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 Liquid Helium Cooled Metastable Helium Beam Source for Laser Cooling/Trapping Experiments

MORITA, Norio

For laser cooling/trapping of atoms, it is preferable that the initial velocity of an atomic beam is as small as possible, because the higher velocity requires the longer length for stopping the atoms and, therefore, results in the more significant divergence of the beam. For the helium atom, this requirement is more difficult to satisfy, not only because of the small mass, but also because the atoms that can be decelerated and trapped by lasers are only metastable atoms; metastable atoms are, more or less, heated through the excitation procedure, such as discharge. For this reason, metastable helium atoms are, so far, usually produced by discharge in liquid nitrogen cooled circumstances. In the present study, however, we have developed a discharge cell cooled by liquid helium, and investigated the performance of this metastable atomic source. As a result, for ^{4}He, we have found that the metastable beam velocity can be as small as 250 m/s at the peak of the velocity distribution with a width of about 50 m/s, while it is as large as 750 m/s with a liquid nitrogen cooled discharge cell. For ^{3}He, the peak velocity and width are 290 m/s and about 60 m/s, respectively. These results mean that for both ^{4}He and ^{3}He the length enough to stop the atoms is only 15 cm, which is one ninth of the one necessary for stopping metastable atoms produced with a liquid nitrogen cooled source. We can expect that such dramatic shortening of the stopping length will much reduce the difficulty in the cooling/trapping experiments on metastable helium atoms.

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 physical properties of superfluid liquid helium.

II-C-1 Laser Spectroscopic Studies of Eu Atoms in Liquid and Solid Helium: Helium Pressure Dependences

MORIWAKI, Yoshiki[1]; MORITA, Norio
([1]Toyama Univ.)

Spectra of Inner shell transitions in Eu atoms distributed in liquid helium have relatively sharp peaks accompanied with long tails of phonon sidebands. The sharp peaks are zero-phonon lines (ZPL), and are largely shifted along with the sidebands, depending on the helium pressure. In this study, we have investigated this pressure shift for both ^{4}He and ^{3}He over a wide pressure range including the solidification region. The pressure shifts of ZPL's in excitation spectra of the inner shell transition $4f^6(^7\mathrm{F})5d6s^2\ ^8\mathrm{F}_{7/2} \leftarrow 4f^7 6s^2\ ^8\mathrm{S}_{7/2}$ at 1.1 K are plotted in Figure 1. As seen in Figure 1, for both ^{4}He and ^{3}He the ZPL is shifted toward longer wavelength at approximately the same rate, which is about 0.06 nm/MPa. For ^{4}He, the ZPL is slightly split above the solidification pressure (2.5 MPa), and two kinds of split pattern are seen, depending, for example, on the procedure of solidification. This might suggest the presence of two crystal structures in solid ^{4}He. Above the solidification pressure, the ZPL wavelength is almost constant and the overall spectral profile keeps unchanged. However, the spectral intensity abruptly increases when the pressure is increased across the solidification pressure. This may indicate that, in solid ^{4}He, Eu atoms are trapped in the solid and cannot freely diffuse. On the contrary, for ^{3}He, neither such abrupt increase of spectral intensity nor the split pattern of the ZPL is observed, while the ZPL wavelength and overall spectral profile keep unchanged above the solidification pressure, just like ^{4}He. This may suggest that, unlike ^{4}He, Eu atoms can move around and diffuse in ^{3}He even in the solid state.

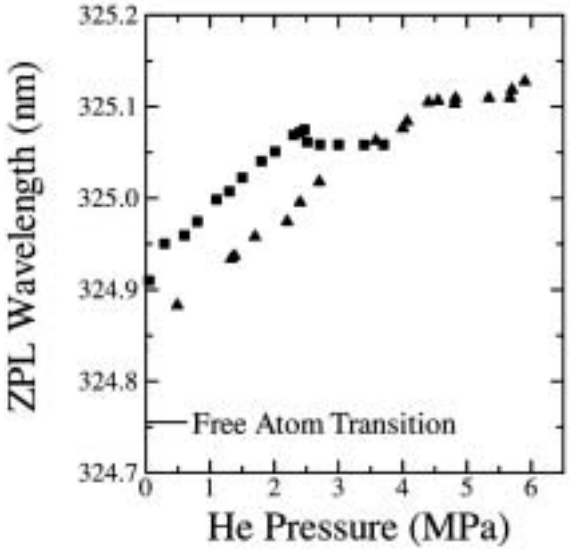

Figure 1. Helium pressure dependence of the wavelength of the zero-phonon line (ZPL) in the excitation spectrum of the $4f^6(^7\mathrm{F})5d6s^2\ ^8\mathrm{F}_{7/2} \leftarrow 4f^76s^2\ ^8\mathrm{S}_{7/2}$ transition of Eu atoms in liquid and solid helium at 1.1 K; ■ represents the ZPL for ^{4}He, and ▲ the one for ^{3}He. At 1.1 K, ^{4}He solidifies at 2.5 MPa, while ^{3}He at 4.3 MPa.

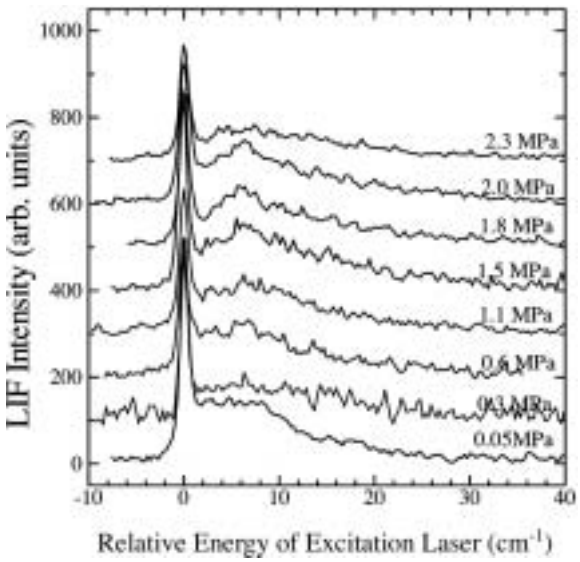

Figure 1. Excitation spectra of the $4f^6(^7\mathrm{F})5d6s^2\ ^8\mathrm{F}_{7/2} \leftarrow 4f^76s^2\ ^8\mathrm{S}_{7/2}$ transition of Eu atoms in liquid ^{4}He at several pressures; the peak shift of the zero-phonon line is ignored for all spectra.

II-C-2 Laser Spectroscopic Studies of Eu Atoms in Liquid ^{4}He: Roton Spectra

MORIWAKI, Yoshiki[1]; MORITA, Norio
([1]Toyama Univ.)

In our previous studies on spectra of the inner shell transition $4f^6(^7\mathrm{F})5d6s^2\ ^8\mathrm{F}_{7/2} \leftarrow 4f76s^2\ ^8\mathrm{S}_{7/2}$ of Eu atoms in liquid ^{4}He, we found some structure of the phonon sideband tail of this transition, and inferred that this structure may be roton spectra because the energy separation between the structure and zero-phonon line roughly agreed to the excitation energy (6 cm^{-1}) of the roton. In order to confirm this inference, in the present study, we have investigated the pressure dependence of the spectra: excitation spectra of this transition at 1.1 K have been measured at several pressures. The results are shown in Figure 1, in which peak shifts of the zero-phonon lines are ignored. In Figure 1, we can find that the peak on the long tail of the phonon sideband is gradually shifted toward lower energy with the increase of the liquid pressure. This characteristic behavior is the same as seen for roton peaks previously observed in two-roton Raman spectra.[1)] This fact strongly supports the inference that the peaks in our spectra are also due to the roton excitation.

Reference

1) K. Ohbayashi *et al.*, *Phys. Rev. B* **58**, 3351 (1998).