# GASKINETIC MAGNETIC RESONANCE

V. D. Borman, L. L. Gorelik, B. I. Nikolaev, and V. V. Sinitsyn

Submitted 2 August 1967; resubmitted 29 September 1967.
ZhETF Pis'ma 6, No. 11, 945-948 (1 December 1967)

It is known that the transport coefficients of gases with nonspherical molecules are decreased in a magnetic field [1-6]. The effect is attributed to the fact that the nonsphericity of the molecules causes the precession of their magnetic moments in the magnetic field to increase their effective collision cross section. We present in this note the results of an investigation of this effect in mutually perpendicular constant and alternating magnetic fields ("crossed" fields). Since in such fields the end of the molecule angular-momentum vector describes a three-dimensional curve (and not a circle as in the case of a constant field), it can be assumed that an additional increase in the collision cross section should take place in such fields. In addition, taking into account the resonant character of the precession in these fields [7], it can be assumed that the aforementioned increase should have a maximum when the alternating-field frequency equals the precession frequency. We present below results of experiments confirming the existence of a resonance effect, using the thermal conductivity of oxygen as an example.

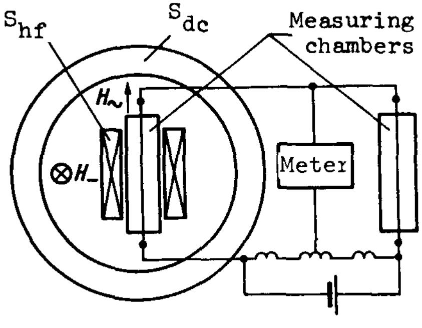

Fig. 1

Figure 1 shows the schematic diagram of the setup.* The pickup consists of two interconnected glass chambers (inside diameter 15 mm), through which are drawn electrically heated platinum filaments of 50 μ diameter. The latter serve as two arms of a Wheatstone bridge. A photooptic amplifier (F-116/1) is connected in the diagonal of the bridge. One of the chambers is placed in a solenoid ($S_{hf}$), which produces a high-frequency magnetic field ($H_\sim$) along the chamber. This chamber, together with the "high frequency" solenoid, is placed inside a large solenoid ($S_{dc}$), which produces a constant field ($H_-$) perpendicular to $H_\sim$. To prevent capacitive coupling between the platinum filament and the high-frequency solenoid, the latter is encased in an electrostatic shield. The remaining low-frequency circuits are also shielded. The relative change produced in the thermal conductivity ($\epsilon_\sim = -\Delta\lambda_\sim/\lambda$) when the magnetic field $H_\sim$ is turned on can be estimated from the unbalance of the bridge. In the experiments described below we investigated the dependence of $\epsilon_\sim$ on the frequency (f) of the alternating field at specified values of $H_\sim$ and $H_-$. The measurements were made at a pressure (p) $6 \times 10^{-2}$ mm Hg (with allowance for the temperature drop between the platinum filament and the surrounding gas), at room temperature, in the range $H_- = 0 - 3.3$ Oe and at $H_\sim = 0.4$ Oe, with f varied from 50 Hz to 2 MHz. The absolute error in the measurement of $\epsilon_\sim$ was approximately $\pm 8 \times 10^{-5}$. The average variation of $\epsilon_\sim(f)$ was determined, in the mean, with 10% accuracy.** The absence of parasitic phenomena was confirmed, in particular, by the fact that in argon, in the indicated range of fields and frequencies, the effect was equal to zero.

For linear molecules, the average precession frequency can be estimated from the formula

$$\Omega = \mu H/M,$$

where $\mu$ is the effective magnetic moment of the molecule. For $O_2$ molecules in the state $\sigma = \pm 1$ ($\sigma$ - projection of the electron spin on the direction of M), $\mu = \mu_0$ ($\mu_0$ - Bohr magneton) and $\Omega \simeq 1.5$ MHz for $H_- = 3.0$ Oe.

Figure 2 shows a plot of $\epsilon_\sim(f)$ at $H_- = 3.3$ Oe (when $H_-/p \simeq 60$ Oe/mm Hg). The function $\epsilon(H_-/p)$ exhibits saturation (with respect to $H_-$) in this case, so that under the conditions of our experiments the addition of a constant field ~0.4 Oe in either direction produced practically no change of $\epsilon$. As seen from the figure, $\epsilon$ reaches a maximum at $f \simeq \Omega$. The half-width of the maximum of the $\epsilon_\sim(f)$ curve (≈2/5) is determined by the statistical distribution of the values of M and by the ratio $H_\sim/H_-$. We note that a change of $H_-$ from 0.4 to 0.8 Oe nearly doubles $(\epsilon_\sim)_{max}$ and increases the half-width by approximately two times. The foregoing data indicate that the resonance curve in question is due to the gaskinetic resonance phenomenon proposed by us. An additional confirmation can be obtained from Fig. 3, which shows a comparison of $\epsilon_\sim(f)$ curves for different values of $H_-$. For the $H_- = 0$ curve we show only the relative variation. This curve, as expected, has no resonance. Starting with f ~ 0.1 MHz,

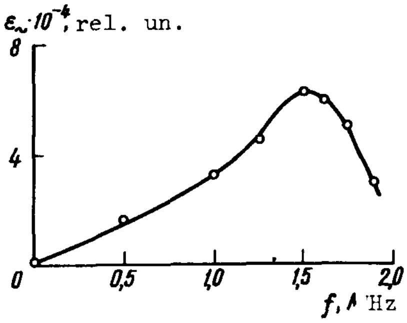

Fig. 2

which is of the same order of magnitude as the molecule collision frequency, a noticeable monotonic decrease of $\epsilon_\sim$ is observed with increasing f. This is similar to a phenomenon previously observed by us, the influence of an alternating electric field on the transport coefficients in polar gases [8]. Since the function $\epsilon(H_-/p)$ does not reach saturation in fields $H_- = 1.1$ and 2.2 Oe, this phenomenon leads to a distortion of the initial section of the resonance curve for these fields, especially in the former case. Nonetheless, the curves presented confirm the presence of gaskinetic resonance and give an idea of its character. It is seen from the figure that the values of f corresponding to $(\epsilon_\sim)_{max}$ are proportional to $H_-$.

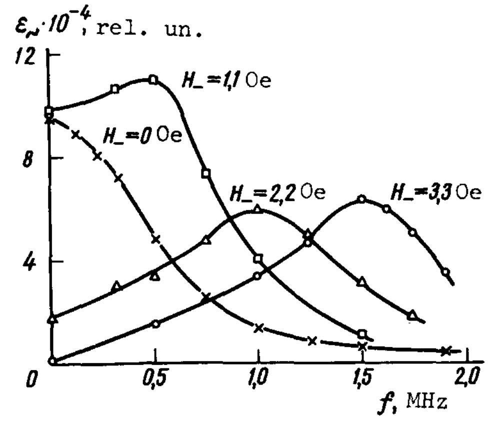

Fig. 3

It is obvious that the effect observed by us should occur also in nonparamagnetic gases. It can be assumed that in this case the resonance should be much sharper than in the case of oxygen: Since the rotational magnetic moments are proportional to their mechanical moments, the precession frequencies of all the molecules will be the same. It is also obvious that such an effect should be observed in polar gases placed in crossed electric fields.

We propose to carry out in the future more precise investigations in oxygen (in particular, an investigation of resonance for molecules with $\sigma = 0$), similar investigations in nonparamagnetic gases, and also in polar gases in crossed fields.

In conclusion, the authors are grateful to I. K. Kikoin for stimulating interest in the work, N. A. Kolokol'tsov for help with the work, L. A. Maksimov and Yu. V. Mikhailova for a useful discussion, and V. I. Nikolaev for help in preparing the instruments.

[1] H. Senftleben and J. Pietzner, Ann. der Physik 19, 907 (1933).
[2] E. Rieger, ibid. 31, 453 (1938).
[3] J. J. M. Beenakker, G. Scoles, H. F. P. Knoap, and R. M. Jonkman, Phys. Lett. 2, 5 (1962).
[4] L. L. Gorelik and V. V. Sinitsyn, Zh. Eksp. Teor. Fiz. 46, 401 (1964) [Sov. Phys.-JETP 19, 272 (1964)].
[5] L. L. Gorelik, Yu. N. Redkoborodyi, and V. V. Sinitsyn, ibid. 48, 761 (1965) [21, 503 (1965)].
[6] J. Korving, The Influence of Magnetic Field on the Transport Properties of Gases of Polyatomic Molecules, Dissertation, Leiden, 1967.
[7] A. A. Abragam, The Principles of Nuclear Magnetism, Oxford, 1961.
[8] V. D. Borman, L. L. Gorelik, B. I. Nikolaev, and V. V. Sinitsyn, ZhETF Pis. Red. 5, 105 (1967) [JETP Lett. 5, 85 (1967)].

[*] It is analogous to some degree to the setup described in [4].

[**] Doubts are expressed in [6] concerning the validity of the use of the "heated filament method" to measure $\epsilon$ at pressures $\sim 0.1$ mm Hg. It should be noted in this connection that the data presented in [1,2,4,5] refute these doubts.

# ERRATA

Article by V. D. Borman et al., Vol. 6, No. 11.

The ordinates of Figs. 2 and 3 on pp. 363 and 364 are marked "$\epsilon_{\sim}$ x $10^{-4}$ rel. un." They should read "$\epsilon_{\sim}$ x $10^{4}$ rel. un."