The first test experiment performed at the electron cooler of storage rings in Lanzhou

L J Meng1,2, X Ma1, H P Liu1, X D Yang1, J W Xia1, H S Xu1, Z G Hu1, X L Zhu1, M Wang1, R S Mao1, D C Zhang1, L J Mao1, J Li1, G H Li1, Y Liu1, J C Yang1, Y J Yuan1, J H Zheng1, X T Yang1, G Q Xiao1, W L Zhan1
1 Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, 730000, China
2 The Graduate University of the Chinese Academy of Sciences, Beijing, 100049, China

E-mail: x.ma@impcas.ac.cn

Abstract. The cooler storage ring (CSR) project was launched in 2000 at the Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou. In 2007, the installation was completed and the commissioning of CSRs gained great success, a new highly precise generation of collision experiments will become accessible even for the heaviest ion species. A commissioning RR experiment was performed at the electron cooler with Ar18+ ions, the results are reported. And the further development of the experiments at cooler will be discussed.

1. Introduction
Recombination between electrons and ions is one of the most fundamental atomic collision processes for all kinds of plasmas in the universe. The cross sections and the rate coefficients are required for understanding of astrophysical processes and fusion plasma. For the investigation of these processes, the experimental environment at the electron cooler storage ring is in particular well suited. Here the interaction of cooled heavy ions with electrons can be studied under well controlled conditions via the spectroscopy of projectile x-rays and by the analysis of projectile charge-exchange. In the electron cooler environment, two processes compete: dielectronic recombination (DR) and radiative recombination (RR). The rate coefficient, most important parameter in plasma modelling, can be obtained for various electronic configurations and in addition, detailed information on the atomic structure can be deduced. Theoretical investigations of the DR process show that DR might be a powerful tool for the investigation of the influences of nuclear effects on the atomic structure and may even be used to obtain model independent information on the nuclear structure, e.g. the nuclear charge radius. This has just been confirmed experimentally at the experimental storage ring (ESR) in Darmstadt [1].

2. The cooler storage rings and experimental devices
The cooler storage ring (CSR) project was launched in 2000 at the Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou. The project consists of two rings, the main cooler storage ring (CSRm) and the experimental cooler storage ring (CSRe), as shown in figure 1. The CSRm works as a synchrotron which can accelerate the ions energy up to GeV/u (for light ions) and up to 500MeV/u (for heavy ions) [2]. Both CSR rings are equipped with electron cooling devices, the third
generation of electron cooler, which can produce different electron density distributions [3]. In 2007, the installation was completed and the commissioning of CSRs gained great success, a new highly precise generation of collision experiments will become accessible even for the heaviest ion species. The CSR provides unique and unprecedented conditions for experiments based on the use of highly charged ions and in particular for research in the realm of atomic and nuclear physics. The interaction of the brilliant beams of cooled high-Z ions with low-dense gaseous matter as well as with electrons can be now studied under almost completely background free experimental conditions and with highest luminosity [4].

Between CSRm and CSRe a radioactive beam line was constructed, defined as RIBLL2 in figure 1. The ions in CSRm are accelerated to energy range of 100–500 MeV/u and then extracted fast to produce radioactive ion beams by nuclear fragmentation or highly charged heavy ions by thin foil stripping. The secondary beams (RIB or highly charged heavy ions) will be accepted and stored by the experimental ring, and RR and DR experiments can be performed at the CSRe cooler. DR experiments at CSRe will open a novel way for studying the ground-state properties of nuclei far from stability.

The recombination experiments were carried out at the electron cooler, the charge changed ions were detected by a particle detector located down stream after the dipole magnet, see figure 2 for details. In the present experiment, a plastic scintillator is employed as a particle detector. The particle detector is installed in a detector pocket which isolates the detector from ultra-high vacuum environment by a

Figure 1. Overview of the Cooler Storage Rings and the heavy ion research facility at Lanzhou.
30µm stainless steel window. The position of the particle detector together with the pocket can be controlled by a step motor through computer network.

![Figure 2](image)

**Figure 2.** Layout of the electron cooler section at CSRm and configuration of the particle detectors.

3. Experimental results

The first test experiment was carried out at CSRm cooler with \( \text{Ar}^{18+} \) ions at an energy of 21.44 Mev/u. The electron beam energy was set at the cooling point (11.765 keV) and the electron beam was always switched on during injection. The cooling of the beam is very effective, figure 3 shows the coasting beam lifetime in the CSRm, where electron beam intensities were set to 200mA, 150mA, 100mA, 50mA, and 0mA in the experiments. As can be seen from the fig. 3, for higher electron beam intensities cooling is better. The stored beam is lost quickly when the cooling electron beam was switched off right after the injections. This indicates that the interactions between stored ions and residual gas, the instability in magnetic fields may be the dominant contributions.

![Figure 3](image)

**Figure 3.** Stored ion beam lifetime measured at different cooling electron beam intensities.
Registered ion counts as a function of the product of the electron beam intensity $I_e$ and the coasting beam intensity $I_f$ in units [mA$^2$]. The data points are measured at different electron beam intensities. The solid line represents a linear fit to the data points.

In the electron cooler the ions recombine with electrons resulting in the reduction of one charge unit of the projectile. The ions deviate the coasting beam orbit in the magnetic field and are recorded by the particle detector. Figure 4 shows the registered ion counts versus the electron beam intensities and the coasting beam intensities. It is clear that the recombination rates are proportional to the products of the electron beam intensities and the coasting beam intensities.

4. Outlook
In the commissioning of the CSR C$^{6+}$, Ar$^{18+}$ and Xe$^{44+}$ ions were injected, accelerated, and stored, and the first radiative recombination experiments was performed at the electron cooler. It is a good opportunity to study the interactions of highly charged ions with matter at the CSR in Lanzhou. Further RR and DR experiments are being prepared. A program has been launched for fast fine detuning of the electron beam energy relative to the stored ion beam in order to perform high precision DR experiments.

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