Absolute and ratio measurements of the polarizability of Na, K, and Rb with an atom interferometer

William F. Holmgren, Melissa C. Revelle, Vincent P. A. Lonij, and Alexander D. Cronin*
Department of Physics, University of Arizona, Tucson, Arizona 85721, USA
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We measured the ground-state electric-dipole polarizability of sodium, potassium, and rubidium using a Mach-Zehnder atom interferometer with an electric-field gradient. We find $\alpha_{\mathrm{Na}} = 24.11(2)_{\mathrm{stat}}(18)_{\mathrm{sys}} \times 10^{-24}\mathrm{cm}^3$, $\alpha_{\mathrm{K}} = 43.06(14)(33)$, and $\alpha_{\mathrm{Rb}} = 47.24(12)(42)$. Since these measurements were all performed in the same apparatus and subject to the same systematic errors, we can present polarizability ratios with 0.3% uncertainty. We find $\alpha_{\mathrm{Rb}}/\alpha_{\mathrm{Na}} = 1.959(5)$, $\alpha_{\mathrm{K}}/\alpha_{\mathrm{Na}} = 1.786(6)$, and $\alpha_{\mathrm{Rb}}/\alpha_{\mathrm{K}} = 1.097(5)$. We combine our ratio measurements with the higher-precision measurement of sodium polarizability by Ekstrom *et al.* [Phys. Rev. A **51**, 3883 (1995)] to find $\alpha_{\mathrm{K}} = 43.06(21)$ and $\alpha_{\mathrm{Rb}} = 47.24(21)$.

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I. INTRODUCTION

Precision measurements of polarizability serve as benchmark tests for methods used to model atoms and molecules [1,2]. Accurate calculations of van der Waals interactions, state lifetimes, branching ratios, indices of refraction, and polarizabilities all rely on sophisticated many-body theories with relativistic corrections, and all of these quantities can be expressed in terms of atomic-dipole matrix elements. Polarizability measurements, such as the ones presented here, are some of the best ways to test these calculations.

Over 35 years ago, Molof *et al.* [3] measured ground-state alkali-metal and metastable noble-gas polarizabilities with an uncertainty of 2% using beam deflection and the E-H gradient-balance technique. More recently, atom interferometers were used to measure the polarizability of lithium [4] and sodium [5] with an uncertainty of 0.7% and 0.35%, respectively. Near-field molecule interferometry was used to measure the polarizability of C_{60} and C_{70} with 6% uncertainty [6], and guided Bose-Einstein-condensate (BEC) interferometry was used to measure the dynamic polarizability of rubidium with 7% uncertainty [7]. A fountain experiment was used to measure the polarizability of cesium with 0.14% uncertainty [8]. The measurements of potassium and rubidium polarizability made by Molof *et al.* remained the most precise until now.

In this article, we present absolute and ratio measurements of the ground-state electric-dipole polarizability of sodium, potassium, and rubidium using a Mach-Zehnder atom interferometer with an electric-field gradient. The uncertainty of each absolute measurement is less than 1.0% and the precision of each ratio measurement is 0.3%. Our interferometer is constructed with nanogratings that diffract all types of atoms and molecules and enable us to measure the polarizabilities of different atomic species in the same apparatus. The systematic errors are nearly the same for the different atomic species and cancel when calculating polarizability ratios. Finally, we combine our polarizability ratios with the absolute measurement of sodium polarizability by Ekstrom *et al.* [5] to provide measurements of potassium and rubidium polarizabilities with 0.5% uncertainty.

A unique feature of this work compared to references [4,5] is that we use an electric-field gradient region rather than a septum electrode. In addition, we use a less collimated beam to increase the flux and reduce the systematic error caused by velocity-selective detection of atoms in the interferometer.

II. APPARATUS

Our apparatus is described in detail elsewhere [9,10]. In brief, we use three 100-nm period nanogratings to diffract a supersonic beam of sodium, potassium, or rubidium atoms and form multiple Mach-Zehnder interferometers (see Fig. 1). An atom diffracted by the first and second gratings may be found with a sinusoidal probability distribution at the plane of the third grating. The third grating acts as a mask of this interference pattern and also diffracts the interferometer output. We measure the flux as a function of grating position to determine the phase and contrast of the fringe pattern. We detect 10^5 atoms/s with a typical contrast of 30% using a hot-wire detector 0.5-m beyond the third grating.

We measure the output of the two interferometers formed by first-order diffraction from the first and second nanogratings (see Fig. 1). Although other interferometers are present, they do not contribute to the measured phase shift because they either are not white-light interferometers, have fringes with a periodicity different than that of the third grating, or are simply not incident upon the detector. The interferometers formed by second-order diffraction from the first grating [11] contribute less than 1% of the detected signal and cause an error in our polarizability measurements of less than 0.01%.

Before the second grating, the path separation in the interferometer is

$$s = \frac{\lambda_{\mathrm{dB}}}{d_{\mathrm{g}}} z = \frac{h}{mvd_{\mathrm{g}}} z \quad (1)$$

where $\lambda_{\mathrm{dB}} = h/mv$ is the de Broglie wavelength of an atom with mass m and velocity v, d_{g} is the grating period, and z is the propagation distance from the first grating. We adjust the beam velocity for each atomic species such that $s \approx 50\ \mu$m in the interaction region, where the beam width of each diffraction order is approximately 80 μm. We designed the beam parameters to be similar for each atomic species

*cronin@physics.arizona.edu

