Production of cold metastable helium atoms in a cryostat

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Abstract

Aiming at constructing a compact magneto-optical trap for metastable helium gas (He^*), we have produced cold He^* atoms in a simple helium cryostat. The He^* atoms are generated by a RF discharge in a vapor above a liquid He bath, which is cooled to 1.2K by pumping the cryostat. The temperature and density of the He^* atoms are estimated to be 30 K and 10^{11} atoms/cc, respectively, from laser spectroscopy of the 2^3S_1-$2^3P_{2,1}$ transitions.

Key words: Bose-Einstein condensation, helium, laser cooling

1. Introduction

Metastable helium (He^*) is an attractive atomic species for studies of quantum effects, such as Bose-Einstein condensation (BEC) and Fermi degeneracy. First, the quantum effects can be easily observed because of its light mass. Second, one can control the abundance of Bosonic and Fermionic species, ^4He and ^3He, with an arbitrary ratio. This enables us to create a novel Bose-Fermi quantum many-body system. Third, the metastable state, which is inevitably produced for laser cooling, has large internal energy. This may provide us a new method of detecting individual quantum-degenerate atoms, employing highly sensitive devices such as a microchannel plate.

There has been a number of studies of laser cooling He^*, including the observations of BEC[1]. In most of the experiments, the He^* atoms were produced by a DC discharge in a gas. Since the He^* is light and the discharge thermalizes the gas, a transversal cooling system and a long Zeeman slower are subsequently required for loading a magneto-optical trap (MOT). Although the discharge region is cooled by liquid N_2[2], the system has to be very large scale and complicated, and it makes the loading of the MOT less efficient. For the intensive studies of He^* quantum gas, it is crucial to develop a compact, and efficient He^* source.

In order to construct a compact MOT without the Zeeman slower, we attempt to make a new source of intense, and low velocity He^* atoms. We make a RF discharge in a low temperature vapor phase above a pumped liquid He bath, which is cooled to 1.2 K. In this paper we report our preliminary study of production and characterization of the He^* atoms.

2. Experimental

The cold He vapor is prepared above a liquid He bath in a cryostat. The liquid He is stored in a transparent glass dewar, whose inner diameter is 42 mm. The liquid is cooled to 1.2 K by pumping the vapor. The vapor pressure is about 100 Pa.

We have made the He gas discharge by an inductive method, employing a 10-turns solenoid made of 1.0 mm diameter Cu wire. In the first setup, the coil was mounted inside the He dewar, and fixed about 50 cm from the bottom of the dewar. To study the influence of joule heating from the coil, we have then wound the coil around the outside of the He dewar. In this second configuration, the coil is cooled by liquid N_2 bath, and its position, i. e. the distance between the coil and the

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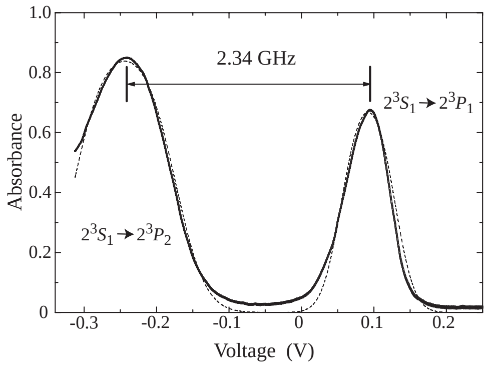

Fig. 1. Adsorbance at the two transitions. The data are taken as a function of the controller voltage, which corresponds to the laser frequency. The dashed line is a Gaussian fit. The He* temperature is estimated to be 30 K from the linewidths (see text).

liquid He surface, can be widely varied. A continuous RF of 50 MHz and of typically 3 W is supplied to the coil, to discharge the He vapor.

We have performed laser spectroscopy of the triplet 2S-2P transitions at the wavelengths of 1083 nm. The resonant light is produced by an external cavity semiconductor laser. The light is introduced to the region around the coil, and the absorption of light by the transitions is monitored by a photodiode. We measure the intensity of light passing through the He gas regime, changing the laser frequency for several GHz by applying a triangular voltage to the laser controller. We observe two resonant lines, which correspond respectively to the 2^3S_1-2^3P_2 and 2^3S_1-2^3P_1 transitions. The two transitions are separated by 2.34 GHz. We derive absorbance as a function of voltage applied to the laser controller. From the intensity and the Doppler broadening of the resonance lines, we have estimated the density and the temperature of the He* atoms.

3. Results

Figure 1 shows typical data of absorbance spectrum, obtained in the first configuration, where the RF coil was inside the He dewar. The data are plotted as a function of voltage applied to the laser controller. Because the laser frequency does not change in proportional to the applied voltage, the Doppler broadening is different between the two lines.

In order to estimate the He* temperature, we have made a preliminary analysis as follows: The data are divided into two resonance curves, the 2^3S_1-2^3P_2 and 2^3S_1-2^3P_1 transitions. For each absorbance peak, we assume a linear relationship between the laser frequency and the controller voltage, and make a fitting with a Gaussian function. The fitted curves are plotted in Fig. 1. We have estimated the temperature of the He* gas from the adsorbance linewidths.

As is easily seen, the 2^3S_1-2^3P_2 absorbance is more broadened than the 2^3S_1-2^3P_1 one is. Hence the temperature is overestimated from the former data, and underestimated from the latter. We have determined the temperature to be 30 K from the data of Fig. 1, by taking an average of the two estimated temperatures. The density of He* is estimated to be 10^{11} atoms/cm^{-3} near the location of the coil.

We have measured the He* temperature as a function of distance between the coil and the liquid surface. The temperature decreases monotonically with decreasing the distance, but it becomes to be kept constant at about 30 K as the coil approaches the surface within 10 cm.

After the RF is applied, the He* temperature starts to increase and saturates within a minute. This suggests that the gas temperature increases by the discharge, and it can be lowered by applying pulsed RF. We have found no significant difference in the He* temperature for the location of the coil; inside or outside the He dewar. This shows that the joule heating of the coil wire is ruled out from the cause of the He* heating.

To summarize, we have constructed a compact source of low temperature He* atoms, by utilizing a simple He cryostat. Improvements to obtain lower velocity, and higher density atoms are underway. A MOT which is directly connected to the He* source, is being constructed.

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