawatt laser. The latter will be used over the next six months to test some of the basic concepts underlying the petawatt and serve as a test-bed for components of the laser, which will be retrofitted onto Nova's 10-beam chamber. Initial testing of the petawatt is slated for December.

UMR to Open Ferrous Metallurgy Grant Program

Beginning this fall, the University of Missouri—Rolla (UMR) will begin promoting the industry through the Ferrous Metallurgy Grant Program (FMGP), which is supported by the Iron and Steel Society Foundation. The program is funded through a three-year grant of $50,000 per year and targets both undergraduate and graduate students, but "is geared mainly to attract undergraduate students to manufacturing metallurgy areas," said Chris Ramsay, a UMR associate professor of metallurgical engineering. Ramsay is the 1995 Ferrous Metallurgy Grant Award recipient and director of the program at UMR.

Students participating in the program will work on research projects in UMR's metallurgical engineering department, take part in industrial conferences and get hands-on experience by working in steel mills during summer months.

As part of the program, Ramsay will direct research for graduate students in a project called "slag splashing," which teaches the technique used to coat the inside of basic oxygen furnaces to protect the refractory materials that line those furnaces to give them longer life.

The graduate students will also take part in projects dealing with ceramic coatings for cast iron and steel alloy tool steel molds, and producing cast premium-grade tool steel. "This process will provide a cast net shape that is more economical to build a mold from," Ramsay said.

According to Ramsay, the iron and steel industry is still not completely clean but is much more so than it was 30 years ago.

Also taking part in FMGP are The Ohio

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State University, University of Toronto, Colorado School of Mines, Carnegie-Mellon University, Queen's University, Michigan Technological University, and Illinois Institute of Technology.

Cells Encapsulated in Porous Ceramic Gels

Matech Advanced Materials, under the direction of Edward J.A. Pope, has developed a class of material known as "living ceramics" in which live cells, such as animal tissue cells, microorganisms, and plant cells, are encapsulated in a porous ceramic gel. The key advantage of encapsulation in Pope's proprietary gel matrix is immunoisolation, preventing the recipient's immune system from destroying the transplanted tissue. Pope began his research by encapsulating *saccharomyces cerevisiae* in suspended animation for one year, then reviving it. He is continuing his research in a collaborative project with Sansum Medical Research Foundation of Santa Barbara to develop sol-gel as treatment for diabetes.

Greenhouse Gas Chemically Trapped to Form Carbonate Minerals

Researchers at Los Alamos National Laboratory proposed a method to avert the greenhouse effect caused by the buildup of carbon dioxide produced by burning coal and oil. Klaus Lackner of the Fluid Dynamics Group proposed locking up carbon dioxide by combining it chemically with abundant raw materials to form stable carbonate minerals.

Minerals containing substantial amounts of magnesium oxide or calcium oxide react with carbon dioxide, forming limestone, dolomite, or magnesite. These minerals pick up carbon dioxide from the atmosphere at room temperature, but at rates measured in geologic time. However, it is possible to speed up these natural reactions to the point where carbon dioxide can be captured at the same rate that it is generated in the burning of fossil fuels, Lackner said.

In a paper to appear in *Energy, the International Journal*, Lackner said two of the most promising materials, peridotites and serpentinites, could be processed either through direct carbonation at high temperatures or through a standard aqueous chemical process.

At higher temperatures, the carbonation reaction accelerates. Each mineral has an optimum carbonation point. Carbon dioxide piped from a coal-burning power plant could be pumped into pulverized, heated rock. The result would be a stable carbonate from which the carbon dioxide could not escape.

Lackner said the energy released in the carbonation process could be used to heat the rock to the process temperature. It may even be possible, he said, to pump the carbon dioxide directly into an underground deposit of porous, magnesium- or calcium-bearing rock. The carbonation process would proceed slowly, but it might be economical for materials relatively poor in calcium and magnesium oxide. The major difficulty lies in finding deposits that are sealed from the outside yet allow transport of the carbon dioxide throughout the deposit without cementing in and clogging the injection well.

A more complex but efficient way to lock up carbon dioxide would be to use a liquid solution to extract the magnesium and calcium from minerals. In a system similar to that used by industry to extract magnesium from sea water, magnesium could be leached from the rock with hydrochloric acid. The acid could be recycled for continuous mineral treatments.

Lackner collaborated on the project with Darryl Butt of Los Alamos's Materials Technology: Metallurgy Group, Ed Joyce of the Energy and Process Engineering Group, David Sharp of the Complex Systems Group, and Christopher Wendt at the University of Wisconsin—Madison.

Automotive-Scale Fuel Cell Undergoes Testing

Researchers at Los Alamos have started testing an automotive-scale fuel cell as part of the second phase of a joint project with General Motors, Los Alamos, and the Department of Energy.

Phase one of the project was recently completed at Los Alamos with the development of a 10-kilowatt gross output engine. An electric vehicle's engine will require between 30 and 50 kilowatts to perform as well as today's gas-powered automobiles.

To reach the wattage goal, project researchers are designing an electrochemical engine that runs on stacks of proton-exchange membrane fuel cells and the liquid fuel methanol. An onboard fuel processor converts the methanol into hydrogen and carbon dioxide. The fuel cell electrochemically combines the hydrogen with oxygen from outside air to produce direct current electricity. The electricity, in turn, powers the traction motors that turn the car's wheels.

Microbe Munchers Take Bite Out of Nitrate

Scientists at Pacific Northwest Laboratory (PNL) demonstrated in a laboratory that microbes energized by vegetable oil can filter nitrate from simulated underground aquifers. The process works by injecting vegetable oil into the earth around the base of a well. As it enters the earth's subsurface, the oil becomes trapped in pockets between the various layers of sediment. The nitrate filtration takes place as the contaminated water flows past a zone of naturally occurring microbes that use the carbon in the oil as an energy source. The microbes metabolize the nitrate and transform it into nitrogen gas, which is absorbed into the water. The water then can be pumped from the earth free of the nitrate. The microbes remain underground until they die. This process has reduced nitrate levels as high as 180 parts per million to a level well below the drinking water standard of 10 parts per million.

Siegel to Head MS&E at RPI

Richard W. Siegel has been named Robert W. Hunt Professor and head of the Materials Science and Engineering Department at Rensselaer Polytechnic Institute (RPI). Siegel, internationally known expert in defects in metals and nanophase materials, comes to RPI from Argonne National Laboratory.

Siegel's research has concentrated on the nature and physical properties of defects in metals, atomic diffusion, and most recently on the synthesis and processing, characterization, and properties of nanophase materials, including both ceramics and metals. He co-founded Nanophase Technologies Corporation in 1989 and serves as its chief scientific consultant and as a member of its Board of Directors.

Siegel also received an Alexander von Humboldt Foundation Senior Research Award to establish a research project this year at the Max Planck Institute for Microstructure Physics in Halle, concentrating on the nanostructuring of semiconductor-based composite materials.

An honorary member of the Materials Research Societies of India and Japan, Siegel has been a visiting professor in Israel, India, and Switzerland. He is on the Council of the Materials Research Society and is chair of the International Committee on Nanostructured Materials. He received a bachelor's degree from Williams College and a master's and a doctorate from the University of Illinois at Urbana-Champaign. After two years of postdoctoral materials research at Cornell University, he served from 1966–1976 on the faculty of the State University of New York at Stony Brook. He has been at Argonne since 1974.

Recently Announced CRADAs

Argonne National Laboratory (Argonne, Illinois), **Eichrom Industries, Inc.** (Darien, Illinois), and **Wayne Circuits** (Yorkville, Illinois) signed a $125,000, two-year agreement to develop a method for extracting and recycling metals from electroplating operations.

Association of American Ceramics Components Manufacturers Consortium One (AACCMCI) (Westerville, Ohio), **Los Alamos National Laboratory** (Los Alamos, New Mexico), and **Sandia National Laboratories** (Albuquerque, New Mexico) entered into an agreement to develop improved manufacturing technologies for advanced ceramic materials.

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