

The reduction of the measurement data was carried out for the  $Mn^{2+}$  ion. The effect can be described with the aid of the R-tensor, the structure of which is similar [6]. Unlike [6], the use of perturbation theory for the interpretation of the EPR spectrum is impossible, and the spin Hamiltonian is diagonalized exactly. The equation for the energy of the states was represented in the form of a sixth-degree polynomial, the roots of which can be readily obtained for the transition in question by an iteration method. The energy correction brought about by the electric field was calculated in first-order perturbation theory. Comparison with the experimental values of the splittings yielded the constants

$$R_{122} - R_{111} = 0,12 \frac{\text{MHz-cm}}{\text{kV}} ; R_{123} = -0,07 \frac{\text{MHz-cm}}{\text{kV}} .$$

The constant  $R_{133}$  was not determined, since its contribution to the line splitting in the investigated transition lies within the limits of the measurement error.

More detailed results of the influence of the electric field of these ions will be published later.

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#### CHANGE IN THE REFRACTIVE INDEX OF A LIQUID COMPRESSED BY A SHOCK WAVE. ANOMALOUS OPTICAL PROPERTIES OF CARBON TETRACHLORIDE

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1. The dependence of the refractive index ( $n$ ) of a liquid on the density ( $\rho$ ) was determined in experiments on the diffraction of light by ultrasound [1] and also under adiabatic [2] and isothermal [3-5] compression to pressures of several kbar. All the results were obtained at a relatively small change in density and do not reveal the variation of  $n$  with  $\rho$  when the density is appreciably higher than normal, yielding only the slope

$$\frac{dn}{d\sigma} = \rho_0 \frac{dn}{d\rho} .$$

The results of these experiments indicate that they can be described by means of the Gladstone-Dale formula

$$n - 1 = (n_0 - 1)(\sigma - 1) \tag{1}$$

and point to noticeable deviations from the theoretical relations of Lorentz-Lorenz (L-L) and Drude. The experimental data on the dependence of the refractive index on the compression  $\sigma = \rho/\rho_0$  far from the edge of the absorption band  $\nu_0$  can be described also by the single-term

dispersion equation

$$n^2 - 1 = A\sigma / \nu_0^2(\sigma) - \nu^2. \quad (2)$$

In this formula, according to [5,6], account is taken of the influence of the internal field and of its variation on the refractive index. When the material is compressed, the edge of the absorption band shifts towards larger wavelengths (for benzene, for example, this is confirmed by direct measurements [7]). Calculation shows that the values of  $n(\sigma)$  obtained for benzene from (1) and (2) coincide approximately up to  $\sigma \lesssim 2.0$ . It becomes necessary to carry out experiments to determine the actual course of  $n(\sigma)$  at such compressions.

Information on the optical properties of liquids at high densities can be obtained from experiments with shock waves, by methods described in [8]. Figure 1 shows the results of the measurements on glycerine and benzene. Since glycerine remained transparent in the investigated range of shock compressions, it was possible, just as in the case of water, to determine the refractive index of the shock-compressed liquids by two methods: from the course of the rays in the compressed layer,  $n_g$ , and from the reflectivity of the shock front,  $n_f$  (assuming the Fresnel formulas to be valid). The agreement of the results obtained by the two methods is evidence that in the entire investigated band the transition of the matter into the compressed state occurs within a layer of thickness  $l < \lambda/2\pi$  within a time  $\tau = l/D_{s.w.} \leq 10^{-11} - 10^{-12}$  sec.

The plot for glycerine shows also the experimental values of  $n_g$  taken from [9]. Similar results were also obtained for ethyl alcohol. These investigations allow us to conclude that the refractive index of liquids that lose part of their transparency under shock compression can be determined only by measuring the coefficients of light reflection from the shock front. Similar results for benzene are shown in Fig. 1. The solid lines on the plots correspond to  $n(\rho)$  according to (1), and the dash-dot plots are in accord with Lorentz-Lorenz. Thus, experiments with glycerine and benzene, as well as with ethyl alcohol, acetone, and toluene, have shown that when liquids are compressed by a factor 1.5 - 2 their refractive index varies linearly. The best empirical relation fitting the results is the

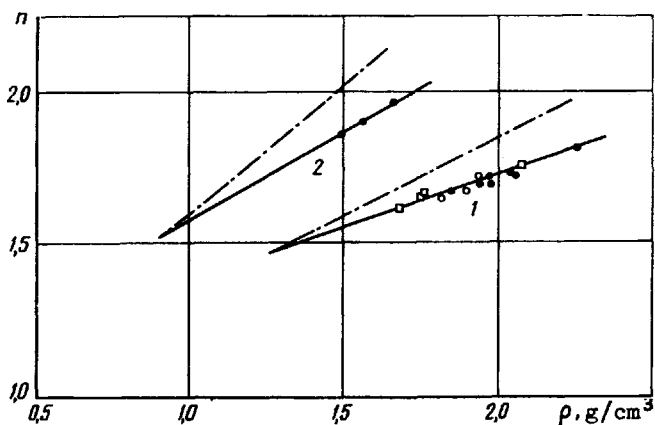


Fig. 1. Dependence of the refractive index of shock-compressed glycerine (1) and benzene (2) on the density. — G-D. - · - · - L-L. (○ -  $n_g$ ; ● -  $n_f$  - our measurements), □ -  $n_g$  from [9].

Gladstone-Dale (G-D) relation. This conclusion is evidence that the electron polarizability of the liquids is decreased by compression. The results obtained for water [8], where a disparity between the two methods was observed at large compressions, are more likely to be an exception than a general rule.

2. Measurements in  $\text{CCl}_4$  have shown that up to compressions  $\sigma \lesssim 1.9$  the reflectivity of the front is determined by the variation of  $n$  as given by (1) and (2). At larger compressions, however, the reflection coefficient begins to rise rapidly, reaching values  $R \approx 18\%$  at  $\sigma \sim 2.2$  and  $\varphi \approx 30^\circ$  (Fig. 2), whereas according to (1) and (2) we should have  $R = 3\%$  for  $\sigma = 2.2$  and  $\varphi = 30^\circ$ . Measurements made in different sections of the spectrum have indicated no dispersion of  $n$  in the visible region. Attempts to explain the results lead to two alternatives: either this effect is due to the large refractive index of compressed  $\text{CCl}_4$  ( $n = 3.6$  at  $\sigma = 2.2$ ) and the loss of transparency does not play a decisive role in this case, or else "metallization" takes place and the large reflectivity is due to the values  $k > 0.1$  ( $k$  is the imaginary part of the complex refractive index  $N = n - ik$ ). \* It is possible to separate  $n$  and  $k$  in the reflected light by measuring separately the  $R_s$  and  $R_p$  components of the reflected light [10]. In an explosion experiment it is more convenient to measure the coefficients of light reflection at different angles. Such measurements were made in  $\text{CCl}_4$ , and also in toluene and Plexiglas for control purposes. Figure 3 shows nomograms in  $R(70^\circ)$  and  $R(45^\circ)$  coordinates for different  $n$  and  $k$ , as well as the experimental results. For  $\text{CCl}_4$  the latter actually lie in the region of the values  $n = 1.2$ , and  $k \geq 0.3$  for  $\sigma \geq 1.95$ . This allows us to conclude that  $\text{CCl}_4$  becomes metallized when  $\sigma \geq 1.9$ . It is possible that such a state is realized only on the shock wave front and not in the entire thickness of the compressed matter.

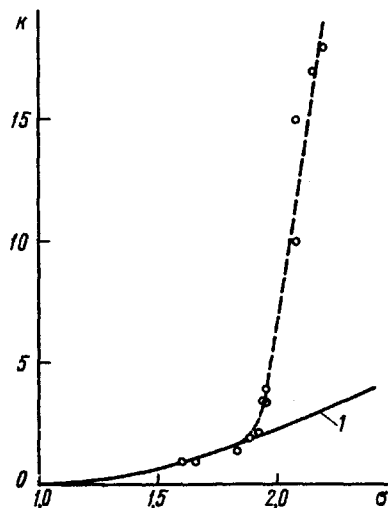


Fig. 2. Reflectivity of the shock wave front in  $\text{CCl}_4$  at different compressions  $\sigma$ . 1 - calculated according to Gladstone-Dale.

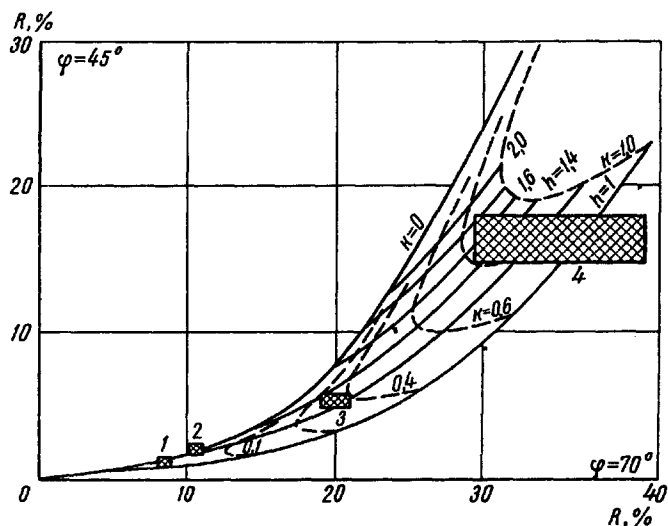


Fig. 3. Nomogram for the calculation of the real part  $n$  and the imaginary part  $k$  of the complex refractive index. 1) Plexiglas,  $\sigma = 1.72$ ; 2) toluene,  $\sigma = 1.76$ ; 3)  $\text{CCl}_4$ ,  $\sigma = 1.95$ ; 4)  $\text{CCl}_4$ ,  $\sigma = 2.12$ .

In conclusion we note that our results, as well as those obtained with ionic crystals [11], allow us to introduce a correction for the reflection from the front in temperature measurements (see [14]). This correction is small for almost all investigated substances, and plays a significant role only for  $\text{CCl}_4$  at pressures  $P > 200$  kbar.

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\* All liquids compressed in a shock wave lose their transparency as the intensity is increased ( $\text{CCl}_4$ ,  $P \geq 60 - 80$  kbar [12];  $\text{H}_2\text{O}$ ,  $P \geq 300$  kbar). The mechanism of transparency loss is apparently connected with absorption of light by free electrons, just as in ionic crystals [13].

#### SPECIFIC HEAT OF ANHYDROUS NICKEL CHLORIDE AT LOW TEMPERATURES

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Anhydrous nickel chloride  $\text{NiCl}_2$  experiences a transformation into the antiferromagnetic state at a temperature  $T_c \sim 52^\circ\text{K}$  and belongs to the class of layered antiferromagnets, which were first considered by Landau [1]. In these antiferromagnets the spins are ferromagnetically arranged in the layers, and a relatively weak antiferromagnetic interaction takes place between the layers.

Crystallographically, the layered structure of  $\text{NiCl}_2$  is of the  $D_{3d}^5$  type, and the symmetry axis  $C_3$  is directed perpendicular to the layers of the Ni ions.  $\text{NiCl}_2$  is fully isotropic [2], both above and below  $T_c$ , and we can assume in this connection that in the antiferromagnetic state the spins are oriented in the basal plane.

Electron resonance was observed in single-crystal  $\text{NiCl}_2$  at 9.2 GHz below  $T_c$ , down to  $10^\circ\text{K}$ , and is attributed to the presence of a low-frequency antiferromagnetic-resonance branch [3].

The specific heat of  $\text{NiCl}_2$  was measured earlier above  $14^\circ\text{K}$  [4,5]. Measurements of the specific heat of  $\text{NiCl}_2$  between  $1.8$  and  $16^\circ\text{K}$  were undertaken in the present work to ascertain the singularities of the energy spectrum of layered antiferromagnets.