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FINAL PROGRESS REPORT
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"Spontaneous Force Optical Traps"

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Project Description

From mid 1987 to the present we have been funded to study spontaneous force optical traps and their application. In the first section of this proposal we will report on the work which has been carried out during this period, primarily concentrating on the period from fall 1990 to the present. The extensive list of publications and lectures which have come out of this work are given at the end of this section. In the second section we discuss the work we propose to do during the grant period 10/93 to 9/96. The relevant references are listed at the end of each respective section (page 9 and page 24) The budget follows the second section.

Section 1. Report on work done during the past grant period..

During the past grant period (10/90 - present) we have made advances in laser trapping and cooling on several fronts. These efforts cover a spectrum which goes from developing new technology which has immediate application in the construction of better atomic clocks at one end, to developing basic physics ideas on how to achieve a Bose condensed vapor, at the other. This latter subject is one where it is likely to be many years before the full implications of this proposed new state of matter, and its possible applications are fully realized.

I. Growing importance of work done during '87-'90 grant period.

Before discussing our progress during the past 2.5 years, it might be worth noting how the work done under the previous grant period ('87-'90) has grown in significance as it has become more widely appreciated and our results applied.

a) Our work was the first to identify light induced collisional loss and hyperfine-state collisional loss in optical traps.[1] Our interpretation has now become universally accepted, and the techniques we demonstrated for studying these processes have become widely used. This has been largely responsible for the establishment of a subfield of collision physics devoted to the experimental and theoretical study of these ultracold collisions.

b) We provided the first demonstration and interpretation of radiative repulsion between atoms in optical traps.[2] The concepts and results we put forth are now considered basic to the behavior of optically trapped atoms and are used in most experiments involving optically trapped atoms. After a number of years of effort, rigorous theoretical efforts by several groups are now confirming the details of our basic model for the atom-atom interactions. Groups at MIT and ENS have developed experimental techniques based on our model which allow them to attain higher densities in optical traps, and there is theoretical work which extends our model to explain why the temperature depends on the density and number of trapped atoms.

c) In this period we introduced the technology of the vapor cell optical trap[3] and diode lasers for cooling and trapping[4]. These are well on there way to becoming standard tools of the atomic physics community. They are now used widely in laser cooling and trapping experiments, and the application of trapping and cooling to a broader range of problems in physics and metrology. In the past few years several companies have begun to sell diode lasers with grating feedback. as a commercial product. Our demonstration of the usefulness

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of this technology was a significant component in the growth of interest in this market, and some of the designs of the commercial products are very similar to what we developed.
d) Rincon Research Corporation is continuing commercial development of a cs atomic clock based on our vapor cell diode laser trap[5]. The company has now received a large federal grant (much more than our ONR grant) to carry out this effort.
d) Finally, our magnetically trapped atoms with a temperature of 1 microKelvin still stands as the lowest kinetic temperature ever produced[3]. Although this is of limited scientific importance, it has brought considerable attention[6] and favorable publicity to the general field of laser trapping and cooling, particularly because it was achieved with a relatively simple and inexpensive apparatus..

II. Accomplishments during current (10/90 to present) grant period.

This work has involved the development of many new experimental techniques and technology in addition to carrying out a number of measurements. In actual practice all of this work is intertwined, but for the purposes of this report we have classified the work according to the time scale of its possible applications. While the central focus of work during this period was to attain the density and temperature conditions needed for Bose-Einstein condensation of a trapped cesium vapor, we have also pursued new experimental ideas and techniques which have more immediate applications and significance. In the section discussing the development of ideas relating to BEC we provide some overview of how these technologies relate to the central focus.

a) Development of technology and experimental techniques with potential for immediate application to improved atomic clocks and other areas.

1. We completed a careful characterization of our diode laser system which uses optical feedback from a grating to narrow and control the laser output spectrum. We then published a detailed discussion of the performance such a system and how to construct it.[7] This article has received very wide circulation (we have received several calls from people with "third-hand" copies) and there have been many requests for preprints and reprints.

2. We demonstrated that with a very simple coupling scheme and a low power microwave source it was possible to put substantial modulation sidebands on a grating-feedback-diode-laser at microwave frequencies. We have produced sidebands at the frequencies corresponding to the hyperfine transitions in cesium and rubidium and demonstrated that using this technique it was possible to make a good vapor cell optical trap with only a single laser, rather than the two which have been used previously.[8] This simplification is an obvious benefit in a commercial product such as an atomic clock, as well as for many other experiments which use optical traps. We have also used a laser with modulation sidebands to drive the cesium clock transition by a two-photon Raman process.[9] This has been done before; however, this is the first time it has been done with a grating stabilized lasers which, as we have shown in our previous work, are far more useful and reliable devices than free-running diode lasers. This demonstration shows that it will be possible to make a diode laser trapped atom clock without the need for a microwave cavity. This will greatly simplify the actual construction of the instrument and reduce its size.

b) Technology/science with potential application on an intermediate time scale.

1) We continued our studies of the vapor cell trap.[10] Although this type of trap was quickly adopted by many researchers, there had been no detailed study of the capture process, and hence no clear idea of how to choose parameters to optimize collection rate, which is the primary quantity of interest. Also it was impossible to reliably predict how well it would work for new systems. We carried out a study in which we examined how the collection process depended on magnetic field gradient, laser power, laser beam diameter, and laser frequency. We also studied the effects of modulating the laser frequency. Because many of these factors are interrelated, thus making a complex multidimensional parameter space, it was necessary to obtain a large amount of data. We also carried out an extensive computer modelling of the capture process which was compared with the data in order to fully understand the capture process. Ultimately our model agreed very well, even surprisingly well considering the complexity of the system, with the data. Although it is not at all obvious a priori, we found that the basic capture process can be approximated quite well as a simple one dimensional slowing of the atom due to a counterpropagating laser beam. The other laser beams have surprisingly little influence, and the multilevel nature of the atoms makes a rather simple correction. In the course of this work we refuted a number of claims which had been made in the literature which were based on incorrect assumptions. These included predictions as to the beneficial effects of the magnetic field and of chirping the laser frequency. In fact our experiments showed, and our model explained, that the little effect the magnetic field has on the capture process is largely detrimental, and that chirping reduces the capture rate. Finally, our work showed that the optimum diameter of the trapping laser beams is much larger than anyone had previously realized.

2) We have studied a number of new types of magnetic traps for holding optically cooled atoms. First, we carried out the first demonstration of an AC magnetic trap.[11] This trap has the unique feature that, unlike all previous magnetic traps, it can contain atoms in their lowest spin state. This is likely to be important for achieving and/or studying Bose condensation in a magnetically trapped system because it eliminates the possibility of spin-flip collisional loss from the trap. This loss process has been the primary obstacle to attaining Bose-Einstein condensation in magnetically trapped hydrogen. Furthermore, although our recent work has indicated that it is likely that BEC can be attained in heavy alkalies which are in higher energy spin states, it has been predicted that the spin-flip loss rate will be much higher in the BEC state. Thus it is likely that, for longer term studies and applications, the atoms will need to be confined in a trap similar to our AC trap. Our measurements of the trap depth, oscillation frequencies and the dynamics of the trapped atoms agreed well with our predictions.

After demonstrating the AC trap and studying how it trapped very low temperature cesium atoms, we realized that the only relevant parameters in the trapping were the ratio of mass to magnetic moment of the object to be trapped, and its velocity. This means that if one has an object with the same values of these parameters as our cold cesium atoms it will also be confined in this trap. We found that macroscopic pieces of ferromagnetic material would satisfy this criteria, and thereby could be trapped. We successfully demonstrated and published this concept.[12] This provides a new type of magnetic suspension system which has a number of unique features which may find use in specialized applications.

We also made the first demonstration of a new type of DC magnetic trap which we call a "baseball" trap because the coil windings resemble the seams on a baseball.[13] Although this type of trap was proposed some time ago, it was it was thought to be of little value and was never pursued. However, we realized that its perceived deficiencies were not necessarily serious and it had some features which are very valuable when it is used with optically trapped and cooled atoms. First, there is no zero of the magnetic field in the trap so there are no Majorana transitions leading to trap loss. Second, it is unique in allowing convenient optical access to the center of the trap along three perpendicular axes. This is very important for laser cooling, and, as our work has shown, optical probing of magnetically trapped atoms is a very powerful technique for doing a variety of experiments. Third, this type of trap is a very efficient design in that it provides a relatively large confinement force for a given current, compared to other types of magnetic traps. This confinement force is more important than the depth of the trap when carrying out collision studies and in attaining BEC. We used this "baseball" trap for carrying out the low temperature cesium elastic scattering experiments discussed below.

Our final accomplishment involving magnetic trapping technology was the demonstration of "multiple loading" of a magnetic trap.[11,14] This was done by optically trapping atoms in a region of relatively high pressure and then launching them upward into a magnetic trap. The atoms were optically pumped so that they saw the magnetic trapping fields as a potential energy hill rather than a valley. They would be launched with just the right velocity so that they would come to a stop at the center of the magnetic trap. Pulsed magnetic fields were used to focus the cloud to a small image at the center of the trap. Laser light would then be used to optically pump them into the spin state which was confined by the magnetic fields. This allowed us to put many clouds from the optical trap into the magnetic trap without disrupting the atoms which were already there. Although this technique has obviously great potential to produce very high densities of magnetically trapped atoms in a region of very low background pressure, it practice we found we were unable to achieve densities as high as we had hoped. The primary reason was aberrations in the magnetic focusing. Aberrations in optical systems have been studied at great length and various ways have been found to reduce them. There have been similar developments in the field of charged particle focusing by electric and magnetic fields. However, here we are dealing with the focusing of neutral atoms moving at finite speeds through magnetic fields, which is a subject on which there is very little work, and the results from the previous two fields are of limited use. One obvious way to reduce the effect of aberrations is simply to start with much larger clouds, but this would require a high power ti-sapphire laser which ONR was unable to provide the funds to purchase. Without that option, in order to realize the full potential of multiple loading it appears that a substantial amount of time developing the field of neutral atom magnetic optics will be required. Because that is beyond the scope of this research program, we have turned to other approaches to get higher densities.

c) Fundamental science with potential long term applications

The central direction of this research program during the past grant period has been working to produce the conditions necessary for Bose-Einstein condensation (BEC) in a dilute vapor of cesium. The necessary condition is to reach a combination of temperature and density such that the Debroglie wavelength is larger than the interparticle spacing. Our thinking as to the best way to achieve this has evolved as we have explored various experimental approaches, obtained new data, and as we have gained new insights as to the relevance of various factors. Part of this evolution has also resulted from our knowledge of the theoretical calculations of Verhaar's group which have been carried out in response to our requests. Although we are still some distance from the experimental realization of BEC, our work of the past few years has resulted in a major change in the perception of ourselves and others about this field. When we proposed the idea, BEC in a vapor of laser cooled alkali atoms was considered highly speculative with little hope of success and many unknowns. Now many of these unknowns have been eliminated and it appears that it is very likely just a question of "when" rather than "if". This has resulted in an explosion of interest in the field with many groups now pursuing the goal, many using techniques closely related to what we have proposed.

Our approach from the beginning was to use optically cooled and trapped atoms which would then be loaded into a magnetic trap.[15] The magnetically trapped atoms would then be cooled by evaporation. This seemed attractive because evaporative cooling of magnetically trapped hydrogen had already demonstrated that it could reach temperatures far below the photon recoil limit of laser cooling. It remains the only cooling technique which has reached that limit in 3 dimensions. The trapped hydrogen work was limited by spin-flip and three-body collisional loss. Our initial hope several years ago, which has been largely confirmed, was that because of the lower temperatures which could be achieved in cesium it would be possible to work at densities where the collisional loss processes would not be a problem.

The demonstration of the AC trap showed that it was possible to trap atoms and completely eliminate the spin flip trap loss. At that time it was thought that the primary impediment to achieving BEC would be this loss, but the low temperature elastic scattering cross section was completely unknown. It is this cross section which determines the density required to allow rethermalization of the sample, and hence evaporative cooling. However, as discussed above, we found that we could not achieve high enough densities using the technique of multiple loading of the AC trap to attain evaporative cooling. We then decided to carry out a more detailed analysis of the exact relationship between the cross section and the critical density for evaporative cooling, and set out to measure the relevant elastic scattering cross section. On general grounds we expected it to be large because of the large polarizability of cesium, but theoretical efforts to calculate it were unsuccessful because it was excessively sensitive to the exact position of the last bound state in the potential, and hence the form of the potential.

We have carried out a Monte Carlo simulation of evaporative cooling and rethermalization of a cloud of cesium atoms trapped in harmonic potential.[13,16] We find that there must be at least 150 elastic collisions during the time an atom remains trapped in order for evaporative cooling to lead to an increase in phase space density. If this collision rate is achieved, the phase space density will continue to increase and evaporative cooling can continue down to arbitrarily low temperatures. We then set out to measure the elastic collision cross section at very low temperatures. This was quite challenging because it involves measuring the transfer of nothing but kinetic energy between atoms (no state changes). Also the amount of energy transferred in on the order of 10^{-9} eV, which is vastly smaller than what had been detected in other collision experiments, even the ultralow temperature collisions such as we had studied previously. We developed a new experimental technique for carrying out this measurement. A very low temperature cloud of cesium atoms was put into a magnetic trap with the kinetic energy not equally partitioned between the different directions. Then we watched how long it took for the energy to be redistributed in the cloud as it tended towards thermal equilibrium. This allowed us to observe energy transfers as low as 10^{-10} eV/(sec atom). This extraordinary sensitivity allowed us to successfully measure the Cs-Cs S wave cross section, and thus gave us the design parameters for an apparatus which will allow us to cool to the BEC transition temperature.[13] Although the cross section is not as large as we might have hoped, it does confirm our intuition of years ago that the ratio of the cross sections for "good" (elastic) collisions to "bad" (spin-flip loss) is far better for heavy alkalies than it is for hydrogen. In this work we also measured the heating of the trapped atoms due to glancing collisions of very hot background atoms. These collisions are somewhat interesting in their own right because, although the incident atom have a very large amount of angular momentum, because the energy transfer is so small the collision must be treated quantum mechanically rather than classically.

During the course of this work we have come to realize that the ratio of the good to bad cross sections is favorable enough that, unlike the hydrogen case, the primary oncern in heavy alkalies is in achieving the required density rather than suppressing spin flip loss collisions. For this reason we believe that it will be best to start with a DC magnetic trap, and only switch to the AC trap if it becomes necessary at very low temperatures. There are several other reasons for the attractiveness of the DC traps which have come out of our study of the route to BEC. First, we realized that turning up the trap spring constant will enhance the evaporative cooling rate. Although it does not increase the phase space density directly, magnetically compressing the atoms does increase the elastic collision rate and hence evaporative cooling and thus indirectly leads to phase space compression. Much larger spring constants can be achieved with DC magnetic traps than with AC. Second, we realized that, unlike hydrogen, alkali atoms have m levels of the lowest hyperfine state which can be trapped in a DC magnetic trap. At very low temperatures, there is a centrifugal barrier which suppresses the spin-flip collision loss from these states in a DC trap. To take advantage of this barrier one must operate at a low bias field, but the DC magnetic traps we have developed make that possible. After we realized this, we asked Verhaar to carry out a more detailed calculation of the magnetic field dependence of cross sections for atoms in this particular spin state. The calculations of his group confirmed our initial hypothesis that the spin flip loss would be suppressed, but they also revealed an exciting new phenomena.[17] This phenomena is that there are strong resonances in the collisional processes as a function of magnetic field. We expect to be able to see these and use them to increase the rate for desirable collisions. Furthermore, this also suggests that it will be possible to tune the sign of the scattering length by changing the magnetic field. This should have a profound effect on the nature of the Bose condensate. The work in hydrogen was started because it was known that the triplet state had no bound states and the sign of the scattering length corresponded to a net repulsive potential. We have now come to realize that it is very likely possible to have magnetically trapped alkalies in states where the sign (and to a large extent the magnitude) of the scattering length can be selected by the experimenter! This not only makes it a much more interesting system to explore, but also makes it much more likely that BEC can be achieved in these systems. Thus, as information has been gained about magnetically trapped alkalies we have become far more confident that it will be possible to achieve BEC in this system. This view is becoming rapidly accepted, as evidenced by the number of groups which have recently begun work in this area, building on our ideas.

References- past work

1. D. Sesko, T. Walker, C. Monroe, A. Gallagher and C. Wieman, "Collisional losses from a light force atom trap," Phys. Rev. Lett. 63, 961 (1989).
2. T. Walker, D. Sesko and C. Wieman, "Collective behavior of optically trapped neutral atoms," Phys. Rev. Lett. 64, 408 (1990). D. Sesko, T. Walker and C. Wieman, "Behavior of neutral atoms in a spontaneous force trap," J. Opt. Soc. Am. B 8, 946-958 (1991)
3. C. Monroe, W. Swann, H. Robinson and C. Wieman, "Very cold trapped atoms in a vapor cell," Phys. Rev. Lett. 65, 1571-1574 (1990).
4. C. Wieman and L. Hollberg, "Using diode lasers for atomic physics," (invited review) Rev. Sci. Instrum. 62, 1-20 (1991).
5. C. Monroe, H. Robinson and C. Wieman, "Observation of the cesium clock transition using laser-cooled atoms in a vapor cell," Opt. Lett. 16 50-52 (1991).
6. Discover Magazine, Feb. 1993 cover story, and N. Y. Times Science Times section C1 May 28, 1991
7. K. B. MacAdam, A. Steinbach and C. Wieman, "A narrow band tunable diode laser system with grating feedback, and a saturated absorption spectrometer for Cs and Rb," Am. J. Phy. 60, 1098-1111 (1992).
8. C. J. Myatt, N. R. Newbury and C. E. Wieman, "Simplified atom trap using direct microwave modulation of a diode laser", Optics Letts., 47 649-651 (1993).
9. to be published
10. K. Lindquist, M. Stephens and C. Wieman, "Experimental and theoretical study of the vapor-cell Zeeman optical trap," Phys. Rev. A 46, 4082-4090 (1992).
11. E. A. Cornell, C. Monroe and C. Wieman, "A multiply-loaded, ac magnetic trap for neutral atoms," Phys Rev. Lett. 67, 2439-2442 (1991).
12. C. Sackett, E. Cornell, C. Monroe and C. Wieman, "A new magnetic suspension system for atoms and bar magnets," in press, Am. J. Phys., March, 1993.
13. C. Monroe, E. Cornell, C. Sackett, C. Myatt and C. Wieman, "Measurement of Cs-Cs elastic scattering at T=30 μK", Phys. Rev. Lett., January 25, 1993, and Chris Monroe Ph. D. thesis, Univ. of Col. 1992.
14. C. Monroe, E. Cornell and C. Wieman, "The low (temperature) road toward Bose-Einstein condensation in optically and magnetically trapped cesium atoms," Proceedings, Enrico Fermi International Summer School on Laser Manipulation of Atoms and Ions, Varenna, Italy, July, 1991.
15. C. Wieman, C. Monroe and E. Cornell, "Fundamental Physics with optically trapped atoms" in Laser Spectroscopy X, (M. Ducloy, ed., World Scientific, 1992) pp. 77-82.
16. to be published.
17. E. Tiesinga, A. Moerdyk, B. Verhaar, H. Stoof, Phys. Rev. A.46, 1167 (1992)

Publications and talks

There have been 16 papers and 42 lectures given on this work during the past grant period, as listed below.

Publications

C. Wieman and L. Hollberg, "Using diode lasers for atomic physics," (invited review) Rev. Sci. Instrum. 62, 1-20 (1991).

D. Sesko, T. Walker and C. Wieman, "Behavior of neutral atoms in a spontaneous force trap," J. Opt. Soc. Am. B 8, 946-958 (1991).

C. Monroe, W. Swann, H. Robinson and C. Wieman, "Very cold trapped atoms in a vapor cell," Phys. Rev. Lett. 65, 1571-1574 (1990).

C. Monroe, H. Robinson and C. Wieman, "Observation of the cesium clock transition using laser-cooled atoms in a vapor cell," Opt. Lett. 16 50-52 (1991).

C. Wieman, T. Walker, D. Sesko and C. Monroe, "Curious behavior of optically trapped atoms" in Atomic Physics 12, (J. C. Zorn and R. R. Lewis, Eds., American Institute of Physics, 1991), pp. 58-73.

H. Patrick and C. Wieman, "Frequency stabilization of a diode laser using simultaneous optical feedback from a diffraction grating and a narrowband Fabry-Perot cavity," Rev. Sci. Instrum. 62, 2593-2595 (1991).

E. A. Cornell, C. Monroe and C. Wieman, "A multiply-loaded, ac magnetic trap for neutral atoms," Phys Rev. Lett. 67, 2439-2442 (1991).

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K. MacAdam, A. Steinbach and C. Wieman, "A narrow band tunable diode laser system with grating feedback, and a saturated absorption spectrometer for Cs and Rb," Am. J. Phy. 60, 1098-1111 (1992).

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Arimondo, W. Phillips, and F. Strumia, Eds., 1992) pp. 361-377.

C. Monroe, E. Cornell, C. Sackett, C. Myatt and C. Wieman, "Measurement of Cs-Cs elastic scattering at T=30 μK," Phys. Rev. Lett., 70 414-417 (1993).

C. Myatt, N. Newbury and C. Wieman, "Simplified atom trap using direct microwave modulation of a diode laser," Optics Letts., 47 649-651 (1993).

S. Gilbert and C. Wieman, "Laser cooling and trapping for the masses," Optics & Photonics News, to be published July, 1993.

M. Stevens, K. Lindquist and C. Wieman, "Optimizing the capture process in optical traps," J. Hyperfine Int., to be published.

Talks on ONR work by Carl Wieman

"Laser trapping and cooling," University of Wyoming, Physics Department Colloquium, Laramie, Wyoming, March, 1990.

"Laser trapping and cooling," Invited lecture, IQEC'90, Anaheim California, May, 1990.

"Laser trapping and cooling," Division of Atomic, Molecular and Optical Physics of APS Annual Meeting, Santa Cruz, California, May, 1990.

"Laser trapping," 12th International Conference on Atomic Physics, Ann Arbor, Michigan, July, 1990.

"Laser trapping and cooling," Telluride Workshop on Laser Cooling and Trapping, Telluride, Colorado, August, 1990.

"Laser trapping and cooling," University of Oregon Physics Retreat, Eugene, Oregon, October, 1990.

"Laser trapping," Max-Planck-Institute-for Quantum Optics Colloquium, Munich, Germany, October, 1990.

"Laser trapping," College de France, Lecture, Paris, France, October, 1990.

"Laser trapping and cooling," Clarendon Laboratory Lecture, Oxford University, Oxford, England, October, 1990.

"Research Physicist in Curriculum Development," Plenary Lecture, APS Workshop, Denver, Colorado, November, 1990.

"Laser trapping and cooling," Johns Hopkins Applied Physics Laboratory Colloquium, Baltimore, Maryland, December, 1990.

"Laser trapping," Snowbird Conference, Salt Lake City, Utah, January, 1991.

"Laser trapping," Plenary Lecture, Annual Meeting of the German Physical Society, March, 1991.

"Laser trapping," Seminar, SUNY, Long Island, New York, March, 1991.

"Expanding the limits of table top physics," Loeb Lectures, Harvard University, Cambridge, Massachusetts, April, 1991.

"Laser trapping of radioactive isotopes," Invited lecture, ISOLDE Workshop, Leysin, Switzerland, May, 1991.

"Fundamental physics with cold trapped atoms," Invited lecture, TENICOLS'91 Conference, Villetaneuse, France, June, 1991.

"The low (temperature) road to Bose-Einstein Condensation," Invited lecture, Enrico Fermi Summer School, Varenna, Italy, July, 1991.

"Laser trapping and cooling," Invited lecture at the Optical Society of America Annual meeting, 1991.

"Cold collisions and Bose Condensation," Invited lecture at the Harvard Smithsonian Symposium on Cold Atom Collisions. (This Symposium was largely devoted to theoretical analysis and experimental extensions of our previous work on cold collisions.) 1991.

"Laser cooling and trapping," Physics Department Colloquium given at Pennsylvania State University, February, 1992.

"Laser cooling and trapping," Physics Department Colloquium at Colorado School of Mines, March, 1992.

"Laser cooling and Bose-Einstein condensation," Physics Department Colloquium, University of Texas, Austin, February, 1993.

"Laser cooling and trapping," Physics Department Colloquium, University of Northern Colorado, Greeley, April, 1993.

Interviews, Other

An article was done about Carl Wieman's work in Discover Magazine, February, 1993 issue.

A science spot was done on Carl Wieman's work by CNN Science News television, 1993.

Talks on ONR Work by Postdocs and Students

"Getting to Bose-Einstein condensation in a cesium vapor," lecture given by postdoc Eric Cornell, University of Virginia, Spring, 1991.

"An oscillating-gradient magnetic trap for strong-field-seeking neutral atoms," lecture given by postdoc Eric Cornell, 1991 QELS meeting, Baltimore, Summer, 1991.

"Magnetic traps, multiple loading schemes, and Bose condensation," Lecture given by postdoc Eric Cornell, Joint Institute for Laboratory Astrophysics, Summer, 1991.

"Cesium atoms below a microkelvin: New techniques and new results," Invited lecture by postdoc Eric Cornell, ILS Meeting, Monterey, California, September, 1991.

"Atom trapping tricks: New routes to Bose-Einstein condensation in a vapor," Departmental Colloquium presented by postdoc Eric Cornell, University of Virginia, Charlottesville, South Carolina, November, 1991.

"Getting to Bose condensation in an atom trap," Departmental Colloquium given by postdoc Eric Cornell, University of California, Berkeley, December, 1991.

"An experimental route to Bose condensation," Joint departmental colloquium and JILA seminar given by postdoc Eric Cornell, University of Colorado, January, 1992.

"Getting to Bose condensation in an atom trap," Departmental colloquium given by Eric Cornell, Haverford College February, 1992.

"Getting to Bose condensation in an atom trap," Modern Optics Seminar given by postdoc Eric Cornell, MIT, Cambridge, February, 1992.

"Magnetically trapped atoms, cold collisions, and Bose condensation," Departmental Colloquium given by postdoc Eric Cornell, Colorado State University, Fort Collins, September, 1992.

"Atom traps, nanoelectronvolt collisions, and Bose Condensation," Invited lecture given by Eric Cornell, University of Chicago, March, 1993.

"Prospects for Bose condensation in heavy alkalis," Invited lecture given by Eric Cornell, APS Division of Atomic, Molecular, and Optical Physics, Reno, May, 1993.

"Beyond the atom: Can we optically cool molecules, crystals and beer?" Atomic Physics seminar given by Eric Cornell, NIST, Gaithersburg, Maryland, June, 1993.

"Topics in Bose condensation and light," Invited lecture at the Workshop on New Theoretical Methods in Quantum Optics given by Eric Cornell, University of Colorado, July, 1993.

"Studies of the vapor cell atom trap," Contributed paper, coauthor (given by postdoc M. Stephens) at the DAMOP meeting, 1992.

"The quest for Bose Einstein Condensation," invited paper presented by graduate student Chris Monroe at the QELS/CLEO Convention Center, Anaheim, April, 1992.

"Possibility of Bose Einstein Condensation," Lecture given by graduate student Chris Monroe at the NIST Ion Storage Group Seminar, Boulder, Colorado, November, 1992.

"Cooling ^{87}Rb in a magnetic trap," talk given by postdoc Nate Newbury at the DAMOP meeting, Reno, Nevada, May, 1993.