Testimony of

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"Views on Science Policy of the Nobel Laureates from the National Institute of Standards and Technology"

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Chairman Ehlers and members of the Subcommittee, please allow me to briefly introduce myself and my research. My name is Eric Cornell and I was hired by the National Institute of Standards and Technology (NIST) in 1992 to do research in quantum optics. Then as now NIST was known in the world of the physical sciences as a place where great technology meets great ideas, so I was thrilled to get the job. Management at NIST encouraged me to pursue a high-risk research program at the cutting edge of modern physics. NIST continues to be something of an incubator for quantum science in the U.S. Many of the leaders in the field have come through a NIST lab at one time or another in their careers.

For my part, I set out to make the World's Coldest Gas, building on techniques developed by my fellow NIST scientists, Drs Jan Hall and Bill Phillips. Why would we want to make the World's Coldest Gas? There were several reasons. It turns out that cold gases are a useful environment for making extremely precise measurements, which is a capability at the heart of NIST's standards mission. Perhaps more important to me personally was that I knew that often times you can do the most exciting science if you can work right at the boundary of a current technological frontier, and one of science's key frontiers is the frontier of very low temperature. Every time we've been able to reach new heights (really "depths") in low temperature, exciting physics has followed.

I won't use the Committee's time to ramble on about my favorite topic, the physics of extreme low temperatures, but I will tell you that when a gas, made of atoms, gets colder and colder, those atoms, sure, move slower and slower. But there are also more subtle changes. For one thing, at room temperature, atoms act like little billiard balls, bouncing off the walls and off each other. But close to the very lowest possible temperatures, (known as "absolute zero") atoms stop acting like little balls and start acting instead like little waves. And at the VERY lowest temperatures, within a millionth of a degree of absolute zero, the atoms all merge together to form one super-atom-wave, a new state of matter called a Bose-Einstein condensate (BEC). Predicted by Albert Einstein back in 1925, the Bose-Einstein condensate had never been achieved until we finally found it at NIST in 1995. It was for this achievement that I shared (with my colleague from University of Colorado, Carl Wieman and with Wolfgang Ketterle) the 2001 Nobel Prize in physics.

Where has Bose-Einstein condensation led us, in the ten years since we first created it? What, in particular has it been good for? BEC has found several direct applications, and in particular we and other research groups around the country are trying to develop precision accelerometers, gravitometers, and gyroscopes, to be used for remote sensing and navigation by dead reckoning. In the long run, BEC is likely to be still more important because of its role as a scientific building block, a tool to help us understand and tame quantum mechanics, and to put quantum mechanics to use on problems with relevance to our economy, our health, and our national security.

Let me share with you two examples of how the taming of quantum mechanics may make a big difference to our country in the coming two decades. The first is quantum computing.

Quantum computing is one of the most amazing concepts to come out of the 1990s. What puts the "quantum" in quantum computing is so-called "quantum bits". In an ordinary computer, there are millions of tiny switches, called bits, that can be either on or off, one or zero. The bits are the memory of the computer, and the bits are what a computer uses to make calculations. A "quantum bit," or "qbit", transcends the traditional requirement that a bit be either "on" or "off". A qbit instead can simultaneously be in a combination of "on" or "off". The power of this possibility comes in when you start stringing many qbits together. With ten bits in a row, with different combinations of "ones" or "zeros", you can represent any number between zero and 1023. With ten quantum bits in a row, each in a superposition of one and zero, you can simultaneously represent every number between one and a thousand.

Why would one want to do that? We can take as an example a computational problem which is extremely important to our national security and our economy - breaking large numbers up into their prime factors. Prime factors are at the heart of our cryptography systems, which allow for secure military and diplomatic communications, but also are at the heart of our banking and finance system. Businesses, banks, and increasingly ordinary consumers do not send cash or even checks for transactions - they send encrypted ones and zeros. If this system of cryptography is threatened, it could cripple our economy in days or hours. Roughly speaking, very large numbers are the code, and the prime numbers that divide in evenly are the key to the code.

Here is where quantum computing comes in. Suppose you want to find out what are the factors of 999,997. One way you could do that is to take every number from one to a thousand, and try to divide it into 999,997. The ones that go in evenly, those are the prime factors! Even for a modern computer, it takes a while to do one thousand divisions. Suppose instead your computer is made of quantum bits. What you can do is take your ten quantum bits, which simultaneously represent every number between one and a thousand, and try to divide that number into 999,997. In one single mathematical operation, you can find out if any of those numbers divide in evenly, and thus crack the code in one operation instead of in one thousand.

For cryptography, you don't care about numbers like 999,997 - you care about numbers that are a trillion trillion times larger, and what are the prime factors of those numbers. Using a quantum computer, you could answer that question in principle a trillion times faster than you can with an ordinary computer, even a so-called "super-computer." The implications for secure communications and economic transactions are profound.

There are other extremely difficult problems in computing, problems which are too hard for even the fastest modern computers to solve. One of these is the problem of protein folding, the way in which chains of amino acids bundle in on one another to form the parts that make up living biological cell. If this folding goes wrong, you get mad cow disease. The flip side is if you can learn to control and predict protein folding, you have a very powerful tool for designing the next generation of drugs. This is the sort of problem that a breakthrough in quantum computing could hugely impact, again by allowing one to do trillions of calculations all at once.

None of this is going to happen tomorrow. What I have left out of this whirlwind geewhiz presentation of the potential of quantum computing is that there is no working quantum computer now, and don't count on there being one in 2007, either! The scientific and technical challenges associated with constructing quantum bits, and stringing them together into an integrated computer, are immense. In a modern conventional computer, there are literally billions of zero-one bits. A modern quantum computer would be so much more powerful than a conventional computer that it would not need billions of quantum bits in order to do amazing things. But it would need thousands of quantum bits. Currently the best experimental quantum computing teams are able to string together about four, maybe six quantum bits. Still, my own opinion is that quantum computing is such a powerful idea, it really must be explored.

So why is it important that the U.S. conduct this research? As with any problem, human nature dictates that there will always be curious people trying to come up with a solution. Quantum physics is no different. Teams from around the globe are conducting research trying to solve the riddle of quantum computing. If the US stays on the sidelines, then we will watch others make profound discoveries that will ultimately improve the competitiveness of their industries and quality of life. The big question is what is going to be the big new industry of 2020? If I knew the answer, I would not be here in front of you testifying -- I'd be off setting up my own high-tech venture capital company instead. No one knows the answer for sure, that is why scientific research and discovery is so important. Without knowing for sure what the next big thing will be, we can remain cautiously optimistic that that big thing will be an American thing. The reason for optimism is that, over the last fifty years, as the American economy has benefited from many cycles of emerging technology, the one big thing that hasn't changed has been America's lead in science research. The reason for caution is that, while our lead has remained in place for 50 years, it need not remain for another 50. It needs to be nurtured!

I'd like to conclude my testimony by pointing out in that not every measure that Congress could take to nurture science research requires additional spending. In my personal opinion, one fact that has made American high tech research and industry so successful over the years has been the steady influx of brilliant, creative, and hardworking science and engineering students from all around the world. After their graduation, many of these students have stayed on in our country to contribute to the vitality of our high-tech sector. When this happens, the big winners are American industry and the American people. Other nations' brain drain has been America's brain gain! When we make it easier for the smartest of the world's young people to come here to study, and easier for them to stay here afterwards and put their skills to work in the American economy, we help no one more than we help ourselves.

I would like to thank the Subcommittee once again for allowing me to testify before you today. I will be happy to answer any questions.

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Degrees

- B.S., Physics, with honor and with distinction, Stanford University, 1985
- Ph.D., Physics, MIT, 1990

Appointments

- Fellow, JILA, NIST and University of Colorado at Boulder, 1994-present
- Senior Scientist, National Institute of Standards and Technology, Boulder, 1992-present

- Professor Adjoint, Physics Department, University of Colorado, Boulder, 1995-present
- Assistant Professor Adjoint, Physics Department, University of Colorado, Boulder, 1992-1995
- Post-Doctorate, Joint Institute for Laboratory Astrophysics, Boulder, 1990-1992
- Summer Post-Doctorate, Rowland Institute, Cambridge, 1990
- Research Assistant, MIT, 1985-1990 Teaching Fellow, Harvard Extension School, 1989
- Research Assistant, Stanford University, 1982-1985

Honors and Awards

- Member, National Academy of Sciences, 2000
- Fellow, Optical Society of America, Elected 2000 R. W. Wood Prize, Optical Society of America, 1999
- Benjamin Franklin Medal in Physics, 1999
- Lorentz Medal, Royal Netherlands Academy of Arts and Sciences, 1998
- Fellow, The American Physical Society, Elected 1997
- I. I. Rabi Prize in Atomic, Molecular and Optical Physics, American Physical Society, 1997
- King Faisal International Prize in Science, 1997
- National Science Foundation Alan T. Waterman Award, 1997
- Carl Zeiss Award, Ernst Abbe Fund, 1996
- Fritz London Prize in Low Temperature Physics, 1996
- Department of Commerce Gold Medal, 1996
- Presidential Early Career Award in Science and Engineering, 1996
- Newcomb-Cleveland Prize, American Association for the Advancement of Science, 1995-96
- Samuel Wesley Stratton Award, National Institute of Science and Technology, 1995
- Firestone Award for Excellence in Undergraduate Research, 1985
- National Science Foundation Graduate Fellowship, 1985-1988