

Testimony of

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Mr. Chairman and members of the committee: As a Federal Employee and, like each of you, a public servant, it is a great pleasure for me to appear before you. And it is an honor to appear along with Eric Cornell and Jan Hall, friends and colleagues in government service, and distinguished scientists whose work has had such a profound influence on my own research. I have worked for the National Institute of Standards and Technology (formerly the National Bureau of Standards) for more than 27 years. I was hired to make precision electrical measurements—an activity directed toward the NIST missions of providing the high quality measurement services needed for modern industry and science and of exploring the frontiers of knowledge relating to measurement science. At the same time I was encouraged by the management of NIST to pursue, as a side interest, topics in laser physics that could benefit NIST’s mission, broadly interpreted.

In my spare time, with scrounged equipment and funds, I investigated a seemingly crazy idea—that you could cool something by shining laser light on it. The “something” I wanted to cool was a gas of atoms, and the motivation was to make the atoms move more slowly, since colder simply means that the atoms are moving more slowly. Why? Because if the atoms were moving more slowly, we could measure them better, and better measurement is one of the key services we at NIST deliver. In particular, I wanted to make better atomic clocks—to make our best timekeepers even better.

How could laser light cool a gas of atoms? The idea was to use the light to push on the atoms in such a way as to make them slow down. Or at least that was the dream that I pursued, in odd moments, as a young physicist in 1978. I was inspired by the fact that earlier that year, Dave Wineland and his colleagues at the NIST laboratories in Boulder CO had done just that—laser cooling ions, electrically charged atoms that were easier to hold onto. It was going to be harder to do that with neutral atoms, which, lacking an electric charge, were harder to control and confine. And I was eager to take on the challenge.

With the strong support of NIST and of the ONR, by 1988 laser cooling had become my sole assignment. The international scene had changed considerably. In 1978 a lone group in the Soviet Union was our only competitor in laser cooling of neutral atoms. By 1988 groups across the US and around the world had joined in the fun. At NIST, we had first learned how to slow down beams of atoms from well over the speed of sound to human running speeds. We learned to trap the atoms, suspending them in vacuum using first magnetic fields and then lasers. Things were going well. We were learning to use the tools of laser and magnetic manipulation of atoms to make them do what we wanted. But there were problems. Things were not behaving exactly as our calculations had predicted. We tried modifying the theory in reasonable ways, but nothing worked.

Physicists are, by nature and by training, driven to make sense out of what we see in the world and in the laboratory. And things were not making sense. Things were working well enough, and we were well on our roadmap to slow our atoms down, but not everything was adding up. And we could not let it rest. We turned our attention to figuring out what was going wrong. Or, more precisely, what was going *on*. And, after

something like a year of investigation, we learned, much to our surprise, and to the surprise of colleagues around the world, that the strange behavior was tied to the fact that we were cooling our atoms to temperatures far lower than we or anyone had thought possible. We were astounded! Experiments rarely work better than expected, and, in trying to get temperatures as low as possible, we had gotten to temperatures a lot lower than thought possible.

The results were so unexpected that we confirmed them four different ways before we reported them publicly. After other laboratories had reproduced our results and theorists had deduced a new mechanism for laser cooling, we eventually (in 1995) reached temperatures more than a hundred times lower than had been thought possible. We achieved temperatures lower than millionth of a degree about absolute zero—at that time, the coldest temperature ever achieved. It was one of the most exciting and satisfying experiences a scientist could hope for, and it illustrates an important feature about mission driven science and basic research. We had set out to laser cool a gas of atoms in order to make better clocks. We were sidetracked by basic scientific questions about the nature of the interaction of light and matter, and by studying those questions, we learned new and unexpected things about light and matter. And although we did not know at the outset how important it would be, that knowledge, gained through our digression into basic research, was what made it possible to achieve our mission goal of making a better clock.

Today, clocks using laser cooled atoms provide the official definition of the second, the unit of time. Clocks based on this principle are in use at the US Naval Observatory, and laser cooled clocks provide the accurate timekeeping needed for modern military and commercial needs. The Global Positioning System or GPS, which guides everything from jeeps in the desert to commercial aircraft to private cars, is synchronized using laser cooled clocks. The best of these clocks is NIST's F-1 cesium fountain clock with a fractional inaccuracy of better than 5×10^{-16} , or less than one second in 60 million years. At NIST, this is known as “close enough for government work.”

So, laser cooling is already in use for military and commercial purposes. But this has only been the beginning of the story. A still more advanced generation of clocks using both laser cooled ions and laser cooled neutral atoms is under development and these clocks have achieved performance that already promises to be ten times better than the best current clocks. But most of the things that laser cooling is now used for were completely unanticipated when we began our studies. (This is a common feature of the fruits of basic research—the best of those fruits are often evident only well after the inception of the work.) One of the most exciting applications of ultracold atoms is in the emerging field of quantum information. Here, single atoms or single ions are used to store information in the form of quantum bits or “qubits.” Computation and communication of information with qubits can perform feats impossible with ordinary computers or ordinary secure communications systems. Eric Cornell will say more about this in his remarks. Among the most important applications of quantum information are code breaking and eavesdropping-proof communications. These applications are crucial to issues of national security, and NIST is pursuing them. Quantum communication is

now a reality, with a testbed at NIST producing quantum cryptographic code at live-video rates. Quantum computers are still a distant dream, with a great deal of both basic research and technological advancement needed before they are a reality.

The committee has asked for a discussion of the role that NIST plays in my work and my field generally. To put it succinctly: I do not believe that I would have done any of this work had I not been at NIST. When I was a young postdoctoral fellow at MIT, I had lots of ideas about where to take my future research. One of those ideas was laser cooling. But had I gone to a university or to an industrial research laboratory, I would have pursued other goals. It was because the mission of NIST involves measurement and improving measurement science that I decided to pursue laser cooling. In this case, the application provided the motivation. But it was the environment of NIST that made the research flourish. NIST encourages its scientists to think “outside the box,” to take a long and broad view of our mission, and to pursue targets of scientific opportunity at the same time that we are attending to the problems at hand. My dabblings in basic atomic physics were not just tolerated—they were encouraged and supported. And some of the things that my colleagues and I accomplished laid the foundations for the things that Eric Cornell and Jan Hall achieved, just as their achievements enabled much of what *we* did and set us onto new directions.

NIST holds a leading position in Atomic, Molecular and Optical Physics. The three recent Nobel prizes in the area are but one testament to that fact. The strong research environment in this area was crucial to the development of my own research program, and the cross-fertilization was and continues to be extremely important.

This brings me to what is probably the most important aspect of the NIST scientific environment—the quality of the researchers themselves. People often ask me why I am still at NIST; why I have not accepted offers of greater salaries in other institutions. The main answer is my colleagues. I cannot imagine a better and more stimulating environment than the one I enjoy at NIST. The colleagues in my own research group, plus people like Eric Cornell, Jan Hall, and a long list of others from whom I learn and benefit on a daily basis, are what makes working at NIST such a rewarding and stimulating experience. When I hear someone characterize government workers as clock-watching slackers, I know they haven’t met my colleagues. When I hear claims that the government should hire people who are just good enough to do the job I am horrified. NIST has assembled some of the best scientists in the world, and has kept them by providing an atmosphere which nurtures the best kinds of research. The pay-off has been obvious: three Nobel prizes in eight years; world leadership in measurement science; and lines of research with present and future applications in commerce, science, industry and the military.

Finally, you have asked for my perspective on what the federal government can do to improve the competitiveness of US scientific research. When we speak of the competitiveness of American science, there are two aspects. One is how well science itself competes with the science of the rest of the world. The other is how well American science contributes to the economic competitiveness of the US in the global marketplace.

My view is that the one enables the other. We often talk, quite rightly, about technology transfer. But most important is having technology to transfer. I think that resources of the federal government devoted to discovery are extremely productive, and that the good results will be taken up commercially as long as the environment for doing that is kept friendly and relatively free of artificial impediments. I must emphasize that these perspectives are my own personal ones and not necessarily those of NIST's management. Also, while I may be an expert in laser cooling, I am not an expert on the sociology and economics of science research. But I have developed some ideas about what makes American science strong and what we need to do to continue to maintain our position in the increasingly competitive international research landscape.

First I believe it is essential to maintain and in fact increase support for basic research, especially in the physical sciences. Post WWII, the physical sciences had strong support, in large part because of the correct understanding that a legacy of basic research had played a key role in the development of such crucial wartime technologies as radar and nuclear weapons. That strong support for physical science research led to the development of a computer and consumer electronics market where American leadership in innovation has allowed us to retain a strong position in the face of cheaper production overseas. Similarly, advances in medical and life sciences were underpinned by strength in the physical sciences. Tools like magnetic resonance imaging and other modern medical diagnostic tools had their roots in the basic physics research conducted earlier in the 20th century. That basic research was being carried out in a wide variety of environments—university labs, supported by both civilian and military agencies, military and non-military government labs, as well as industrial labs.

The invention of the transistor at Bell Telephone Labs set the stage for a booming electronics industry that has sustained much of the US economy. It came from a strong and sustained program in basic research at Bell Labs, one that was mirrored in other industrial labs like RCA, Raytheon, Ford, Xerox, IBM, and so forth. Today, many business analysts seriously contend that AT&T never got a significant return on its research investment and denigrate the value of any long-range, basic research in any industry, focusing instead on very short-term return on investments. Today, Bell Labs is a shadow of its former self in regard to basic research and that sort of far-sighted support of research has virtually disappeared from American industry. I don't know if we can ever expect to return to the golden age of industrial research, but I strongly believe that we must, as a nation, regain and maintain that level of basic research if we are to remain competitive in a world economy. If industry cannot or will not take its traditional share of this responsibility, I believe that government must compensate. Furthermore, in my opinion it is vital that government laboratories like NIST, with a mission focus, do not fall into the same short-term thinking about research that infects industry. Imagine where the US economy would be today if we as a nation had not made the long-term investments, done in part by industrial labs, which led to the current semiconductor electronics industry. My reading of our history is that NIST has always recognized the importance of substantial investment in basic research for the long haul, and I commend this attitude to all other mission agencies, both civilian and military.

The recent initiatives by the executive and legislative branches of the federal government to dramatically increase the support for basic research in physical sciences certainly have the right spirit in regard to basic and long-term research, and I applaud these efforts.

In a global economy where both manufacturing and service can be provided half a world away, it is through innovative use of new knowledge that America can expect to maintain a competitive edge. And the first ones with the best opportunity to make use of new knowledge are the ones who create it in the first place. That is why basic research is so vital, and why America continues to compete successfully in a world where labor and other costs are so much less elsewhere. But unless we strengthen our position in basic research investment, we run the risk of losing what edge we have. I believe that it particularly important to make these investments in both good times and bad. One never wants to be in a position of eating one's seed-corn, and a reduction of our research portfolio in times of tight budgets would amount to exactly that. An extension of that reasoning says that for Defense purposes we should invest in basic research both in times of war and peace, and in times of global superpower competition and in its absence. Being able to respond to threats with technology depends greatly on having the basic understanding that underpins that technology, and basic research is the way one gets that.

I believe that one of the great strengths of the US research climate compared to that of other nations is the diversity of environments for doing research and of sources of funding for research. Many countries have their research centralized under a "ministry of science" and one periodically hears calls for similar centralization in the US. My opinion is that this would be a big mistake. Here in the US we have university labs, military labs, national labs, both civilian and government operated, with both classified and unclassified work. Each has a different environment and culture and therefore a different opportunity to make discoveries. I firmly believe that we need to maintain this diversity of research opportunities and maintain the strength of all of these different parts of our research landscape.

Similarly, researchers can go to a multitude of agencies for support of research in their own institutions. The National Science Foundation, NASA, the Dept. of Energy, the intelligence agencies, and the various military agencies like DARPA, ONR, AFOSR, and ARO all provide opportunities for funding basic research with different missions, styles and cultures. The NSF relies on extensive peer review from multiple outside experts, while the ONR often makes decisions based on the judgment of a single internal program manager. NASA often provides support for projects over decades while DARPA changes its portfolio on a much shorter time scale. I got my start in large part because a single manager at the Office of Naval Research believed in me and was interested in the military applications of better clocks. Different aspects of my work have, at various times also been supported by NASA and the NSA. I am keenly aware of the importance of the ability to seek support from agencies with different agendas and styles. And I believe that it is vital that we maintain each of these various sources, with their individual cultures, with a strong basic research component: I do not believe that any research institution is well served if it lacks a strong *basic* research program. I urge that we resist attempts to homogenize the approach to funding. I do not believe we would be well

served if all agencies acted like DARPA, or if they all acted like the NSF. I do not believe we would be well served if all research were done in universities or if all research were done in mission agencies like NIST. We need that diversity—it is one of the most important things that makes our nation great in the sphere of research.

Finally, just as the research environment that we enjoy at NIST has been crucial to the success of our NIST mission, the research environment in the US is essential to American competitiveness on the global scene. That environment has been the magnet that has drawn the best scientific minds from around the world to the US to study, to collaborate with US scientists, and often to remain in the US, become Americans, and add permanently to our scientific strength. Unfortunately, legitimate concerns about national security may have the unintended consequence of isolating the US scientifically. There is a strong perception among many foreign scientists that the US has become a less hospitable place for scientific collaboration. The organizing committees of some international conferences are avoiding venues in the US because of concerns that some participants may be denied visas. US researchers are concerned that students or visitors from certain countries may be unable to work in their laboratories because of deemed export regulations regarding who is allowed to work with certain classes of equipment. Foreign students, who provide a substantial fraction of the manpower for the discovery engine of American university research, are now choosing other countries in which to pursue advanced degrees in part because of their perceptions about the US attitude toward foreigners. Today, close to one half of the high tech science and engineering positions filled in the US are filled by foreign born workers. We need to improve the educational pipeline supplying American workers for our high-tech needs, and we need to find ways, compatible with our real national security needs, to continue to welcome the best of the foreign scientists as students, visitors, collaborators, and immigrants. If we do not, we run the risk of marginalizing the US scientific enterprise, of putting ourselves outside of the mainstream marketplace of ideas; we run the risk of not being in the game.

The beginning of the 21st century is an incredibly exciting place to be for any scientist. We look at a physical world that is still full of mystery—unsolved problems of the most fundamental sort, problems whose solutions are likely to change our lives in unanticipated ways, just as the revolutionary discoveries of the 20th century did. I want the US to be the world leader in making the great discoveries of this century and in claiming the fruits of those discoveries. I know that you do as well, and I trust that you will work hard to make it happen. I know that I will.

Thank you very much for your concern and for your attention. I will be happy to respond to questions.

William D. Phillips,
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Date of Birth: 5 November 1948
Place of Birth: Wilkes-Barre, Pennsylvania, USA
Citizenship: United States



Education:

Camp Hill High School, Camp Hill, Pennsylvania, diploma (Valedictorian) 1966.
Juniata College, Huntington, Pennsylvania, B.S., Physics, summa cum laude, 1970.
Massachusetts Institute of Technology, Cambridge, Massachusetts, Ph. D., Physics, 1976.
Thesis under Prof. Daniel Kleppner, thesis title: I. The Magnetic Moment of the Proton
in H₂O; II. Inelastic Collisions in Excited Na.

Scientific Experience after Ph.D:

1978-present: Physicist, National Bureau of Standards (Now National Institute for
Standards and Technology; 1990-96: Group Leader of the Laser Cooled and Trapped
Atoms Group of the Atomic Physics Division; 1996-98, NIST Fellow; 1998-present:
NIST Fellow and Group Leader of the Laser Cooling and Trapping Group.

2001-present: Distinguished University Professor, University of Maryland, College Park
MD (on leave).

2002-2003 George Eastman Visiting Professor, Balliol College and Clarendon
Laboratory, Department of Physics, University of Oxford

1992-2001: Adjunct Professor of Physics, University of Maryland, College Park.

1989-1990: Visiting Professor at Ecole Normale Supérieure, Paris, in the laboratory of
Claude Cohen-Tannoudji and Alain Aspect:

1976-1978 Chaim Weizmann Postdoctoral Fellow at Massachusetts Institute of
Technology:

Awards and Honors:

Pennsylvania State Scholarship 1966-1970
C. C. Ellis Memorial Scholarship 1969-1970
Election to Juniata College Honor Society 1969.
Woodrow Wilson Fellow 1970
National Science Foundation Fellow 1970-1973
Chaim Weizmann Postdoctoral Fellow 1976-1978
Outstanding Young Scientist Award of the Maryland Academy of

Sciences, 1982.
 Scientific Achievement Award of the Washington Academy of
 Sciences, 1982
 Silver Medal of the Department of Commerce, 1983
 Samuel Wesley Stratton Award of the National Bureau of Standards,
 1987
 Arthur S. Flemming Award of the Washington Downtown Jaycees,
 1988
 Gold Medal of the Dept. of Commerce, 1993.
 Election to American Academy of Arts and Sciences 1995
 Election as a NIST Fellow, 1995
 Michelson Medal of the Franklin Institute 1996
 Distinguished Traveling Lecturer (APS-DLS) 1996-98
 Election to the National Academy of Sciences 1997
 Nobel Prize in Physics 1997
 Nobel Prize Citation: “for development of methods to cool and trap atoms with laser
 light” The 1997 prize was shared with Steven Chu of Stanford University and Claude
 Cohen-Tannoudji of the Ecole Normale Supérieure, Paris.
 Honorary Doctor of Science, Williams College 1998
 Doctor Honoris Causa de la Universidad de Buenos Aires 1998
 Arthur L. Schawlow Prize in Laser Science (APS) 1998
 Honorary Doctor of Science, Juniata College 1999
 American Academy of Achievement Award 1999
 Gold Medal of the Pennsylvania Society 1999
 Richtmeyer Award of the Am. Assoc. of Physics Teachers 2000
 Election to the European Academy of Arts, Sciences and Humanities
 (titular member), 2000
 Condon Award of NIST 2002
 Archie Mahan Prize of the OSA
 Election as an Honorary Freeman of the Worshipful Company of
 Scientific Instrument Makers, London 2003
 Election as an alumni member of Juniata College's chapter of Omicron Delta Kappa, the
 National Leadership Honor Society 2004
 Election as an Honorary Member of the Optical Society of America
 Appointed an Academician of the Pontifical Academy of Sciences 2004.