L.3: Development of a magneto-optical trap for cooling of fermionic ^{83}Kr atoms

The laser cooling and trapping of noble gas atoms is usually accomplished in the excited state, because the ground state excitation using lasers is difficult. For example, the difference between the first excited state and the ground state for the Krypton atom is ~10 eV (~ 120 nm). Therefore noble gas Kr atoms are generally excited to $4p^5 5s[3/2]_2$ metastable state (denoted as Kr*) by using RF discharge. This state has lifetime of ~ 40 s and practically serves as ground state for the laser cooling purpose. A laser at 811.5 nm wavelength is used to excite transition between this metastable state ($4p^5 5s[3/2]_2$) and the higher state $4p^5 5p[5/2]_3$. The laser cooling of metastable bosonic and fermionic isotopes of Krypton atom provides an opportunity to study cold collisions in fermionic and bosonic mixture, ionization physics, etc. The applications of cooling and trapping Kr atoms include nanolithography, geological dating, atom trap trace analysis (ATTA), etc.

Laser cooling of even isotope of Kr atoms such as ^{82}Kr, ^{84}Kr and ^{86}Kr is less complicated as they have no hyperfine structures due to the absence of nuclear spin. Consequently, no repumping laser is required for cooling of even isotopes of Kr atom. On the other hand, the laser cooling of any fermionic isotope, such as ^{83}Kr, is more complicated due to complex hyperfine structures involved which requires several repumping lasers along with the cooling laser. In the absence of repumping laser beams, cooling process ceases due to transfer of the atoms into the dark hyperfine states during absorption-emission cycle. In order to bring atoms back into the cooling cycle, one or more repumping laser beams are required in addition to a cooling beam.

In the case of atomic beam loaded Krypton magneto-optical trap (MOT), pre-cooling of ^{83}Kr atoms is performed in a Zeeman slower device before the final cooling and trapping in the MOT. Therefore cooling and repumping laser beams are needed for MOT as well as for Zeeman slower, in order to load ^{83}Kr*-MOT. Recently, the MOT for laser cooling of ^{83}Kr* atoms has been setup successfully and trapping of ^{83}Kr* atoms in it is demonstrated in a laboratory at Laser Physics Applications Section, RRCAT.

In this atomic beam loaded ^{83}Kr*-MOT, pre-cooling of ^{83}Kr* atoms is done in a Zeeeman slower before loading of MOT. In the Zeeman slower, the Doppler shift in the cooling laser frequency for a moving atom is compensated by the Zeeman shift in the atomic transition frequency. This results in resonant interaction of the properly detuned Zeeman slower cooling laser beam with the fast moving atoms. Two repumping laser beams tuned near to F=11/2 to F'=13/2 (R1) and F=9/2 to F'=11/2 (R2) hyperfine transitions and a cooling laser beam (C) tuned red side to F=13/2 to F'=15/2 closed transition are required for pre-cooling in Zeeman slower.

The schematics of the experimental setup along with the CCD image of the ^{83}Kr* cold atom cloud (inset) is shown in Fig. L.3.1. We used circularly polarized beams in the Zeeman slower which were red detuned by ~70 MHz relative to cooling and repuming transitions. Three red detuned (~6 MHz) circularly polarized cooling laser beams were used in retro-reflection mode for MOT formation. Here two repumping laser beams R1 and R2 were mixed in one of the cooling beams (Fig. L.3.1). A pair of quardupole coils was used to obtain a magnetic field gradient of ~10 Gauss/cm in axial direction to form MOT. The Krypton gas first flows into RF discharge glass tube through the gas inlet chamber (C1). The glass tube has inner diameter of 10 mm and length of 150 mm. The Kr* atoms are produced in this discharge tube by RF-driven discharge (frequency~30 MHz). The Analysis chamber (C2) is evacuated to a pressure (~10^{-5} Torr), lower than that of discharge tube (~10^{-3} Torr), to facilitate the flow of excited Kr atoms into this chamber. This gas subsequently flows into the Zeeman slower and finally to the MOT chamber (~10^{-8} Torr). The pumping of the setup was performed by several Turbo Molecular Pumps. A stainless-steel tube of inner diameter 5 mm and length 50 mm has been used between the discharge tube and analysis chamber (C2) for creating a desired differential pressure. The Zeeman slower (length ~ 80 cm) along with an extraction coil are connected between pumping chamber and MOT chamber to slow down the ^{83}Kr* atomic beam.

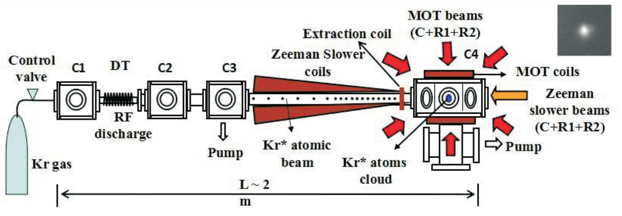

Fig. L.3.1: Schematics of the experimental setup for MOT of ^{83}Kr atoms. C1: Kr gas inlet chamber, C2: analysis chamber, C3: pumping chamber, C: cooling beams, R1 and R2: repumping beams. The inset shows the CCD fluorescence image of cold atom cloud of ^{83}Kr* atoms in the MOT.*

After successful operation of Zeeman slower for ^{83}Kr* atomic beam, the loading of ^{83}Kr* atoms in MOT was successfully observed. The temperature and the number of ^{83}Kr* atoms in the cloud was estimated to be ~ 500 μK and ~ 1×10^5 atoms respectively with atom number density of ~ 1×10^7 atoms/cm^3.

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