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DEPARTMENT OF PHYSICS
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

Technical Report PTR-81-4

PROPAGATION OF SOUND THROUGH THE EARTH'S
ATMOSPHERE:

- I. MEASUREMENT OF SOUND ABSORPTION IN THE
AIR AND
- II. MEASUREMENT OF GROUND IMPEDANCE

By
Roger W. Meredith
and
Jacob Becher

Principal Investigator: Allan J. Zuckerwar
(from January 1 to September 28, 1980)

Final Report (Revised)
For the period July 1, 1980 - June 30, 1981

Prepared for the
National Aeronautics and Space Administration
Langley Research Foundation
Hampton, Virginia

Under
Research Grant NAG1-15
Harlan K. Holmes, Technical Monitor
Instrument Research Division



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P.O. Box 6369
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By

Roger W. Meredith¹ and Jacob Becher²

SUMMARY

This report summarizes work accomplished under NASA grant NAG1-15 since July 1, 1980. This work is described under four major subject headings: (1) acoustic ground impedance meter, (2) automatic data-processing system, (3) cooling system for the resonant tube, and (4) final results of sound absorption in N₂-H₂O gas mixtures at elevated temperatures.

ACOUSTIC GROUND IMPEDANCE METER

The fabrication of parts for the acoustic ground impedance meter has been completed, and the instrument has been tested. The volume velocity source, using the five-lobed cam and the LED-photodiode monitor, functioned as expected. However, mechanical vibrations from the volume velocity source produced chatter to such an extent as to overwhelm the microphone signal. This problem was eliminated by unscrewing the resonator neck from the chamber and reconnecting the two parts by means of a rubber hose to suppress vibration. The neck is currently being modified for mounting on the center post of a camera tripod. It can be lowered to a favorable height above the chamber and connected with the rubber hose.

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AUTOMATIC DATA-PROCESSING SYSTEM

The Datel Interfaced analog-to-digital converter model ADC-HC12B has been successfully hardwired into the Apple II computer detection system. A sample driver for handshaking the converter with the computer and controlling the conversion rate is listed in Appendix I. The program first initializes the computer interface with the converter, then a 512, 8-bit, byte base page is set up to store the 256 2-byte output from the converter. Memory location 06 contains a code which controls the conversion rate from 6 to 500 Hz. The 256 conversions are sequentially stored in the base page.

By controlling the sample rate, each free-decay curve representing the sound absorption at that frequency can be stored as 256 digital data points. The digital data can be stored directly on magnetic disk with the following restrictions intrinsic to the computer's disk operating system. Each free-decay frequency (256 digital data points) will be stored under a separate file name and 105 file names are allowed per disk. Each set of 256 digital data points requires 1,024 disk bytes for storage where 252 digital points require only 768 disk bytes. This is due to the way in which information is encoded on the disk. Software for graphing the digital data and evaluating the free-decay curves has been initiated.

COOLING SYSTEM FOR THE RESONANT TUBE

When the initial cooling system proved ineffective in cooling the resonant tube to 0° C (32° F), the cooling system piping was insulated. Even with the added insulation, the cooling system was ineffective. The cooling system was modified to use liquid nitrogen coolant by passing liquid nitrogen from a nearby trailer. The liquid proved to be sufficient to cool the resonant tube to the required temperature; however, the temperature gradient within each of the four tube sections reached unacceptable levels. Figure 1 shows the results of the cooling test and the

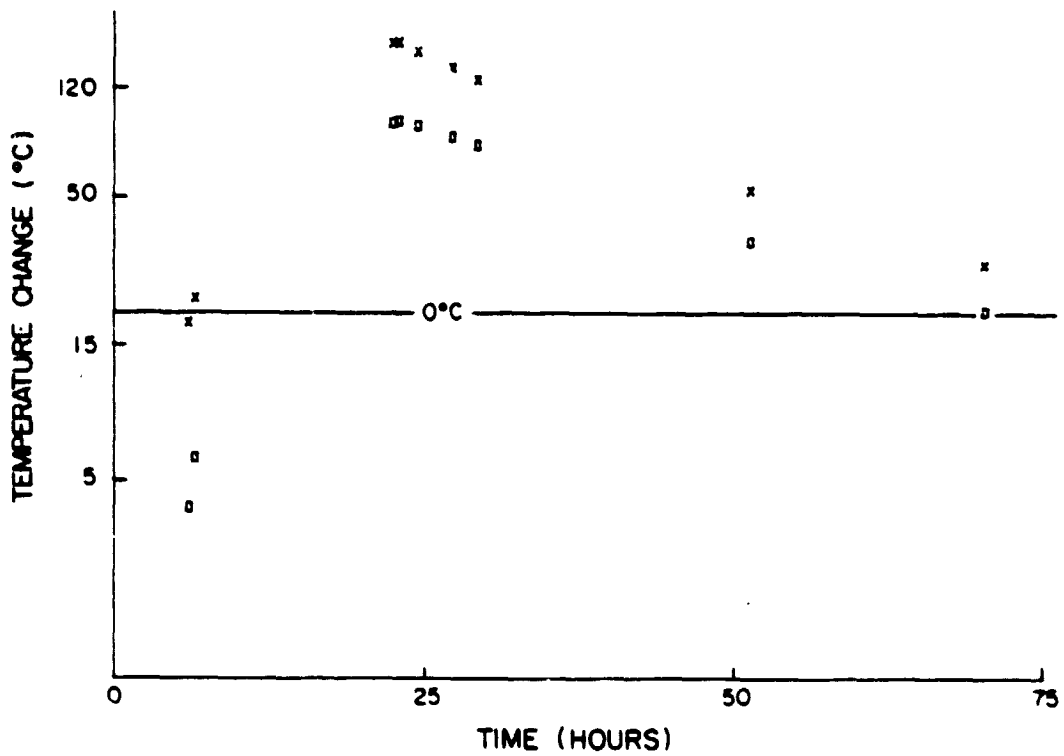


Figure 1. Temperature gradient in one tube section. The large temperature gradient results from liquid N_2 going in one end and gaseous N_2 coming out the other end of the tube section.

resulting temperature gradient for one tube section. Modifications to the cooling system are presently being designed and implemented so that each tube section can be cooled more uniformly.

FINAL RESULTS OF SOUND ABSORPTION IN N_2 - H_2O GAS MIXTURES
AT ELEVATED TEMPERATURES

Final measurements of deexcitation of nitrogen by water vapor were reported at the 100th Meeting of the Acoustical Society of America in the fall of 1980. The results indicate that the physical process responsible for the deexcitation is not the direct vibration-translation energy transfer, but is a vibration-vibration energy transfer. The results also indicate that ANSI Standard S1.26/ASA 23-1978 predicts an excessive shift of the nitrogen relaxation frequency with humidity. This paper is reproduced in Appendix II.

APPENDIX I

LISTING FOR CONTROLLING A/D CONVERTER

<u>OP CODE</u>	<u>MNEMONIC</u>	<u>COMMENTS</u>
A9 34	LDA	#\$34
8D A1 CO	STA	\$COA1
8D A3 CO	STA	\$COA3
A9 25	LDA	#\$25
85 08	STA	\$08
A9 00	LDA	#\$00
85 FA	STA	\$FA
A9 95	LDA	#\$95
85 FB	STA	\$FB
A9 02	LDA	#\$02
85 09	STA	\$09
A2 3C	LDX	#\$3C
A0 FF	LDY	#\$FF
A5 06	LDA	\$06
20 A8 FC	JSR	\$FCA8
A9 34	LDA	#\$34
8D A1 CO	STA	\$COA1
8A	TXA	
8D A1 CO	STA	\$COA1
C6 08	DEC	\$08
DO FC	BNE	\$93E1
AD A0 CO	LDA	\$COA0
91 FA	STA	(\$FA),Y
88	DEY	
AD A2 CO	LDA	\$COA2
29 OF	AND	#\$0F
91 FA	STA	(\$FA),Y
CO 00	CPY	#\$00
FO 03	BEQ	\$93F9
88	DEY	
DO DA	BNE	\$93D3
C6 FB	DEC	\$FB
C6 09	DEC	\$09
DO D2	BNE	\$93D1
60	RTS	

APPENDIX II

SOUND ABSORPTION IN N_2 - H_2O GAS MIXTURES AT
ELEVATED TEMPERATURES

By

Allan J. Zuckerwar and Roger W. Meredith

Presented at the 100th Meeting of the Acoustical
Society of America, fall 1980.

SOUND ABSORPTION IN N₂-H₂O GAS MIXTURES AT
ELEVATED TEMPERATURES

By

Allan J. Zuckerwar and Roger W. Meredith

The purpose of our measurements is to make a decisive determination of the physical process responsible for the deexcitation of nitrogen by water vapor, and to compare the measured temperature dependence of the sound absorption with that of the new ANSI standard, "America National Standard Method for the Calculation of the Absorption of Sound by the Atmosphere" (S1.26/ASA 23-1978).

The first slide shows the results of sound absorption measurements in a typical mixture of nitrogen and water vapor at three different temperatures. The water vapor content for this particular composition is 3500 parts per million. The sound absorption μ , in nepers/wavelength, is plotted against frequency/pressure (f/P) ratio. The data define a pronounced peak - the vibrational relaxation peak of nitrogen - at each temperature. The value of f/P at the crest of the peak is called the "relaxation f/P" or "(f/P) max" and lies at about 60 Hz/atm for this mixture.

The data appear in a more or less uniform band about a baud curve, owing to the random nature of the background damping. With increasing temperature the accuracy of the measurement improves considerably as the peak soars above the background. The solid lines represent the best fit to the Debye relaxation curve, (f/P) max being the only adjustable parameter. The peak height was computed with the aid of the Planck-Einstein formula. Eight such sets of data were taken at humidities ranging from 10 ppm to a maximum of 3 mole %.

Slide 2. Here (f/P) max is plotted against humidity for 21 of the 24 measured relaxation peaks. The data for the lowest value of humidity fall beyond the range of the graph and are not shown. At low humidities all the data lie on the same straight line, having a slope of 184 Hz/atm·mole %, which is independent of temperature. This agrees well with Griffin's room-temperature slope of 200 Hz/atm·mole %, reported at the Cambridge meeting last year (ref. 1). At high humidities the data deviate from the linear

fit. At 298° K the deviation falls within the experimental error. At the higher temperatures the deviation lies well beyond the error and is considered a real physical effect.

Slide 3. On this slide the relationship between relaxation frequency, referred to 1 atm, and humidity is compared with past results. At low humidities our slope shows good agreement with that obtained by Evans (ref. 2). The data of Chang, Shields, and Bass (CSB) (ref. 3), taken at much higher humidities (starting at 4 mole %), yield the somewhat greater slope of 260 Hz/atm·mole %. The problem is to reconcile the existence of two different slopes at low and high humidities. Fortunately, theory enables us to do this.

Slide 4. The nitrogen-water vapor system is an example of a two-component system, where both components are excitable. Deexcitation of the vibrational degrees of freedom takes place by means of five reactions. The reaction rate k_{10} for the deexcitation of nitrogen by itself is extremely slow and will be neglected. The second reaction rate k_{20} represents the deexcitation of nitrogen by water through direct vibrational-translational transfer. Traditionally this reaction has been assumed to be dominant and leads to a strictly linear relationship between $(f/P)_{\max}$ and humidity, that is, to a single slope. In the model that we propose here k_{20} is considered small, and the deexcitation process takes place through the last three reactions. Rate k_{30} represents vibrational-vibrational transfer between the nitrogen and water molecules, k_{40} the deexcitation of water by itself, and k_{50} the deexcitation of water by nitrogen.

Slide 5. The Tuesday-Boudart analysis yields the following expression for the slope of the $2\pi(f/P)_{\max}$ vs. h relationship in terms of the reaction rate constants. It should be noted that the matrix formulation by Bauer for this particular system yields identical results, but the Tuesday-Boudart analysis is chosen because it lends itself more readily to physical interpretation. The reaction rates k_{20} and k_{10} are neglected. Now consider the remaining fraction. At low humidities only the leading terms in the numerator and denominator are important, and these determine the low-humidity slope S_1 . At high humidities the latter terms in the numerator and denominator become dominant; and when only these are retained, we obtain a different slope—the high-humidity slope S_2 . Thus, the theory leads to one value of slope at low humidities and another value of

slope at high humidities. The situation is quite different in the oxygen-water vapor system, where the reaction k_{03} is so large that the second term in the denominator never really becomes dominant for values of humidity normally encountered.

Slide 6. The function $S(h)$ is plotted against humidity on a logarithmic scale. The circles are Griffin's data points at room temperature. The triangles are the data of the CSB group (ref. 3). The solid line is the best fit of the Tuesday-Boudart formula to both sets of data with k_{40} as the only adjustable parameter. Thus the V-V model not only accounts for the existence of two slopes, but also fits both sets of data. There are two possible objections to the V-V interpretation. First, the rate constant k_{40} for the deexcitation of water by itself is smaller than the values obtained from past experiments. The dash lines are similar plots using other values of k_{40} derived from the literature. Actually, a value of k_{40} as high as 5×10^7 is consistent with the data. Secondly, it might be argued that a single straight line, with a slope somewhat less than 1.5×10^5 , would fall within the error bounds of the bulk of the data. This is true for the room-temperature data and is our primary motivation for obtaining the more accurate data at elevated temperatures.

Slide 7. Here we see slope versus log humidity for all three temperatures. As before the solid lines are best fits of the Tuesday-Boudart formula. At room temperature the existence of two slopes is barely noticeable and concealed within the experimental error. The situation changes at higher temperatures, where the change of slope at high humidity lies well beyond the experimental error. A triangle represents a CSB point at the closest corresponding temperature. Agreement is quite good.

Slide 8. This is a Landau-Teller plot for the V-V process. The solid circles are derived from the low-humidity slope. The rate constant represents a series combination of k_{30} and k_{50} and is independent of temperature. The remaining data belong to the high-humidity slope k_{30} . The solid line is the best fit to our own and past data. The data chosen to determine the line are those points whose error bars intersect the line; these include Henderson's point (ref. 4), three CSB points, Evan's point, and three of our own. Each point is weighted according to how many humidity values were used to establish the slope. The shock tube data

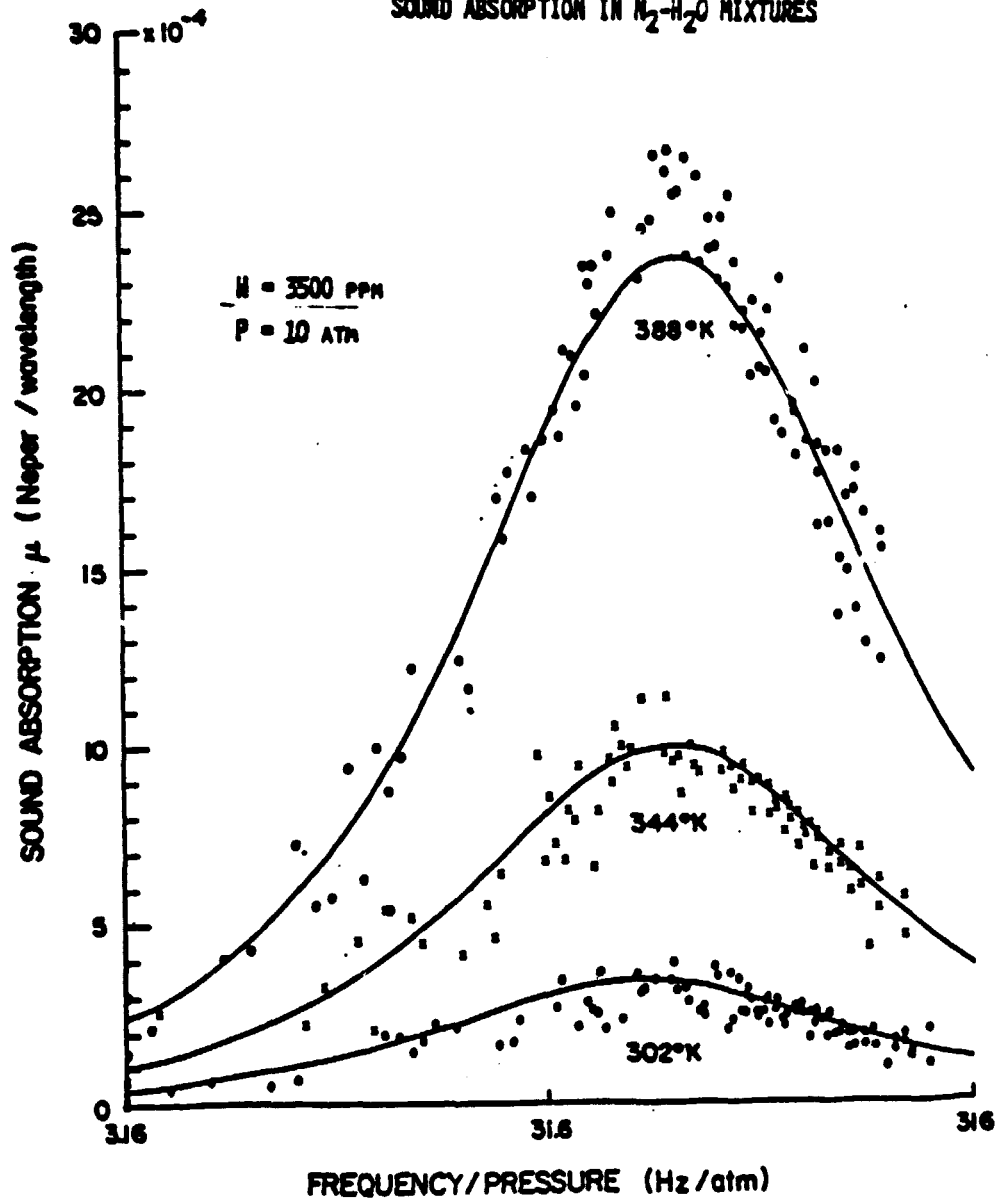
of Huber and Kantrowitz (ref. 5) show too much scatter and are not included. Once we get above room temperature the error assigned to the various data points demonstrates the existence of two slopes beyond any doubt.

Slide 9. We analyzed our own data and accounted for the 78 percent dilution in air to compare our measured relaxation frequencies with those specified by the new ANSI Standard. The values chosen correspond to the extremes of temperature and humidity specified in the standard. The first thing to notice is that the standard predicts far too great a shift of the nitrogen relaxation frequency with humidity. The standard is in error anywhere from 35 to 75 percent. Secondly, the standard does not account for the change in slope. However, a tenfold increase in humidity produces only a slightly greater than tenfold increase in relaxation frequency, so that the error due to the two-slope effect is not very serious. Finally, a 40° C increase in temperature increases the relaxation frequency by a factor of 8.5 according to the standard but by a factor of 13 according to measurement. For frequencies below 2000 Hz, where sound absorption in nitrogen becomes the dominant process in the Earth's atmosphere, the new ANSI Standard, while more accurate than anything available previously, could still lead to a substantial measurement error.

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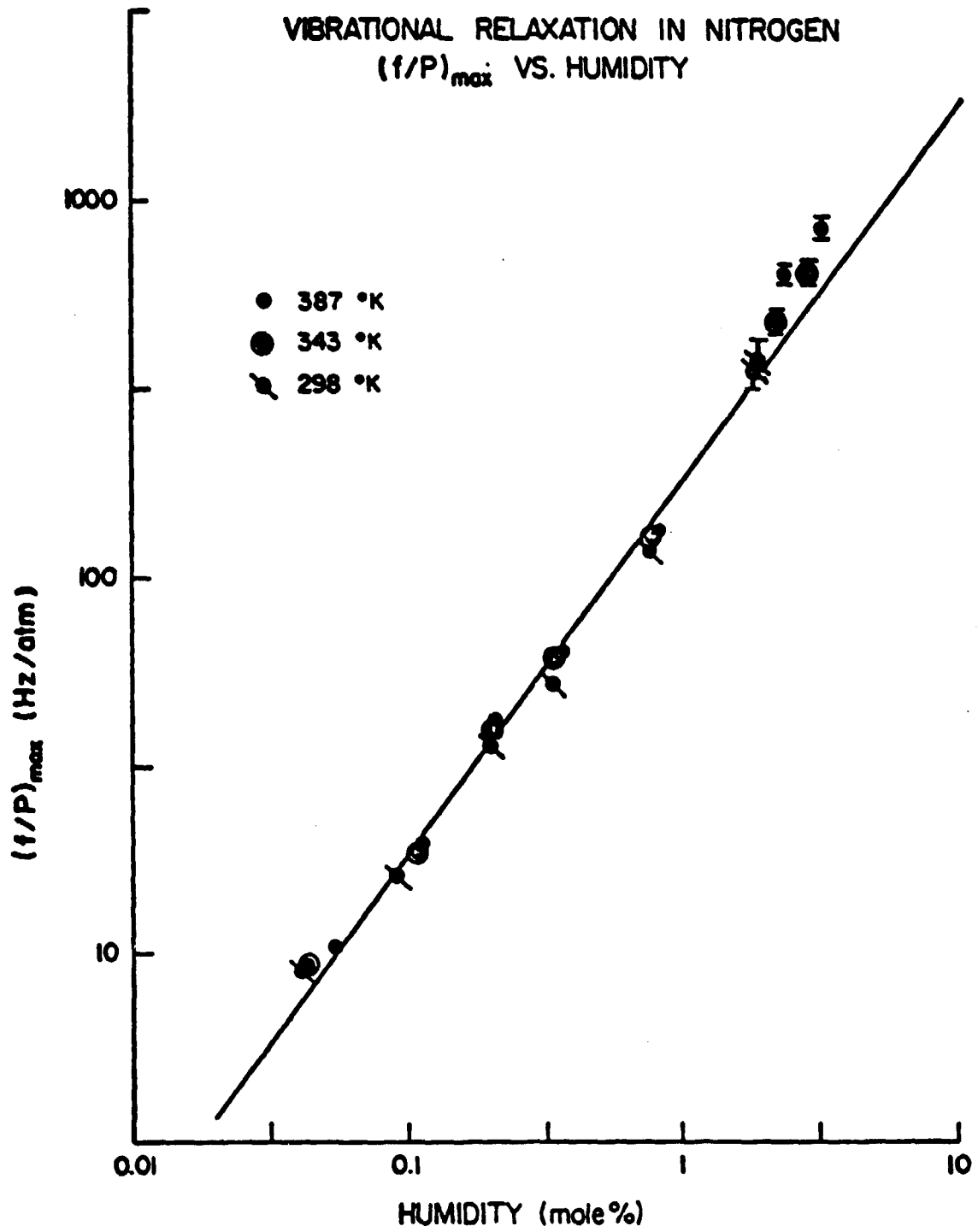
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2. L.B. Evans, J. Acoust. Soc. Am. 51, 409-411 (1972).
3. D. Chang, F.D. Shields, and H.E. Bass, J. Acoust. Soc. Am. 62, 577-58 (1977).
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SOUND ABSORPTION IN N₂-H₂O MIXTURES

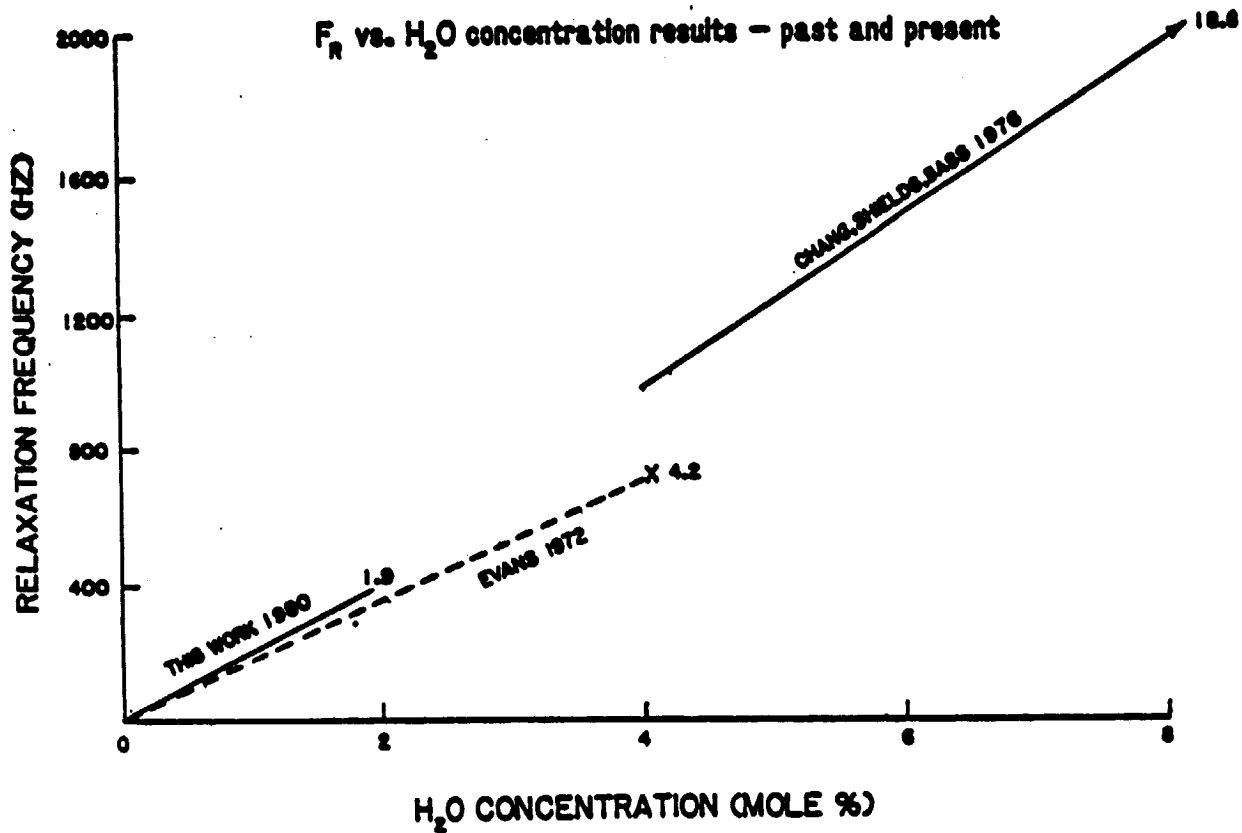


Slide 1

VIBRATIONAL RELAXATION IN NITROGEN
 $(f/P)_{max}$ VS. HUMIDITY

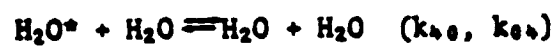
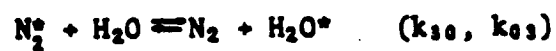
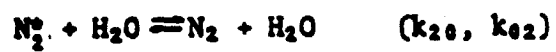


Slide 2



Slide 3

Reaction Rates



Slide 4

Slope According To Tuesday - Boudart

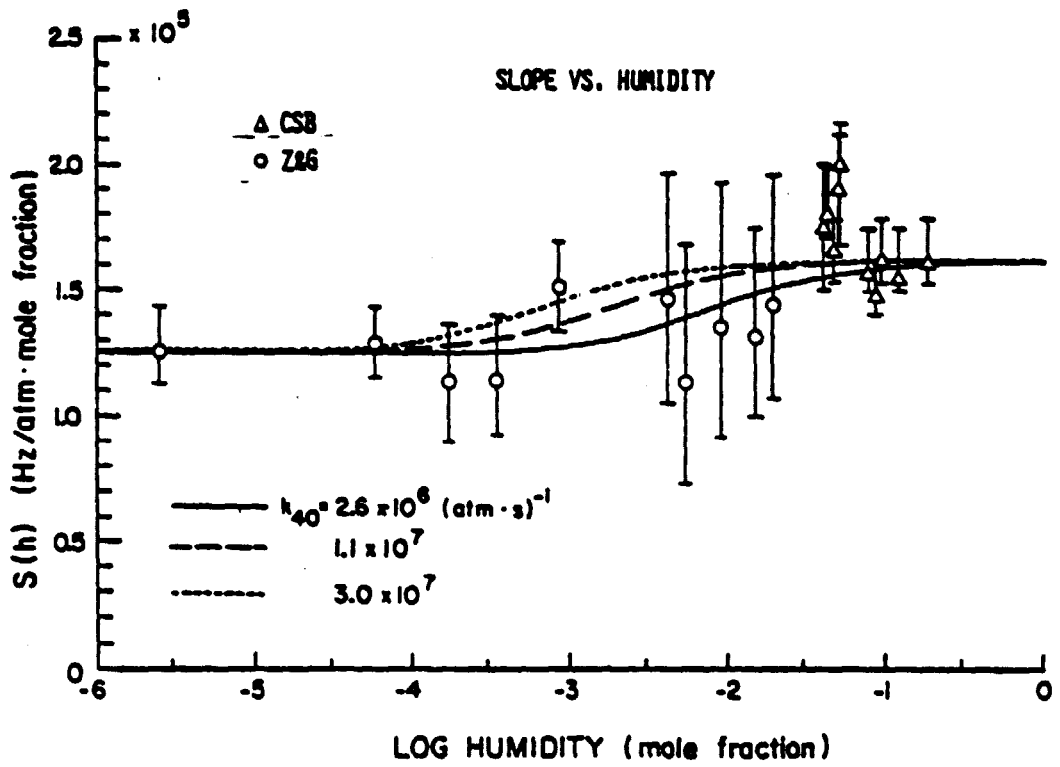
$$S(h) = \frac{[2\pi(\mathcal{E}/P)_{\text{MAX}} - k_{10}]}{h}$$

$$= k_{20} - k_{10} + \frac{k_{30}k_{50} + k_{30}(k_{40} - k_{50})h}{k_{03} + k_{50} + (k_{40} - k_{50} - k_{03})h}$$

$$S(h) \rightarrow S_1 = k_{20} - k_{10} + \frac{k_{30}k_{50}}{k_{03} + k_{50}} \quad (h \text{ small})$$

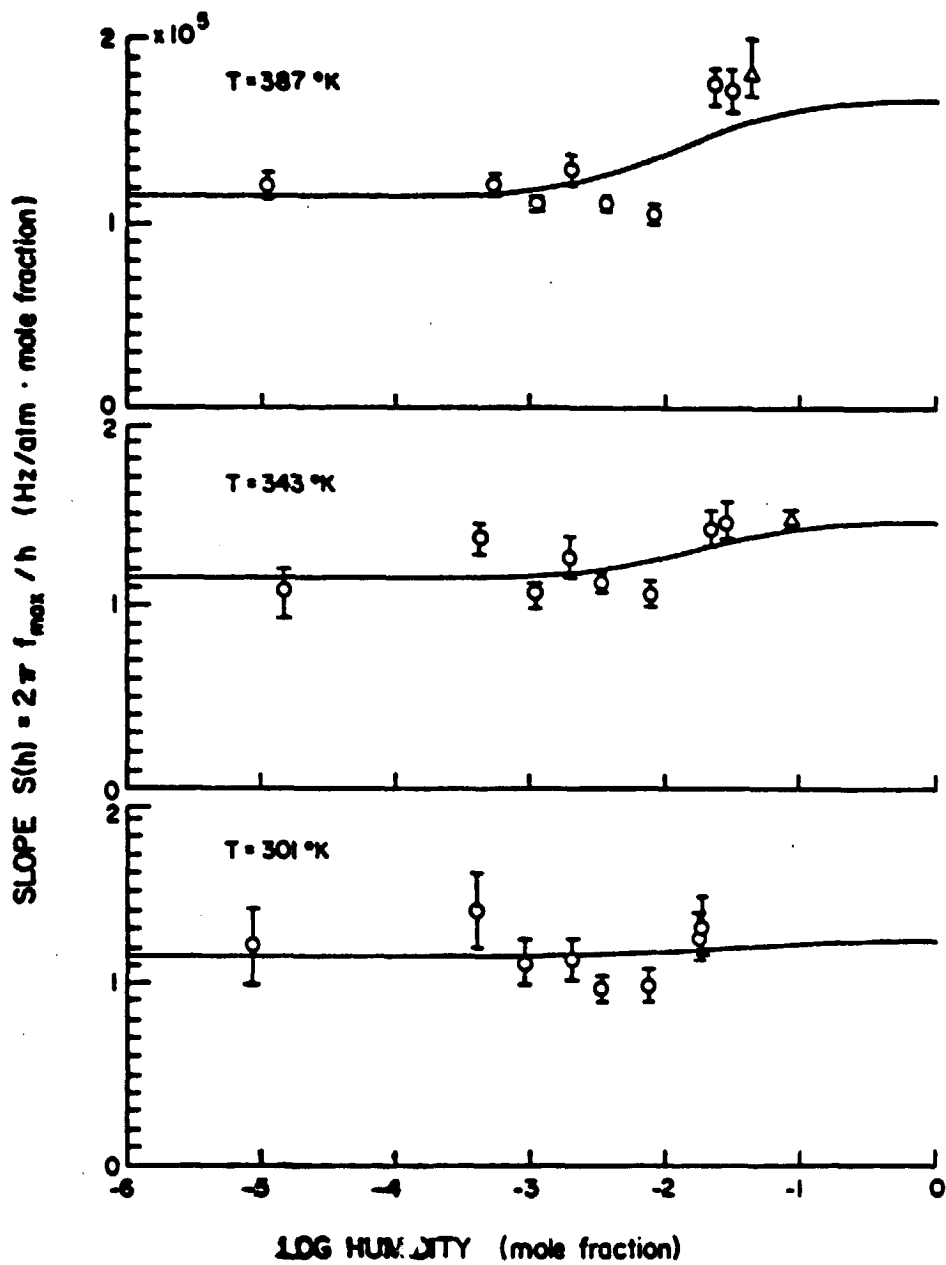
$$S(h) \rightarrow S_2 = k_{20} - k_{10} + \frac{k_{30}(k_{40} - k_{50})}{k_{40} - k_{50} - k_{03}} \quad (h \text{ large})$$

Slide 5

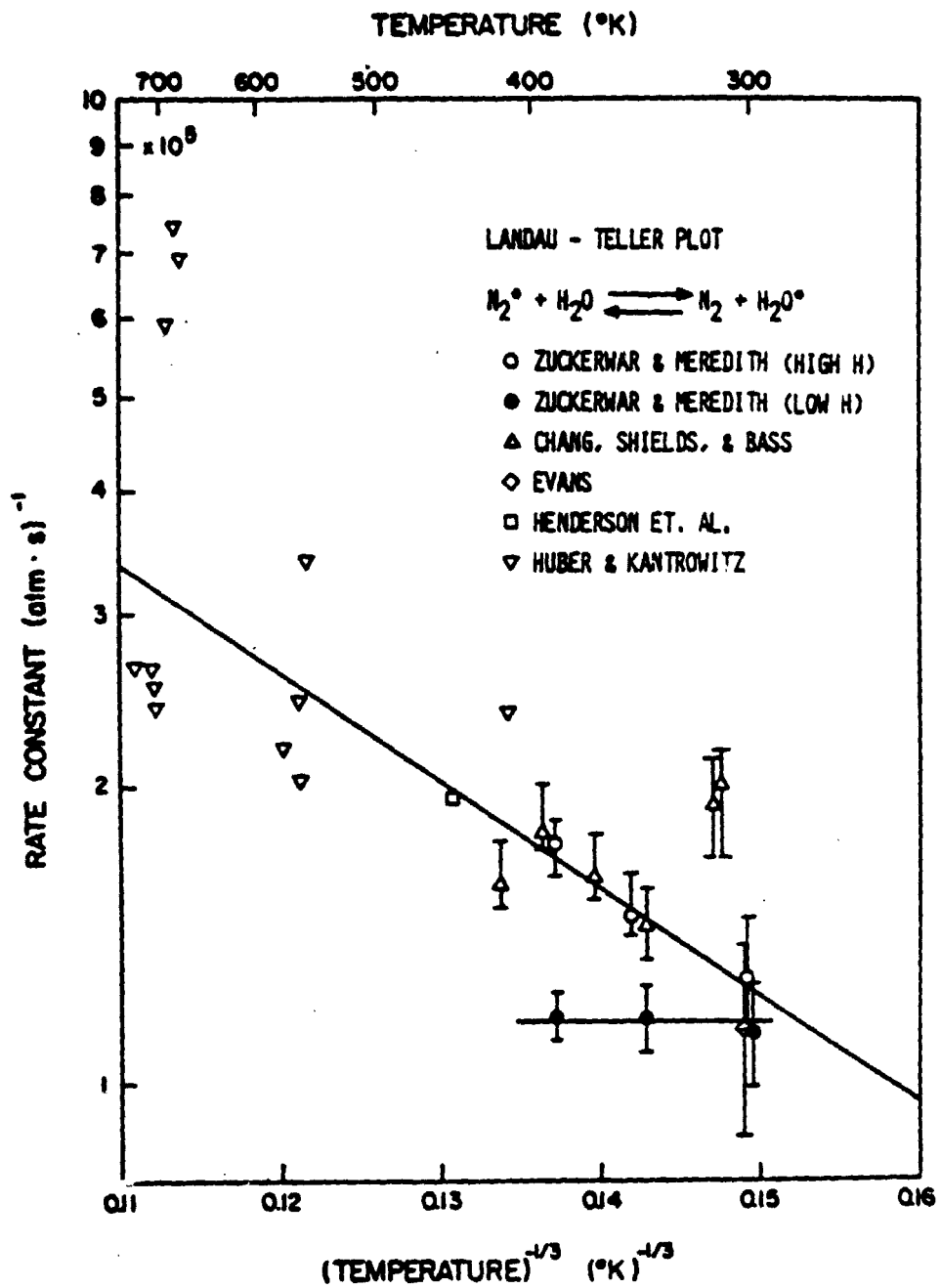


Slide 6

SLOPE VS. HUMIDITY



Slide 7



Slide 8

RELAXATION FREQUENCY OF NITROGEN IN AIR AT 1 ATM

		R.H. = 10%	R.H. = 100%
T=273°K	Z&M	8.65 Hz	87.18 Hz
	ANSI	21.11	211.05
T=313°K	Z&M	108.17	1154.44
	ANSI	179.19	1791.90

Slide 9