II-B 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 interesting information on the structure and dynamics of the bubbles but also to contribute to the study on physical properties of superfluid liquid helium.

II-B-1 Laser Spectroscopic Studies of Mg Atoms in Cold Helium Gas

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In our previous laser spectroscopic study[1)] on Mg atoms in liquid helium, since both the peak shift and width of the emission spectrum of the $3s3p\ ^1P \rightarrow 3s^2\ ^1S$ transition were significantly larger than those expected from a simple bubble model, we inferred that a $Mg(3s3p\ ^1P)He_{10}$ exciplex was formed in a bubble, just similar to the case of excited alkaline atoms in liquid helium. Such exciplexes are known to have a characteristic structure in which helium atoms form a ring in the nodal plane of the excited *p*-electron of an impurity atom, and our theoretical spectrum calculated based on a similar exciplex model showed better agreement with the experimental spectrum in comparison with the one calculated with a simple bubble model. In the case of Mg, however, unlike alkaline atoms, the 3*s* electron lies around the nodal plane of the 3*p* electron, and so there is a possibility that the 3*s* electron prevents helium atoms from forming the ring structure due to the Pauli repulsive force. This means that the formation of the $Mg(3s3p\ ^1P)He_{10}$ exciplex is still ambiguous. In the present study, therefore, we have investigated the emission spectrum of Mg atoms in cold helium gas, and have compared it with the calculated spectrum as well as the experimental spectrum obtained for liquid helium. Consequently, as seen in Figure 1, we have found that the spectrum for gaseous helium is in very good agreement with the one calculated based on the model of the $Mg(3s3p\ ^1P)He_{10}$ exciplex formation. This result strongly supports our inference that Mg atoms in liquid helium can form $Mg(3s3p\ ^1P)He_{10}$ exciplexes in spite of the presence of the 3*s* electron.

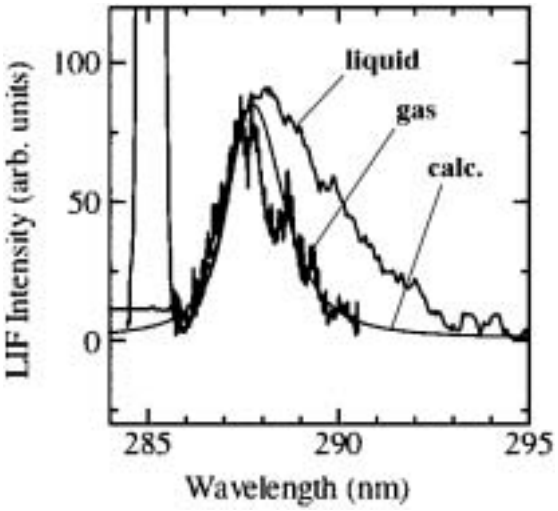

Figure 1. Emission Spectra of Mg atoms in gaseous and liquid helium at 1.4 K. A calculated spectrum is also plotted.

Reference

1) Y. Moriwaki and N. Morita, *Eur. Phys. J. D* **5**, 53 (1999).

II-B-2 Observation of Remarkable Difference between Mobilities of Impurity Eu atoms in Solid Helium-3 and Helium-4

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We have measured emission spectra of Eu atoms in liquid and solid helium at 1.4 K over a wide pressure range across the solidification pressure. Consequently, as seen in Figure 1, we have found that the behavior of the spectral intensity across the solidification pressure remarkably differs between ^3He and ^4He; while for ^4He the intensity drastically increases above the solidification pressure, no significant change is seen for ^3He across the solidification pressure. This difference can be interpreted as a manifestation of the difference in mobility of Eu atoms. Since the helium atom is so light that even its zero-point vibration has a quite large amplitude, the position exchange between neighboring helium atoms frequently occurs even in solid due to the tunnel effect. Therefore, each helium atom in solid helium always moves around, and impurity atoms can also move and diffuse following the motion of helium atoms. No significant change seen for ^3He across the solidification pressure means that impurity Eu atoms in solid ^3He can diffuse with almost the same mobility as in liquid. On the other hand, the drastic intensity increase seen for ^4He shows that the mobility of Eu atoms in solid ^4He is significantly small in comparison with the one in solid

^{3}He. A possible reason may be the larger mass of ^{4}He atom, which results in a smaller amplitude of the zero-point vibration. Another possible reason might be that solid ^{4}He is (partly) a Bose condensate at 1.4 K, while there is no condensate in solid ^{3}He. In a Bose condensate many helium atoms coherently vibrate, and this might cause the less position exchange between neighboring atoms.

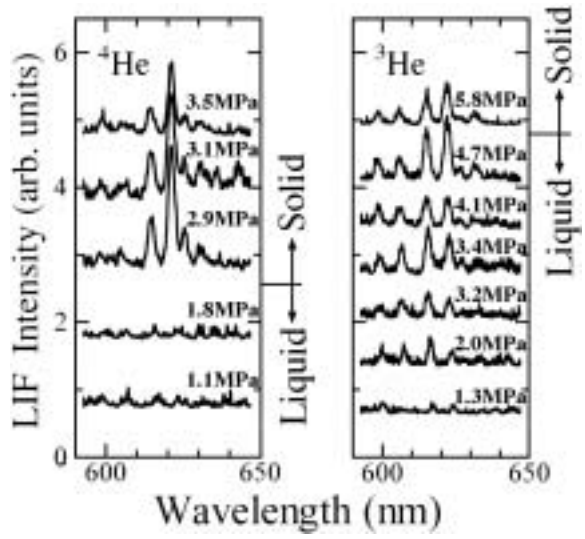

Figure 1. Pressure dependences of emission spectra of Eu atoms in liquid ^{3}He and ^{4}He at 1.4 K; liquid ^{4}He and ^{3}He at this temperature solidify at about 2.5 and 5.0 MPa, respectively.