

Dynamic dipole polarizabilities of rubidium

M. Marinescu, H. R. Sadeghpour, and A. Dalgarno

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138

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We present a procedure for the calculation of dynamic polarizabilities and we obtain numerical values of the dynamic polarizabilities of rubidium to compare with recent measurements at the frequency of the Nd:YAG (neodymium-doped yttrium aluminum garnet) laser at 1064 nm. We obtain at 1064 nm a polarizability of $711.4a_0^3$ compared to the measured value of $(769 \pm 61)a_0^3$.

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I. INTRODUCTION

Bonin and Kadar-Kallen [1] have presented the theory of an elegant method which uses a light-force technique to measure the electric dipole polarizability of atoms. The light-force technique provides an absolute measurement of the dynamic polarizability at the frequency of the standing-wave laser. Bonin and Kadar-Kallen [1] carried through the measurement for rubidium using a Nd:YAG laser operating at a wavelength of 1064 nm. In order to compare with the experimental value of the static polarizability of Molof *et al.* [2], they scaled their value to infinite wavelength using a set of discrete oscillator strengths measured by Shabanova and Khlyustalov [3] and photoionization cross sections measured by Marr and Creek [4] in the formula

$$\frac{\alpha(\omega)}{\alpha(0)} = \frac{\sum_n f_n / (\omega_n^2 - \omega^2)}{\sum_n f_n / \omega_n^2}, \quad (1)$$

where ω_n is the frequency of the transition of the valence $5s$ electron to the excited np state and the summation includes an integration over the continuum p states.

The explicit addition of the individual terms of Eq. (1) can be avoided. With the adoption of a model potential to characterize the motion of the valence electron, together with a correction for the polarization of the core by the valence electron, the dynamic polarizability can be calculated as a function of frequency. The method should be reliable for frequencies less than the core excitation frequency.

II. THEORY AND RESULTS

We represent the ground state of rubidium by the eigenstate $|0\rangle$ and eigenenergy E_0 . Then the dynamic polarizability at frequency ω may be expressed in the form

$$\alpha(\omega) = \frac{4\pi}{3} \{ \langle 0 | \mathbf{d} | \chi(\omega, \mathbf{r}) \rangle + \langle 0 | \mathbf{d} | \chi(-\omega, \mathbf{r}) \rangle \}, \quad (2)$$

where \mathbf{d} is the effective dipole moment of the valence electron and $\chi(\omega, \mathbf{r})$ is the dipole response function at frequency ω [5]. We adopt for the valence-electron Hamiltonian,

$$H = \frac{1}{2} \mathbf{p}^2 + \sum_l V_l \sum_m |lm\rangle \langle lm|, \quad (3)$$

where $V_l(r)$ is an l -dependent model potential, chosen so that the eigenvalues of H match the experimental energies, and the dipole moment \mathbf{d} is given by

$$\mathbf{d} = \mathbf{r} \left\{ 1 - \frac{\alpha_c}{r^3} [1 - \exp(-r/r_c)^3] \right\}, \quad (4)$$

where \mathbf{r} is the position vector of the valence electron, α_c is an empirical core polarizability, and r_c is a cutoff parameter [5], chosen so that the calculated static polarizability equals the measured value $(319.2 \pm 6.1)a_0^2$ [2]. We used $\alpha_c = 9.076$ and $r_c = 4.399773$. Then

$$(H - E_0 + \omega) \chi(\omega, \mathbf{r}) = -\mathbf{d} |0\rangle. \quad (5)$$

We solve Eq. (5) for the response function by the Numerov integration method [5]. The calculated values of $\alpha(\omega)$ are shown in Figs. 1 and 2. The structures in Fig. 2 arise from the transitions $5s-5p$, $6p$, and $7p$. They are not represented accurately in the figure within the line profiles. Within the line profile at resonance frequency ω_n , it is simpler to use the expression

$$\alpha(\omega) = \frac{2}{3} \frac{f_n}{(\omega - \omega_n)^2 + \Gamma_n^2/4}, \quad (6)$$

where Γ_n is the radiative width.

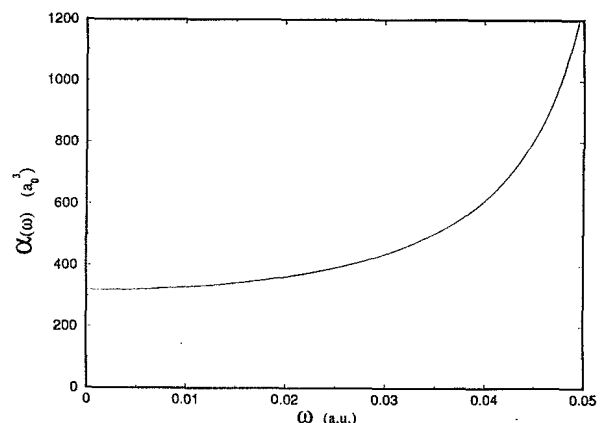


FIG. 1. Dynamic dipole polarizabilities $\alpha(\omega)$ of rubidium in units of a_0^3 , below the first p resonance.

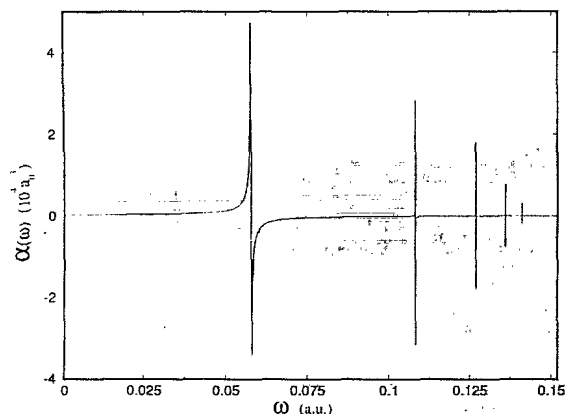


FIG. 2. Same as Fig. 1, below the ionization threshold, in units of $10^4 a_0^3$.

The measured polarizability at a wavelength of 1064 nm is $(769 \pm 61) a_0^2$ [1], in agreement within experimental uncertainty with the calculated value of $711.4 a_0^3$.

The measurements yield a ratio $\alpha(\omega)/\alpha(0)$ at $\omega = 0.04298$ a.u., corresponding to the laser wavelength of 1064 nm, of 2.42 ± 0.24 . Bonin and Kadar-Kallen [1] used Eq. (1) and calculated a ratio of 2.12. The ratio cal-

TABLE I. Oscillator strengths of the $5s$ - np transitions.

n	Ref. [3]	Ref. [6]	This paper
5	1.0000	1.0600	1.06471
6	0.01327	0.0141	0.01547
7	0.00197	0.0026	0.00256
8	0.00061	0.0012	0.00084

culated from data given by Dalgarno and Davison [6] is 2.21 and our prediction is 2.23. The small discrepancies in the theoretical ratios can be attributed to different values of the oscillator strengths shown in Table I. The experimental and theoretical values of the oscillator strengths agree within the probable experimental errors. More precise measurements of the dynamic polarizability should yield accurate estimates of the oscillator strengths.

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- [1] K. D. Bonin and M. A. Kadar-Kallen, Phys. Rev. A **47**, 944 (1993).
- [2] R. Molof, H. L. Schwartz, T. M. Miller, and B. Bederson, Phys. Rev. A **10**, 1131 (1974).
- [3] L. N. Shabanova and A. N. Khlyustalov, Opt. Spectrosc. (USSR) **56**, 128 (1984).

- [4] G. V. Marr and D. M. Creek, Proc. R. Soc. London, Ser. A **304**, 233 (1968).
- [5] M. Marinescu, H. R. Sadeghpour, and A. Dalgarno, Phys. Rev. A **49**, 982 (1994).
- [6] A. Dalgarno and W. Davison, Adv. At. Mol. Phys. **2**, 1 (1966).