論文 / 著書情報
Article / Book Information

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著者(和文)	宮澤裕貴
Author(English)	Yuuki Miyazawa
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Category(English)	Doctoral Thesis
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論 文 要 旨

THESIS SUMMARY

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学生氏名： Student's Name	宮澤　裕貴	指導教員（主）： Academic Supervisor(main)	上妻　幹旺
		指導教員（副）： Academic Supervisor(sub)	山口　昌英

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Ultracold atoms with a large magnetic moment interact with each other with long-range and anisotropic magnetic dipole-dipole interaction. Therefore, the nature is expected to be significantly different from that of other ultracold atoms. In recent years, strongly dipolar atomic species of Cr, Dy, and Er have been brought to quantum degeneracy and rich dipolar phenomena have been observed such as d-wave collapse, deformation of the Fermi surface, and Rosensweig instability, quantum droplets, and dipolar supersolid. Considering such results, I focused on the europium atom (Eu), which has a large dipole moment. Unlike other dipolar atoms such as Cr, Dy, and Er, Eu has stable bosonic isotopes with hyperfine structures. Therefore, the s-wave scattering length of bosonic Eu can be controlled with maintaining spin degrees of freedom. Bose-Einstein condensate with magnetic dipole interaction and spin degree of freedom is expected to show rich quantum phases where spin angular momentum and orbital angular momentum couple each other. Europium is a good candidate to search such quantum phases systematically.

In this thesis, I report on the first realization of Bose-Einstein condensate of europium atoms. This thesis in particular describes how to cool Eu atoms. Due to the complex energy structure of the Eu atom, the standard laser cooling method cannot be applied to create a Eu BEC. It is revealed in my master course study that the only $J¥rightarrow J+1$ strong transition has large optical leaks to six metastable states with a probability of 10^{-3}. This value is too high to slow down the Eu atomic beam, which makes it difficult to laser cool Eu. Considering the result, I optically pump atoms to $a^{10}¥mathrm{D}_{13/2}$ metastable state and implemented Zeeman slowing and magneto-optical trapping with a quasi-cyclic transition at a wavelength of 583¥,nm and nurtural linewidth of 8.2¥,MHz.

The starting point of this thesis is the metastable magneto-optical trap of europium mentioned above. Since the metastable state is not stable enough to produce a BEC, I optically pumped back the trapped cold metastable atoms to the ground state and captured them in a magneto-optical trap operating with a transition at a wavelength of 687¥,nm and a natural linewidth of 97¥,kHz. Although this transition has large optical leaks to three metastable states, I plugged the leaks by repumping atoms from the metastable state to the ground state with three color infrared laser lights. In this way, I successfully trap $4.7¥times 10^7$ ^{151}Eu atoms in the ground state. Thanks to the narrow natural linewidth of the cooling transition, the temperature reached to 6¥,$¥mu$K, which is a good starting condition for direct loading to an optical dipole trap. In addition, we measured the optical leak probabilities from the excited state to the metastable state, which was estimated to be $2.7¥times 10^{-2}$ in total.

Then we loaded the cold atoms to an optical dipole trap operating at a wavelength of 1550¥,nm for evaporative cooling, resulting in almost pure condensates of ^{151}Eu with $1.5¥times 10^4$ atoms. The effect of dipole-dipole interaction of the BEC was observed as the deformation of the expanding Eu condensate; the shape of the BEC after free expansion strongly depends on the orientation of the atomic dipole moments. By comparing the deformation of the condensate to the numerical simulation, I extracted an s-wave scattering length of $a_s =135¥,a_B$. In addition, I found a Feshbach resonance at a magnetic field of 1.3¥,G, and the shape of the condensate deformed in the vicinity of the resonance, which suggests a change of the s-wave scattering length.

This study paves the way for quantum simulation using a strongly dipolar BEC. The unique properties of Eu BEC might open new directions of investigation in the field of strongly dipolar quantum gases.