II-B Laser Cooling and Trapping of Metastable Helium Atoms

In the past two decades, extensive developments have occurred in the laser cooling and trapping of neutral atoms, with many workers reporting the application of these techniques to such diverse atomic species as alkali atoms, alkali earth atoms, and rare gas atoms. Among these, the helium atom is unique on account of its small mass, simple energy level structure, and easy availability in two isotopic forms (^{3}He and ^{4}He) of differing quantum statistics. For this reason, we have been studying the laser cooling and trapping of helium atoms.

II-B-1 New Design for Efficient Magneto-Optical Trapping of Metastable Helium Atoms

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The first step for Bose-Einstein condensation of metastable helium atoms is to realize an efficient magneto-optical trap (MOT). For this purpose, it is especially important to increase the intensity of a metastable atomic beam for loading the atoms into a MOT. To obtain an intense metastable beam, it is necessary to collimate the beam as tightly as possible. In our new apparatus, the metastable beam is collimated using a chain of corner cube prisms and laser beams with two detuned frequencies; the length of the collimation region along the atomic beam is 300 mm. The far detuned laser light can collimate more diverging atoms and the less detuned one collimates less diverging atoms. From our simulation, it is confirmed that this system can collimate an initial divergent beam with a spread of ±70 mrad at a velocity of 850 m/s into an almost collinear beam.

After deceleration through the Zeeman cooling process, the collimated metastable beam at a velocity of 150 m/s is deflected by an angle of 30 degrees using laser beams with curved wavefront, which are produced by a pair of cylindrical mirrors. The metastable beam is then introduced to a small glass cell, in which the atoms are trapped and further cooled for the Bose-Einstein condensation. Due to this deflection of the metastable beam, the trapping region is prevented from the attack of the intense ground state helium beam, and we can expect the longer lifetime of the trap.

While these atomic loading system is designed for a metastable beam source cooled with liquid nitrogen, we are preparing another system for liquid-helium-cooled metastable beam source in order to obtain a further intense metastable beam. Experiments with these systems are now in progress.

II-C Spectroscopic Studies on Atoms and Ions in Liquid Helium

Atoms and ions in liquid helium are known to reside in bubble-like cavities due to the Pauli repulsive force between electrons. Physical properties of these exotic surroundings are determined by the potential energy of the impurity-He$_n$ system, the surface tension energy of the liquid helium, and the pressure-volume work. Spectroscopic studies of such impurity atoms and ions in liquid helium are expected not only to give information on the structure and dynamics of the bubbles but also to contribute to the study on the property of superfluid liquid helium.

II-C-1 Laser Spectroscopy of Eu Atoms in Liquid ^{3}He and ^{4}He

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Spectra of impurity atoms in liquid helium often explicitly reflect physical properties of the liquid. In this meaning, it may especially be interesting to investigate the spectral difference between impurity atoms in liquid ^{3}He and ^{4}He, because each liquid has much different physical properties at a temperature below the lambda point (2.1 K); for example, the fluidity is super and normal for ^{4}He and ^{3}He, respectively, the dispersion relation is well determined for ^{4}He but not well for ^{3}He, and the number density and surface tension are much different between ^{3}He and ^{4}He.

In this study we have experimentally obtained some spectra of Eu atoms in liquid ^{4}He and ^{3}He. Excitation spectra of the $4f^6(^7F)5d6s^2\ ^8F_{7/2} \leftarrow 4f^76s^2\ ^8S_{7/2}$ transition at several temperatures are shown in Figure 1. With decreasing the temperature, very sharp spectra appear and their intensities both in liquid ^{4}He and ^{3}He are increased. It is reasonable to interpret these sharp spectra as zero phonon lines, because the interaction between He atoms and the inner-shell electron excited in Eu atom is quite weak during the transition. Side bands are also seen, but they are only in the upper energy side for both liquid ^{4}He and ^{3}He. The shift of the zero phonon line and the spectral width of the side band are both smaller for liquid ^{3}He than for ^{4}He. This fact can be understood by the difference in the number density and surface tension between ^{4}He and ^{3}He: smaller number density and surface tension of ^{3}He result in the smaller spectral shift and width. An especially interesting spectral feature is that, only for liquid

^{4}He, some peaks other than the phonon side bands are also seen at a temperature of 1.1 K, but they are not seen for ^{3}He. It is quite possible that these are roton or maxon spectra of liquid ^{4}He. Further investigation is now in progress.

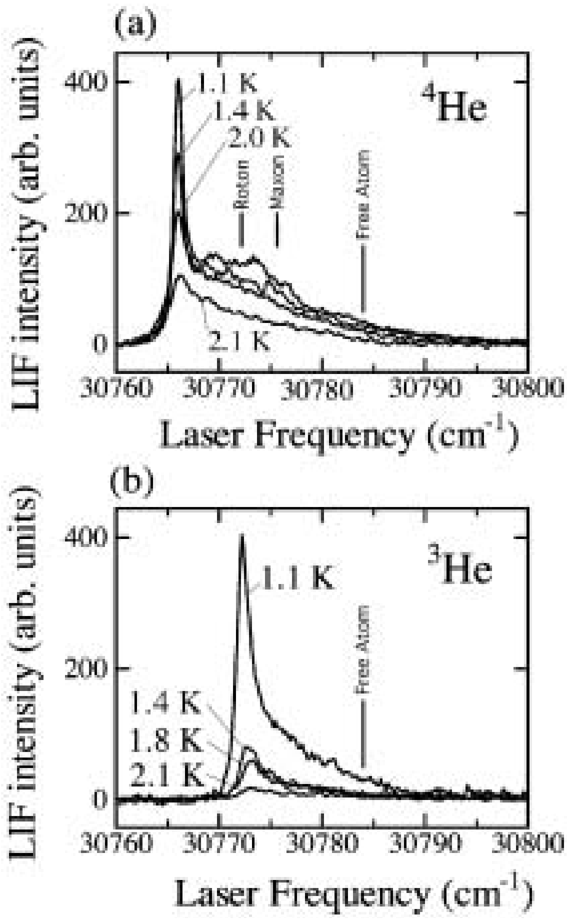

Figure 1. Excitation spectra of the $4f^6(^7F)5d6s^2\ ^8F_{7/2} \leftarrow 4f^76s^2\ ^8S_{7/2}$ transition of Eu atoms in (a) liquid ^{4}He and (b) liquid ^{3}He at several temperatures.