$$a_{f(b)} = \mu_{f(b)} E, \quad w = \frac{1}{\tau_{fb}\,\tau_{bf}\,(a_f - a_b)^2},$$

$$a = \frac{1}{(a_f - a_b)}\left(\frac{1}{\tau_{fb}} - \frac{1}{\tau_{bf}}\right),$$

$$b = \frac{1}{(a_f - a_b)}\left(\frac{a_f}{\tau_{bf}} - \frac{a_b}{\tau_{fb}}\right),$$

$$z = w(x - a_b t)\,(a_f t - x), \quad I_0(u) = J_0(iu),$$

and $I_1(u) = -iJ_1(iu)$, where J_0 and J_1 are Bessel functions of the first kind.

[12]H. Margenau, Phys. Rev. 69, 508 (1946).

[13]Thus, we assume that the functional dependence of μ_f with respect to E is independent of the density of the He gas, while μ_0 has a density dependence which we obtain by fitting the experimental data of v_d versus E in the high-E region, i.e., where $v_d \propto (E)^{1/2}$.

Thermomagnetic Torque in NH₃[†]

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A study of the thermomagnetic torque (Scott effect) in NH₃ is reported. The small positive Scott torque is measured as a function of magnetic field for absolute pressures of 0.028, 0.043, 0.048, 0.057, and 0.078 Torr. At maximum torque, the magnetic field H_0 for each pressure P is given by $H_0 = b(P + a)$, where $a = -4.4 \times 10^{-3}$ Torr and $b = 3.18 \times 10^3$ Oe/Torr.

INTRODUCTION

In 1967 Scott, Sturner, and Williamson[1] opened an exciting new field with the discovery of a thermomagnetic torque on a torsion pendulum suspended in a polyatomic gas. The torque is present when there is a temperature difference between the cylinder and the surrounding gas and when a magnetic field is applied along the axis of the cylinder. The direction of the torque depends on the direction of the magnetic field, the sign of the gyromagnetic ratio g_J of the molecules, and the direction of the thermal gradient. When a gas of spherical molecules or atoms like argon or helium is introduced there is no torque. Also, there is no torque in ³He which has a magnetic moment.[2] This thermomagnetic torque (Scott effect) is related to the Senftleben-Beenakker (SB) effect[3] which causes a change of viscosity and thermal conductivity with magnetic field.

Extensive theoretical work has been carried out on the SB effect,[4] and a large amount of theoretical work has been done on the Scott effect.[5-9] Levi and Beenakker,[5] using solutions of the Boltzmann equation based on the third Chapman-Enskog approximation, conclude that the product of torque times pressure (τP) should be a universal function of the field divided by pressure (H/P). Van Dael[10] has confirmed this with measurements in nitrogen gas.

It has been pointed out by Beenakker that torque measurements on H₂ and D₂ give strong evidence that the Scott effect is more closely related to the SB viscosity effect than to the SB thermal conductivity effect. This is because the maximum Scott torque occurs at an H/P value of the same order as the viscosity $(H/P)_{1/2}$, while the thermal conductivity $(H/P)_{1/2}$ is an order of magnitude larger as we shall see. The quantity $(H/P)_{1/2}$ is the value of H/P where the viscosity or the thermal conductivity reaches half of its saturation value.

Korving[11] has measured the viscosity SB effect in NH₃ and has found that the viscosity increases when a magnetic field is applied. This is unusual since for all other gases measured the viscosity decreases in a magnetic field. The positive viscosity effect in NH₃ raises the question of whether the Scott torque has the same sign as the molecular g_J factor in ammonia as it does in all other gases. The research reported here shows that NH₃ is quite normal. Progress on a detailed theory for the transport properties of nonsymmetrical polyatomic molecules was reported at a recent symposium of The American Physical Society[12] and quantitative results on NH₃ should prove useful to its development.

EXPERIMENTAL

Early attempts to measure the Scott effect in NH₃ were unsuccessful and indicated that if a torque exists it is no larger than 2×10^{-5} dyn cm. In this laboratory we have developed an extremely sensitive torsion pendulum[13] with which torques as small as 6.4×10^{-7} dyn cm can be measured. The system consists of a test cylinder 2.2 cm in diam and 10 cm long suspended at the center of a heated outer cylinder 6.3-cm i.d. and 50 cm long. The test cyl-
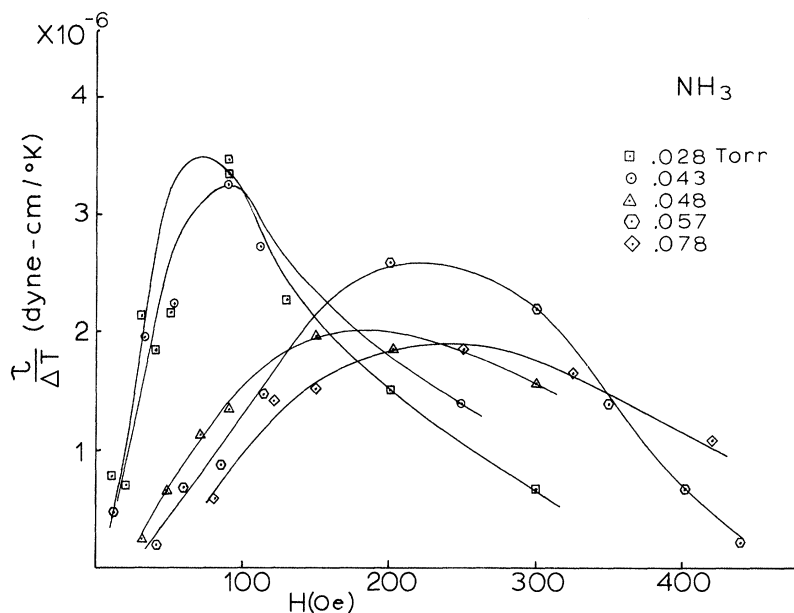
FIG. 1.   Scott torque normalized to $\Delta T = 1\,°K$ as a function of the magnetic field.

inder is supported by a 0.076-cm quartz rod which is supported by the torsion fiber. The fiber has a torsion constant of 5.31×10^{-2} dyn cm/rad. Details of the apparatus can be found in a paper by Avery.[13]

In the earlier, preliminary experiments on the Scott effect, a torque was observed in zero magnetic field which appeared to be due to vertical thermal gradients, and measurements had to be corrected for this nonmagnetic torque. The new apparatus[13] used in the present work gave no measurable torque at zero magnetic field, and therefore no correction was needed.

The ammonia was high-purity gas from the Matheson Gas Products Company with a stated purity of 99.99%. The gas was analyzed on a mass spectrometer, and the major contaminants were found to be nitrogen and oxygen.

The torque, normalized to a temperature difference of $1\,°K$, is plotted in Fig. 1 as a function of the magnetic field for absolute pressures of 0.028, 0.043, 0.048, 0.057, and 0.078 Torr. These curves are similar in shape to the ones found for such gases as nitrogen,[1] but the torque values are very much smaller.

It has been pointed out by Scott, Smith, and Fry[14] that the magnetic field H_0 at maximum torque for each pressure P is given by

$$H_0 = b(P + a). \tag{1}$$

The constant a depends on the gas and the dimensions of the apparatus while b is characteristic of the gas only. Figure 2 shows the field at maximum torque plotted versus the pressure. These data indicate that NH_3 also obeys Eq. (1) with a value of $a = -4.4 \times 10^{-3}$ Torr and $b = 3.18 \times 10^3$ Oe/Torr. Corresponding values of b for N_2 and O_2 are 1750

and 62 Oe/Torr, respectively.

In Table I $(H/P)_{max}$ for the Scott torque[1,13-16] is compared with $(H/P)_{1/2}$ for the SB effect on thermal conductivity[17] and viscosity.[11] As can be seen, each gas has a value of $(H/P)_{max}$ significantly less than $(H/P)_{1/2}$ except for oxygen, which has two peaks one
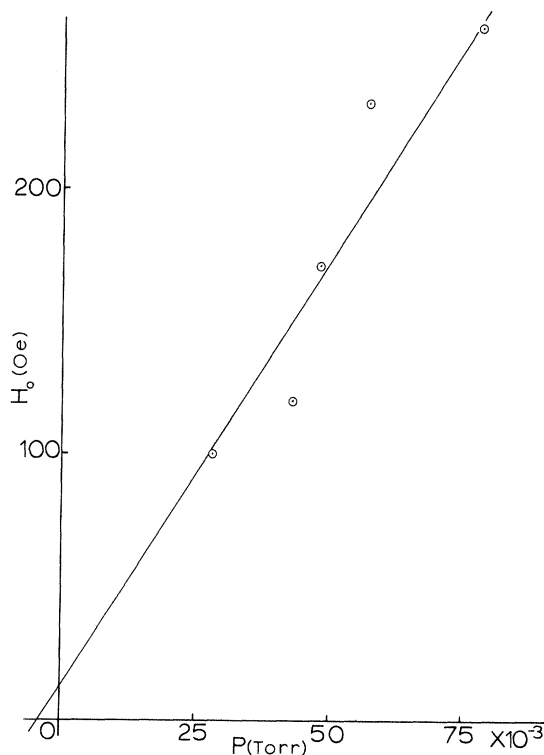

FIG. 2.   Magnetic field at maximum torque for each pressure as a function of pressure.

TABLE I. Senftleben-Beenakker parameter $(H/P)_{1/2}$ for thermal conductivity and viscosity compared to Scott-torque parameter $(H/P)_{max}$. The parameter $(H/P)_{1/2}$ is the value of H/P where the thermal conductivity or the viscosity reaches half of its saturation value. These data are for the magnetic field normal to the thermal gradient. The parameter $(H/P)_{max}$ is the value of H/P where the Scott torque has its maximum value.

Gas	Scott torque $(H/P)_{max}$ (Oe/Torr)	Thermal conductivity (Ref. 17) $(H/P)_{1/2}$ (Oe/Torr)	Viscosity (Ref. 11) $(H/P)_{1/2}$ (Oe/Torr)
N_2	1 750 (Ref. 1)	4 800	2 750
O_2	$\begin{cases}70\\3\end{cases}$[a] (Ref. 15)	9.3	5.1
CO	2 100 (Ref. 14)	5 100	3 650
NO	12 (Ref. 14)		33.5
CH_4	2 130 (Ref. 14)	6 800	4 200
$n-H_2$	50 (Ref. 13)	2 100	145
$p-H_2$	50 (Ref. 13)	1 800	125
$n-D_2$	100 (Ref. 16)	2 400	220
HD	$\begin{cases}55\\135\end{cases}$[a] (Ref. 14)	1 800	410
CD_4	3 340 (Ref. 14)	11 500	5 000
NH_3	3 500		14 800

[a]Two peaks.

of which gives $(H/P)_{max}$ larger than $(H/P)_{1/2}$. The gas HD likewise has two Scott peaks and exhibits an anomalously small ratio of $(H/P)_{max}$ to $(H/P)_{1/2}$. The ratio in NH_3 is also small but the gas appears to be normal in other respects.

DISCUSSION

Measurements here indicate that NH_3 has a Scott torque in the positive direction. A torque in the direction of that for hydrogen is defined as positive and is in the direction of the magnetic field vector when the inner cylinder is hotter than the outer surrounding gas. When the data from Fig. 1 are plotted as $\tau P/\Delta T$ versus H/P in a manner suggested by the theory of Levi and Beenakker,[5] each curve has a maximum at $(H/P)_{max} = 3200$ Oe/Torr. For pressures equal to or larger than 0.043 Torr the maximum value of $\tau P/\Delta T$ is 12.8×10^{-8} dyn cm Torr/ °K which is about 4% of the value observed in hydrogen gas.[13] For all gases in which a Scott torque has been found, the sign of the torque[18] is the same as the sign of the molecular g_J factor. This factor for NH_3 is positive,[19] and thus the torque and g_J have the same sign. We do not have a clue as to the strange behavior reported by Korving[11] in his viscosity studies with magnetic fields.

It was shown by Smith and Scott[20] that the molecular g_J factor could be calculated from Scott-torque data using

$$g_J = 1.27 \times 10^{16}\, \sigma \bar{v}/QbT,$$

where σ is the collision cross section, $\bar{v}$ the average molecular velocity, T the temperature, and Q a constant equal to 4π. The quantity b is taken from Eq. (1). Using $b = 3.18 \times 10^3$ Oe/Torr, $\sigma = 5.955 \times 10^{-15}$ cm^2, and $\bar{v} = 6.08 \times 10^4$ cm/sec, we calculate a value of $g_J (NH_3) = +0.384$. This agrees roughly with the value $+0.477$ given by Jen.[19]

Our value of $(H/P)_{max}$ for NH_3 is not too different from the values for CD_4 and CH_4. As molecular tops engaged in collisional processes, these molecules appear to be somewhat similar. It would be interesting to see a confirmation and extension of Korving's viscosity studies[11] in which the behavior of ammonia seems to be quite different from that of the methanes.

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