Collisional broadening of intra-Doppler resonances of selective reflection on the D_2 line of cesium

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The broadening of selective reflection resonances for cesium atom concentrations N such that collisional resonance broadening γ_c is less than the Doppler broadening is investigated. A method is proposed for measuring γ_c at the center of the atomic line. It is found that the N-dependence of the reflection resonance width for the D_2 line is $\gamma_c = (1.15 \pm 1.12) \times 10^{17} N$ Hz.

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Experimental study of collisional resonance broadening γ_c of atomic lines with strong oscillator strength $f \sim 1$ is of great interest for spectroscopy and the physics of atomic collisions.[1,2] It is known from theory[1,3] that the resonance collisional broadening at the center of the line and in the wings differs in magnitude and mechanism. In principle, it is possible to measure γ_c at the center and in the wings of a resonance line from the shape of the absorption line. However, at pressure for which broadening is greater than the radiation width γ_r, it is difficult to satisfy the condition of an optically thin gas layer for the resonance line with $f \sim 1$ and the shape of such a line near the center is distorted by self-absorption effects.[1] For this reason, in the most commonly used method, γ_c is measured from the wings of the absorption line.[2,4] In our work, we proposed and realized a method for measuring γ_c at the center of the line from the width of the intra-Doppler resonance of selective specular reflection.

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Selective specular reflection (SSR) refers to the resonance behavior of the coefficient of specular reflection from a glass–gas boundary near the absorption line of the gas. Intra-Doppler resonance in the SSR contour appear at gas pressures for which homogeneous broadening of the line $\gamma = \gamma_r + \gamma_c$ is less than Doppler broadening $\Delta\nu_D$. The existing theory[5] explains the formation of intra-Doppler resonances in the SSR contour for $\gamma < \Delta\nu_D$ by collisions of gas atoms with the cell window, which lead to loss of polarization induced by the external field and, more precisely, asymmetry in the velocity distribution of polarized atoms arising in this case. The results of experimental studies of SSR from sodium[6,7] and cesium[8,9] vapors, in which intra-Doppler resonances were observed with $\gamma < \Delta\nu_D$, qualitatively confirm the results in Ref. 5. The spectral dependence of SSR with $\gamma \ll \Delta\nu_D$ and small detuning of the incident radiation frequency from resonant radiation $|\Delta\nu| \ll \Delta\nu_D$ can be represented by the following asymptotic approximation[5]:

$$R(\Delta\nu) \sim \ln[(4\Delta\nu^2 + \gamma^2)\Delta\nu_D^{-2}] \cdot \tag{1}$$

Previously, we noted[9] that the frequency interval between the inflection points on the theoretical curve is $R(\Delta\nu)$, where $R''(\Gamma/2) = 0$, is equal to $\Gamma = \gamma$ (we call the quantity Γ the width of the peak). From a calculation of the convolution, it is also easy to find that for a Lorentzian contour, its width δ enters additively into the measured width of the SSR peak, $\Gamma = \gamma + \delta$, i.e., the collisional broadening constant k can be easily measured from the dependence of Γ on the concentration of gas atoms N, $k = d\Gamma/dN$.

In this work, we confirm the theoretical dependence (1) for the peaks of the intra-Doppler SSR resonance and with the help of the method proposed we measure the resonance broadening at the center of the D_2 line of ^{133}Cs ($\lambda = 852.1$ nm, $\gamma_r = 5.3$ MHz). We used an injection laser with external dispersion resonator operating in the single-frequency continuous regime, as a source of frequency tunable monochromatic radiation. The generation frequency could be smoothly tuned over the range 2–3 GHz, the laser power was ~ 3 mW and the width of the generation line did not exceed 1 MHz. The characteristics of the laser were described in greater detail in Ref. 10. The laser radiation, collimated into a parallel beam with a 1 cm cross section, was directed onto a glass cell with the cesium vapor, which was placed in a two-section thermostat. A constant temperature difference $T - T_0 = 25$ K was maintained between the working volume and the arm with the drop of metallic cesium. We determined the concentration of atoms in the arm N_0 from the Langmuir-Taylor equation,[4] and in the working volume from the condition that the flow of atoms through the channel connecting both volumes is equal, $N_0\sqrt{T_0} = N\sqrt{T}$. The laser radiation, reflected from the glass-cesium vapor boundary, was recorded with a photodiode, whose signal was introduced into an automatic plotter or oscillograph. The angle between the incident and reflected beams was 0.1 rad. The coefficient of selective reflection was measured by comparing it with the resonant reflection from the cell window, $R_0 = 4.5\%$. The frequency scale in the spectral measurements was determined from the transmission resonances of a confocal interferometer with a free dispersion range of 234.4 MHz. The SSR spectra of the long-wavelength component of the D_2 line with $N = 3 \times 10^{13}$ cm^{-3} and $N = 2.6 \times 10^{14}$ cm^{-3} are shown in Fig. 1(a) and 1(b), respectively. Figure 1(c) shows the relative intensities of the atomic transitions.

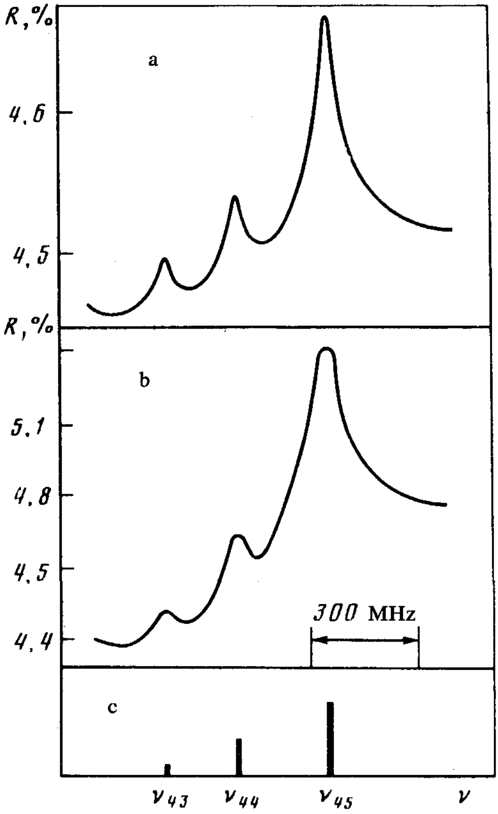

FIG. 1.

The collisional broadening was measured from the intra-Doppler SSR resonance for the strongest transition in the D_2 line $6S_{1/2}(F=4)-6P_{3/2}(F=5)$ (frequency ν_{45} in Fig. 2). In order to record the first derivative, we modulated the generation frequency of the laser and performed a narrow-band amplification of the signal at 7 kHz. The spectral dependences of the derivative at $N=1.6\times10^{14}$ cm^{-3} and $N=2.6\times10^{14}$ cm^{-3} are shown in Fig. 2(a) and 2(b). Together with the experimental curves, the points indicate the computed dependences of the derivative $R'(\Delta\nu)\sim\Delta\nu/(4\Delta\nu^2+\Gamma^2)$ (the quantity Γ is set equal to the interval between the extrema on the experimental curve). From a comparison of the experimental and theoretical data, it is evident that near the resonance peaks the SSR contour is described quite well by dependence (1), but as Γ increases, the region $\Delta\nu$ in which approximation (1) is valid becomes narrower.

The experimental points of the N-dependence of the quantity Γ [Fig. 2(c)] follow quite well a straight line with slope $k=(1.15\pm0.12)\times10^{-7}$ Hz cm^{-3} (the residual width $\Gamma=29$ MHz for $N\rightarrow0$ is approximately equal to $(\gamma_r+\Delta\nu_D\sin\theta)$).[6] A possible error of up to 10% is due primarily to the inaccuracy in determining N near the cell window. Let us compare the value of k obtained with other experimental results. The relation $kf=1.08\times10^{-7}$ Hz cm^{-3} was obtained in Ref. 4 for the wings of the D_2 line of cesium. Using the value $f=0.81$, we obtain $k=1.34\times10^{-7}$ Hz cm^{-3}. The ratio of

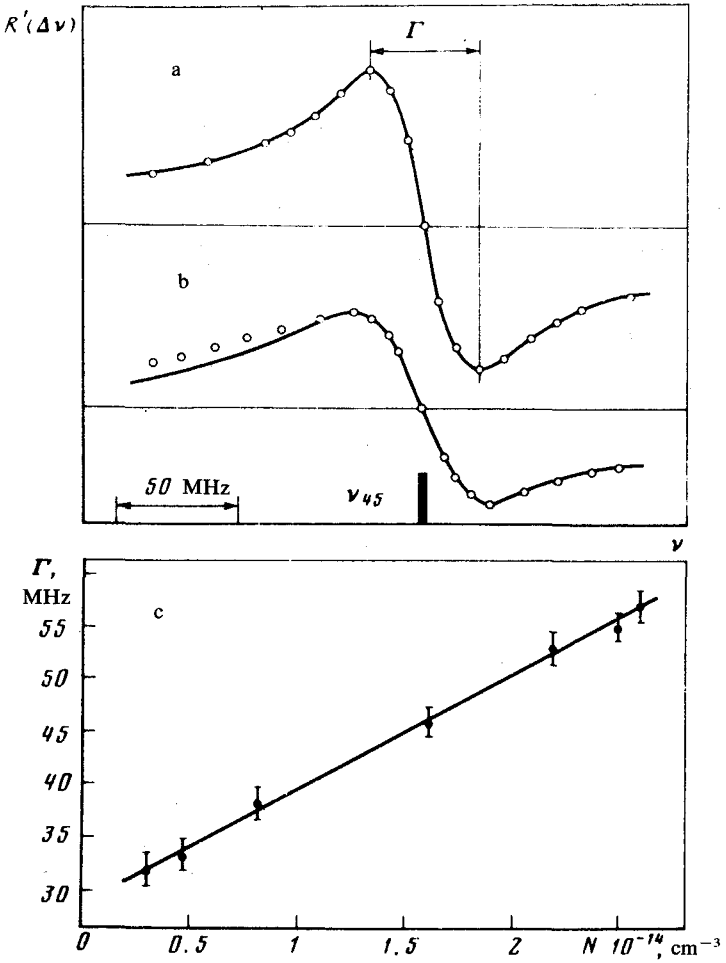

FIG. 2.

the broadening constants at the center of D_2 line, obtained for the first time in our work, to the broadening constant at the wings, obtained in Ref. 4, is close to the theoretical ratio of the impact and quasistatic broadening for D_2 lines of alkali metals, $1.86/2.15 = 0.87$.[3]

In conclusion, we note that it is desirable to have a more detailed theoretical justification for the proposed method, since the SSR theory used[5] is constructed from a rather simplified model of the phenomenon, in which collisional broadening is introduced phenomenologically.

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