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An INTERVIEW with Dr. Wolfgang Ketterle

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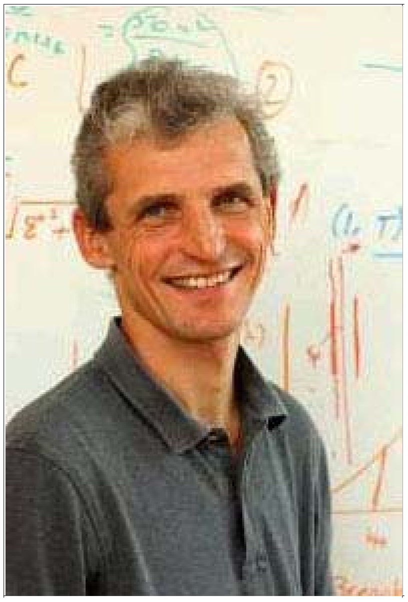
In this interview, Special Topics correspondent Gary Taubes talks with Wolfgang Ketterle about his highly cited work in the field of Bose-Einstein condensates. According to our analysis of this field over the past decade, Dr. Ketterle is the most-cited scientist, with 74 papers cited a total of 5,824 times—six of these papers appear in our listing of the top 20 papers. His most-cited paper, "Bose-Einstein condensation in a gas of sodium atoms," (*Phys. Rev. Lett.* *75[22]: 3969-73, 27 November 1995), ranks at #2 on our list. In the ISI Essential Science Indicators℠ Web product, Dr. Ketterle's work can be found in the field of Physics. Dr. Ketterle was one of the Nobel Prize winners in Physics in 2001, along with Eric Cornell and Carl Wieman. Dr. Ketterle is the John D. MacArthur Professor of Physics at MIT, where he is one of the principal investigators in the Atomic, Molecular and Optical Physics Group in the Research Laboratory of Electronics.

ST: Your lab has six of the top 20 papers in Bose-Einstein condensation research. How do these papers reflect the progress in the field, and what was the context in which this research was done?

There have been two phases of Bose-Einstein condensation research. One was the discovery of Bose-Einstein condensation in 1995, and then the immediate improvements in techniques, like creating a Bose-Einstein condensate in a tightly confining magnetic trap, which was just engineering a better system: we were able to observe Bose-Einstein condensation in a more controlled way with a larger number of atoms. So phase one was to establish Bose-Einstein condensation as a phenomenon and as a system which can be studied. Phase two was the pioneering studies of the properties of the condensate and establishing Bose-Einstein condensation as a coherent source of atoms. The latter was celebrated as the observation of a pulsed atom laser. It was those two phases on which the Nobel Committee put significant weight in their considerations.

ST: What was the biggest challenge to doing the Bose-Einstein condensation research?



“The amazing thing is that the level of excitement just keeps

The challenge was to develop the technology and put a complex experiment together. That took not just technical expertise, but also experimental ingenuity, creativity, knowing what to do, what not to do, and when to do things. It really was an experimental tour de force. It needed the ideas and the vision, but also a lot of knowledge of how to do it. From the point of view of atomic physics, the developments in 1993, 1994, and 1995 revolutionized technical aspects of atomic physics experiments. Nobody in the field knew how to operate high-current power supplies for magnetic traps before then. Nobody had done absorption imaging—to take shadow pictures of atoms. There were early precursors of magnetic traps in the 1980s, but between 1993 and 1995, we developed room-temperature magnetic traps with high-current power supplies, and all that had to be engineered. Everything had to be done at ultrahigh vacuum, which was not the case with previous experiments. It sounds very mundane because those techniques are now standard in many atomic physics labs around the world. But after Bose-Einstein condensation was first observed, it took other groups two years to repeat it. This was the challenge they had to overcome. They had to learn all these techniques, and then get everything to work at once.

ST: Does that two-year gap explain why half of the top 20 papers come from either your lab or Eric Cornell's lab in Boulder?

Yes. That has been unprecedented. For two years the only two productive experiments were the Boulder experiment and ours.

ST: Did this surprise you?

Yes. In 1995, we didn't really realize how many technologies we had put together in the two years before Bose-Einstein condensation was realized. Back then I thought that within a few months labs in Europe and the U.S. would all realize Bose-Einstein condensation and join in. And at every conference, we were waiting. When are all the other groups coming? A whole year went by. A year and a half. Only in the spring meeting of 1997 did other labs announce that now they had caught up. But the explosion in theoretical research came immediately. Hundreds of papers were published on the subject but the only experiments to refer to were coming out of MIT and Boulder. It gave an enormous focus to our papers, and that's what made them so highly cited.

ST: How has the field evolved since 1997?

The field has dramatically developed. People are now using Bose-Einstein condensates for research studies that I never even imagined early on. For example, condensates in optical lattices, superfluidity, atom optics with condensates. A very rich field is the study of rotating condensates—there are hundreds of papers now just on rotating condensates.

ST: What are you focusing on now in your laboratory?

I have four labs working now. One is working on condensed matter physics with Bose-Einstein condensates: phase transitions, optical lattices, superfluidity. Two of my labs work on the atom-optical aspects of condensates: interference, magnetic wave guides for condensates, but also some independent aspects, like optical properties of condensates, a phenomenon called superradiance. The fourth lab works on the frontier of cold fermions. There the most important goal is to understand the physics of correlated fermions. That is where we may penetrate very, very deeply into the frontiers of condensed matter theory.

ST: What has been the most exciting part of this decade of research?

The amazing thing is that the level of excitement just keeps going. Every year or so there is a major surprise, a major discovery, and we really feel elated and excited about the new physics. Not a single year goes by when some real surprise hasn't happened; where you say, "That's just amazing. It's too good to be true." Here's one concrete example: this is the year of cold molecules. These have very different properties than cold atoms. People thought that achieving cold molecules of Bose-Einstein condensation would be very difficult, and then groups developed very different methods to do it. This year, in an absolutely surprising simple way, within one month three groups observed Bose-Einstein condensation of molecules. That actually made some headlines just last month. These were the Innesbruck group, the Boulder group, and my group at MIT.

And that actually relates directly to the 1998 highly cited paper on Feshbach resonances (S. Inouye, M.R. Andrews, J. Stenger, H.J. Miesner, D.M. Stamper-Kurn, W. Ketterle, "Observation of Feshbach resonances in a Bose-Einstein condensate," *Nature* 392[6672]: 151-4, 12 March 1998). It is really very difficult to cool a molecule to ultra-low temperature. People have not really solved that. There's no standard technique to do it. But we can cool atoms very well. So why not take very cold atoms and form molecules out of them using chemical reactions? Then you scratch your head and say, but chemical reactions release heat. But if the molecule has a binding energy close to zero, that means the two free atoms and the molecule itself have almost the same energy. Then the two atoms can form a molecule and there's no heat released. And therefore ultra-cold atoms form ultra-cold molecules, without needing any means to cool molecules directly.

This coincidence, that a molecular state has the same energy as the two colliding atoms, is called a Feshbach resonance. Then the formation of molecules becomes a resonance process. This enhances the rate of formation, and at the same time, there's no excess energy that has to be released.

ST: What do you see for the next five years of research on Bose-Einstein condensation?

One goal is the use of condensates for advancing atom optics, to develop new or improved matter wave sensors. In condensed-matter physics, we have two big goals. We would like to use ultra-cold atoms to realize new forms of matter. You could call it designer matter. You take atoms, you turn on a magnetic field, you adjust the interactions between the atoms, shape the external potential, maybe add a lattice by interfering laser beams, maybe add magnetic fields, maybe add a spin mixture. In this way, you've created a form of matter that shows, in a very clean way, properties like anti-ferromagnetism or different forms of magnetic ordering, superfluid behavior. The other big goal would be to realize new forms of superfluidity. That would hopefully help to close the gap in our understanding of high-temperature superconductivity. That's my dream.

ST: Is it within your grasp?

I am much more optimistic because of the breakthroughs of the last few months. We put a system together which should show a high-temperature, new form of high-temperature superfluidity. But the question until a few months ago was if you put the system together, would it be stable or would the atoms form molecules and release heat or do something else, and would the system destroy itself? There were reasons to expect that. But as an experimentalist, you try it anyway, and the result was too good to be true. It's not yet high-temperature superfluidity. What you have in high-temperature superfluidity, you have very strong pairing between atoms. They form Cooper pairs, and we haven't seen those yet. But we have observed that those atoms can form molecules even more tightly bound than Cooper pairs. So in some sense, we realized the tightest binding of Cooper pairs. Sometimes, in life, as in physics, you understand the extreme limits of behavior first. The tight binding limit of Cooper pairs are molecules, and then superfluidity of Cooper pairs is Bose-Einstein condensation of molecules. That's sort of trivial. That's well understood. But now there is feverish activity in my lab and in others to loosen up the binding energies of these molecules and turn them into Cooper pairs.

ST: It sounds as though the level of competition in the field, like the excitement level, has not diminished in the past eight years or so?

I agree.

ST: Does it ever get exhausting?

Well, you can't rest. If you work at a high level, then you have built up experimental set-ups; you've educated people who are top scientists. So you've built an excellent team of collaborators. It's not as if every year you have to start from scratch. But, of course, that two-year technology gap we had has now been closed. Now there are several excellent groups around the world and there is a tight competition. But that's normal when something is truly exciting. If there was no competition, that would be a bad sign.

ST: Is there another Nobel Prize in this research?

Usually, you can't predict major discoveries. In the next five or ten years, very exciting things can happen. If an improved understanding of superfluidity is realized, that would be big. But we haven't even really started. We're just at the beginning. But the field is very vibrant and rapidly moving. It still shows the dynamics of a field that might lead to surprising discoveries. However, for a Nobel Prize, something singular has to happen, and this is completely unpredictable.

ST: Has the progress and the rate of advance surpassed your expectations from before the original discovery?

Yes, in many regards, and again and again. To be in a field now, eight years after the discovery of Bose-Einstein condensation, and to still see no signs of slowing down, that's quite amazing.

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***Also see*:**

- Science Watch® Interview
  by: **Ketterle, W** (from Jan/Feb 1999)

- Fast Breaking Comments
  Wolfgang Ketterle answers a few questions about his fast breaking paper in field of Physics in December 2003.

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