Magnetic field calibration system for measuring hyperfine splitting of ^{85,87}Rb atoms in superfluid helium

S. Sasamori,[*1,*2] A. Takamine,[*2,*3] K. Imamura,[*2,*4] Y. Hirayama,[*1,*2] T. Sensui,[*1,*2] S. Takahashi,[*1,*2] H. Ueno,[*2] and Y. Matsuo[*1,*2]

We are developing of laser spectroscopy method for unstable nuclei using superfluid helium (He II) as a stopping material for highly energetic RI beams with a nearly 100% efficiency. We applied the laser-radiofrequency (RF)/microwave (MW) double-resonance method for the neutralized RI atoms in He II. We can measure the energy splitting of Zeeman sub-levels hyperfine structures that reflect the properties of the nuclear structure using this method. We successfully measured the hyperfine structure splitting of stable ^{133}Cs atoms in He II with an accuracy and a precision of 10^{-6} using the laser sputtering method for introducing atoms into He II.[1)] Our next aim is measuring the hyperfine structure splitting energy of Rb, which has two natural isotopes, in He II with an accuracy and a precision of 10^{-6}. This will enable us the discussion of hyperfine anomalies of atoms in He II.

However, the inhomogeneity of the external magnetic field has hindered the achievement of this level of accuracy and precision in the measurement.[2)] We introduced a calibration system for external magnetic field compensation to solve this problem.

The system consists of two components. First, the magnetic field applied to the atom from the radio wave sweep is derived. Second, an external magnetic field correction coil is used to counteract the effects of the ambient magnetic field.

The system is expected to acquire date more reliable accuracy and precision than previous measurements.[2)]

A double resonance experiment was conducted using an Rb-encapsulated glass cell with a He buffer gas to evaluate the validity of this method.

The magnetic field can be calculated from the radiofrequency resonance spectrum using the following equation:

$$\frac{\Delta W_{zeeman}}{h} = g_F \times \frac{\mu_B}{h} \times B \tag{1}$$

The effect of magnetic field inhomogeneity should be added to the microwave resonance frequency. The atomic sub level energies is expressed by the Breit-Rabi formula:[4)]

$$E^B_{hfs}\left(F = I \pm \frac{1}{2}, m_F\right) = -\frac{\Delta E^{B=0}_{hfs}}{2(2I+1)} + g_I \mu_B B m_F \pm \frac{\Delta E^{B=0}_{hfs}}{2}\sqrt{1+\frac{4m_F x}{2I+1}+x^2} \tag{2}$$

We measured both the radiofrequency and microwave resonances at several magnetic fields and two polarizations of circularly polarized light σ^+ and σ^-. We performed a fitting using Eq. (2). The result is shown in Fig. 1.

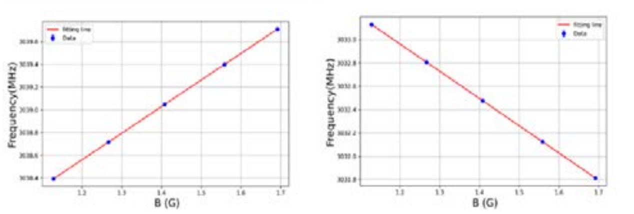

Fig. 1. Breit-Rabi fitting for the laser-microwave double-resonance frequencies under different magnetic fields with optical pumping with σ^+ (right) and σ^- (left) circularly polarized laser lights.

The derived hyperfine splitting was 3035.75 87(18) MHz under a zero magnetic field. The value of hyperfine splitting in a vacuum is 3035.732 439(5) MHz in a literature.[5)] The discrepancy between the measured and literature values is attributed to pressure shift, which occurs due to the helium buffer gas and microwave power shift; we conducted additional measurements. The pressure shift was measured in two Rb-filled glass cells at 100 and 300 torr. The hyperfine splitting under a zero magnetic field increased with the pressure increased. The pressure shift was thus derived as 227(18) Hz/Torr. The hyperfine splitting was derived as 3035.7360(37) MHz when the pressure shift was considered. The result agrees with that in the literature value within uncertainty. We found that the pressure shift should be considered when the splitting energy is discussed with six significant digits. The microwave power shift did not have an effect within the sixth significant digit.

We constructed a system to derive the transition frequency under a zero value magnetic field with an accuracy of six significant digits. We thus successfully developed a method of measuring the energy splitting of atoms in a helium environment with an accuracy of six digits solving magnetic field problems. We are planning to use this method to measure the hyperfine structure splitting of ^{85,87}Rb atoms in superfluid helium.

References
1) K. Imamura *et al.*, Hyperfine Interact. **230**, 73 (2015).
2) M. Doi *et al.*, RIKEN Accel. Prog. Rep. **53**, 154 (2020).
3) G. Breit, I. Rabi, Phys. Rev. **38**, 2082 (1931).
4) E. Arimondo *et al.*, Rev. Mod. Phys. **49**, 31 (1977).
5) E. Arimondo, M. Inguscio, P. Violino, Rev. Mod. Phys. **49**, 31 (1977).

*1 Department of Advanced Sciences, Hosei University
*2 RIKEN Nishina Center
*3 Department of Science, Kyushu University
*4 Japan Synchrotron Radiation Research Institute (JASRI)

DOI:10.34448/RIKEN.APR.58-176