Experimental observation of a new maximum and central fine structure in gas-kinetic magnetic resonance in molecular oxygen

L. L. Gorelik and V. V. Sinitsyn

I. V. Kurchatov Institute of Atomic Energy, and V. P. Goryachkin Agricultural Engineering Institute, Moscow

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A new gas-kinetic magnetic resonance (GMR) maximum is observed experimentally for O_2. The ratio $(f/H)_r$ of the central resonance frequency to the stationary magnetic field strength is found to be ≈ 0.125 MHz/Oe, which is four times less than $(f/H)_r$ for the GMR peak identified previously. The center of the new maximum contains a dip ("central fine structure") with width and depth equal to $\sim 30\%$ and $\sim 10\%$ of the halfwidth and height of the peak, respectively.

A decrease in the thermal conductivity of molecular gases in crossed dc and rf magnetic fields H_0 and $H\sim$ was first detected experimentally in Ref. 1 for the case of O_2. The decrease is greatest when the precession frequency of the molecular magnetic moments in the field H_0 is equal to the frequency f of the field $H\sim$ (this is called gas-kinetic magnetic resonance, or GMR).

According to the approximate GMR theory developed for O_2 in Ref. 2, the decreased thermal conductivity observed in Ref. 1 is due to the precession of O_2 molecules with electron spin projections $\sigma = \pm 1$ (spins parallel or antiparallel to the kinematic momentum). The results in Ref. 1 are in qualitative agreement with the theory. In what follows we report experimental results in which a new GMR peak with a central fine structure was detected in O_2.$^{1)}$

The basic measurement configuration (Fig. 1) was similar to the one described in Ref. 1. The detector consisted of two identical glass chambers 1 and 2 of diameter 18 mm; the platinum thermistor sensors were arranged along the axes of the chambers, which were in mutual contact. The thermistors were connected to a Wheatstone bridge and heated to 100 °C by passing a current through them; we used ~0.2-mm-wide thermistor strips to increase the sensitivity.[4]

An amplifier was included in the measurement diagonal, and the modulation technique was similar to the one described in Refs. 3 and 5. The amplifier was tuned to a low-frequency (~0.3 GHz) pulsed field H_p which was parallel to and superposed on the principal *dc* field H_0. The pulsations of the thermal conductivity caused by the field H_p produced signals at the output of the amplifier. Both fields were generated by two coaxial solenoids, and the two chambers were positioned transverse to the field H_0; the active chamber was contained in an rf solenoid 3 which produced a field $H\sim \perp H_0$, while the second (comparison) chamber was used to correct for the Sanftleben effect (changes in the thermal conductivity for $H\sim 0$), which in our case was the source of background noise. The second chamber also stabilized the measurements. The bridge was fed by an ac current of frequency 1 kHz, and the measuring amplifier consisted of an interconnected input amplifier (1 kHz carrier frequency), low-frequency detector, and low-frequency (modulation-frequency) amplifier. In each experiment we measured the relative (resonant) change ε_r in the thermal conductivity as a function of the frequency f. The Sanftleben effect was used to estimate the absolute value of $\varepsilon_r(f)$ experimentally.

The experiments were carried out at room temperature, pressures $P = 20$–30 mtorr, and fields $H_0 = 8$–13Oe, $H_p = 7$–10 Oe, $H\sim = 3$–4 Oe. The results are shown in Figs. 2 and 3. Figure 2a shows $\varepsilon_r(f)$ found for $H_0 = 8$Oe, $H_p = 7$ Oe, $H\sim = 3$ Oe, and $P \sim 30$ mtorr by subtracting the dependence $\varepsilon_r(f)$ recorded in the fields H_0 and $H_0 + H_p$. The signs of the changes in ε_r are opposite for the two peaks A and B found by this method. The positions of the peaks are determined by H_0 and $H_0 + H_p$, respectively, which indicates that the change in the conductivity depends on the frequency divided by the field strength. The same behavior can be seen in Fig. 2b, which shows that the resonance frequency of the positive peak A depends linearly on H_0 (the peaks A_1 and A_2 correspond to the fields $H_0 \sim 8$ and 13 Oe). We also see that the position of the peak is independent of the pressure. The value of $|\varepsilon_r|$ at the center of the resonance was $\sim 10^{-3}$.

The ratio $\gamma^* = (f/(H_0 + H_p))_r$ at the center of the resonance was ~0.125 MHz/Oe, which is roughly 4 times less than γ^* for the peak previously detected in Ref. 1. We note that the theory in Ref. 2 predicts one GMR peak for $\sigma = \pm 1$ and one peak for $\sigma = 0$, with $H_{r,\sigma=0}/H_{r,\sigma=\pm 1} = 15$ at the centers of the resonance lines. However, since the theory is essentially qualitative, it seems plau-

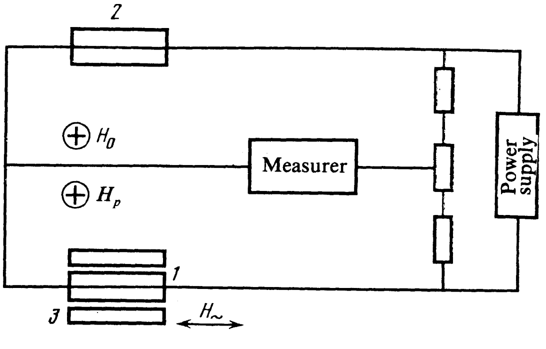

FIG. 1.

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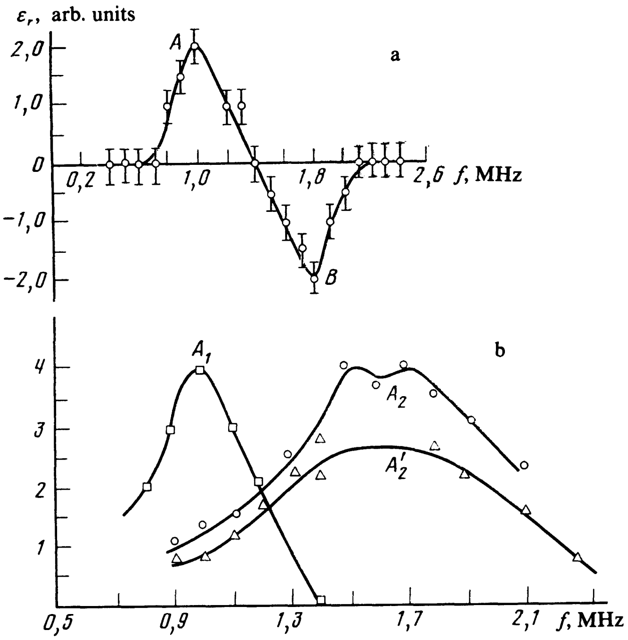

FIG. 2. Part a: $H_0 = 8$ Oe, $H_p = 7$ Oe, $H\sim\ = 3$ Oe, $P_{O_2} = 30$ mtorr. Part b, peak A_1: $H_0 = 8$ Oe, $H_p = 7$ Oe, $H\sim\ = 3$ Oe, $P_{O_2} = 30$ mtorr; peak A_2: $H_0 = 13$ Oe, $H_p = 10$ Oe, $H\sim\ = 4$ Oe, $P_{O_2} = 30$ mtorr; peak A'_2: $H_0 = 13$ Oe, $H_p = 10$ Oe, $H\sim\ = 4$ Oe, $P_{O_2} = 20$ mtorr.

sible that the peaks observed in Ref. 1 and in the present work correspond to $\sigma = \pm 1$. This assumption is supported by the fact that two peaks were observed experimentally in Ref. 6 for longitudinal GMR ($H_0 \| H\sim$) for the same values of γ^* as for transverse GMR, and that the theory developed there assigns these peaks to $\sigma = \pm 1$. The fundamental assumptions of the theory2) seem to be equally valid for the peaks observed for transverse GMR. In addition, the assignment of the peaks to $\sigma = \pm 1$ is further supported by the GMR peak observed in Ref. 7 for O_2 at $(f/H)_r \sim 0.015$ MHz/Oe; we believe that this peak is due to GMR involving molecules with $\sigma = 0$, as in the case of longitudinal resonance.[6]

A series of experiments carried out for $H_0 = 13$ Oe, $H_p = 10$ Oe, and $H\sim\ = 4$ Oe showed that a small dip was present at the center of the resonance (Fig. 3). The width of the dip was ~30% of the halfwidth of the peak and its depth was ~10% of $\varepsilon_r(f)$ at the center of the resonance. Such a central fine structure was predicted theoretically in Ref. 2 for nonparamagnetic gases; this dip appears to indicate that the theory is also approximately valid for paramagnetic gases.3) According to the theory in Ref. 2, the central fine structure should be present for $\omega_1/\nu \geqslant 1/\sqrt{8}$, where ω_1 is the molecular precession frequency due to the ac field $H\sim$, and ν is the collision frequency (for the spherically symmetric part of the collision cross section). In our experiments ω_1/ν was 20–30 times greater than $1/\sqrt{8}$. However, we note that no central fine GMR structure was observed for N_2 in Ref. 8, although the measurements were quite accurate; however, ω_1/ν there exceeded the threshold by only a factor of 3. This indicates that the theory[2] is not quantitatively valid.

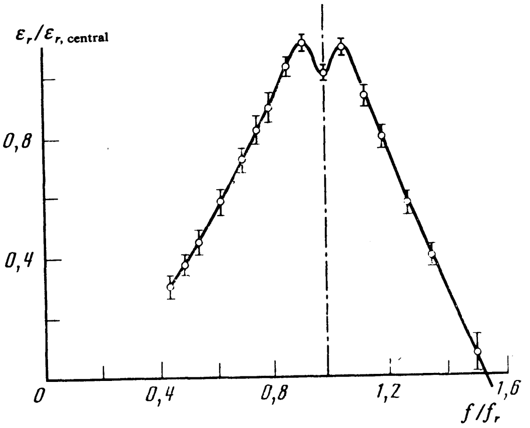

FIG. 3.

We thank A. A. Sazykin and L. A. Maksimov for a helpful discussion of the results.

1) These results are mentioned in Ref. 3.

2) No assumption is made there about the relative directions of H_0 and $H\sim$, but conditions are improved on the anisotropy of the equilibrium part of the distribution function, and the experimental conditions ($H\sim, p, f$, and the angle between **H** and grad T) are specified.

3) The GMR central fine structure for O_2 was confirmed by a series of experiments carried out by the authors in collaboration with V. D. Borman, V. S. Laz'ko, B. I. Nikolaev, and V. I. Troyan.

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