EFFECT OF PERIODIC VARIATION OF THE COEFFICIENT OF HEAT TRANSFER IN THE KNUDSEN MOLECULAR GAS PLACED IN MAGNETIC FIELD

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The authors present an experimental investigation of the heat transfer in molecular gases N_2, NF_3, CO in a constant magnetic field when the free path is comparable with the characteristic scale of the container. A periodic dependence of the coefficient of heat transfer on the magnetic field is obtained. The paper demonstrates that in the pressure interval under investigation the magnitudes of the field for which the maxima in the variation of the heat flux are observed do not depend on pressure.

It was predicted theoretically[1] that the coefficient of heat transfer in a rarefied molecular gas contained between two plane walls, is a periodic function of the constant magnetic field H which is normal to the surface of the walls, when the mean free path λ is much greater than the distance L between the walls. Under such conditions the heat transfer is determined only by the interaction between the molecules and the wall. If the internal energy of the molecule transferred during the collision with the wall depends on the angles of mutual orientation **v** and **M** (**v** and **M** are the velocity and the angular momentum of the molecule) in the plane of the wall, then, as shown in[1], the external field will affect the heat transfer through precession of the molecules which have a magnetic moment. The predicted periodic dependence of the coefficient of heat transfer on the field corresponds to the molecular precession of the first, second and higher orders during the time when the molecule moves from one wall to the other. The theory predicts that the relative variation of the heat flux in the field does not depend on pressure and should be determined by the product of the angular frequency of precession $\omega = \gamma H$ (γ is the gyromagnetic ratio) and the time of the motion of the molecule from one wall to the other $\tau = L/v_{av}$.

Note that in those pressure intervals for which $\lambda \gg L$, the effect of the intermolecular collisions can be neglected, and the well-known Senftleben effect (the dependence of the coefficient of the heat transfer on the ratio H/p[2]) should vanish.

In the present paper we present the results of experiments in the course of which the new phenomenon predicted in[1] has been discovered. This phenomenon consists in the periodic variation of the coefficient of heat transfer in a rarefied molecular gas with variation of magnetic field. Since this effect is caused by the transfer between the molecule interval energy to the wall, its detailed investigation will allow us in principle to obtain basically new information on the nature of the inelastic non-spherical interaction between molecules and a solid surface.

The experiments were performed in gases NF_3 and N_2 by means of a detector which consisted of two glass chambers with internal diameter 20 mm, and flat thermoresistors elements placed in the diametral section of the chambers[1)]. The heat flux measurement procedure was similar to that used by Gorelik et al.[3] for studies of the Senftleben effect. The experiments were performed in the pressure range 7–100 μ Hg and the magnetic field varied from 0 to 200 Oe (estimates of the magnetic fields at which there should be periodic variations of the heat flux in the substance under investigation, give the value of H of the order of several tens of Oersteds).

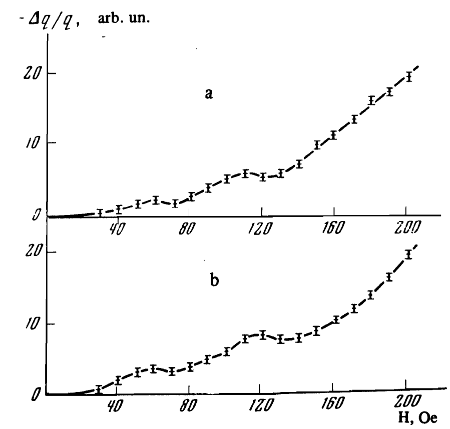

FIG. 1. Relative variation of the heat flux $\Delta q/q$ vs. the magnetic field H at different values of the gas pressure in NF_3: a—p = 10^{-2} μ Hg, b—p = 10^{-1} mm Hg.

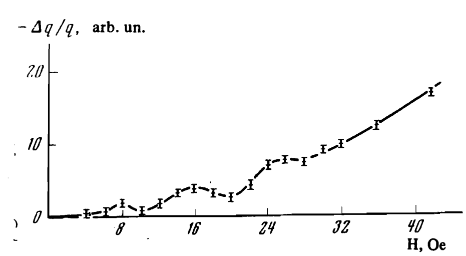

FIG. 2. Relative variation of the heat flux $\Delta q/q$ vs. the magnetic field H for nitrogen, p = 3 X 10^{-2} mm Hg.

[1)]These thermoresistors were developed by us together with L. L. Gorelik and V. V. Sinitsyn.

On Figs. 1 and 2 we present the experimentally obtained plots of relative variation of the heat flux $\Delta q/q$ against the field. The ordinates are proportional to $\Delta q/q$. The coefficient of proportionality depends on the kind of the gas and the geometry and was not determined in the course of experiments. One can see from the figures that in the field interval 0–30 Oe for nitrogen and 0–150 Oe for NF_3 the relation between $\Delta q/q$ and H is periodic. As shown by measurements carried out at pressures 7, 10, 15, 30, and 100 μ Hg, the field at which one observes the maxima of $\Delta q/q$ is independent of pressure within the experimental accuracy. This result is also in agreement with the theory according to which the effect should depend only on H at any given geometry.

As one can see from the figures, $\Delta q/q$ varies monotonically with further increase of the field ($H > 30$ Oe for nitrogen and $H > 150$ Oe for NF_3). This behavior of $\Delta q/q$ can be attributed to the influence of the Sentfleben effect on the heat transfer. Indeed, in our experiments the chosen pressure range corresponds to $\lambda \approx 1-0.1$ cm, i.e., $\lambda \approx L$. Therefore, it is obvious that the intermolecular collisions contribute considerably into the heat transfer. In the ranges of field under investigation, at a pressure values $p = 30\ \mu$ Hg for nitrogen and $p = 10-100\ \mu$ Hg for NF_3, the relative variation of the heat conductivity $\Delta\kappa/\kappa$ was found to be proportional to H^2 [3,4]. The observed dependence of $\Delta q/q$ on H at $H > 30$ Oe for nitrogen and $H > 150$ Oe for NF_3 is close to quadratic.

Note that in the experiments performed with the CO gas (the mass and the g-factor of CO molecules are close to the respective values for N_2) the values of the field for which the maxima were observed were nearly equal to the respective figures for N_2.

Unfortunately, the possibilities for the quantitative comparison of the experimental data with the theory developed in[1] were limited because the geometry of the detector was considerably different from planar; furthermore, in[1] the authors considered heat transfer between two identical surfaces, whereas in our experiments the surfaces were essentially different. In addition, as follows from the theory, the dependence of $\Delta q/q$ on H is determined to a great extent by the adaptation coefficient, which was not under control in the present experiments.

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[1] V. D. Borman, B. I. Nikolaev, L. A. Maximov, and V. I. Troyan, Dokl. Akad. Nauk SSSR **206**, 1972 (in press).

[2] J. J. M. Beenakker and F. R. McCourt, Ann Rev. Phys. Chem., **21**, 47 (1970).

[3] L. L. Gorelik, V. I. Rukavishnikov, and V. V. Sinitsyn, Phys. Lett., **28A**, 737 (1969).

[4] J. J. de Groot, L. J. F. Hermans, C. J. N. Van den Meijdenberg, and J. J. M. Beenakker, Phys. Lett., **31A**, 304 (1970).

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