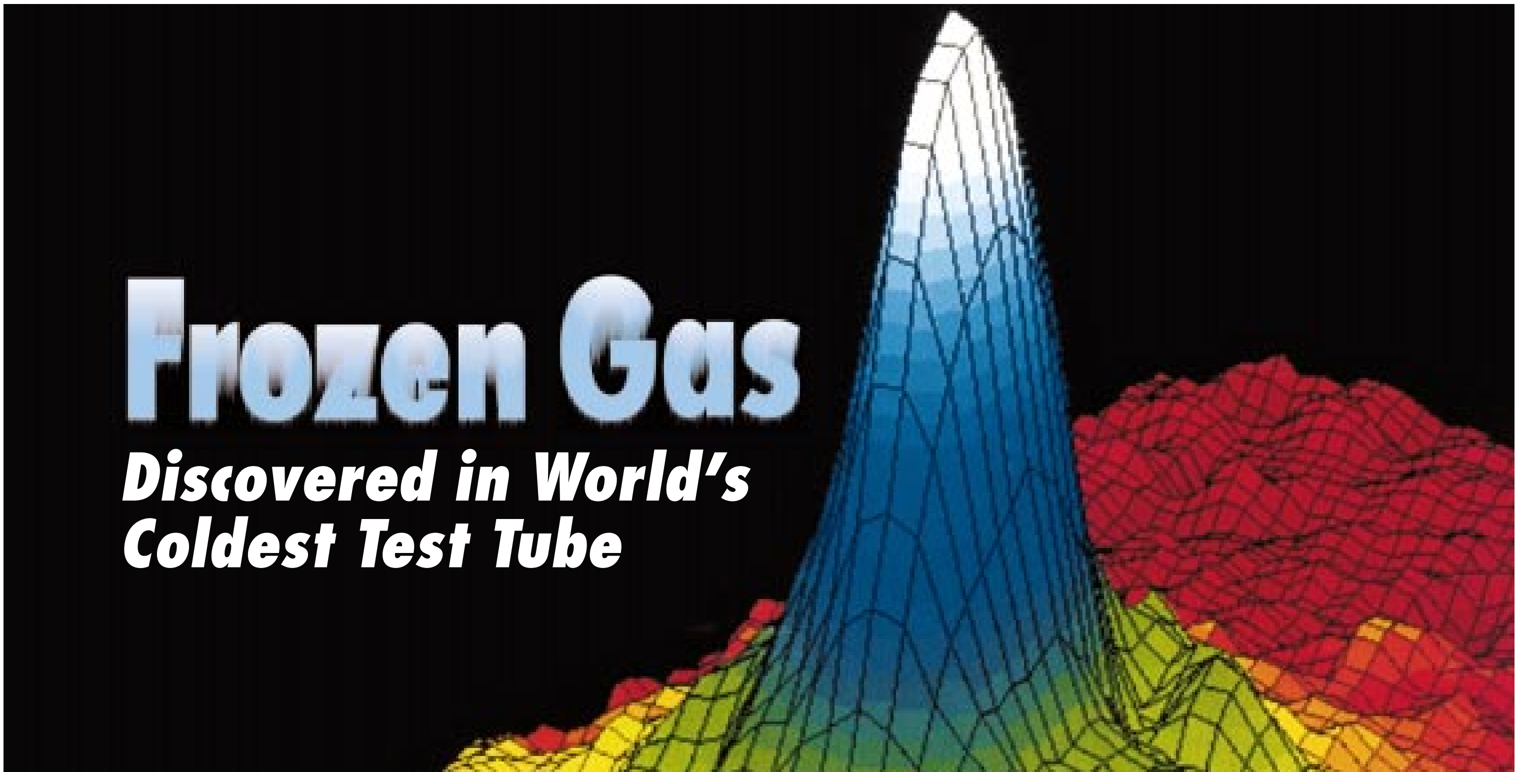


Frozen Gas
Discovered in World's Coldest Test Tube

Read the article *Frozen Gas* from *Chem Matters, October 1996* then **answer these questions:**

1) What does BEC stand for? ___________________________ When was BEC predicted to exist? _______
2) How did Cornell and Wieman cool down the rubidium atoms to get so close to absolute zero?

3) Sometimes these atoms, which exist close to zero, are called a "superatom." Why?

by Roberta Baxter

"I was coming into the lab every hour or so. I knew we were close. I could sense it."

"We were so excited we could barely speak."

"I was excited but tried to force myself to be skeptical."

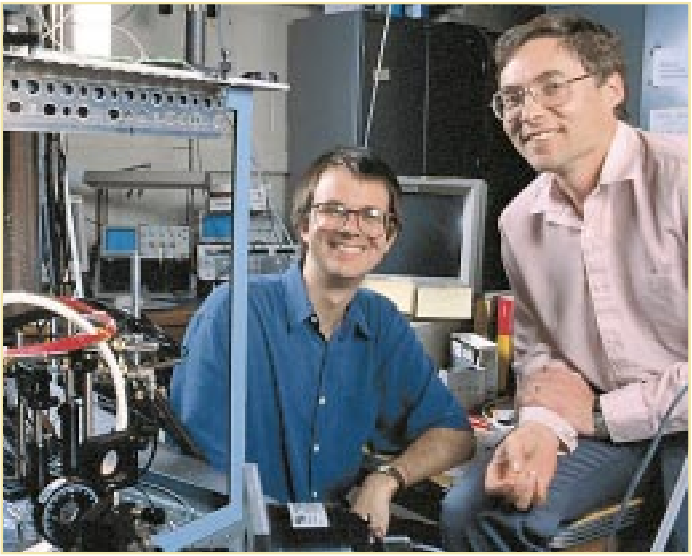
These quotes are comments made by researchers after a stupendous discovery was made in their laboratory. On June 5, 1995, a new form of gas was created in the laboratory of Carl Wieman and Eric Cornell in Boulder, Colorado. "It really is a new state of matter. It has completely different properties from any other kind of matter," said Wieman.

These two scientists and their team of researchers work at the Joint Institute of Laboratory Astrophysics (JILA), a joint project of the National Institute of Standards and Technology and the University of Colorado. Graduate students Jason Enser and Michael Matthews, as well as postdoctoral researcher Michael Anderson worked on the BEC research team.

Seventy years ago, Albert Einstein and Indian physicist Satyendra Nath Bose predicted a strange new condition that was later called the Bose–Einstein condensate (BEC). For most of the past 70 years, their prediction was a fantasy. But about 15 years ago, scientists began developing techniques to reach temperatures close to absolute zero. In theory, atoms have no motion at absolute zero, –273.15 °C (–459.67 °F). Scientists have long been fascinated with reaching a temperature as near as possible to absolute zero and have edged closer and closer. The experiments in the JILA laboratory finally came extraordinarily close to absolute zero, and the Bose–Einstein condensate appeared, just as predicted.

When the temperature was lowered to 1.7 ten-millionths of a degree above absolute zero, the number of slow-moving atoms increased —as Bose and Einstein predicted in 1924. In this image the white peak represents thousands of near-stationary atoms that have merged their electrons into a single "superatom." At the time of this discovery, this was the only sample of Bose–Einstein matter anywhere in the universe because such low temperatures do not occur naturally. Even outer space is a few degrees above absolute zero.

The experiment was conducted with rubidium atoms in the gas phase. The atoms were captured in a trap by lasers similar to the ones that drive compact disk players. The lasers are set to a wavelength that slows down and cools the atoms, rather than producing



Eric Cornell (left) and Carl Wieman with the equipment they constructed to make the first Bose–Einstein matter. Working at the University of Colorado on a government-funded research project, they formed the first Bose–Einstein matter on June 5, 1995. The two researchers had worked on this problem for six years, assisted by 11 university students.

the heat that we usually associate with lasers. Then the atoms are put into a magnetic trap for further cooling.

Several other research teams had used magnetic traps for cooling atoms. The warmer atoms hop out of the magnetic field, while the cool ones congregate in the center of the trap. The shape of the trap caused one big problem for Cornell and Wieman. The magnetic field had the shape of a funnel with no field at the center, leaving an exit hole. Unfortunately, the coldest atoms leaked out the hole. Cornell came up with a solution. He added another magnetic field that moved the hole around the funnel faster than the atoms could leak out. “It’s like playing keep-away with the atoms,” Cornell said. Now the team had a trap that could hold the coldest atoms in the universe.

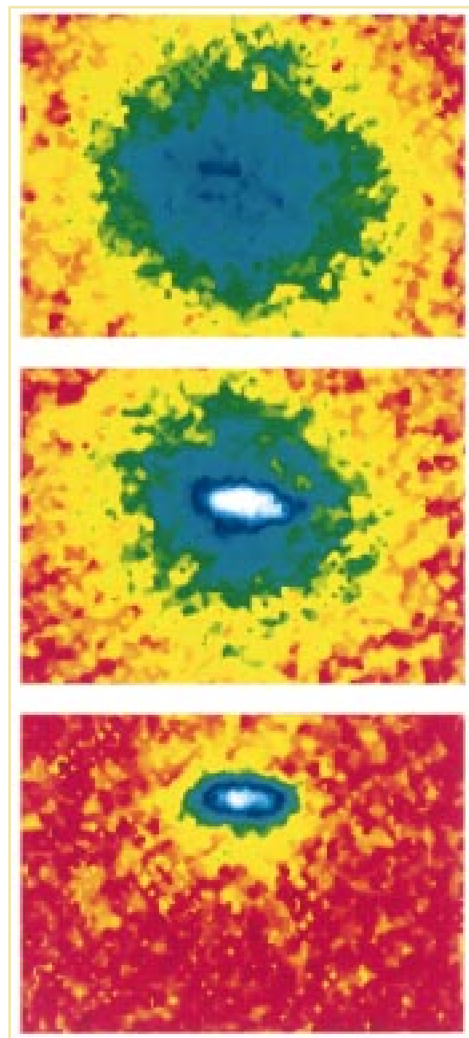
When about 2,000 rubidium atoms had cooled down to the coldest temperature ever, the Bose–Einstein condensate formed. The atoms lost their individuality and acted in unison. On the computer display, it appeared as a single large object. The atoms can be compared to a group of children at play, moving in every direction. When the school bell rings, they line up and march in step, almost as one child. The diagrams show the atoms as balls bouncing wildly at room temperature. At very cold temperatures, they slow down significantly. But at the ultra-cold temperature, almost all motion is gone, and the atoms change to a new form of gas. Some have called it a “superatom,” although Cornell points out that they still have individual nuclei.

Cornell offered a comparison of the speed of the atoms. “Atoms in a room-temperature gas normally move about 1,000 miles per hour and slow down as the temperature drops. The normal atoms at these low temperatures (non-BEC) move about 3 feet per hour. The Bose–Einstein condensate atoms move a lot slower, too slow for us to measure yet.”

The team led by Wieman and Cornell has opened a door to a whole new realm of science. Carl Wieman says, “My goal was not just to produce it, but to make it in a simple manner which would allow many of its properties to be easily studied, because I knew they should be very unusual.” No one is sure where this new discovery will lead. Many research groups are replicating the formation of BEC, as scientists try to define the BEC’s properties and characteristics. Keith Burnett, physicist at Oxford University, England, said, “This is really only the beginning for the field and should, I believe, be looked upon in the same way as the development of the laser.”

When Carl Wieman was in high school, he had a small interest in science but was not considering it as a career. He became more interested his freshman year in college when he worked in a physics lab. He says, “For me, the most appealing aspect of science is that it allows me to understand most everything of how the world around me works. Also in the research, there is a sense of creating something new and unique that will exist long after I am gone, in much the same way a statue or a painting would.”

Wieman had been working on BEC for about six years. It will probably take more years than that to understand the properties and possibilities of the coldest substance ever formed.



Speed map. These images were computer-generated from laser measurements of the speed of atoms in a cloud of rubidium. The color indicates the fraction of the atoms that are moving at extremely low speed. In red and orange regions, only a small percentage of the atoms are moving slowly; blue and white indicate a high percentage of slow atoms. At room temperature, the speed of gas atoms is about 1,000 miles per hour. The atoms in the white regions of this image move at about 0.0006 mile per hour.

Roberta Baxter is a freelance science writer who lives in Colorado Springs, Colorado. She is a regular contributor to *Chem Matters*.

FOR FURTHER INFORMATION:

Anderson, M. H.; Ensher, J. R.; Matthews, M. R.; Wieman, C. E.; Cornell, E. A. “Observation of a Bose–Einstein condensation in a dilute atomic vapor.” *Science* **1995**, *269*, 198–201.

Culotta, E. “Molecule of the Year: A new form of matter unveiled.” *Science* **1995**, *270*, 1902–3.

Freedman, D. H. “Bose and Einstein in Boulder.” *Discover* **1996**, *17*(1), 58–59.

Oxford BEC Page. http://eve.physics.ox.ac.uk/Personal/ruprecht/BEC/BEC.html

Taubes, G. “Physicists create a new state of matter.” *Science* **1995**, *269*, 152–53.