Erratum: Accurate determination of an alkali-vapor–inert-gas diffusion coefficient using coherent transient emission from a density grating [Phys. Rev. A 103, 023112 (2021)]

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(Received 3 October 2024; published 12 March 2025)

DOI: 10.1103/PhysRevA.111.039903

I. INTRODUCTION

Our article contains an error in our spectroscopically determined value of the N_2 pressure in a commercially fabricated cell. This error was brought to our attention by a reader [1] and changes our previously reported value of 564 Torr at 50 °C to 553 ± 2 Torr at 50 °C.

In addition to the spectroscopic correction, we (in collaboration with Tiesinga and Kłos) have made several improvements in our analysis to obtain D in the process of preparing the results of the next phase of this experiment [2]. These improvements significantly impact the previously published result. Specifically, they include (i) a model for the decay curve which includes the effect of an offset arising from the heterodyne detection technique, (ii) a model for the decay time as a function of angle which includes the effect of residual light from the acousto-optic modulators (AOMs), (iii) a systematic correction due to the transit time of atoms across the excitation beams based on two different models for the spatial profiles of the population grating and the read-out laser beam, and (iv) estimations of systematic error due to the modeled transit-time correction as well as a separate systematic error due to wave-front curvature. All of these changes result in a final determination of D_0 for a ^{87}Rb-N_2 mixture at 50 °C of $0.1490 \pm 0.0014\ \mathrm{cm}^2/\mathrm{s}$ without systematic errors and 0.149 ± 0.005 when systematic errors are included, in comparison with our published value of $D_0 = 0.1819 \pm 0.0024$, which only reported statistical errors.

II. SPECTROSCOPIC PRESSURE CORRECTION

We had inferred the collisional shift and broadening of the rubidium D_2 line by comparing spectra from the experimental cell containing a mixture of isotopically pure ^{87}Rb and N_2, heated to 47 °C, and a reference cell containing naturally abundant rubidium vapor at room temperature. The relative shift of the resonance lines between these two cells was incorrectly inferred because of an error in calibrating the frequency scan.

We had calculated the shift as if the centers of the room-temperature Doppler-broadened reference features in ^{87}Rb corresponded to the experimentally measured ground-state hyperfine splitting in ^{87}Rb [3]. The correct calibration procedure [1] should involve calculating the composite line shape (black curve in Fig. 1) obtained by adding the 12 constituent Doppler-broadened resonances in ^{85}Rb and ^{87}Rb using the relevant line strengths and relative frequencies [3,4] and matching to the spectrum from the reference cell to determine the frequency axis.

We also incorrectly determined the broadening and shift from the widths and peak frequencies of the two collisionally broadened clusters in the spectrum from the experimental cell. The correct procedure should fit the spectra from the experimental cell to the composite line shape obtained by shifting and broadening the underlying resonances (see Fig. 2) and determining the broadening and shift by comparing the underlying features to their counterparts in the reference spectrum (Fig. 1).

Based on these two corrections, we obtain a corrected pressure of 544 ± 2 Torr at 47 °C. This value scales to 553 ± 2 Torr at 50 °C, in comparison to our previous value of 564 Torr at 50 °C.

III. IMPROVEMENTS IN ANALYSIS

We have also made several improvements to the analysis of the data collected in our published work. These improvements are explained in detail in Ref. [2], but are briefly described and contrasted with the previous approach here.

A. Fitting model for decay curves detected by a heterodyne detector

In our published work decay curves were fit to the model $f(t) = Ae^{-t/\tau} + B$, where A, B, and τ are adjusted fit parameters for the amplitude, decay time constant, and background amplitude of the decay curves, respectively. This model was based on Eq. (5) of our paper as well as the observation that the recorded decay curves featured an offset that was associated with noise arising from the heterodyne detection method. We did not appreciate that the noise contributing to the offset also changed the value of τ. In our improved model, the averaged decay curve is instead found to converge to $f(t) = \sqrt{A^2 e^{-2t/\tau} + B^2}$, as

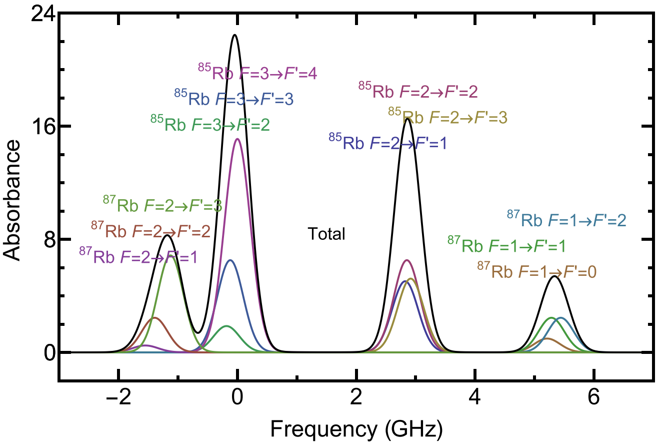

FIG. 1. Calculated composite D_2 line shape for naturally abundant Rb at room temperature shown in black. Line centers and strengths are taken from Refs. [3,4]. We have assumed an atomic density of 10^{10} cm^{-3} and a cell length of 5 cm.

described in detail in Ref. [2]. Using this model, we are able to extract a value of τ that is unaffected by the noise arising from the detection technique.

B. Fitting model for decay time as a function of angle

In our published work we plotted the decay time τ as a function of θ^{-2}, obtained D from the slope, and converted it to D_0 based on our spectroscopic pressure determination (using $DP = D_0P_0$, where P_0 is atmospheric pressure). This method assumes that the decay time τ is related to θ by $\tau = \frac{1}{D(k\theta)^2}$, which implies that the experiment is not sensitive to other effects such as residual light. In Ref. [2] we have adopted a more general model that is inclusive of collisional effects such as spin destruction and residual light. The decay rate in this model can be expressed as

$$\frac{1}{\tau} = \frac{1}{n} n_{\text{atm}} D_0 (k\theta)^2 + n\langle\sigma' v\rangle + \mathcal{W}(\nu, T, p)\Gamma_{\text{opt}}. \tag{1}$$

Here n is the density of the buffer gas, $\langle\sigma' v\rangle$ is the spin-destruction cross section, n_{atm} is the number density of the buffer gas at atmospheric pressure, $\mathcal{W}(\nu, T, p)$ is a collisionally broadened and shifted Voigt profile, and Γ_{opt} is the signed optical pumping rate which is dependent on the residual light intensity from both AOMs. We find, on the basis of pressure-varying experiments [2], that $\langle\sigma' v\rangle$ is effectively zero under the conditions in our published work. However, $\mathcal{W}(\nu, T, p)\Gamma_{\text{opt}}$ can be significant. To quantify this effect and to decouple it from our determination of D, it is more appropriate to plot the decay rate $1/\tau$ as a function of $(k\theta)^2$.

This fit, which is shown in Fig. 3, gives a value of D at 553 Torr and 50 °C of 0.2049 ± 0.0019 cm^2/s, compared to the value of 0.245 ± 0.002 cm^2/s reported in our published work. These values scale to values at atmospheric pressure of $D_0 = 0.1490 \pm 0.0014$ and 0.1819 ± 0.0024 cm^2/s, respectively.

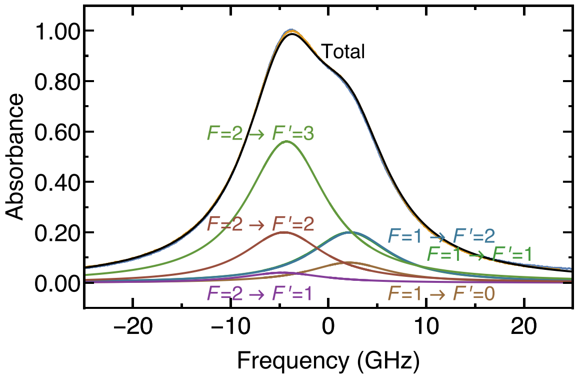

FIG. 2. Data from the experimental cell fitted to the composite spectrum for ^{87}Rb resonances. Blue and yellow curves show data from the upward and downward frequency scan, respectively; the best fit to both of these curves is shown in black. Individual resonances are shown with broadening and shift parameters determined by the fit and strengths and centers relative to each other taken from Ref. [3].

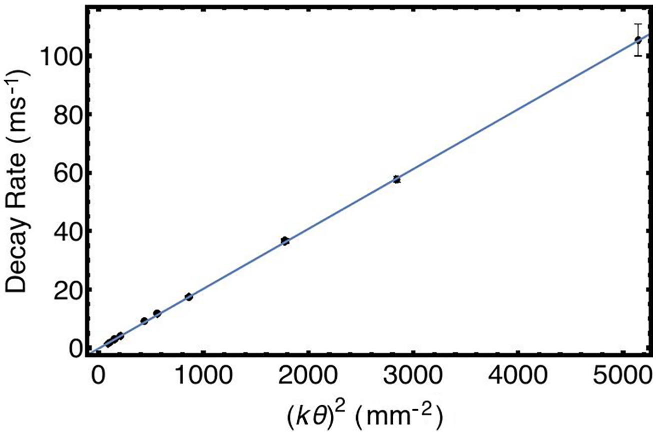

FIG. 3. Corrected fit using the model presented in Eq. (1), which provides a value that is insensitive to systematic errors from residual light.

C. Systematic effects of transit time and wave-front curvature

A transit time correction is estimated by simulating the signal decay based on two analytical models that take into account the diffusion of the Rb populations gratings beyond the spatial extent of the read-out beam [2]. To calculate the analytical signal, we take the $\vec{k}_1 - \vec{k}_2$ Fourier component in the product of $\rho_{Fm_F}(\vec{x}, t)$ and $E_{\mathrm{RO}}(\vec{x})$, where $E_{\mathrm{RO}}(\vec{x})$ describes the profile of the electric-field amplitude of the read-out beam.

We also considered a second systematic effect which relates to the curvature of the laser wave fronts that are incident on the aperture used to spatially filter the excitation beams in order to measure angle θ. This effect does not change the fitted value of τ but does introduce an additional fractional uncertainty of 1.5%. This uncertainty was estimated by translating a circular aperture across the excitation beam profiles and finding the measured angle to vary linearly by as much as 130 μrad per millimeter of translation. As the maximum uncertainty in the placement of the aperture is 0.2 mm, the maximum systematic uncertainty in the angle is 26 μrad, resulting in an impact on the $D(T, p)$ of 1.5%.

IV. CONCLUSION

Combining the value of D with the corrected pressure of 553 ± 2 Torr and including systematic errors associated with the transit time correction and wave-front curvature, we obtain a new value of $D_0 = 0.149 \pm 0.005\ \mathrm{cm}^2/\mathrm{s}$ for an Rb-N_2 gas mixture at 50 °C. Other work using this technique, in which both the angle and the pressure of the buffer gas are varied, obtains a value of $D_0 = 0.132 \pm 7$ at 24 °C. If we scale this value to 50 °C using the improved $T^{1.730}$ scaling law discussed in Ref. [2], we obtain a value of 0.153 ± 0.008, which is in agreement with the measurement in our published work.

ACKNOWLEDGMENTS

We acknowledge Krishna Myneni of U.S. Army DEVCOM Aviation and Missile Center, Redstone Arsenal, for pointing out our error and for useful discussions; Eite Tiesinga of NIST, U.S.; and Jacek Kłos of the University of Maryland.

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[1] K. Myneni (private communication).

[2] A. Pouliot, E. Chomen Ramos, G. Carlse, T. Vacheresse, J. Randhawa, L. Marmet, A. Kumarakrishnan, J. Kłos, and E. Tiesinga, companion paper, Measurements of diffusion coefficients for rubidium–inert-gas mixtures using coherent scattering from optically pumped population gratings, Phys. Rev. A **111**, 033108 (2025).

[3] D. Steck, Rubidium 87 D line data, available at https://steck.us/alkalidata/ (2023), version 2.3.2.

[4] D. Steck, Rubidium 85 D line data, available at https://steck.us/alkalidata/ (2023), version 2.3.2.