Development of co-located ^{129}Xe and ^{131}Xe nuclear spin masers with external feedback scheme†

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Precision measurement of the frequency of a nuclear spin is important in fundamental physics experiments such as searches for an electric dipole moment. To achieve high precision, we have developed a nuclear spin maser with an external feedback framework,[1–3] which enables us to extend the spin precession far beyond the transverse relaxation time. In our previous works on ^{129}Xe, the frequency precision was found to be limited by the changes in the environmental magnetic field and the effective magnetic field due to the Fermi contact interaction between a Xe atom and a Rb atom. In order to eliminate the sources of uncertainty, we newly introduced a ^{131}Xe maser as a co-magnetometer for the ^{129}Xe experiment. In addition to the frequency drift caused by the change in environmental fields, the system of ^{129}Xe and ^{131}Xe co-located in a common cell can eliminate the frequency instability that stems from the change in the effective magnetic field, because the interaction strengths between ^{129}Xe-Rb and ^{131}Xe-Rb[4] are almost the same. Thus, comagnetometry using ^{131}Xe may provide more efficient cancellation of uncertainties for the ^{129}Xe experiments, as compared to that using ^{3}He, which has been widely used in this field. The shortened measurement time due to quadrupole relaxation, which is one of the difficulties for the ^{131}Xe comagnetometer, can be overcome by introducing the maser scheme.

In order to investigate the long-term stability of the masers, frequency responses (*i.e.*, susceptibilities) to operational parameters of the experiment (magnetic field, cell temperature, power and frequency of laser lights) were measured. By combining the obtained susceptibilities and the measured instabilities of the individual parameters, the maser frequency instabilities caused by the parameters were evaluated. Figure 1 shows the standard deviation of the maser frequency evaluated from the drifts in the cell temperature (which leads to change in the Rb number density, and hence change in the effective magnetic field) and environmental magnetic fields as a function of the averaging time. It was found that frequency drifts due to the magnetic effects on ^{129}Xe were reduced by two orders of magnitude by applying the appropriate correction based on the measured ^{131}Xe spin precession frequency. This result indicates the efficient performance of the proposed comagnetometry using ^{131}Xe co-located with ^{129}Xe. Because of the enhanced stability of masers, the frequency drifts at a level of μHz associated with the drifts in the power of the laser lights were also revealed. Experimental investigation of the origin of this instability and its reduction are subjects of our ongoing work.

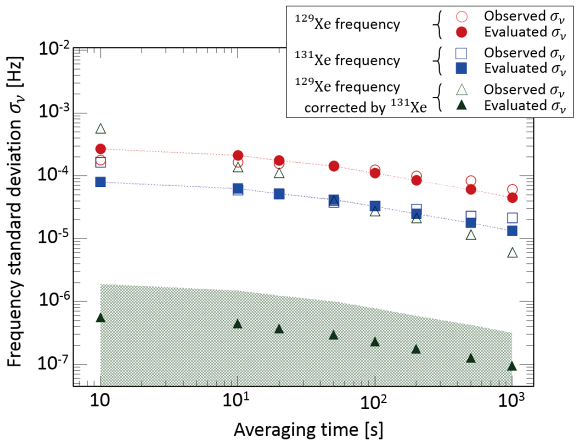

Fig. 1. Long-term stability of masers and the evaluated contribution from the instabilities of magnetic effects. Closed symbols represent the evaluated contributions from the frequency instabilities due to magnetic effects for frequency of masers. Hatched band represents the error associated with the evaluated standard deviation of maser frequency σ_ν. Open symbols represent the measured standard deviations of the frequency of masers.

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References

1) A. Yoshimi *et al.*, Phys. Lett. A **304**, 13 (2002).
2) A. Yoshimi *et al.*, Phys. Lett. A **376**, 1924 (2012).
3) T. Inoue *et al.*, Eur. Phys. J. D **70**, 129 (2016).
4) M. Bulatowicz *et al.*, Phys. Rev. Lett. **111**, 102001 (2013).