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Abstract

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Determination of the Oscillator Strength of the Ruby R_1 Line at 78°K by Rozhdestvenskii's Hook Method

(Presented by Academician I. V. Obreimov, 11 XII 1964)

In a previous work (1) we obtained the value of the oscillator strength of the ruby R_1 line at room temperature. The temperature dependence of the oscillator strength is of interest, since both the width and the intensity of the R_1 line change strongly with temperature. The present communication describes a measurement of the oscillator strength of the ruby line at the temperature of liquid nitrogen.

As shown in (2,3), the most accurate method for determining oscillator strengths is the hook method of D. S. Rozhdestvenskii. However, there exists an opinion that the hook method cannot be applied to the study of dispersion on narrow lines of crystals, since these lines are considerably weaker than lines in metal vapors, on which measurements by this method have hitherto been carried out.

Let us estimate the possibility of applying the hook method to the study of dispersion on the R_1 line in ruby. For this purpose we shall calculate the numbers of dispersive electrons in 1 cm^3 in metal vapors and in a ruby crystal. According to data (4), for the thallium line 3776 Å at 600°C, and according to (1) for 0.05% ruby at room temperature, values of the same order are obtained, $Nf = 10^{13}$ (here N is the number of atoms in 1 cm^3 that are on the lower level, and f is the oscillator strength of the transition). For a given number of dispersive electrons in 1 cm^3, the possibility of obtaining a sharp, readily measurable hook depends on the width of the absorption line. The width of the R_1 line at 78°K is tenths of a reciprocal centimeter, i.e., it approaches the width of lines in metal vapors. Consequently, in 0.05% ruby at 78°K it is possible to investigate dispersion by the hook method. As is clear from the estimate given, for undiluted crystals the hooks should be obtained well also at room temperature.

We modified the usual optical arrangement for obtaining hooks, adapting it to the study of narrow polarized lines in crystals. Instead of the Rozhdestvenskii interferometer we used a polarization interferometer, described by one of the authors (5), which makes it possible to obtain anomalous dispersion of light on a sharply polarized absorption line by measuring the frequency dependence of the birefringence in the region of the line under investigation.

Fig. 1. Optical arrangement for observing Rozhdestvenskii hooks on narrow polarized lines in crystals

Figure 1: Fig. 1. Optical arrangement for observing Rozhdestvenskii hooks on narrow polarized lines in crystals

The optical arrangement is presented in Fig. 1. From the light source, through lenses L_1, L_2, L_3, the light filter KS-14, and polarizer P_1, the light falls on quartz wedges KK. The optical axes in the quartz wedges KK are mutually perpendicular and parallel to the optical axes in the specimen O under study and in the compensating quartz crystal K. The principal planes of the polarizers P_1 and P_2 make an angle of 45° with the optical axes of the wedges. Lens L_4 projects the image of the interference pattern onto the slit of the spectrograph C.

As is seen from Fig. 1, the optical path difference is equal to

$$(\mu_0 - \mu_e)(d_1 - d_2) + (\mu_1 - \mu_2)l_0 + (\mu_0 - \mu_e)l_K = n\lambda. \tag{1}$$

Here μ_0 and μ_e are the refractive indices of quartz for the ordinary ray; d_1, d_2 are the variable thicknesses of the quartz wedges; l_k is the thickness of the compensating crystal; μ_1 and μ_2 are the refractive indices of the crystal under study; l_0 is its thickness. All refractive indices, except μ_1, which is associated with the polarized absorption line, may be regarded, in the narrow spectral region around this line, as independent of the wavelength λ. If the compensating crystal is oriented so that the normal course of its dispersion deflects the interference fringes in the direction opposite to the deflection of the fringes by the crystal under study in the region of the absorption line, then, provided that the condition
$(\mu_1 - \mu_0)l_0 \ll (\mu_0 - \mu_e)l_k$ is fulfilled, hooks can be observed.

Fig. 1. Optical arrangement for observing Rozhdestvenskii hooks on narrow polarized lines in crystals

We investigated ruby crystals with concentrations of 0.098 and 0.044%, and a length of 24.04 mm. The ruby crystals were placed in a Dewar with liquid nitrogen. Quartz was taken as the compensating crystal; its thickness was selected so that the hooks were located at a distance of 10–20 half-widths from the R_1 line (Fig. 2). At this distance from the absorption line, the dispersion curve for μ_1 can be described by the dispersion formula for an isolated line with resonance wavelength λ_0

$$\mu_1 = \bar{\mu}_1 + B/(\lambda - \lambda_0). \tag{2}$$

Here

Fig. 2. Rozhdestvenskii hooks near the R_1 and R_2 lines in a ruby crystal. Thickness of the quartz plates $l_k = 44.75$ and 129.30 mm

Figure 2: Fig. 2. Rozhdestvenskii hooks near the R_1 and R_2 lines in a ruby crystal. Thickness of the quartz plates $l_k = 44.75$ and 129.30 mm

$$B = \frac{fe^2Nl_0}{4\pi mc^2\bar{\mu}_1}\lambda_0^3;$$

$\bar{\mu}_1$ has the meaning of the mean value of the refractive index μ_1 in the region of the absorption line. Using the dispersion curve for μ_1 in the form (2) and the equation for the n-th interference fringe (1), following (2), one can obtain the formula for calculating the oscillator strength

$$(\delta_1 + \delta_2)^2 k = Cf. \tag{3}$$

Here $\delta_1 + \delta_2$ is the distance between the hooks; k is the constant of the hook method;
$C = e^2\lambda^3 Nl_0/\bar{\mu}_1\pi mc^2$; c, m, e are known constants. In calculating f, we neglect the difference between the effective field of the light wave in the crystal and the field in vacuum, as well as the interaction between chromium ions. In deriving the formula for f, it was assumed that there is a single absorption line. In reality, at 78° K the R_1 line in ruby consists of two strongly overlapping components of similar intensity, with a separation between maxima of 0.38 cm^{-1} and a half-width of each component of 0.3 cm^{-1} (6). Calculation shows that the error introduced by using the formula for a single line does not exceed 2% when measuring hooks at a distance of 15 half-widths from the absorption line.

The oscillator strengths of the R_1 line calculated from (3) for ruby crystals of both concentrations are identical within the limits of error and are equal to $1.5 \cdot 10^{-6}$. The measurement error for the ruby sample with a concentration of 0.098% Cr^{3+} is 6%, and for the sample with a concentration of 0.044% Cr^{3+} is equal to 7%. It is composed of measurement errors, which amount to 4% for the ruby crystal with the higher concentration and 5% for the crystal with the lower concentration, and of errors in determining the number of absorbing atoms, equal to 2%*.

Fig. 2. Rozhdestvenskii hooks near the R_1 and R_2 lines in a ruby crystal. Thickness of the quartz plates $l_k = 44.75$ and 129.30 mm.

Thus, when the temperature is lowered from room temperature to 78° K, the oscillator strength of the ruby R_1-line does not change and remains equal to $1.5 \cdot 10^{-6}$.

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* The concentrations of Cr^{3+} ions in the ruby samples were measured by the optical method by S. V. Grum-Grzhimailo, to whom the authors express their deep gratitude.

Note: Figure translations are in progress. See original paper for figures.

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