Laser Cooling of Matter

INTRODUCTION

Laser cooling of neutral atoms in the past decades has been a very active and increasingly visible field of research. This was highlighted by the Nobel prize in physics in 1997, awarded to S. Chu, C. Cohen-Tannoudji, and W. D. Phillips, and by the realization of Bose–Einstein condensation and the corresponding Nobel prize in 2001 to E. Cornell, W. Ketterle, and C. Wieman.

The history of the investigation of the mechanical effects of light on matter dates to very old times. Indeed, Kepler's explanation of the tail of comets is considered the first mention that radiation exerts a pressure. The beginning of the past century saw the first experimental investigations of the mechanical effects of light on atoms and molecules, but it has been the use of the laser that brought a breakthrough in the understanding of their dynamics and led to the seminal proposals of laser cooling of atoms and ions that appeared in the mid 1970s. However, it was not until the mid 1980s that the manipulation of atomic motion by means of light-induced forces started to develop rapidly.

Since then several milestones have been reached, involving new concepts, such as magneto-optical trapping and sub-Doppler and subrecoil cooling, as well as new technologies, such as semiconductor diode lasers. Most of those breakthroughs have spread very quickly among the various research groups following announcements at conferences and publications in journals. Among those journals, two special issues of the *Journal of the Optical Society of America B* that appeared in 1985 and 1989 have had particular influence.

In the issue on "Mechanical Effects of Light" in 1985, several contributions focused on light forces on two-level atomic transitions, with mainly theoretical papers and a few experiments testing general principles. Just a few years later, in 1989, a second special issue on "Laser Cooling and Trapping of Atoms" proved how active this field had become. Here several contributions presented experimental results on cooling of atoms and ions, while theory papers analyzed the effect on the atomic motion caused by the coupling between the atom's complex internal structure and light fields.

As the evolution of this field has shown, these contributions set many of the foundations of laser cooling for the years to come. Laser cooling of atoms and ions became a well-established research area, allowing for the development of other fields, such as atom optics, metrology, and quantum information processing with atomic systems. In 1995 there was the major breakthrough in the field of cold atoms, with the achievement of Bose–Einstein condensation with dilute gases. In parallel with these achievements with neutral atoms, the field of ion cooling and trapping experienced remarkable advances. The steep confinement inherent in ion traps has led to the development of techniques that have allowed the ion motion to be cooled into the ground state of the confining potential. This fulfilled the prerequisite for the first experimental realizations of the coherent control of the quantum mechanical dynamics with single and then with few ions, successfully implemented in the past years. Today, magneto-optical trapping, Sisyphus cooling, and sideband cooling are standard preliminary steps in experiments with cold atoms. Nevertheless, laser cooling remains an active field of research in the atomic physics community, for instance, in experiments aiming at stable atomic clock transitions and, in the ion-storage ring community, in experiments aiming at ordered ion and electron beams. The area of applications has also been extended, now including the problems of realization of cold molecules, cold neutral plasmas, cold solid-state samples, and cold antimatter. In this context, ideas, concepts, and techniques developed for basic systems such as atoms and ions are useful and could be adapted to the more complex systems, and vice versa.

It has thus been our idea to try to combine in a single issue contributions from different communities in order to allow easy access to such papers across community borders. To give the reader access to neighboring research communities, this issue contains invited review papers as well as original contributions. This provides a general introduction to the various fields (with many references leading back to important original contributions) together with a sample of original papers reporting on state-of-the-art cooling techniques.

This special feature has been motivated by a conference (Cooling 2002) organized by some of us in Sweden in the summer of 2002, where we gathered speakers from different communities to present their work on cooling. We have regrouped the contributions into four sections. The first section is about "Cooling and Trapping Schemes of Neutral Atoms," with a subsection dedicated to "Cooling and Trapping of Nonalkali Atoms." The second section is devoted to the well-established field of "Cooling and Trapping of Ions" and is followed by a section collecting contributions on "Condensed Phase Cooling." Finally, the section entitled "Cooling of Interacting Systems" contains contributions about, among other topics, cooling of atoms in a cavity field, cold molecules, and cold neutral plasmas.

We hope that this issue will further the knowledge acquired in different communities and stimulate new ideas for "laser cooling of matter."

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