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Waveguide Interferometer for Measuring Electric Susceptibility in Gases

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***Abstract*—A simple, quick, and accurate method employing a magic-T interferometer for the measurement of electric susceptibility in gases is presented in this short paper. The electric susceptibility of five substances in a gaseous state has been measured satisfactorily as a function of pressure at room temperature with the help of this setup.**

INTRODUCTION

The electric susceptibility of gases in the microwave region is usually determined by two techniques. The first technique is based on the measurement of the shift in the resonant frequency of a cavity with the dielectric material kept inside it. This method has been used by Jen [1] and Birnbaum *et al.* [2]. In the second method, the shift in the standing wave is measured with the experimental gas in the waveguide cell. This method has been used by Hershberger [3], Krishnaji [4], and Srivastava [5].

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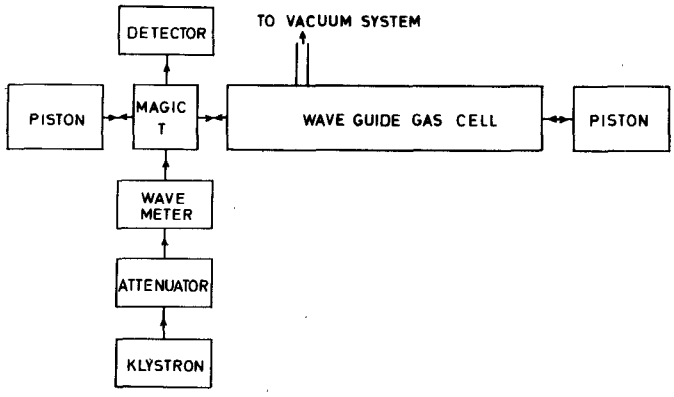

Fig. 1. Block diagram of interferometer setup used.

With the method presented here, a magic T is used to detect the change of phase when the gas is introduced into the cell. From this change of phase, the electric susceptibility can be calculated easily.

Experimental Setup

The block diagram of the interferometer is shown in Fig. 1. The microwave source, the attenuator, and the wavemeter are connected to the *H*-plane arm of Magic T (arm *A*). A 10-ft-long waveguide cell fitted with a mica window shorted at another end is connected to one of arm (*B*) of the magic T. Opposite to arm *B*, a movable short (piston) is connected in arm *C*. The crystal detector with matched load is placed in the *E*-plane arm of the magic T (arm *D*). Adjusting the position of the movable short in arm *C*, the minimum power at the detector arm can be achieved with and without gas in the absorption cell.

If the magic T is not perfect, it can be tuned to a particular frequency at which it works satisfactory. In the setup presented here, the magic T is tuned to a frequency of 9.55 GHz. The plunger used in the arm *C* has a clearance of 0.22 mm from the walls of the waveguide all around; this prevents the leakage of power past it. By means of a micrometer adjustment, the position of the piston could be set up to an accuracy of 0.05 mm. The output power of the crystal detector (IN23B) is fed to a sensitive galvanometer or nanovoltmeter.

THEORY OF THE EXPERIMENT

Let

λ_{fs} free-space wavelength in vacuum;
λ_{vg} guide wavelength in vacuum;
λ_{gg} guide wavelength in dielectric gas;
λ_c cutoff wavelength = $2b$.

Then for the TE_{10} mode in a rectangular waveguide

$$\lambda_{vg} = \lambda_{fs}\left[1 - \left(\frac{\lambda_{fs}}{\lambda_c}\right)^2\right]^{-1/2}$$

and $\epsilon = 1 + \delta$, where δ is the electric susceptibility of gases, the

$$\lambda_{gg} = \lambda_{fs}\left[1 + \delta - \left(\frac{\lambda_{fs}}{\lambda_c}\right)^2\right]^{-1/2}.$$

Therefore

$$\frac{\lambda_{vg}}{\lambda_{gg}} = \left[1 + \frac{\delta}{1 - (\lambda_{fs}/\lambda_c)^2}\right]^{1/2}. \quad (1)$$

With this setup let L be the length of the absorption gas cell, and let β_v and β_g be the phase constant in the vacuum and the gas, respectively. The phase difference introduced by putting the gas in the absorption cell is accounted for by moving the short (piston) to a distance, say x, opposite to the magic T, i.e.,

$$L\beta_g - L\beta_v = x\beta_v, \qquad (\because \beta_v > \beta_g)$$

or

$$\frac{\beta_g}{\beta_v} = \frac{\lambda_{vg}}{\lambda_{gg}} = 1 + \frac{x}{L} \quad (2)$$

comparing (1) with (2) and solving it for δ

$$\delta = \left[\frac{2x}{L} + \left(\frac{x}{L}\right)^2\right]\left[1 - \left(\frac{\lambda_{fs}}{\lambda_c}\right)^2\right]. \quad (3)$$

Since x/L is a very small quantity, and by neglecting the $(x/L)^2$ term in (3), the δ become directly proportional to x, the displacement in the plunger

$$\delta = \frac{2x}{L}\left[1 - \left(\frac{\lambda_{fs}}{\lambda_c}\right)^2\right]. \quad (4)$$

RESULTS

The measurements are made on five substances, ethyl chloride (C_2H_5Cl), chloroform ($CHCl_3$), acetone (CH_3COCH_3), acetaldehyde (CH_3CHO), and formaldehyde (HCHO). The vapors of these substances are introduced in the cell at up to 50 cm of pressure in gradual steps and the shift in the position of the piston of the C arm in achieving the minimum power at the detector is observed. The observed electric susceptibility δ at 9.55 GHz has been plotted as a function of pressure p in Fig. 2. The variation of δ_{vsp} is linear, as expected. The values of δ are shown in Table I. These values of δ have been compared with the calculated values of static electric susceptibility using Debye's relation as

$$\delta_0 = \epsilon_0 - 1 = \frac{4\pi N}{3kT}\mu^2$$

where N is the number of molecules per unit volume of the gas, and μ is the total dipole moment of the molecule. There is good agreement between the observed δ values and the calculated δ_0 values, showing that the effect of other polarization, e.g., atomic and electronic polarizations, on the susceptibility of gases in the microwave region is very small. A similar conclusion was reached also by Hershberger and Walter [6].

DISCUSSIONS

The current setup has several advantages over previous methods other than its simplicity and sensitivity. These are as follows.

1) In this setup the standing wave detector, which creates not only the reflection but also discontinuities in mode patterns, is not used.[1]

2) In the earlier methods it is not possible to isolate the microwave source and detector from waveguide absorption cell. But in this setup, the source and detector are isolated by 3 dB, and isolation can be improved by inserting additional isolators in the source and detector arms.

The accuracy of the measurement in this setup depends on the position of minimum power at the detector. To achieve the sharp minimum position, the modulation technique can be employed. If it is necessary, the phase-sensitive-detector technique may be incorporated to suppress the noise and to increase the signal-to-noise ratio. This certainly would make the sensitivity of the system such that it might be adopted for the line-shape studies and anomalous dispersion studies.

[1] Advantages of the magic T over slotted line section have been mentioned by Pippard [7], including details.

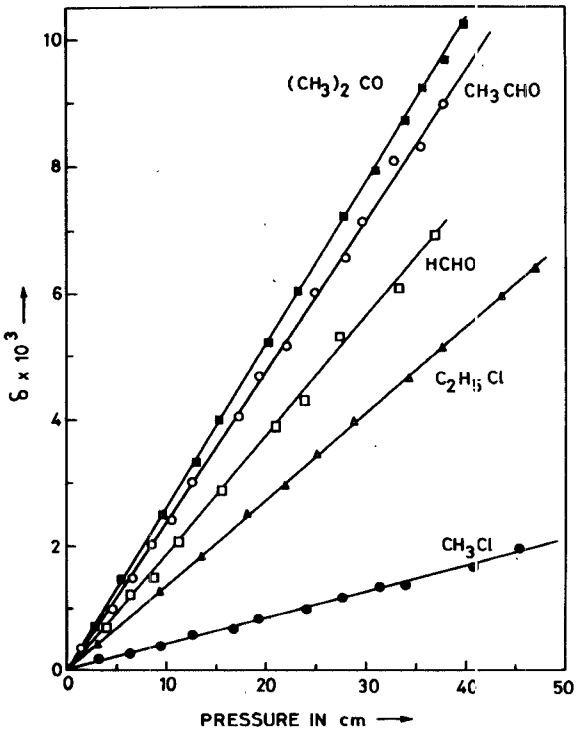

Fig. 2. Variation of δ observed with pressure for the molecules CH_3COCH_3 (■), CH_3CHO (○), HCHO (□), C_2H_5Cl (△), and $CHCl_3$ (●).

TABLE I

Molecules	Susceptibility x 10^3 per atom Observed	pressure Calculated
C_2H_5Cl	10.3	10.50
CH_3CHO	17.8	1756
$CHCl_3$	3.2	3.5
$(CH_3)_2CO$	19.36	19.50
HCHO	14.0	13.6

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