THERMOMAGNETIC FORCE IN OXYGEN*

Mark E. Larchez and T. W. Adair, III
Texas A & M University, College Station, Texas 77843

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A thin disk surrounded by a polyatomic gas has been found to experience a force in a direction normal to its surface when a thermal gradient and an external magnetic field are applied. This force has been measured as a function of field and pressure for oxygen. The nature of the field and pressure dependence indicates that this force effect has its origin in the same molecular-collision processes as does the field-induced decrease of the viscosity (Senftleben-Beenakker effect).

The transport properties of a polyatomic gas may be influenced by an applied magnetic field because the precession of molecular magnetic moments about the field may change the molecular-collision processes. Experimental work has been reported on induced changes in the thermal conductivity and viscosity (Senftleben-Beenakker effect[1-3]). A related discovery is the recently reported thermomagnetic gas torque (Scott effect[4,5]). Measurements are reported here of a new and different thermomagnetic effect which is believed to be a result of the same molecular processes. This effect is a magnetic-field-induced change in the radiometer-type force which a gas exerts normal to a surface on which it acts in the presence of a thermal gradient.

The apparatus (Fig. 1) consists of an aluminum disk of diameter 22.2 mm, thickness 0.02 mm, and mass 19 mg suspended 2.5 mm above a heated copper plate. The disk is suspended by a quartz fiber from a sensitive quartz spring. Deflection of the spring corresponding to a force of 10^{-4} dyn can be measured with a micrometer microscope. Gas pressure is measured with an oil manometer. The plate is heated by a noninductively wound electric heater. Two thermocouple junctions, one on the heater plate and one on a smaller plate mounted above it at the same level as the aluminum disk, give a measure of the thermal gradient. Temperature differences measured are typically 1-4°C. A vertical magnetic field is produced by a pair of externally mounted Helmholz coils.

For any gas, when the heater is on, a steady-state upward force (radiometer type) is exerted on the disk. The pressure dependence of this force is similar to that of the standard radiometer force,[6] with a typical maximum value of 0.2 dyn occurring at about 0.04 Torr. For monatomic gases with spherical molecules (e.g., helium and argon) no change is observed when a magnetic field is applied. But for a polyatomic gas (nonspherical molecules), a magnetic field results in an additional force on the disk with magnitude 1 or 2% of the field-free force. This additional force is directed downward in all gases for which it has been observed: O_2, N_2, and NO. The effect is an even function of the magnetic field.

The field dependence of the magnetic force has been measured in oxygen between 0.19 and 0.73 Torr. Just as with the Senftleben-Beenakker effect, as the field increases the new downward force F increases from zero to a saturation value F_{sat}. Both the value of F_{sat} and the interval within which the increase takes place depend upon the pressure, but at pressures high enough to eliminate Knudsen effects F/F_{sat} depends only on the field-to-pressure ratio H/P.

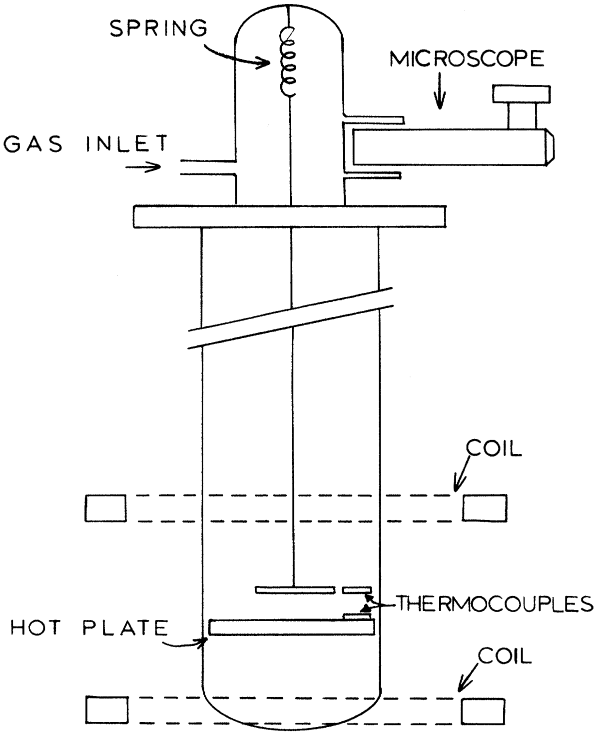

FIG. 1. Schematic diagram of equipment for measuring thermomagnetic force effect.

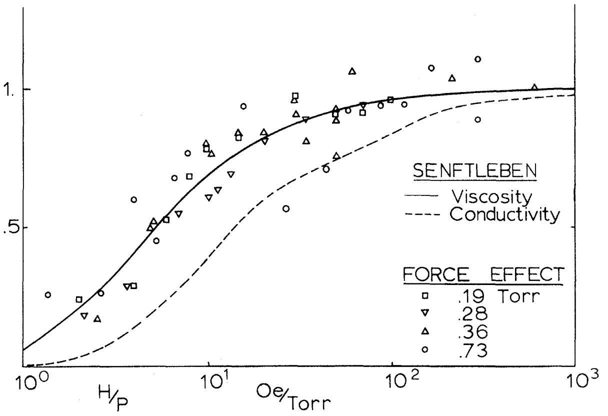

FIG. 2. Normalized thermomagnetic effects in oxygen as functions of H/P. The viscosity Senftleben-Beenakker–effect curve shown represents the quantity $\frac{1}{2}(2\eta_2-\eta_1+\eta_3)$ measured by the authors of Ref. 7. The conductivity curve from Ref. 8 is for the field parallel to the temperature gradient.

In Fig. 2 the normalized force F/F_{sat} for oxygen is shown as a function of the parameter H/P. The saturation values of the force per degree temperature difference are 1.1 mdyn/deg at 0.19 Torr, 1.4 at 0.28, 1.5 at 0.36, and 1.7 at 0.73. Also shown are similarly normalized data for the viscosity Senftleben-Beenakker effect[7] and the conductivity Senftleben-Beenakker effect.[8]

The fact that F/F_{sat} appears to depend on H and P uniquely through the parameter H/P (even though F_{sat} does not), and the fact that the increase to saturation takes place over the same interval of H/P, indicates that the mechanism for the thermomagnetic force must be the same as for the Senftleben-Beenakker effect. It also appears from Fig. 2 that the force is much more closely related to the viscosity Senftleben-Beenakker effect than to that for the conductivity.

The Chapman-Enskog approach has been somewhat successful in the theoretical treatment of thermomagnetic effects in gases.[3] A similar technique should be equally successful when applied to the new effect reported here. The information gained from measurements of this effect should thus contribute to a valuable extension of the theory of polyatomic gases.

In continuing this work we intend to investigate the force produced with the field directed horizontally (i.e., perpendicular to the temperature gradient) and to change the sensing-disk geometry in order to determine the relative importance of edge and surface contributions to the field dependence. It is hoped that this will aid in determining the relationship of the force effect to the other thermomagnetic effects in gases and will improve our understanding of the interactions of polyatomic molecules.

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