Scientific report for the conference "Ultracold PARYS"

(Ultracold **P**lasma **A**nd **Ry**dberg **S**ystems)
Campus du CNRS (Gif-sur-Yvette, France), Monday 14 – Wednesday 16 March 2005

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The international workshop entitled «"Utracold PARYS" on "Utracold **P**lasma **A**nd **RY**dberg **S**ystems » has known a large success with the participation of 52 persons; number initially expected and wanted for a living and fruitful workshop. It was a three-day scientific workshop (March 14-16, 2005), which took place in the CNRS Campus at Gif-sur-Yvette, under the auspices of the European Science Foundation Network CATS "**C**ollisions in **A**tom **T**rap**S**" (coordinated by Nigel Mason) and the INTERCAN "**INTER**national Cold Atoms Network" (coordinated by Robin Kaiser). The aim of this workshop was to explore the frontier between ultra-cold Rydberg gases and plasmas, fields which has known a rapid development these last few years and which has aroused the interest of several experimental and theoretical groups. The program with 37 invited talks has covered the fields of ultracold plasmas (experiments: 3 papers and theory: 3 papers), ionization processes in cold Rydberg gases (3 papers), long-range dipole-dipole interactions (6 papers) and also properties of cold atomic ensemble of Rydberg atoms (6 papers), Rydberg atoms or ions in an atomic Bose-Einstein condensate (4 papers). Due to the many fields involved, the program has also covered the frontier areas as collective motion in cold atomic cloud (1 paper), electronic collisions with cold atoms (2 papers), spectroscopy and manipulation of Rydberg molecules (3 papers), correlated plasma with trapped ions (2 papers), hot plasmas (2 papers), astrophysics (1 paper) and anti-hydrogen (1 paper). We have to add to these invited papers the presentation of ten posters in the field. The abstracts of the different papers are on the web site, and most of the files of the presentations can also be found on this site:
http://www.lac.u-psud.fr/LAC/PARYS/PARYS4.htm

The statistics of the conference can be summarized as follows. Over the 52 participants, 38 have an European nationality (11 German, 10 French, 5 Dutch, 4 English, 2 Italian, 2 Austrian, 2 Danish, 1 Luxemburg, 1 Swiss). The other participants are 9 American citizens, 1 Canadian, 1 Brazilian, 1 Tunisian, 1 Iranian, 1 Chinese. We have been careful that at least one person of each experimental or theoretical group on the main fields of Ultracold PARYS be present. The aim of the Ultracold PARYS workshop was to explore the frontier between ultra-cold Rydberg gases and plasmas, fields which know a rapid development these last few years. It is the first international workshop really completely devoted to this subject. The consequence was the presence of most of the leaders of the research groups. A few papers have nevertheless presented by young researchers, postdocs or even graduate students. Unfortunately, only three papers can be presented by researcher women.

Scientific background and prospects:

Tremendous advances in cooling and trapping of neutral atoms have paved the way towards a new class of experiments with ultracold (T << 1K) atomic or molecular systems. Along these lines, the exploration of ultracold Rydberg gases and ultracold plasmas reveals interesting and unexpected behaviour. For most plasmas, the lowest possible temperature is that at which there are enough energetic electrons to ionize neutral atoms to replenish the ions and electrons lost to walls. Since electron energies of at least 5 eV (55,000 K) are required for impact ionization, it is not surprising that a 10,000 K plasma is considered a cold plasma. While ultracold one component plasmas have been studied for some time, it was not until five years ago that the first nearly neutral ultracold plasmas were reported (Killian *et al.*, PRL 83, 4776 (1999)). Such a plasma can be created by photoionization of atoms in a magneto-optical trap using a pulse laser. The initial observation of this phenomenon was made using 50 µK Xe atoms, but since then similar results have been found using cold Rb, Cs or Sr atoms. To a very good approximation, the initial electron energy is determined by the excess photon energy above ionization limit of the photoionization laser, while the initial positive ion temperature is that of the initially trapped atoms before ionization. After a first burst of photoelectrons leaves the initial laser-atom interaction region, the excess positive charge of the ions traps the remaining electrons, forming a quasi-neutral plasma. Electron collisions rapidly, on a nanosecond time scale, thermalize the electrons, typically to temperatures of tens of Kelvin, which is an extraordinary cold plasma. A variety of fascinating phenomena has been observed in these initially well characterized plasmas, including the expansion of the plasma and recombination to form Rydberg atoms, both of which occur on the time scale of tens microseconds. The fact that such clean experiments can be done has stimulated theoretical interest, and several theoretical papers on the subject have appeared. The papers presented at the conference (for both experiments and theory) have shown the recent advancement in the fine understanding of the behaviour (dynamics, electronic recombination…) of ultracold plasmas. We can note the difficulties to obtain clean measurements of electronic temperature, and the promising experiments with earth alkaline atoms to image the ionic cloud or to laser cool it. Papers in frontier areas (trapped ions, hot plasmas, star clusters, antihydrogen, photoionization spectroscopy…) have shown the potential great richness of the ultracold plasma field. *Finally a challenge in ultracold plasma physics is to reach the correlated regime where the Coulomb energy dominates the kinetic energy.*

Electronic systems in highly excited states touch a wide range of research. Indeed, long-range interactions between cold Rydberg atoms leads to many-body phenomena, “engineering” and manipulation, dipole blockade and quantum information… During the conference, several papers have so considered the frontier between the frozen Rydberg gas, which can be considered as a quasi amorphous solid, and the dipole gas, where the dynamics of the Rydberg gas is more determined by the long-range forces between the Rydberg atoms. The links of Rydberg atoms with plasma physics has also been noticed from a long time. Soon after the creation of an ultracold plasma was reported, a related phenomenon was observed. Cold atoms in a magneto-optical trap excited to Rydberg states of principal quantum number with n > 30, were found to evolve spontaneously to plasma on a time scale of ~ 1 µs (Robinson *et al.*, PRL 85, 4466 (2000)). A similar phenomenon had been observed previously in a thermal sample of cesium atoms but at a density a factory 10,000 higher (Vitrant *et al.*, J. Phys. B 15, L49 (1982)). The evolution of cold Rydberg atoms into a plasma was described by the following scenario. Immediately after laser excitation Rydberg atoms are ionized by photoionization by blackbody radiation and collisions between hot (300 K) and cold (~ 1 mK) Rydberg atoms. The electrons produced leave the magneto-optical trap volume. Just as in the Xe ultracold plasma experiment, when enough ions accumulate, their macroscopic charge traps subsequently produced electrons, which oscillate back and forth through the cloud of Rydberg atoms, rapidly ionizing them and leading to an ultracold quasi-neutral plasma. Several papers, both experimental and theoretical, have been devoted to the study of this evolution, in particular for the ignition of the mechanism, for the role of superelastic collisions, for the possibilities in cooling such a plasma by adding Rydberg atoms… More generally, the role of spurious ions in an atomic Rydberg ensemble, or the role of Rydberg atoms or ions in a quantum gas have been discussed. The experimental approaches evolve towards high resolution excitation of Rydberg sample and new setups for trapping ions and/or electrons.

In conclusion, cold dense samples of Rydberg are fascinating because they are at the intersection of atomic physics plasmas physics, and solid state physics. The links with several fields of the physics have been underlined during this workshop, leading to fruitful discussion, and possible further collaborations. The possibility to have regular workshops on the subject has also been discussed, for helping the establishment of such collaborations. Finally, we have also evoked the organisation of publications of joined articles in a special issue of the European Physical Journal D to increase the visibility of this novel subject concerning “ultracold plasma and Rydberg systems”. We think that this workshop has been really useful to all the participants for defining more clearly the challenges for such a field.

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