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Shock-tube studies of vibrational relaxation in nitrous oxide

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Results of experimental investigations of vibrational relaxation regions of shock waves in nitrous oxide are reported in this paper. The Mach-number range covered was from 1·5 to 7·5 and the photographs of the shocks were made using a Mach-Zehnder interferometer and a spark source. The experimental and calculated values of the over-all density ratio were found to be in good agreement, and the values of the relaxation frequencies were consistent with the data of other workers.

Shock-tube studies of vibrational relaxation regions of shock waves in carbon dioxide have been made at Manchester by Johannesen, Zienkiewicz, Blythe & Gerrard (1962), and Zienkiewicz, Johannesen & Gerrard (1963), and in carbon dioxide and nitrous oxide by Griffith, Brickl & Blackman (1956) at Princeton. The Manchester group found that the over-all density ratios agreed with the theoretical final equilibrium values, while the Princeton group reported the failure of their experimentally determined density ratio to reach the expected values at higher Mach numbers. Instead, both in the case of carbon dioxide and nitrous oxide, it attained a value corresponding to the bending modes being in equilibrium and the two valence modes being unexcited. In order to throw further light on this controversy, it was decided to perform a series of experiments in nitrous oxide. Nitrous oxide is a linear, asymmetric molecule with the same molecular weight as carbon dioxide. It has four normal vibrational modes, viz. a doubly degenerate bending mode (of characteristic temperature of vibration 847 °K), a symmetrical stretching mode (of characteristic temperature 1850 °K) and an asymmetrical stretching mode (of characteristic temperature 3200° K).

Thermodynamic data for N_2O were obtained from McBride, Heimel, Ehlers & Gordon (1963). They differ very slightly from those used by Griffith *et al.* but not enough to show on graphs of the over-all density ratio for shock waves.

The experimental apparatus and evaluation techniques employed were similar to those reported by Johannesen *et al.* Shock waves were produced using nitrogen (and helium) as the driver gas and strengthened by means of a convergence of the tube before the working section. The optical data required were obtained from Landolt–Börnstein (1962).

The density change $\Delta\rho$ is related to the fringe shift ΔN by the equation

$$\Delta\rho = \frac{\lambda\rho_0}{DK}\Delta N. \tag{1}$$

Here λ is the wavelength of light used for monochromatic interferograms and K the value of the Gladstone–Dale factor corresponding to the effective wavelength of the white light. D is the width of the working section and ρ_0 is the density at 1 atm. and 273 °K. In our case D was 8 in., λ was 4370 Å. The effective wavelength of the white light was estimated to be 4700 Å giving a value of

$$K = 0{\cdot}000516.$$

The evaluation constant $DK/\lambda = 240{\cdot}0$. Allowances were made, where appropriate, for the effects of dispersion on ΔN.

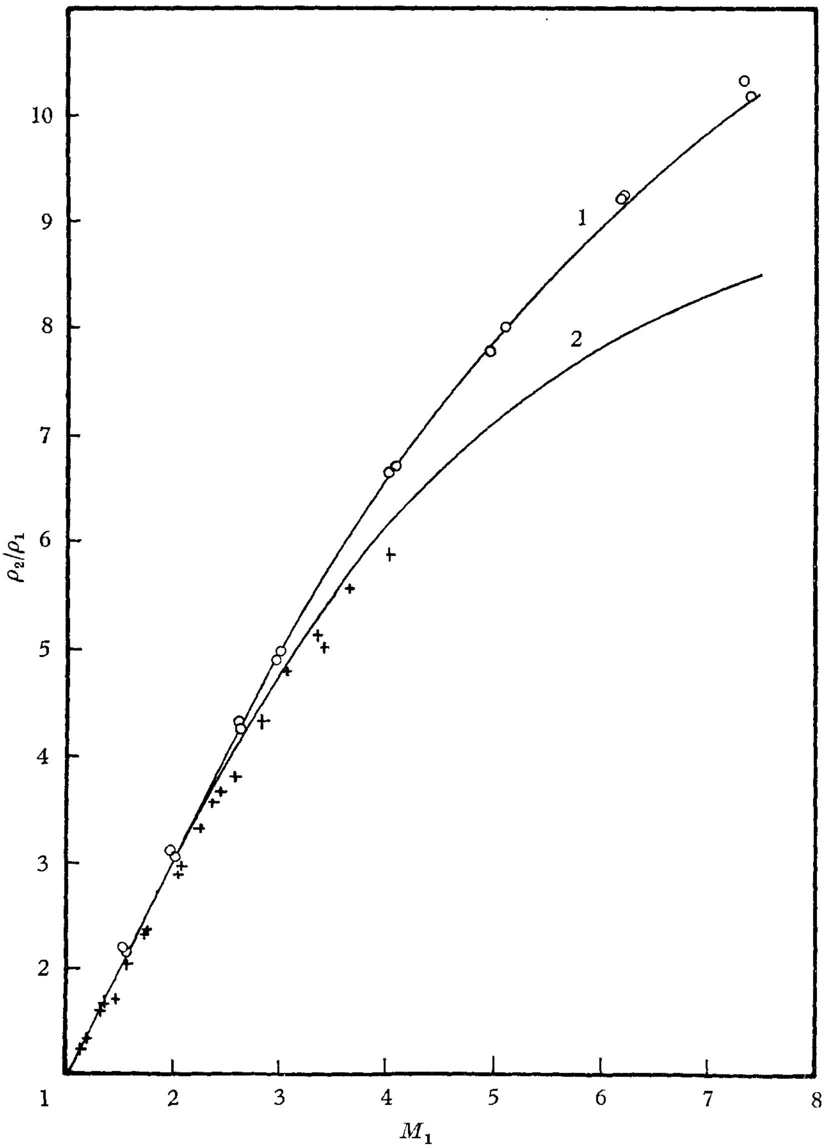

FIGURE 1. Theory: 1, all modes excited; 2, bending modes excited. Experimental values: ○, Manchester; +, Princeton.

Figure 1 shows the experimentally determined values of the over-all density ratio. These are compared with the theoretical curve for full equilibrium, the theoretical curve excluding the contributions from the valence modes, and the experimental results of Griffith *et al.* The estimated maximum error on the experimentally-determined density ratios is 3 %.

The relaxation frequency Φ is defined by the equation

$$d\sigma/dt = \rho\Phi(\bar{\sigma}-\sigma), \quad (2)$$

where σ is the vibrational energy, $\bar{\sigma}$ its equilibrium value, ρ the density and t time.

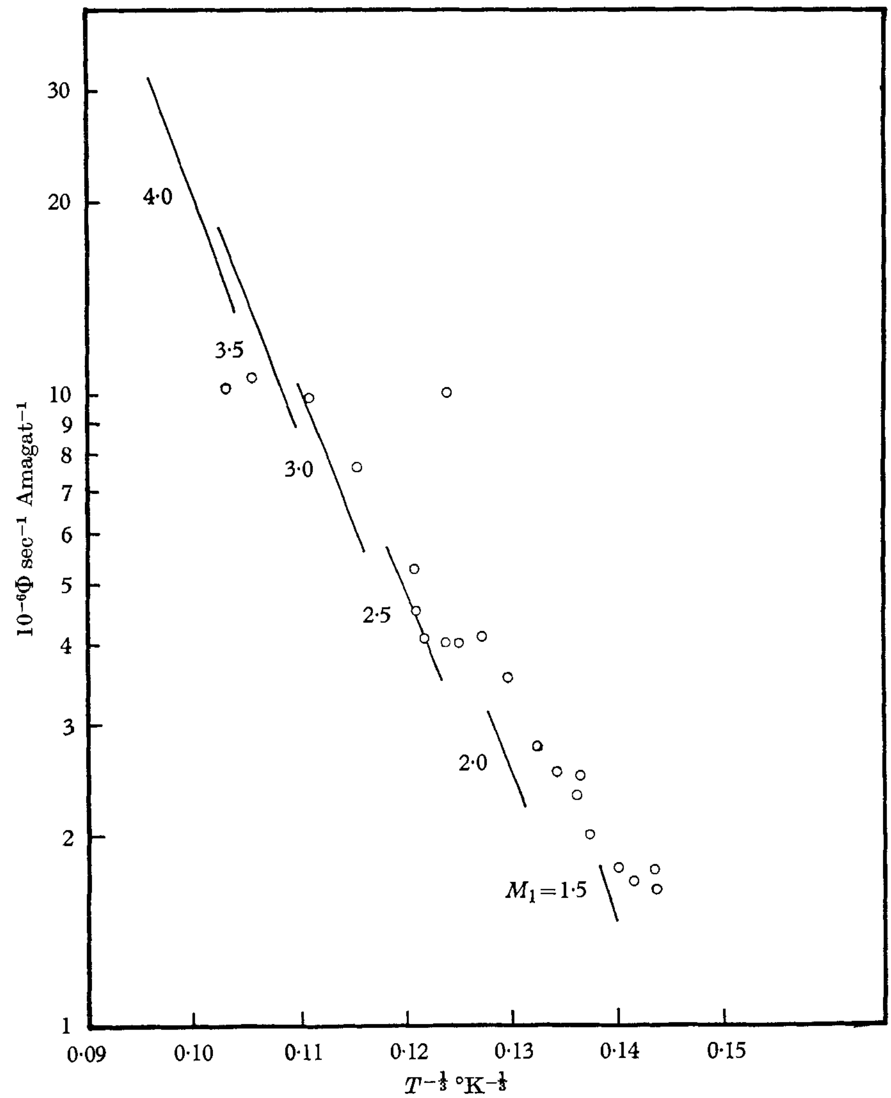

FIGURE 2. Vibrational relaxation frequencies in N_2O. ———, Present experimental results; ○, Princeton values.

The variations of Φ within the relaxation regions corresponding to $T_1 = 295\,^{\circ}$K (where T_1 is the temperature of the undisturbed gas) and shock Mach number $M_1 = 1{\cdot}5$–$4{\cdot}0$ are shown in figure 2. Also shown on figure 2 are the values of Φ obtained by Griffith *et al.* In accordance with our representation of the values of Φ, the data of Griffith *et al.* were modified to correspond to standard density.

Figure 1 shows that the over-all density ratio is in complete agreement with the theoretical value. This confirms the findings of the Manchester group for CO_2, and thus casts further doubt on the Princeton results.

As was the case for CO_2, the relaxation frequency Φ is seen in figure 2 to depend not only on T but also on the location within the relaxation region. The values of Φ are in good agreement with the Princeton results.

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