Oscillatory variation of the thermal conductivity of molecular gases in a magnetic field

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Oscillatory variation of thermal conductivity of some molecular gases as a result of variation of the magnetic field has been observed experimentally. The relative oscillatory variation of the thermal conductivity reaches $\sim 3\times 10^{-7}$ and 2×10^{-5} for H_2 and O_2, and their oscillation period amounts to $\sim$20 Oe and 80 Oe, respectively.

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As is well known, the thermal conductivity κ of molecular gases varies monotonically as a result of monotonic variation of the magnetic field H—the Senftleben-Binaker effect (SBE).[1,2] Similar investigations using sensing techniques showed that the thermal conductivity κ also experiences small oscillatory variations $\Delta\kappa_{OS}$ as a result of variation of H. Such behavior has been established in a broad range of fields and pressures. We present below some results of studies of this "oscillatory" effect (OE) in H_2 and O_2, which has heretofore not been predicted. The main experimental setup is illustrated in Fig. 1. The value of $\Delta\kappa_{OS}$ was determined by using a thermally sensitive, vibration-proof probe in a magnetic field, whose principle and design were described elsewhere.[1,2] It consists of an 18-mm-diam glass chamber along whose axis a thermistor heated by a current to 100 °C is located. The thermistor consists of two gold Π-shaped tapes $\sim$0.1 μm in thickness, on both sides of which an $\sim$5-μm-thick layer of mica was sputtered. The thermistor was connected to a Wheatstone bridge whose measuring arm was connected to a selective amplifier 2. We have used a modulation measuring method similar to that described in Refs. 3 and 4: the main field H_0 was supplemented by a relatively small, low frequency ($\sim$0.3 Hz) pulsating field H_Ω directed parallel to it, to which the amplifier was tuned. The output of the detector-amplifier had a time constant of $\sim$5 min. A recorder was connected to the amplifier. The sweep of the magnetic field H was accomplished by smoothly varying the H_Ω amplitude. The magnetic field was equal to 430 Oe to within an accuracy better than 10% when the current in the coils of the electromagnet was $J = 1$ A. The diagrams produced by the recorder represent the relative imbalance of the bridge (U) as a function of J; $J = J_0 + J_\Omega$, where J_0 is the direct current and J_Ω is the amplitude of the

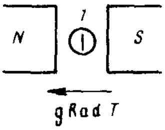

FIG. 1.

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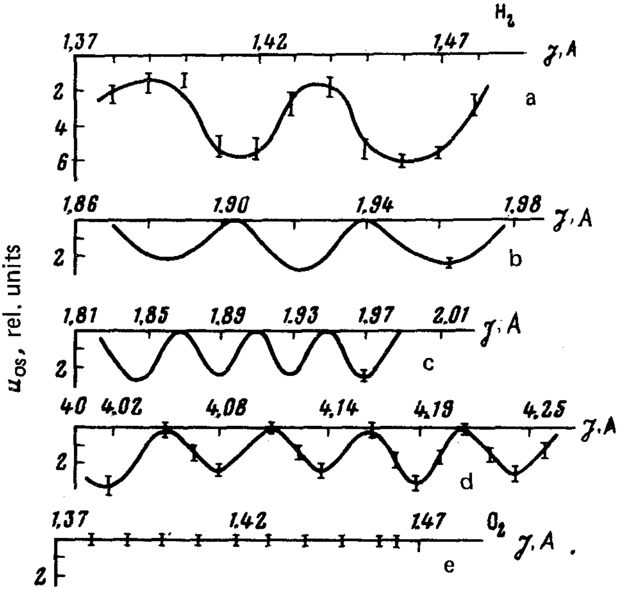

FIG. 2. The scale of (a) and (e) is twice as large as that of (b), (c), and (d).

pulsating current. The signal $U(J)$ is the sum of the monotonic signal due to the background and the signal $u_{OS}(J)$ produced by the OE. The background, which is attributable to the SBE and to the induction of the field H_Ω, was compensated for to a large extent by means of a small circuit that was placed in a magnetic field. The variation of $\Delta\kappa_{OS\ max}/\kappa = \epsilon_{OS}$ was estimated experimentally by comparing it with the ZBE. The experiments were carried out at room temperature.

Figures 2a-2d show some oscillation curves for $u_{OS}(J)$ obtained by using H_2 at $p \sim 0.5$ Torr. The locations of the minima on the curves depend solely on J, irrespective of J_0, J_Ω, and of the sweep range (see, for example, curves 2b and 2c). The oscillation period ΔH_{OS} is equal to 22 Oe to within an accuracy of better than 25% at $J \sim 1.4 - 4A$. ϵ_{OS} turned out to be equal to $\sim 3 \times 10^{-7}$. Figure 2e shows, for comparison, the curve for $u_{OS}(J)$, obtained by using O_2 at $p \sim 0.6$ Torr: under very simi-

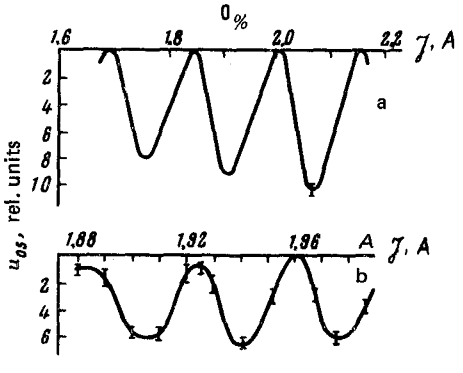

FIG. 3. The scale of (a) is approximately 100 times smaller than that of (b).

lar conditions to those under which curve 2a was obtained; the OE was not observed in O_2.

Figure 3 shows some results of observation of the OE in O_2. Figure 3a shows the curve for $u_{OS}(J)$, which was obtained at $p \sim 0.05$ Torr and $J \sim 1.6\text{A} - 2.2\text{A}$. Under these conditions we observed a large OE in a paramagnetic gas like oxygen: $\epsilon_{OS} \sim 2 \times 10^{-5}$, $\Delta H_{OS} = 70 \pm 10$ Oe. In the other experiments $\Delta H_{OS} = 90 \pm 10$ Oe at $J \sim 2.1\text{A} - 2.9\text{A}$. Figure 3b illustrates a curve obtained by using O_2 at $p \sim 1 \times 10^{-3}$ Torr. ΔH_{OS} decreased approximately fourfold as compared with the preceding experiments using O_2. This indicates that the oscillation period decreases sharply as a result of transition to the Knudsen regime.

The OE apparently can be connected with the variation of the effective cross section ($\Delta\sigma$) for collision of nonspherical molecules due to precession of their magnetic moments, if we assume that the rotational moments ($\mathbf{M}_i$) are quantized, and $\Delta\sigma$ generally depends on the magnitude and projection of $\mathbf{M}_i$ on $\mathbf{H}$. $\Delta\sigma(H)$ was obtained by summing a series of monotonic, nonlinear $\Delta\sigma_i(H)$ curves which were discretely shifted in H; as a result, a small oscillating component can occur in $\Delta\sigma(H)$. It seems that the OE can be used effectively for studying the structure of molecules and the interaction of rarefied-gas molecules with the solid surface. According to the preliminary data, the OE can also be observed in other gases.[1)]

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[1)] Moreover, an OE of resonance nature was observed in gases in crossed, constant, and rf fields. The oscillatory resonance effect was observed in O_2 with the participation of V. S. Laz'ko.

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