GAS-KINETIC ELECTROMAGNETIC RESONANCE

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Using the thermal conductivity of NF_3 as an example, it is shown experimentally that in a static magnetic field and an alternating electric field which are mutually perpendicular and have a certain amplitude ratio, a resonant decrease of the transport coefficients of polar gases occurs when the electric field frequency equals the frequency of molecular precession induced by the magnetic field. Some qualitative and quantitative characteristics of the effects are presented.

It is known that transport coefficients of gases having nonspherical molecules are diminished in magnetic and electric fields.[1-6] This effect is associated with the enhanced collision cross sections of nonspherical molecules possessing magnetic or dipole moments, which precess in the respective fields. It has recently been observed that for oxygen the variation of thermal conductivity in crossed constant and alternating magnetic fields exhibits resonant dependence on the alternating field frequency ("gas-kinetic magnetic resonance").[7] This effect is accounted for by the fact that in the given fields the end of the molecular angular-momentum vector describes a three-dimensional curve (instead of the circle that results in a static field); the consequent additional increase of the collision cross section reaches its maximum when the alternating field frequency equals the precession frequency. The theory of this effect was developed in[8]. It was reasonable to anticipate similar resonance of polar-gas thermal conductivity in mutually perpendicular constant magnetic and alternating electric fields, because molecules of these gases possess both an electric dipole and a rotational magnetic moment. We shall present here experimental results confirming the existence of this resonance effect in the thermal conductivity of NF_3.

The apparatus is represented schematically in Fig. 1. The detecting device consists of two intercommunicating glass chambers (15 mm inside diameter); the platinum filaments of 30-μ diameter that are stretched across these chambers are heated by a 1000-Hz electric current, and form two arms of a Wheatstone bridge having a selective amplifier in its diagonal part. One of the chambers is situated between two metal plates (1 and 2) which generate a high-frequency electric field $E_\sim$ that is interrupted 5 times per second. This chamber and the plates are situated within a solenoid C that generates a constant magnetic field H_-, which is perpendicular to $E_\sim$. The relative change of thermal conductivity, $\epsilon_\sim = -\Delta\lambda/\lambda$, accompanying the switching-on of $E_\sim$ can be determined from the periodically changed unbalance of the bridge, as has been described in[9]. In the experiments to be described here we investigated the dependence of $\epsilon_\sim$ on the electric field frequency f for given values of $E_\sim$ and H_-. The measurements were performed at pressures $P = 0.32–0.64$ Torr (with allowance for the temperature differential between the platinum filaments and the ambient gas), at room temperature, in the range $H_- = 0–1.5$ kOe, for $E_\sim = 20$ V/cm, while varying f from 500 Hz to 400 kHz. The random absolute error of $\epsilon_\sim$ measurements was $(1-3) \times 10^{-7}$. The absence of spurious effects was confirmed by the fact that for the given ranges of pressures, fields, and frequencies the sought effect was not observed in nitrogen.

Figure 2 shows the curves of $\epsilon_\sim(f)$ for $H_- = 0$ (curve 1) and $H_- = 1.5$ kOe (curve 2) at 0.32 Torr. For these values of H_- the relative change of thermal conductivity for NF_3 in a static magnetic field is proportional to $(H_-/P)^2$. Curve 1 reflects the usual dependence of the effect on the electric field frequency, as detected and investigated in[10]. Most of curve 2 amounts to an approximate duplication of curve 1; this can be accounted for in the same way as for curve 1 of[10]. However, in the frequency interval 200–300 kOe curve 2 differs markedly from curve 1; at the middle of curve 2 the curvature changes rapidly. The greatest difference between the curves is observed at 240 kOe, which, as a calculation shows, coincides with the precession frequency of NF_3 for $H_- = 1.5$ kOe.

The foregoing data show that the difference between the curves results from the gas-kinetic electromagnetic resonance, as we have suggested. We represent the resonant change of thermal conductivity by normalizing curve 1 to curve 2 at f = 0 and denoting

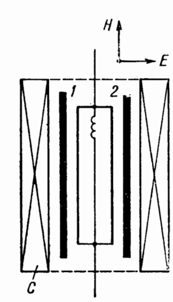

FIG. 1

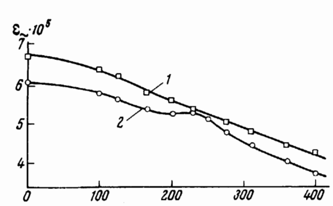

FIG. 2

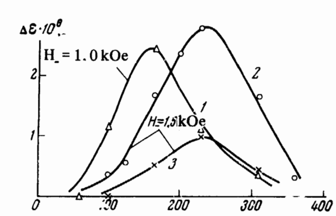

FIG. 3

the difference between the ordinates by $\Delta\epsilon$. Figure 3 shows the curves for $\Delta\epsilon(f)$ at different values of H_- and P ($P = 0.32$ Torr for curves 1 and 2, and $P = 0.64$ Torr for curve 3).

Figure 3 shows that at $\Delta\epsilon_{max}$ the values of f are proportional to H_-. Since the frequency dependence of the $\epsilon_\sim(f)$ curves are approximately identical far from resonance (Fig. 2), we may assume that the distortions shown in Figure 3 are very small. It is therefore of interest that, as can be seen from curves 2 and 3, even for a large change of pressure (which is accompanied by an appreciable change of the usual frequency dependence at $H_- = 0$), the value of H_- uniquely determines the frequency at which $\Delta\epsilon$ becomes maximal. The curves shown here confirm the existence of gas-kinetic resonance and give us an idea of its character. The half-widths of the peaks are apparently determined by the statistical spread of precession frequencies resulting from molecular collisions (since we had small experimental values of H_-/P, for which there is a large ratio between the molecular collision frequency and the precession frequency), and also by the ratio $E_\sim/H_-$. We can anticipate much sharper resonance for sufficiently large H_-/P in conjunction with small $E_\sim/H_-$.

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