

FIG. 2. Magnetoresistance of a cadmium single crystal plotted as a function of H for samples with smooth (1) and damaged (2) surfaces; n is the exponent of the power dependence $R(H)$.

arrangement of the current flow pattern so that it is concentrated in the surface layer (curve 3).

After the production of randomly distributed grooves, 0.5–1 mm deep, on the surface of a sample (by etching with a glass fiber wetted with nitric acid), the power exponent of the dependence $R(H)$ in the same range of fields increased to

1.4 (curve 2 in Fig. 2) and the ballistic measurements showed that the current was concentrated to lesser degree near the surface (curve 4 in Fig. 1).

This interrelationship between the results obtained by independent methods of measurement led us to the conclusion that we had observed one of the consequences of the static skin effect: a linear dependence of the magnetoresistance on the external field.

We take this opportunity to thank I. G. D'yakov for his kind assistance in our measurements.

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INFLUENCE OF A MAGNETIC FIELD ON THE THERMAL CONDUCTIVITY OF GASES WITH NONSPHERICAL MOLECULES

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IT has been shown ^[1,2] that the transport coefficients (viscosity and thermal conductivity) of nitrogen depend on the magnetic field. It has been suggested ^[1] that this effect is due to both the nuclear and rotational magnetic moments of nitrogen molecules resulting from their nonsphericity. A comparison of this effect in nitrogen with the corresponding effect in oxygen, which is due to its paramagnetism (the Senftleben effect), made it possible to estimate the effective magnetic moment μ_{eff} of nitrogen ^[2] and confirm the validity of the suggestion referred to above. It is obvious that such an effect should be present in all gases whose molecules are nonspherical. The present work reports briefly the results of investigations of this effect in N_2 , CO, CO_2 , H_2 and D_2 ,

and gives the average values of the rotational magnetic moments $\bar{\mu}_{\text{rot}}$, together with data on the nonsphericity of these molecules, derived from this study.

A theoretical treatment due to Yu. M. Kagan and L. A. Maksimov (private communication) shows that their theory of this effect in O_2 ^[3] may be adapted to other molecules having moments of inertia of the same order or larger than that of O_2 . For such gases, the relative reduction in the thermal conductivity $\epsilon = -\Delta\kappa/\kappa$ is given by the formula

$$\epsilon = af(\eta), \quad (1)$$

where

$$a = b\lambda^2, \quad \eta = K\mu_{\text{eff}}H/p, \quad K = K_1K_2,$$

$$K_2 = \frac{n^2}{A^{33}} \sqrt{\frac{kT}{2I}},$$

K_1 is a coefficient which depends on the nature of the magnetic moment; K is a coefficient which depends on the molecular-kinetic properties of the gas (the notation is the same as in ^[3]); λ is a nonsphericity parameter; and b is a coefficient depending on the nature of the gas. The form of the function $f(\eta)$ and more detailed data on the coefficients are given in the work of Kagan and Maksimov, according to which $K_1 = \sqrt{\pi}/20$ for O_2 .

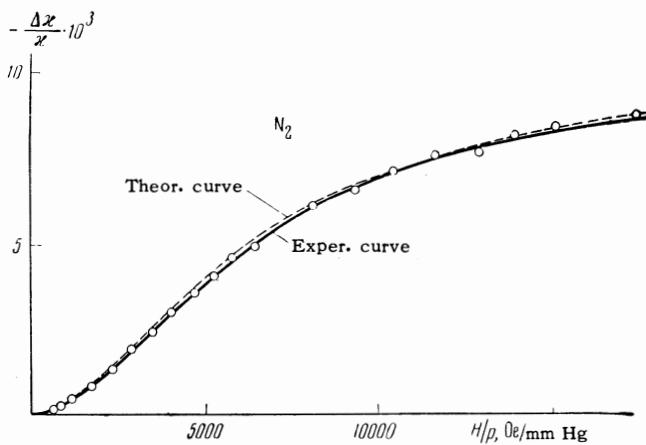


FIG. 1

As shown by L. A. Maksimov and V. Andriyako (private communication), $K_1 = 1/15$ for diamagnetic molecules (for example, N_2 , CO, CO_2). For H_2 and D_2 molecules, Eq. (1) may be regarded only as approximate because the quantum nature of the rotational motion is not allowed for in the derivation of this equation, and allowance for this in the case of molecules with a small moment of inertia (of the H_2 and D_2 type) may lead to a somewhat different expression.

The basis of the apparatus was similar to that described in [2]. The measurements were carried out at room temperature over a range of pressures from 6×10^{-2} to 1 mm Hg, and in fields up to 3200 Oe. The curves showing the obtained dependences of ϵ on H/p are given in the figures.

The absolute values of ϵ were found by calibration using the known effect in oxygen [4] and allowing for the temperature discontinuity, [5] which was determined experimentally by the present authors. The measurements on N_2 , CO, and CO_2 at various pressures (6×10^{-2} – 4×10^{-1} mm Hg) and fields (0–3200 Oe) showed that, in agreement with the theoretical data, ϵ was a function of H/p .

The value of the maximum effect at saturation, ϵ_{\max} , was determined by extrapolation of the experimental curves to higher values of H/p using the theoretical curve (1). This was possible because the relative curve (1) coincided with the experimental curves with an accuracy better than 5% for N_2 , CO, and CO_2 , and 20% for H_2 and D_2 . The values of ϵ_{\max} obtained in this way (with allowance for the temperature discontinuity) are given in the table (for the sake of comparison, the table also includes the data on O_2 [4]). The error in the determination of ϵ_{\max} amounted to $\pm 10\%$ for N_2 , CO, and CO_2 , and $\pm 30\%$ for H_2 and D_2 .

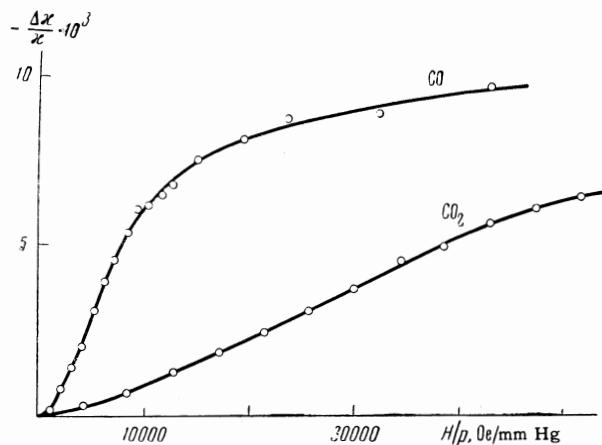


FIG. 2

It is evident from the table that the values of ϵ_{\max} for H_2 and D_2 are relatively small. This may be explained (at least as far as the order of magnitude is concerned) by assuming that the nonsphericity of molecules is associated only with the charge distribution and that

$$\lambda \sim r_n Z, \quad (2)$$

where r_n is the distance between nuclei; and Z is the atomic number. In this case, according to Eq. (1), the values of ϵ_{\max} for O_2 , N_2 , CO, and CO_2 should be approximately two orders of magnitude larger than those for H_2 and D_2 , which is in agreement with the experimental data (cf. the table).

The ratio of the values of ϵ_{\max} for H_2 and D_2 (2.0 : 1.0) determined with an error of less than $\pm 30\%$, is considerably larger than would follow from Eq. (1) on the assumption that $\lambda H_2 = \lambda D_2$ (1.1 : 1.0). This discrepancy may be explained either by the imperfection of the theory or by the fact that $\lambda H_2 \neq \lambda D_2$.

Since, with the exception of μ_{eff} , all the quantities occurring in the argument of η are known, [3, 7] this argument can be found by making the theoretical and experimental curves coincide. The values of μ_{eff} obtained in this way are listed in the table. It is obvious that, since the CO and CO_2 molecules do not have nuclear spins, $\mu_{\text{eff}} = \bar{\mu}_{\text{rot}}$ for these molecules.

An estimate, obtained by L. A. Maksimov, shows that in the fields we used the coupling between the rotational and nuclear moments of the N_2 molecule is virtually broken, i.e., the value of μ_{eff} given for N_2 is, as in the case of CO and CO_2 , equal to $\bar{\mu}_{\text{rot}}$.¹⁾ For the same reason, the values of μ_{eff} for H_2 and D_2 are equal to $\bar{\mu}_{\text{rot}}$. For comparison, we note that the values of μ_{rot}

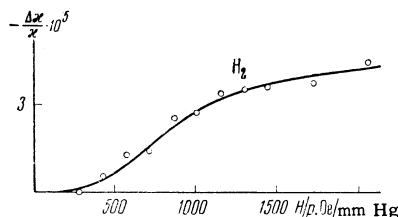


FIG. 3

for H_2 and D_2 at $T = 300^\circ\text{K}$, which we calculated from the known experimental data,^[8] are, respectively, 1.1 and 0.8 nuclear magnetons (n.m.).

We shall now consider the problem of the limits of the validity of Eq. (1). It should be mentioned that the coincidence of our experimental curve for O_2 (which agrees very well with Senftleben's curve^[4]) with the corresponding theoretical curve (1) for $\mu_{\text{eff}} = 1$ Bohr magneton gives a value of the coefficient K_1 approximately half the theoretical value. This means that the value of K_1 calculated by Kagan and Maksimov for O_2 needs revision. In spite of the good agreement between the theoretical and experimental curves for N_2 , CO and CO_2 , we cannot draw final conclusions about the accuracy of the theory in the case of these gases; this is because there are no other experimental data on μ_{rot} of these molecules. However, the results of the measurements of ϵ for H_2 and D_2 and the comparison of our data and published data on $\bar{\mu}_{\text{rot}}$ of these molecules (see above) shows that the theory developed for molecules of the N_2 type is approximately correct. It is obvious that, after refinement of the theory for H_2 and D_2 , it should be possible, depending on the degree of agreement of this theory with the experimental results for these gases, to answer the question about the limits of the applicability of the theory to other gases. At present, the data presented above show that the error in the determination of $\bar{\mu}_{\text{rot}}$ of N_2 , CO and CO_2 is probably less than $\pm 20\%$.

We are proposing to carry out later more accurate measurements on H_2 , D_2 and other gases. Moreover, we are hoping to increase the precision of the determination of $\bar{\mu}_{\text{rot}}$ of various molecules on the basis of an improved theory.

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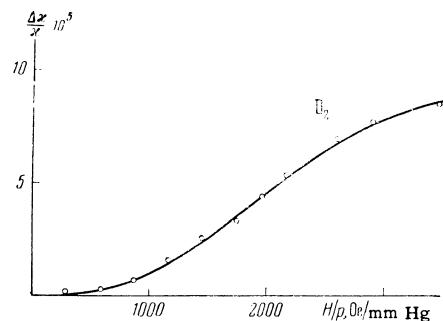


FIG. 4

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¹⁾So far only the method for determining μ_{rot} of the molecules of hydrogen isotopes and alkaline-earth elements (based on the Rabi method) has been published.^[6, 8, 9]

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Gas	$-(\Delta x/x)_{\text{max}} \cdot 10^4$	$\lambda^2, \text{ rel. units}$	μ_{eff}	Gas	$-(\Delta x/x)_{\text{max}} \cdot 10^4$	$\lambda^2, \text{ rel. units}$	μ_{eff}
O_2	120	1.00	1 Bohr magneton	CO_2	110	0.61	0.45 n.m.
N_2	105	0.58	1.30 n.m.	H_2	0.8	$0.45 \cdot 10^{-2}$	1.7 n.m.
CO	105	0.58	0.90 n.m.	D_2	1.6	$0.9 \cdot 10^{-2}$	0.8 n.m.