Pressure Effects of Foreign Gases on the Absorption Lines of Cesium. II. The Effects of Helium on the First Two Members of the Principal Series*

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Cs(1)/He and Cs(2)/He measurements are reported up to 300 and 20 atmospheres, respectively. The shift curves for Cs(1)/He are linear up to a point and then very abruptly change to a new linear region. Half-width curves are all observed to be nonlinear at low pressures. In addition, the half-widths of helium-broadened cesium lines are shown to have a strong temperature dependence, at least as strong as the first power of temperature. There is very little or no temperature effect on the shift within our temperature and pressure range of experimental observations, viz. 40°C–160°C and relative density 0–190 for Cs(1)/He, and 98°C–177°C, and relative density 0–13 for Cs(2)/He.

I. INTRODUCTION

THIS paper reports the shift, broadening and asymmetry of both fine-structure components of Cs(1) and Cs(2) under various pressures of helium up to 300 and 20 atmospheres, respectively. It should be noted that the present work also stresses accurate measurements in the low-pressure region and that, as in the first paper,[1] no attempt is made to correct any of the shift or half-width values for overlap effects which are appreciable at high pressures. The cesium vapor pressures ranged from 2×10^{-6} (for low pressures of He) to 10^{-2} mm Hg (for high pressures of He).

II. RESULTS

A. Cs(1)/He and Cs(2)/He Shifts

The violet shift of Cs(1)/He is shown in Figs. 1 and 2. At low pressures of helium, the curves of shift versus relative density (r.d.) of both components are linear with a rather abrupt change to a second linear region. The slope for the $^2P_{1/2}$ component shift is 0.128 ± 0.005 cm^{-1}/r.d. up to r.d.$=2.7$; then it is 0.186 ± 0.002 cm^{-1}/r.d. up to r.d.$=15$. The slope of the $^2P_{3/2}$ component is a barely measurable 0.015 ± 0.005 cm^{-1}/r.d. up to r.d.$=1.6$; then it is 0.036 ± 0.002 cm^{-1}/r.d. up to r.d.$=15$.

Above r.d.$=15$ the slope of the curve for the $^2P_{1/2}$ component increases, becoming linear again above r.d.$=42$ with a slope of 0.60 ± 0.01 cm^{-1}/r.d. up to at least r.d.$=190$. The slope of the curve for the $^2P_{3/2}$ component also increases above r.d.$=15$, possibly becoming linear above r.d.$=140$ with a slope of 0.72 ± 0.02 cm^{-1}/r.d. Above r.d.$=140$ the $^2P_{3/2}$ component is affected both by the violet-satellite band on one side and by the violet asymmetry of the $^2P_{1/2}$ component on the other side. The effects upon the line position tend to annul one another but the linearity of the shift curve is necessarily uncertain for this component. The shift curve for the $^2P_{1/2}$ component is not affected by overlapping until r.d.$=190$ is reached.

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[1] S. Y. Ch'en and R. O. Garrett, preceding paper, Phys. Rev. 144, 59 (1966), hereafter referred to as I.

Figures 3 and 4 show the violet shift of Cs(2)/He. The results in the low pressure region reported previously by Ch'en and Parker[2] are surpassed in accuracy by the present work. However, their high-pressure results above r.d.$=10$ are valid and are not repeated here. The Cs(2)/He $^2P_{1/2}$ component shift is linear up to r.d.$=0.9$ with a slope of 0.51 ± 0.02 cm^{-1}/r.d. Above r.d.$=0.9$ there is a transition region to r.d.$=7$ above which the slope is again linear with a value 3.5 ± 0.1 cm^{-1}/r.d. The $^2P_{3/2}$ component graph is linear up to r.d.$=3.5$ with a slope of 0.26 ± 0.01 cm^{-1}/r.d. Then this graph curves slowly up with no further linear region apparent.

Any possible temperature effect on the shifts of cesium lines perturbed by helium is within the experimental error and cannot be considered significant. All shift graphs were drawn assuming there is no temperature effect.

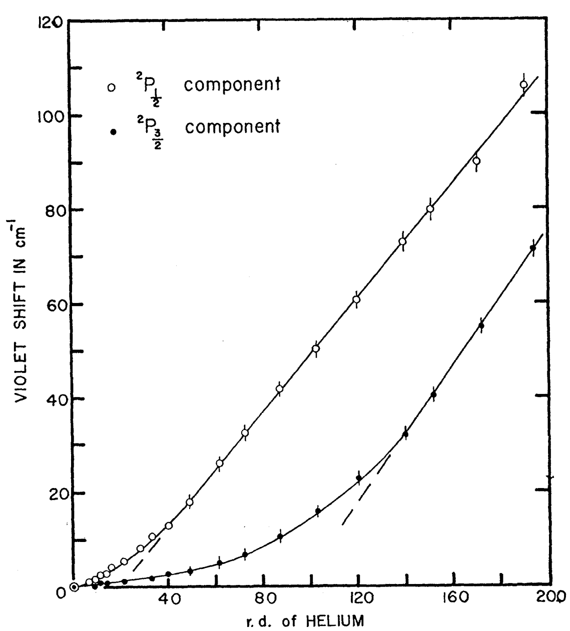

FIG. 1. Violet shift of Cs(1)/He fine-structure lines in cm^{-1}. Dashed lines show limits of linear regions. r.d.≡relative density.

[2] S. Y. Ch'en and W. J. Parker, J. Opt. Soc. Am. 45, 22 (1955).

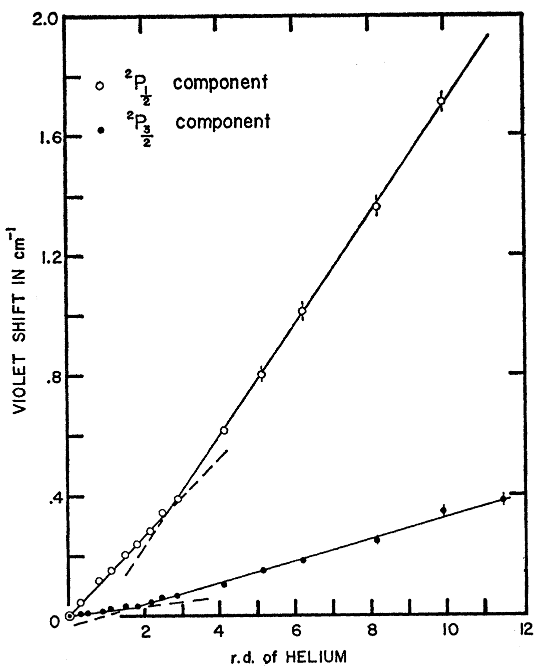

FIG. 2. Low-pressure-region enlargement of the violet shift of Cs(1)/He in cm^{-1}. Dashed lines show limits of linear regions.

B. Cs(1)/He and Cs(2)/He Broadening and Temperature Effect

Figure 5 shows the half-width of the resonance lines of cesium in the presence of helium. It also reveals an unusually strong temperature dependence which must be considered along with the discussion of the half-widths. In Fig. 5 the upper point on the graphs of both components at r.d.$=87$ was obtained at 139°C. The lower point at this r.d. and the other points on each graph connected with it by the solid line were obtained at 114°C. The lower two solid-line sections on each graph were obtained at 96°C and at 82°C. The dashed lines show the probable curve if the lowest temperature, 82°C, had been maintained for all data points. This evidence suggests that a half-width increase of approximately 7% is caused by a temperature increase of 5%.

Figure 6 is an enlargement of the Cs(1)/He half-width curve in the low pressure region. The evidence for a temperature effect here is not conclusive because relatively small temperature changes were made. The three points shown by triangles were obtained at 82°C while other nearby points were obtained at 75°C. The smooth curve was drawn assuming that the temperature effect is negligible for these points.

Assuming a constant temperature, the half-width curves are nonlinear up to r.d.$=3$ or 4. Beyond this point the $^2P_{1/2}$ component has a slope of 0.77 ± 0.02 cm^{-1}/r.d. up to r.d.$=50$ and the $^2P_{3/2}$ component has a slope of 0.70 ± 0.02 cm^{-1}/r.d. up to r.d.$=20$ with a possible slight increase from there to r.d.$=50$. Above r.d.$=50$, the slope of the $^2P_{1/2}$ component graph may decrease and the slope of the $^2P_{3/2}$ component graph may increase with a crossing at about r.d.$=80$. It is within the experimental error for the $^2P_{1/2}$ component graph to be linear in the whole region from r.d.$=4$ to r.d.$=90$. The rise in slope of the $^2P_{3/2}$ component graph above r.d.$=50$ may be due wholly or in part to the effect of overlapping of the violet satellite with the line. No widths were measured above r.d.$=90$ because of experimental difficulties in establishing a base line. This is the point above which the lines begin to overlap one another appreciably.

The low-pressure line widths must be corrected for both the effect of hyperfine splitting and effect of the

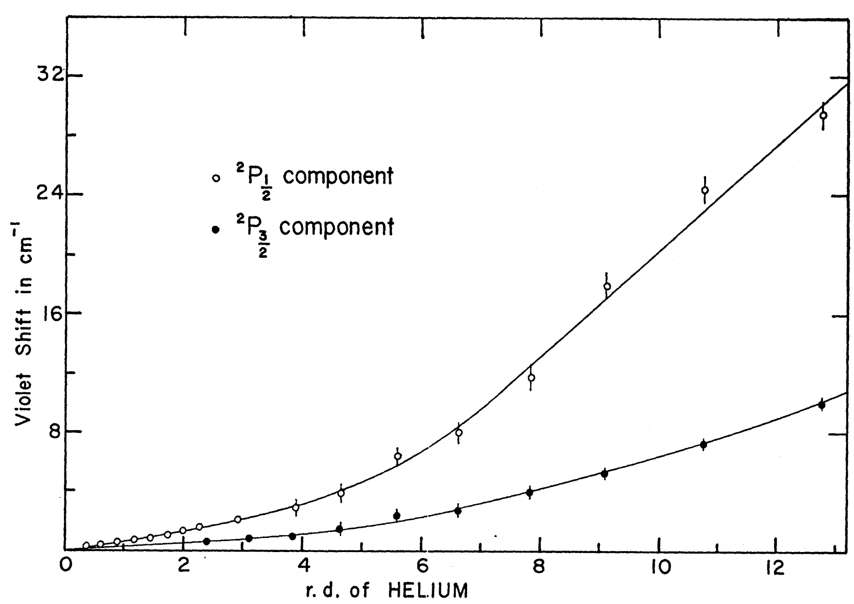

FIG. 3. Violet shift of Cs(2)/He fine-structure lines in cm^{-1}.

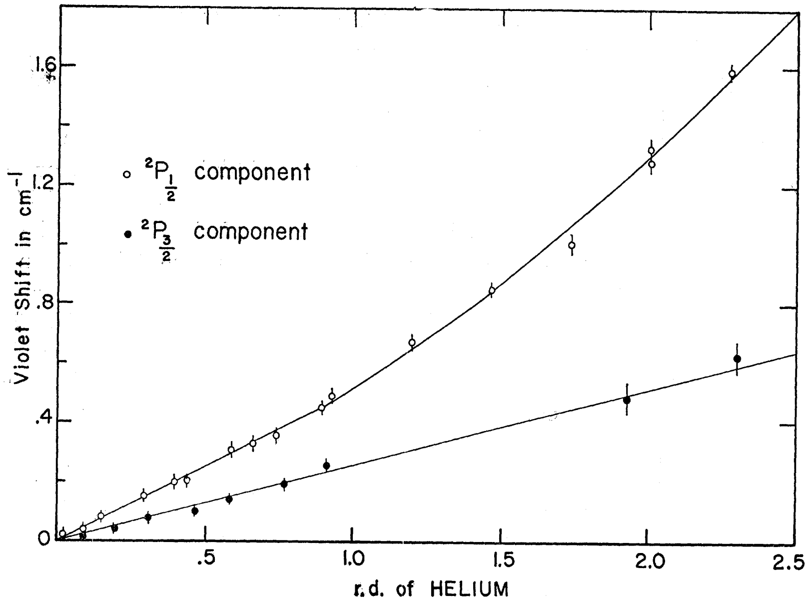

FIG. 4. Low-pressure-region enlargement of the violet shift of Cs(2)/He in cm^{-1}.

slits used. This correction is approximately 0.50 cm^{-1} as described in Paper I.[1]

Figure 7 shows the half-width of Cs(2)/He and again a strong temperature dependence is observed for the helium-perturbed lines. All of the open circles representing $^2P_{1/2}$ component data points were obtained at 177°C with the dotdashed line below them being the average of seven points obtained at 150°C. The majority of the solid circles representing $^2P_{3/2}$ component data points were also obtained at 177°C except the two at r.d.$=2.0$ and 2.8. These two were obtained at 150°C. The dotdashed line below the 150°C data points is the average of ten data points obtained at 122°C.

Figure 8 is an enlargement of the half-width curve of Cs(2)/He in the low pressure region and it also shows a strong temperature dependence. With the exception of the four very low pressure open circles representing

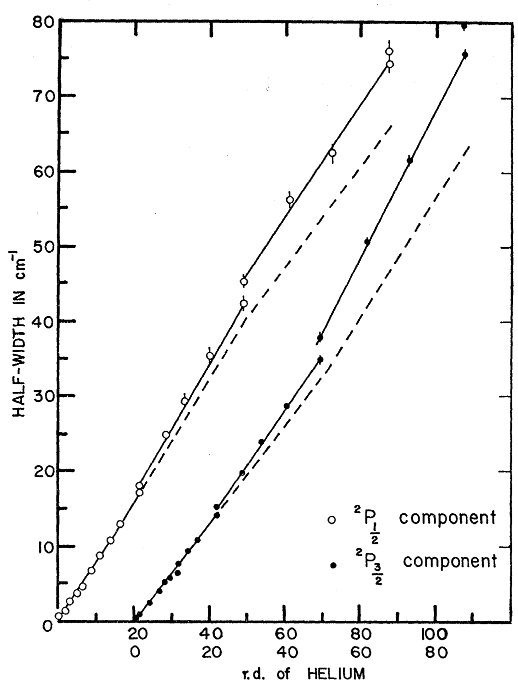

FIG. 5. Half-width of Cs(1)/He fine-structure lines in cm^{-1}. The $^2P_{3/2}$ points are shifted 20 r.d. divisions for clarity. The dashed lines are probable half-width curves if all data were obtained at a constant temperature of 82°C.

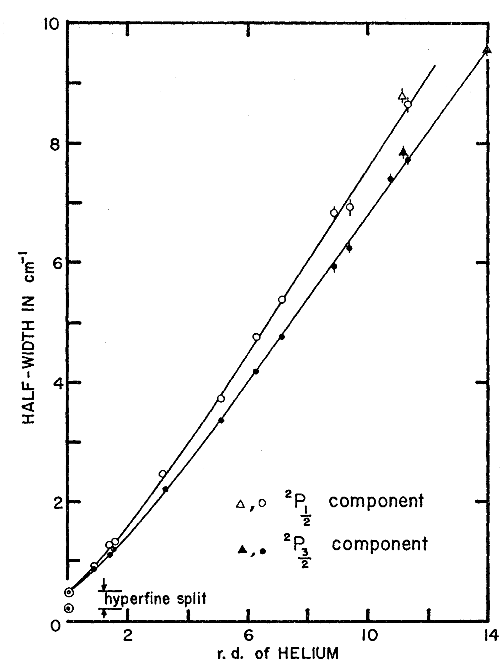

FIG. 6. Low-pressure-region enlargement of the half-width of Cs(1)/He fine-structure lines in cm^{-1}. The three triangular symbols are higher temperature points described in the text.

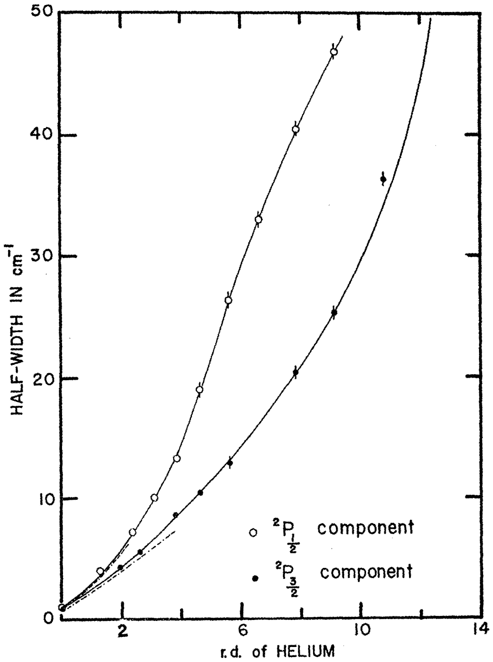

FIG. 7. Half-width of Cs(2)/He fine-structure lines in cm^{-1}. The dotdashed lines represent half-widths of lower temperature points described in the text.

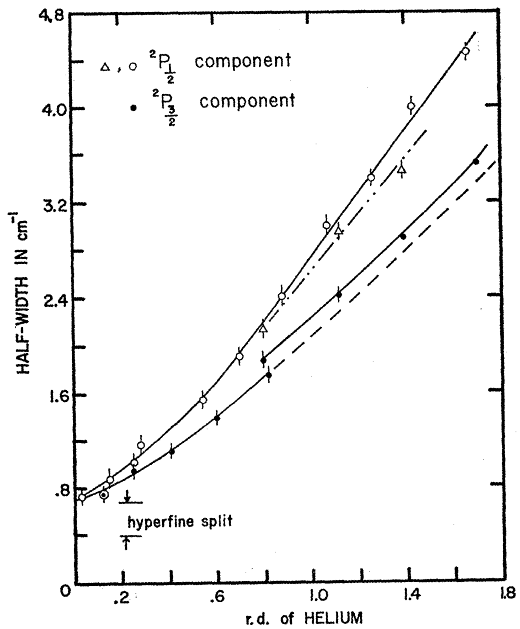

FIG. 8. Low-pressure enlargement of the half-width of Cs(2)/He fine-structure lines in cm^{-1}. The open triangles represent lower temperature $^2P_{1/2}$ points. The dashed line represents a probable low-temperature extension of the $^2P_{3/2}$ points.

$^2P_{1/2}$ component points at 142°C, the open circles were all obtained at 150°C. The three open triangles below the solid curve were obtained at 122°C. The upper four solid circles representing $^2P_{3/2}$ component half-widths were obtained at 122°C. The low-pressure solid circles were all obtained at 98°C. The dotted extension is the probable $^2P_{3/2}$ component half-width curve at a constant temperature of 98°C. The Cs(2)/He half-widths are seen to increase approximately 7% for a 5% increase in temperature just as was observed above for Cs(1)/He half-widths.

As described in Paper I, each of the half-widths for Cs(2)/He must have an approximate 0.66 cm^{-1} correction made to them to take into account hyperfine and slit-width effects. The Cs(2)/He half-width curves are nonlinear in all regions and cross at about r.d. = 13.

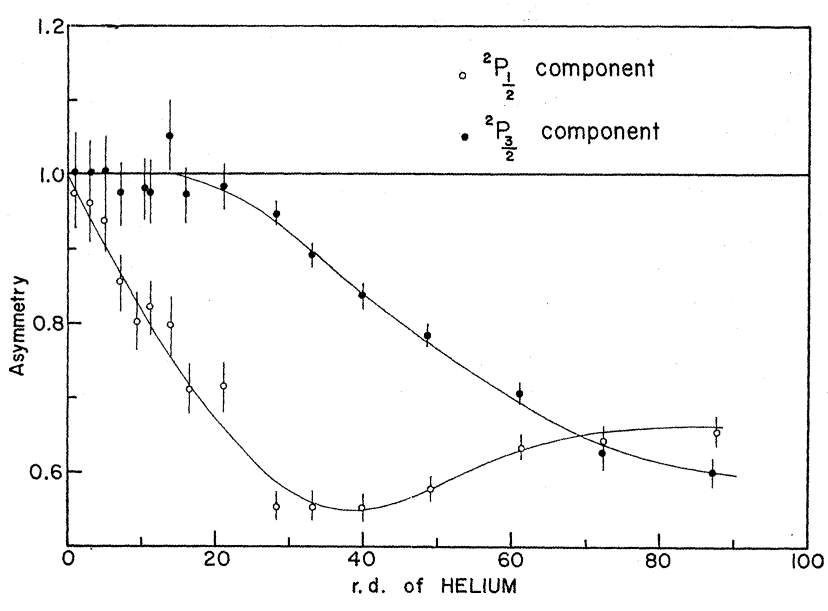

FIG. 9. Asymmetry ratio at half-intensity points for Cs(1)/He fine-structure lines.

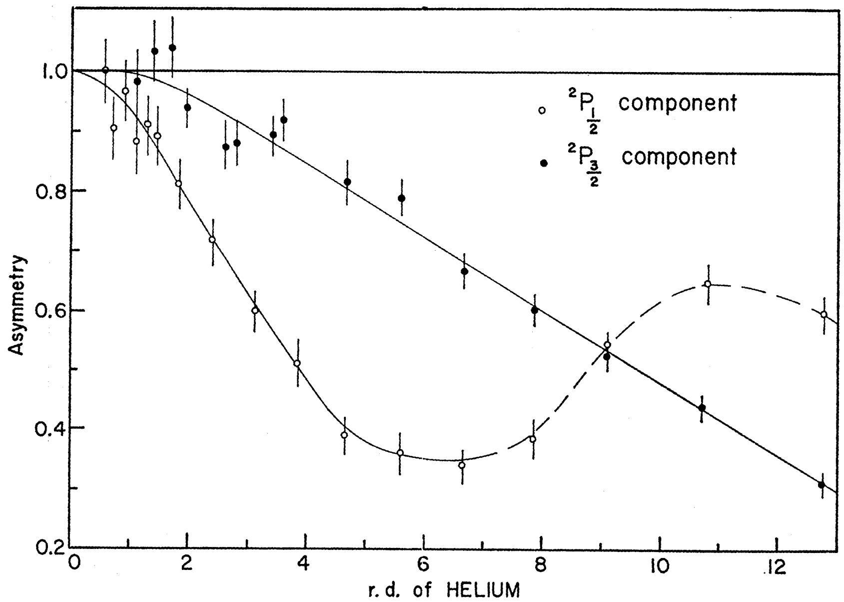

FIG. 10. Asymmetry ratio at half-intensity points for Cs(2)/He fine-structure lines. The dashed part of the $^2P_{1/2}$ component curve represents a section which does not correlate well with earlier data and is to be repeated.

C. Asymmetry

Figures 9 and 10 show the asymmetry ratios for Cs(1)/He and Cs(2)/He, respectively. As noted in Paper I the accuracy in the low-pressure region is not high due to the difficulty in determining the peak position with respect to the half-intensity points for a narrow line.

Unlike the results with argon, Figs. 9 and 10 show that the asymmetry curves of helium-perturbed fine-structure lines do not exhibit similar behavior. Figure 9 shows that the $^2P_{1/2}$ component asymmetry for Cs(1)/He decreases at low relative densities, reaches a minimum value of 0.55 at r.d. = 38, and rises slowly to a plateau value near 0.66 for higher pressures. The $^2P_{3/2}$ component of Cs(1)/He is symmetric up to about r.d. = 15. Its asymmetry then decreases with a possible limit of about 0.58 near r.d. = 100. Figure 10 shows that the $^2P_{1/2}$ component asymmetry for Cs(2)/He decreases, reaching a minimum value of about 0.35 at r.d. = 6.5, then rising to a maximum value of about 0.65 at r.d. = 11. The dashed section is not well established because of an insufficient number of data points. The $^2P_{3/2}$ component is symmetric up to about r.d. = 1 and then it shows a steady decrease in asymmetry ratio to r.d. = 13. Ch'en and Parker's[2] data up to r.d. = 30 suggests that beginning near r.d. = 12, the $^2P_{1/2}$ component asymmetry curve flattens out to a value between 0.6 and 0.7 and the $^2P_{3/2}$ component asymmetry curve also flattens out to a value near 0.4.

III. DISCUSSION

Further evidence was obtained in this experiment which suggests that although all shift curves are linear at very low pressures, a strong deviation from linearity is observed while the pressure is still quite low [r.d. = 1.6 and 2.7 for the two components of Cs(1)/He and r.d. = 0.9 and 3.5 for the two components of Cs(2)/He]. The Cs(1)/He shift curves showed a rather abrupt change from one slope to another (Fig. 2), a phenomenon not predicted by any present theory nor revealed by any previous experiment.

The nonlinear half-widths at low pressures for Cs/He lines (Figs. 6 and 8) are in contradiction to the present collision theory.

The half-widths of helium-broadened cesium lines are strongly affected by temperature in all pressure ranges. A dependence slightly in excess of T was observed. Orthman[3] has found a $T^{1/2}$ dependence with Hg 2537/H_2 but Horodnicsy and Jablonski[4] found only a slight dependence upon temperature for Hg 2537/He. The Graniers[5] measuring the dependence only with shifts on Rb(1)/H_2 and Rb(1)/D_2, found a decrease in shift roughly proportional to an increase in temperature. Further work on the temperature dependence upon pressure broadening is clearly necessary.

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[3] W. Orthman, Ann. Physik **78**, 601 (1926).

[4] H. Horodnicsy and A. Jablonski, Nature **142**, 1122 (1938); **144**, 594 (1939).

[5] R. Granier and J. Granier, Compt. Rend. **257**, 2627 (1963).