Absorption spectroscopy measurements of molecular iodine for magneto-optical trapping of francium atoms

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We have demonstrated absorption spectroscopy measure-ments of molecular iodine (I_2) to develop a permanent electric dipole moment (EDM) measurement system with ^{210}Fr atoms in E7 and ^{221}Fr atoms in the hot lab. Laser cooling of the atoms makes it possible to elongate the interaction time in the EDM measurement. During a few years, the number of Fr atoms produced has been gradually improved toward the realization of the MOT. The laser frequency used to trap the atoms has to be red-detuned by several tens of MHz from the resonance frequency of the trapping transition ($7S_{1/2}$ $F = 13/2 \to 7P_{3/2}$ $F = 15/2$ for ^{210}Fr, $7S_{1/2}$ $F = 3 \to 7P_{3/2}$ $F = 4$ for ^{221}Fr). The frequency range where the atoms can be trapped is $\sim$10 MHz.[1)] We have used the high performance wavelength meter (HighFinesse, WS8-2) with an absolute frequency accuracy of 10 MHz to search for the appropriate frequency for MOT by varying the laser frequency in the vicinity of the Fr trapping transition frequencies reported by previous studies,[1–4)] but have not yet achieved MOT. The frequency references that they rely upon and the wavelength meter that we rely upon are different and not traceable. The Fr trapping transition frequencies with references to the I_2 absorption lines have been reported.[1,2)] In this study we perform I_2 absorption spectroscopy and discuss the Fr trapping transition frequencies based on the results obtained.

The experimental setup for I_2 absorption spectroscopy is shown in Fig. 1(a). In this spectral region, the I_2 cell must be heated above 570 K to observe the absorption well.[1)] It has been reported that the ^{210}Fr trapping laser frequency (-31 MHz detuning[3)]) is +3.38(8) GHz away from the I_2 Doppler broadened P(78)1-9 transition (commonly known as atlas[5)] line number 381) frequency[1)] whereas the ^{221}Fr trapping transition frequency is $-0.5(1)$ GHz away from the I_2 Doppler broadened R(113)3-10 transition (atlas[5)] line number 380) frequency[2)] (Fig. 1(b)). However, these studies do not describe the cell temperature. The I_2 absorption spectrum is a composite of several Doppler broadened hyperfine structure spectra.[6)] Therefore, the peak frequency of the I_2 absorption spectrum may shift at different cell temperatures. We performed absorption spectroscopy of line numbers 380 and 381 at cell temperatures $T = 570$, 590, 610, and 630 K, respectively. The absolute frequency of line 381 ($T = 590$ K) was 417 409 191(10) MHz, that is, -57 MHz away from the I_2 atlas [417 409 248(57) MHz].[5)] Whereas, that of line 380 ($T = 570$ K) was 417 400 090(11) MHz, that is, +40 MHz away from the I_2 atlas [417 400 050(51) MHz].[5)] The trapping transition frequencies for ^{210}Fr and ^{221}Fr reported by previous studies are shown in Figs. 1(c)–(d). They used I_2 atlas,[1)] wavelength meter,[2,3)] and optical resonator[4)] as frequency reference, respectively. Ref. 2) states that the absolute frequency of the I_2 380 line was +30 MHz away from the atlas[5)] with reference to their wavelength meter. Consequently, the present I_2 absorption spectroscopy found that the Fr trapping transition frequencies shown in Refs. 1) and 2) were shifted by -57 MHz ($T = 590$ K) and +10 MHz ($T = 570$ K), respectively, when using our wavelength meter as the frequency reference (red dots in Figs. 1(c)–(d)). Depending on the cell temperature, the center frequency of the absorption spectrum was shifted by up to 28 MHz (No. 381) and 31 MHz (No. 380), respectively. Till date, we have used the frequency range in the blue dashed rectangular (Figs. 1(c)–(d)) as the expected frequencies in MOT searches; however, they must be extended further.

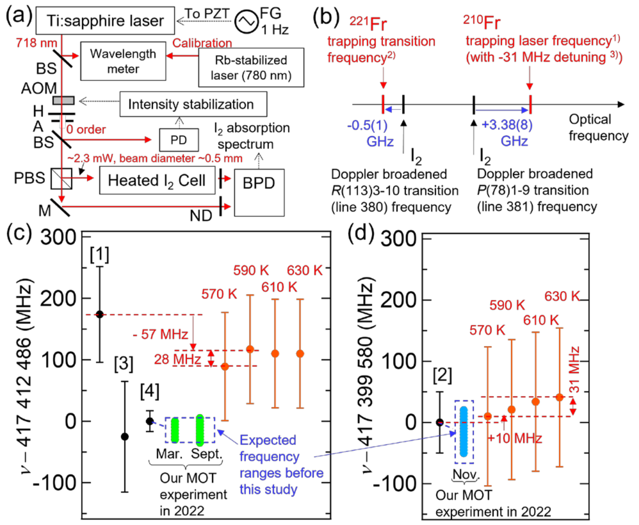

Fig. 1. (a) Experimental setup for I_2 absorption spectroscopy. (b) I_2 lines and Fr trapping transition frequencies. Trapping transition frequencies of (c) ^{210}Fr and (d) ^{221}Fr, respectively.

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