Precision Determination of the Hyperfine Constant of 87Sr+

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Introduction

An ion-trap technique combined with a laser-microwave double resonance spectroscopy has great advantages in precision and in sensitivity to measure the hyperfine structure of the ground state of ions [1]. This is essential for the case of radioactive ions, since the interaction of ions with laser and microwave is observed many times before the radioactive decay of the ions. Also the Lamb-Dicke condition is realized by trapping the ions within a space smaller than the observing wavelength [2-3].

We have constructed an "on-line" ion-trap (RF-type), which is directly connected to an ISOL in order to study the nuclear magnetic moment and the hyperfine anomaly of unstable nuclei [4]. Until now we trapped stable strontium isotopes of mass number 88 and 87, and the ground state hyperfine splitting of $^{87}Sr^{+}$ had been measured with a precision of 10^{-6} (see ref. 5).

Figure 1 shows the low lying states of $^{87}Sr^{+}$. Due to an external magnetic field the hyperfine levels of $F = 4$ and $F = 5$ split into 9 and 11 magnetic sub-levels, respectively. The number of allowed transitions between the Zeeman levels is 27. Since some transition frequencies coincide in a weak field, 19 resonant peaks should be observed. A particularly narrow transition between $|F=4, m_F=0\rangle$ and $|F=5, m_F=0\rangle$ (hereafter denoted as 0-0 transition), whose energy is hardly sensitive to magnetic field fluctuations and inhomogenities, can be utilized to determine the magnetic hyperfine constant A with high precision.

In this paper we report on the remeasurement of A ($^{87}Sr^{+}$) with a precision of two orders of magnitude better than the previous one [5].

Measurements

The strontium ions were produced in an off-line surface-ionization source of the ISOL[8], accelerated up to 30 keV, mass-separated and then implanted onto a surface of a thin

Pt filament located at the ring electrode of the trap. The ions re-ionized by surface ionization were confined in the trap by collisions with buffer gas molecules (H_2 at 10^{-6} mbar). The trapped ions were irradiated by laser light of 421.6 nm for optical pumping and microwave for depumping, and the fluorescence was detected by a photon counting system while the microwave frequency was scanned.

Figure 2 shows the microwave spectra observed by the laser-microwave double resonance method. At a field strength of 0.17 G the peaks gathered within 1 MHz and nineteen narrow peaks and twenty broad peaks clearly appeared (Fig. 2(a)). The strength of the external magnetic field was controlled by three pairs of Helmholtz coils. Figure 2(b) shows the spectrum taken with a step of 100 Hz/ch without modulation near the 0-0 transition. Two narrow peaks of 0-0 and 1-0 plus 0-1 were observed. The broad peaks are considered to be due to a distribution of the efective modulation frequencies due to the ionic macro-motion resulting in the smearing of the side bands [9-10].

Determination of the hyperfine splitting frequency

The ground state hyperfine splitting frequency ν_0 of $^{87}Sr^+$ is given by

$$\nu_0 = \nu_{obs} + \Delta\nu_{shift} + \Delta\nu_{syn},$$

where ν_{obs} is the observed frequency from the peak fitting result, $\Delta\nu_{shift}$ the shift due to the external field as given by the Breit - Rabi formula [11], and $\Delta\nu_{syn}$(-3 Hz) is the correction of the microwave synthesizer (SYSTRON DONNER model 1720), whose time base was calibrated by a Cs frequency standard (HP 5061B) at the National Research Laboratory of Metrology.

In table 1 the experimental results of five runs are summarized. The final result of the weighted mean of the five values gives for the ground state hyperfine splitting of $^{87}Sr^+$ as

$$\nu_0 = 5{,}002{,}368{,}363 \pm 57 \text{ Hz},$$

where the error is a simple sum of statistical (±27 Hz) and systematic (±30 Hz) ones. The systematic error is caused by the frequency switching time of the microwave synthesizer. Other possible sources of frequency shifts are negligible at our level of accuracy.

Conclusion

As a result of the present measurement of the hyperfine splitting of $^{87}Sr^+$ we derived the magnetic hyperfine constant *A* as -1,000,473,673±11 Hz. The present accuracy of 1×10^{-8} is 200 times higher than the previous one [5].

For our purpose (hyperfine anomaly and so on) the present accuracy is sufficient. In the future we would like to extend the present method to radioisotopes, for which much more effort should be made to improve the overall sensitivity of our system.

Acknowledgments

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Table. 1. Experimental results of the 0-0 transition.[a]

	ν_0 (kHz)	χ^2_n	step[b] (Hz/ch)	B (G)	$\Delta\nu_{shift}$ (Hz)
1	5,002,368.351(41)	1.274	100	0.174	−24
2	5,002,368.61(21)	0.983	300	0.210	−35
3	5,002,368.329(62)	1.132	200	0.214	−36
4	5,002,368.336(56)	1.413	200	0.246	−48
5	5,002,368.475(77)	1.045	200	0.276	−60

[a] The peak was fitted with a Gaussian having exponential tails described totally by seven parameters, and the errors include only statistical one with the normalized chi-square value χ^2_n taken into account. For the systematic errors see the text.
[b] No modulation.

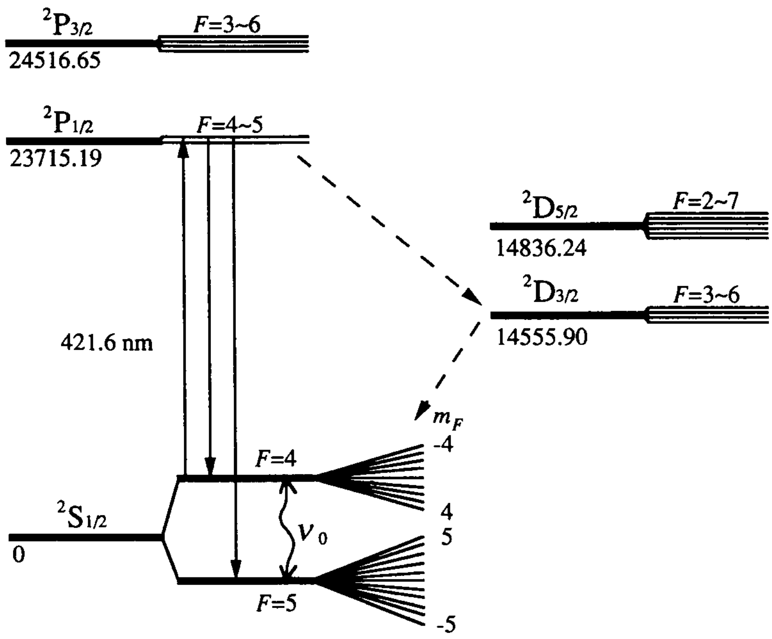

Fig. 1. Low-lying states of $^{87}Sr^+$. The number below the term symbol is the energy of the level in cm^{-1} (ref. 6). The nuclear spin of the ground state of ^{87}Sr is known to be I = 9/2 (ref. 7)

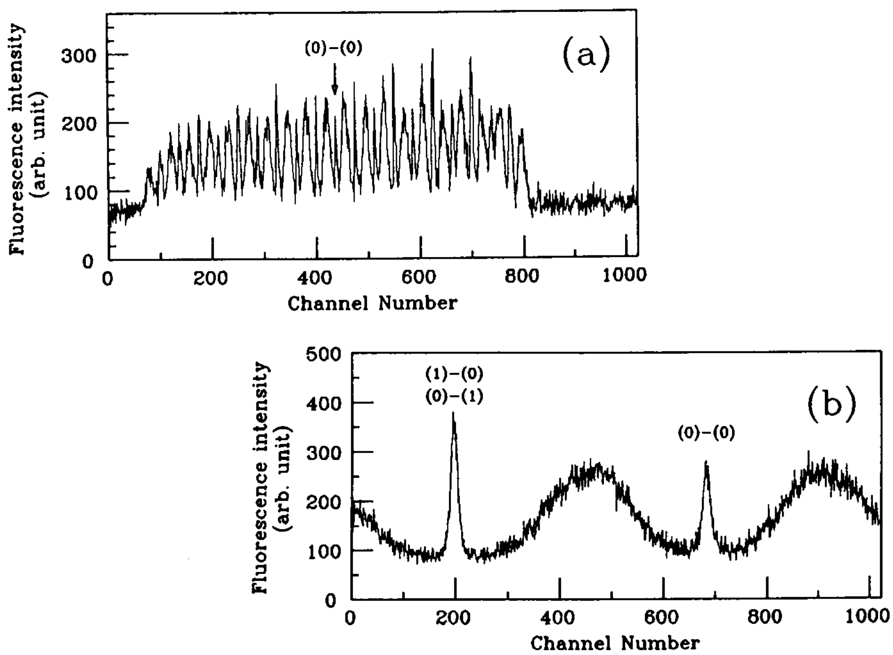

Fig. 2. Microwave resonance spectra of $^{87}Sr^+$. Assignments of magnetic quantum numbers are indicated. Laser frequency is fixed to the F=4 state. The horizontal axis corresponds to the microwave frequency. Magnetic field intensity is 0.174 G. (a) starting frequency is 5,001,800.000 kHz, and the step is 1.3 kHz (3kHz modulation), and (b) starting frequency is 5,002,300.000 kHz and the step is 100 Hz (no modulation).