

## Molecular Absorption of Sound in Gases at High Temperatures

James E. Young and Osman K. Mawardi

Citation: [The Journal of Chemical Physics](#) **24**, 1109 (1956); doi: 10.1063/1.1742698

View online: <http://dx.doi.org/10.1063/1.1742698>

View Table of Contents: <http://scitation.aip.org/content/aip/journal/jcp/24/5?ver=pdfcov>

Published by the [AIP Publishing](#)

---

### Articles you may be interested in

[Ultrasonic Absorption and Velocity Dispersion in Diatomic Gases at High Temperature](#)

J. Acoust. Soc. Am. **40**, 1269 (1966); 10.1121/1.1943149

[Sound Absorption in the Halogen Gases](#)

J. Acoust. Soc. Am. **32**, 180 (1960); 10.1121/1.1908006

[An InfraRed Absorption Cell for Gases at High and Low Temperatures](#)

Rev. Sci. Instrum. **13**, 65 (1942); 10.1063/1.1769974

[The Absorption of Sound in Gases](#)

J. Acoust. Soc. Am. **6**, 199 (1935); 10.1121/1.1915738

[The Absorption of Sound in Gases](#)

J. Acoust. Soc. Am. **6**, 197 (1935); 10.1121/1.1915736

---



plane of the molecule, while for planar ring compounds Bell<sup>3</sup> has developed a fourth power potential energy function. However, these assumptions are not necessary when the coefficients of the linear angle terms are not assumed to be zero.

The condition that all these coefficients must be zero only applies if all the variables in the potential energy function are independent. Now the contribution of the linear angle terms to the potential energy function is  $V = \sum c \Delta \alpha_{ij}$ . For in plane vibrations  $\Delta \alpha_{ij}$  is directly proportional to the displacements of the atoms and so  $c$  must be zero unless  $\sum \Delta \alpha_{ij} = 0$ . Thus, since the sum of the angles round a point or in a ring is constant  $c$  need not be zero for a planar ring compound or molecules such as  $\text{BF}_3$ . For out of the plane vibrations the angle changes are proportional to the square of the displacements of the atoms and so  $c$  can enter into simple harmonic frequency formulas.

This shows that  $c$  need not be zero but does not prove that it is finite. Indeed, if every angle in the molecule is unstrained then the potential energy for each angle is a minimum and so  $c$  is zero. However, there is evidence that not only ring compounds but also molecules such as  $\text{BF}_3$  have strained angles. Thus, in  $\text{BF}_3$ , the success of the force field with repulsion terms used by Heath and Linnett<sup>4</sup> shows the importance of repulsion between the fluorine atoms. This is supported by the repulsion calculated for two neon atoms separated by the  $\text{F} \cdots \text{F}$  distance. Such a repulsion tends to open each angle beyond  $120^\circ$ . The symmetry of the molecule maintains the angles at  $120^\circ$ , but they are strained and so  $c$  terms should enter into the simple harmonic frequency formulas.

This method has been used to derive a frequency formula for the out of the plane vibration of  $\text{B}_2\text{H}_6$ . Taking the frequency for  $\text{B}_2\text{H}_6$  of  $368 \text{ cm}^{-1}$  observed by Lord and Nielsen<sup>5</sup> this formula gives  $266 \text{ cm}^{-1}$  for  $\text{B}_2\text{D}_6$ , while that obtained by Bell and Longuet-Higgins<sup>6</sup> gives  $245 \text{ cm}^{-1}$ . The observed value is  $262 \text{ cm}^{-1}$  with an uncertainty of about  $3 \text{ cm}^{-1}$ . This gives good evidence for the quadratic rather than the fourth-power potential energy function.

After these calculations had been finished it was found that Webb, Neu, and Pitzer<sup>7</sup> had proposed a rather similar treatment for the out of the plane vibration of a strained planar ring. They did not introduce the coefficient of the linear angle term but used that of the quadratic term and the strain angle. The method using the linear angle term has been applied to the out of the plane vibrations of ethylene and benzene as well as  $\text{B}_2\text{H}_6$ .

I should like to thank the Gas Council for a research scholarship.

<sup>1</sup> G. Herzberg, *Infrared and Raman Spectra of Polyatomic Molecules* (D. Van Nostrand Company, Inc., New York, 1945), p. 177.

<sup>2</sup> J. W. Linnett, *Quart. Rev. Chem. Soc.* **1**, 78 (1947).

<sup>3</sup> R. P. Bell, *Proc. Roy. Soc. (London)* **A183**, 328 (1945).

<sup>4</sup> D. F. Heath and J. W. Linnett, *Trans. Faraday Soc.* **44**, 561 (1948).

<sup>5</sup> R. C. Lord and E. Nielsen, *J. Chem. Phys.* **19**, 1 (1951).

<sup>6</sup> R. P. Bell and H. C. Longuet-Higgins, *Proc. Roy. Soc. (London)* **A183**, 357 (1945).

<sup>7</sup> Webb, Neu, and Pitzer, *J. Chem. Phys.* **17**, 1007 (1949).

## Molecular Absorption of Sound in Gases at High Temperatures\*

JAMES E. YOUNG† AND OSMAN K. MAWARDI

Acoustics Laboratory and Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received March 5, 1956)

THE mechanisms for the dissipation of energy in a sound wave which propagates in a gas have been discussed at great length in the scientific literature.<sup>1</sup> It is commonly accepted, nowadays, that the reason for this dissipation is mainly due to viscothermal losses in the body of the gas and at the boundaries of the conduit within which the propagation takes place. Energy can also be dissipated by means of the so-called "molecular" thermal relaxation processes.<sup>2</sup> Measurements pertaining to this latter molecular absorption form the subject matter of this letter.

The measurements have been performed on dry air at 2000 cps for the temperature range  $600^\circ\text{K}$  to  $1200^\circ\text{K}$ . The details of the experimental procedure are described elsewhere.<sup>3</sup> The molecular

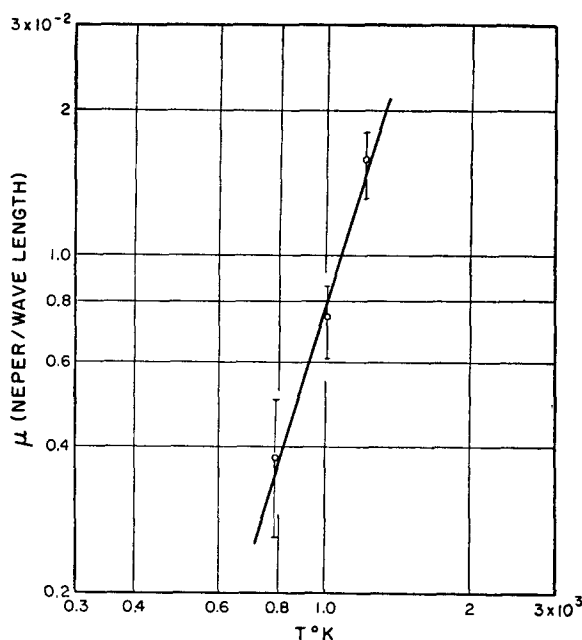


FIG. 1. Molecular absorption vs temperature of dry air.

absorption has been estimated by subtracting from the total acoustic absorption of a resonating cavity that contributed by the viscothermal losses. The results are presented in graphical form in Fig. 1. The molecular absorption has been reduced to an attenuation per (wave guide) wavelength. The absorption is denoted by  $\mu$  and the absolute temperature by  $T$ . Both quantities have been plotted on a logarithmic scale.

The spread in the data is due in part to the difficulty of accurately estimating the boundary layer losses and also to the non-uniformity of the temperature in the resonant cavity. It is possible to fit a functional relation of the form  $\mu = CT^\beta$  to the data shown here. This curve fitting indicates that  $\beta = 1.77 \pm 0.08$  and that  $C = 1.16 \times 10^{-7}$ . The uncertainty in  $C$  can be related to the error in  $\beta$  by an expression of the form

$$\frac{\delta C}{C} = -\delta \beta \log T.$$

The reduction of the absorption data into relaxation times considerably extends the use of the experimental results. These relaxation times are actually related to the number of collisions required for deactivation of the molecular states considered. For the cases on hand, it is the relaxation of the first vibrational level in  $\text{N}_2$  which is of special interest. The air is considered as a  $\text{N}_2$ - $\text{O}_2$  mixture with  $\text{O}_2$  being the nonrelaxing impurity in the parent gas,  $\text{N}_2$ . In this way a relaxation time and an equivalent number of collisions  $N_c$  for deactivation representing the "behavior" of a single  $\text{N}_2$  molecule in an environment of  $\text{O}_2$  molecules can readily be deduced.<sup>4</sup> These numbers, which are functions of the thermodynamic variables of the gas, can then be compared with corresponding values obtained by other workers. For example, it is found that for a temperature of  $606^\circ\text{K}$  and gas pressure of 1 atmos,  $N_c$  is  $6.5 \times 10^{-5}$  for the  $\text{N}_2$ - $\text{O}_2$  mixture, which is not an unreasonable value.

Helpful discussions with Dr. S. J. Lukasik on some phases of this work are gratefully acknowledged.

\* This work was supported in part by Contract No. AF 33(616)-149 with Wright Air Development Center.

† Now Shell B. P. Fellow in the Department of Aeronautical Engineering, The University, Southampton, England.

<sup>1</sup> F. V. Hunt, *J. Acoust. Soc. Am.* **27**, 1019 (1955).

<sup>2</sup> C. Kittel, *Repts. Progr. Phys.* **XI**, 205 (1946-1947).

<sup>3</sup> J. E. Young, Technical Mem. No. 4-Aerothermo-acoustics project-Acoustics Laboratory, Massachusetts Institute of Technology.

<sup>4</sup> F. A. Angona, *J. Acoust. Soc. Am.* **25**, 1116 (1953).