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Historical Background

The accurate evaluation of noise from man-made sources, such as aircraft, requires a reliable procedure for computing standard sound absorption values in air as a function of meteorological conditions, namely temperature, pressure, and humidity. The first widely used standard, issued by the Society of Automotive Engineers as ARP 866 in 1964 and reissued as ARP 866A in 1975 (ref. 1), fulfilled this requirement for many years, despite the fact that it suffers from numerous deficiencies. The standard is based on a single set of laboratory measurements—the 1963 data of Harris (ref. 2)—and employs a crude approach to the theory of molecular absorption in oxygen. Even after "modification" of the theory, the recommended formulas yield poor agreement with experiment at the upper and lower ends of the audible frequency spectrum.

The accuracy of sound absorption values was vastly improved with the appearance of a new standard, ANSI S1.26-1978, published by the American Institute of Physics for the Acoustical Society of America and approved by the American National Standards Institute in 1978 (ref. 3). The discrepancies found in the older standard were resolved by the introduction of two new physical concepts into the kinetic model of air: first, the molecular absorption of sound by nitrogen, which plays a dominant role at low frequencies; second, the vibrational-vibrational exchange of energy between water vapor and oxygen molecules, which is needed to explain the trend of the data at high frequencies. Although the data base was expanded to include the measurements from a great number of investigations, many of which appeared subsequent to ARP 866A, the data were still confined to a frequency interval between 1 and 20 kHz except for one data set below 1 kHz (ref. 4). The latter was not included in the formulation of the new standard because of the lack of confirmation by a second independent source. Furthermore, these data have remained an unexplained anomaly for many years because they yield oxygen relaxation frequencies far below those predicted by the new standard.

The sound absorption measurements in air presented here consist of over 2000 data points in the frequency interval from 10 to 2500 Hz, where prior data are scanty, and accordingly serve a twofold purpose. The first purpose is to provide a substantial data base for an improved evaluation of the relaxation frequency of nitrogen. The data base used to establish this important parameter in the ANSI standard is beset with three fundamental difficulties. First, a significant portion of the data—that of Harris and coworkers (refs. 2 and 4)—contains only a few discrete frequencies below 1000 Hz, for example, only five frequencies in reference 4. For many meteorological conditions a greater number and range of experimental frequencies are needed for accurate determination of the relaxation frequency. Second, some of the studies were conducted in binary N_2-H_2O mixtures, where the relaxation frequency of nitrogen may differ from that of nitrogen in air (ref. 5). Third, other studies were conducted outdoors in the free atmosphere, where the effects of nonstationarity, nonhomogeneity, spreading, and the ground lead to questionable evaluation of the data. Thus a comprehensive set of low-frequency laboratory measurements is sorely needed to establish accurately the relaxation frequency of nitrogen in air. The second purpose of this study is to provide independent sound absorption measurements overlapping those of reference 4 in dry air, with the goal of closing the gap between oxygen relaxation theory and experiment.

This publication is intended primarily to document the measurements of sound absorption versus frequency for given meteorological conditions and therewith to provide the background information needed to explain the experimental results. The following sections describe sound absorption mechanisms in free air and in a resonant tube, the sound absorption measurement program, the method used to evaluate the data, the format for presenting the data, and the procedure for determining the relaxation frequencies of nitrogen and oxygen.

Symbols

c	speed of sound, m-s^{-1}
C_P	specific heat at constant pressure, J-kg^{-1}-K^{-1}
f	experimental frequency, Hz
f_{vn}	vibrational relaxation frequency of nitrogen, Hz
f_{vo}	vibrational relaxation frequency of oxygen, Hz
h	humidity, mole percent
L	length of resonant tube, m
p	acoustic pressure, Pa
p_o	reference acoustic pressure, Pa
P	static gas pressure, atm
P_o	reference static gas pressure, 1 atm (or 0.1013 MPa)
R	radius of resonant tube, m
t	time, sec
T	gas temperature, K or °C
T_o	reference gas temperature, 293.15 K
x	propagation distance, m

α	sound absorption coefficient, Np-m^{-1} or dB-m^{-1}, (1 Np = 8.686 dB)
γ	specific heat ratio
η	viscosity coefficient, kg-m-s^{-1}
κ	thermal conductivity, J-m^{-1}-s^{-1}-K^{-1}
μ	sound absorption coefficient per unit wavelength, Np per wavelength
ρ	density, kg-m^{-3}

Subscripts:

air	air
bg	background gas
cr	classical-rotational
meas	measured
str	structural
vn	vibrational relaxation in nitrogen
vo	vibrational relaxation in oxygen
wall	wall

Abbreviations:

ppm	parts per million
RH	relative humidity
WL	wavelength

Sound Absorption Measurements in Free Air

Absorption Per Unit Length

An acoustic plane wave, attenuated as it propagates through a free (unbounded) medium, is represented by the expression

$$p = p_o \exp(-\alpha x) \exp\left[i2\pi f(x/c - t)\right] \quad (1)$$

The absorption coefficient in free air consists of three fundamental components—$\alpha_{\rm cr}$ the classical-rotational absorption, $\alpha_{\rm vn}$ the vibrational absorption in N_2, and $\alpha_{\rm vo}$ the vibrational absorption in O_2:

$$\alpha_{\rm air} = \alpha_{\rm cr} + \alpha_{\rm vn} + \alpha_{\rm vo} \quad (2)$$

These are given as functions of meteorological parameters in reference 3:

$$\alpha_{\rm cr} = 1.84 \times 10^{-11} \left(\frac{P_o}{P}\right) \left(\frac{T}{T_o}\right)^{1/2} f^2 \quad (3)$$

$$\alpha_{\rm vn} = 0.1068 \left(\frac{T_o}{T}\right)^{5/2} \exp\left(\frac{-3352}{T}\right) \left(\frac{f^2 f_{\rm vn}}{f^2 + f_{\rm vn}^2}\right) \quad (4)$$

$$\alpha_{\rm vo} = 0.01278 \left(\frac{T_o}{T}\right)^{5/2} \exp\left(\frac{-2239.1}{T}\right) \left(\frac{f^2 f_{\rm vo}}{f^2 + f_{\rm vo}^2}\right) \quad (5)$$

with

$$f_{\rm vn} = \left(\frac{P}{P_o}\right) \left(\frac{T_o}{T}\right)^{1/2} \times \left(9 + 350h \exp\left\{-6.142\left[\left(\frac{T_o}{T}\right)^{1/3} - 1\right]\right\}\right) \quad (6)$$

$$f_{\rm vo} = \left(\frac{P}{P_o}\right) \left(24 + 4.41 \times 10^4 h \frac{0.05 + h}{0.391 + h}\right) \quad (7)$$

Figure 1 shows the frequency dependence of the total absorption and of each component process for the example $T = T_o = 293.15$ K, $P = P_o = 1$ atm, and $h = 1.614$ mole percent (relative humidity of 70 percent). For each component process the sound absorption rises as f^2 below the relaxation frequency and then approaches a constant value asymptotically. For the classical and rotational components, however, the relaxation frequencies lie beyond the range of the figure. With increasing humidity the vibrational relaxation frequencies both shift to higher values.

Absorption Per Unit Wavelength

Although the sound absorption coefficient α is of interest when the sound pressure at a specified distance from the source is desired, another measure of sound absorption, the absorption per unit wavelength μ, is preferred in many studies because it is more directly related to the physical properties of the medium. The relationship between μ and α is the following:

$$\mu = \frac{\alpha c}{f} \quad (8)$$

where the sound speed in air has the value

$$c = 343.23 \left(\frac{T}{T_o}\right)^{1/2} \quad (9)$$

As before, the absorption per unit wavelength in air consists of classical-rotational and vibrational components in N_2 and O_2:

$$\mu_{\rm air} = \mu_{\rm cr} + \mu_{\rm vn} + \mu_{\rm vo} \quad (10)$$

Equations (3) to (5), (8), and (9) yield the following expressions for these components:

$$\mu_{\rm cr} = 6.315 \times 10^{-9} \left(\frac{P_o}{P}\right) \left(\frac{T}{T_o}\right) f \quad (11)$$

$$\mu_{vn} = 36.66 \left(\frac{T_o}{T}\right)^2 \exp\left(\frac{-3352}{T}\right) \left(\frac{f f_{vn}}{f^2 + f_{vn}^2}\right) \quad (12)$$

$$\mu_{vo} = 4.386 \left(\frac{T_o}{T}\right)^2 \exp\left(\frac{-2239.1}{T}\right) \left(\frac{f f_{vo}}{f^2 + f_{vo}^2}\right) \quad (13)$$

Figure 2 shows a plot of the absorption per unit wavelength similar to the example of figure 1. In this case, however, each component process is associated with a well-defined relaxation peak, having a crest located at the relaxation frequency. Again, with increasing humidity both vibrational relaxation peaks shift to higher values, and the relaxation frequencies for the classical and rotational processes are so high that the peak crests lie beyond the range of the figure.

In sufficiently dry air, for which the O_2 relaxation peak stands out prominently above the background, the absorption per unit wavelength μ is chosen to represent the sound absorption. In more humid air, for which relaxation in N_2 occurs within the range of experimental frequencies, the scatter in the data generally precludes good definition of the much smaller N_2 relaxation peak. In these cases the sound absorption is more appropriately represented by the absorption per unit length α.

Evaluation of Relaxation Frequencies

Equations (3) to (5) (or eqs. (11) to (13)) are derived rigorously from fundamental thermodynamic principles and from first-order kinetic theory. The numerical constants are obtained from precisely known gas properties and molecular parameters. The inaccuracy in these expressions lies almost exclusively in the formulas for the relaxation frequencies f_{vn} and f_{vo}, as given by equations (6) and (7). Because current relaxation theory offers only an order-of-magnitude estimate at best, the relaxation frequencies are determined in practice through empirical fits of the available data to equations containing gas-kinetic model parameters.

Each constituent of the atmosphere influences the relaxation frequencies of both N_2 and O_2 to a varying extent, ranging from negligible (argon) to extreme (water vapor). To illustrate the effect of the latter, the relaxation frequency of O_2 (eq. (7)) at 20°C and 1 atm varies from 24 Hz in dry air to 89 kHz at 100-percent relative humidity. Similarly, the relaxation frequency of N_2 (eq. (6)) varies from 9 to 816 Hz. The relaxation frequencies are also sensitive to the presence of CO_2, but to a lesser extent because the CO_2 content is small (330 ppm); its effect is included in the h-independent terms in equations (6) and (7). Because most of the data sets in the past were confined to a limited range of frequency, traversing only one relaxation peak, a simultaneous fit of f_{vn} and f_{vo} to the composite data does not necessarily yield the best values of the numerical constants in equations (6) and (7). Rather, the complex task of determining these values from the data can be facilitated immensely through a simplified procedure.

First, it is noted that the N_2 and O_2 relaxation peaks are widely separated at all values of humidity. In figure 2, for example, the N_2 absorption is down 55 dB from the crest of the O_2 peak at the O_2 relaxation frequency, and the O_2 absorption is down 26 dB from the crest of N_2 peak at the N_2 relaxation frequency. Thus the high-frequency data can be used to fit f_{vo} alone, with classical-rotational absorption taken into account but with N_2 absorption neglected. Once f_{vo} is established, then the low-frequency data can be used to fit f_{vn} with both classical-rotational and O_2 absorption as background. Actually, since N_2 dominates the absorption spectrum over the frequency interval from 10 to 2500 Hz except in very dry air, evaluation of f_{vn} is relatively insensitive to the O_2 absorption. For the present data the values for O_2 absorption from the current standard are used in the background for the N_2 absorption. Subsequent adjustment of the O_2 absorption values will affect the evaluation of f_{vn} very little.

Sound Absorption Measurements in a Resonant Tube

Experimental Method

The sound absorption measurements in the present study were conducted by the method of free decay in a resonant tube having a length of 18.261 m and bore radius of 0.0762 m. An acoustical standing wave was excited in the test gas in the tube, the excitation removed, and the sound absorption evaluated from the free decay envelope. The tube and operating procedure are described in reference 6. Over 250 tube modes could be excited, from the fundamental near 10 Hz to a cutoff frequency somewhat above 2500 Hz. The free decay curves were evaluated in real time on an 8-bit microcomputer-based digital data acquisition system (ref. 7).

Additional Sound Absorption Processes in a Tube

In a resonant tube, sound absorption is subject to two additional processes not found in free-field propagation, namely thermoviscous absorption at the tube walls and absorption due to excitation of the structural modes of the tube by the internal test gas. The wall absorption is accurately given by the Kirchhoff formula

$$\alpha_{wall} = \left(\frac{\pi \eta f}{\rho c^2}\right)^{1/2} \left[\frac{1}{R} + (\gamma - 1)\left(\frac{1}{R} + \frac{2}{L}\right)\left(\frac{\kappa}{\eta C_P}\right)^{1/2}\right] \quad (14)$$

but the structural absorption cannot be described by a simple formula, since it is related to the structural

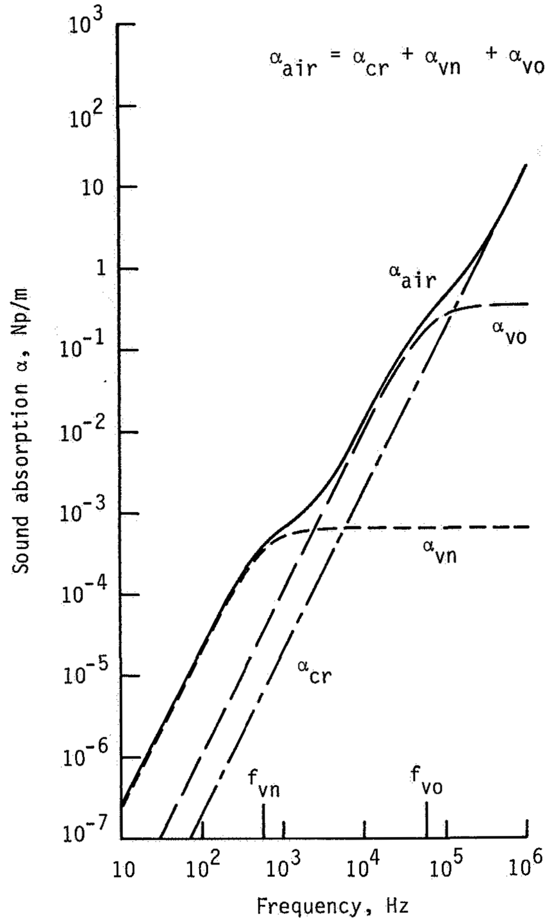

Figure 1. Sound absorption in air versus frequency for $T = 20°C$, $P = 1$ atm, and $h = 1.614$ mole percent (70-percent RH). The vibrational relaxation frequencies as specified by the ANSI standard (ref. 3), $f_{vn} = 574$ Hz and $f_{vo} = 59\,117$ Hz, are indicated on the frequency axis.

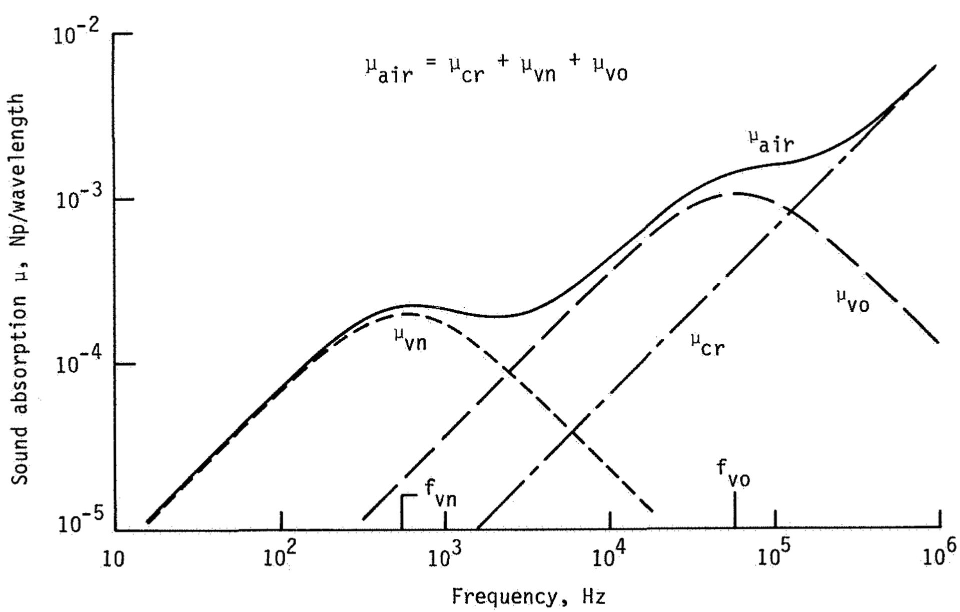

Figure 2. Sound absorption per unit wavelength in air versus frequency for $T = 20°C$, $P = 1$ atm, and $h = 1.614$ mole percent (70-percent RH). The vibrational relaxation frequencies as specified by the ANSI standard (ref. 3), $f_{vn} = 574$ Hz and $f_{vo} = 59\,117$ Hz, are indicated on the frequency axis.

properties of the tube. Nevertheless, the latter process becomes significant when the test gas frequencies lie near the natural frequencies of the tube structure (ref. 8). Such frequencies were generally avoided in the present study, in particular those in the vicinity of 93, 290, and 550 Hz, where excitation of the tube structure was found to be strong.

Evaluation of Constituent Absorption

The sound absorption measurement problem is compounded by the fact that the *constituent* absorption in air α_{air}, consisting of the classical-rotational and vibrational components given by equations (3) to (5), is only 1 to 5 percent of the wall absorption α_{wall}, depending on the frequency and humidity. In order to reduce the error inherent in the attempt to extract such a small effect from a large background, a differential technique was employed using a background gas with (1) negligible constituent absorption and (2) the same sound velocity as air in an effort to match acoustical coupling to the tube structure. Then measurements in the background gas yielded the wall and structural components of the absorption in the tube. A gas mixture consisting of 89.5 percent Ar and 10.5 percent N_2 fulfills both the above requirements, since the N_2 relaxation frequency lies far below any measured frequency. For each sound absorption measurement in air, a corresponding measurement was made in the background gas at the same frequency, pressure, and temperature. The measured absorption contains the following components in air and in the background gas:

$$\alpha_{meas-air} = \alpha_{air} + \alpha_{wall-air} + \alpha_{str-air} \tag{15}$$

$$\alpha_{meas-bg} = \alpha_{wall-bg} + \alpha_{str-bg} \tag{16}$$

For each pair of measurements the constituent absorption can be found:

$$\begin{aligned}\alpha_{air} = \alpha_{meas-air} &- \alpha_{meas-bg} \\ &- (\alpha_{wall-air} - \alpha_{wall-bg}) \\ &- (\alpha_{str-air} - \alpha_{str-bg})\end{aligned} \tag{17}$$

It is apparent from equation (17) that successful evaluation of the sound absorption in air is contingent upon the following conditions:

1. The measurements must be of high precision both in air and in the background gas. This is achieved with the aid of a digital data acquisition system using a 12-bit analog-to-digital converter (ref. 7).

2. The wall losses of both gases must be computed accurately. In other words, the parameters in equation (14) must be known accurately as a function of pressure, temperature, and in the case of air, humidity. The effect of adsorbed H_2O on the wall losses was estimated from the analytical results of reference 9 and found to be negligible.

3. The composition of the background gas must be carefully adjusted to match the frequencies found in air in order to match the coupling to the structural modes of the tube. This ensures that the final term in equation (17) vanishes:

$$\alpha_{str-air} - \alpha_{str-bg} = 0 \tag{18}$$

and consequently

$$\begin{aligned}\alpha_{air} = \alpha_{meas-air} &- \alpha_{meas-bg} \\ &- (\alpha_{wall-air} - \alpha_{wall-bg})\end{aligned} \tag{19}$$

Sound Absorption Measurement Program

Measurement of Gas Composition and Meteorological Parameters

Gas composition. The test air was premixed from constituents by a commercial vendor and delivered in two 210-ft^3 cylinders at 2000 psi. The requested and actual compositions, per certified analysis, are listed in table I(a). The constituents for the background gas, for which the composition is listed in table I(b), were mixed in the resonant tube proper. The mixture was adjusted until the fundamental frequency for air at the prevailing ambient temperature matched the theoretical value, computed from the sound velocity as given in equation (9).

Pressure. The pressure was maintained at nominally 1 atm for all gas compositions, as measured on a strain gauge pressure transducer.

Temperature. A coarse measurement of temperature was provided by four iron-constantan thermocouples located along the axis of the tube. These were also used as sensors for automatic temperature control. A fine measurement was derived from the measured acoustic frequency and its known relation to temperature.

Humidity. Humidity was measured with either of two dew-point hygrometers, the first for dew points in the range from −20°C to 60°C and the second for those below −20°C. The dew-point readings were taken just prior to the acoustical measurements.

Selection of Meteorological Parameters

The acoustical measurements were conducted within the temperature interval from 10°C to 50°C in 10°C steps. Originally it was intended, at each fixed temperature, to vary the relative humidity from 0 to 100 percent in 10-percent steps. At 10°C, however, because the N_2 absorption was found to be too small to be resolved, the measurements were confined to sufficiently dry air that the properties of the O_2 absorption could be investigated. Because of difficulty in attaining saturated H_2O vapor pressures in the tube above 25°C, acoustical measurements were confined to air samples having dew points below or slightly in excess of that temperature. The corresponding maximum relative humidities were 66, 48, and 29 percent at tube temperatures of 30°C, 40°C, and 50°C, respectively.

Meteorological parameters for each of the 30 sets of acoustical data are summarized in table II. For each data set the sound absorption was measured at a number of frequencies from 54 to 92.

Presentation of Data

Constituent Absorption in Air

Figures A1 to A30 (appendix) show the sound absorption in air versus frequency for given values of temperature and absolute humidity, along with the tabulated data. Absorption values for which $\alpha_{\text{air}} < 10^{-4}$ Np/m are not included in the tabulation, as this value represents the limit of the experimental technique. For all but the driest air samples, the sound absorption is evaluated from equation (19). In these cases the O_2 relaxation frequency lies so high that relaxation in N_2 is the dominant process over the range of experimental frequencies. The O_2 relaxation frequency f_{vo} is assumed to be given by the current ANSI standard (eq. (7)) and the N_2 frequency f_{vn} is best-fitted to the data. Thus f_{vn} is varied until the sum

$$S = \sum (\alpha_{\text{air}} - \alpha_{\text{cr}} - \alpha_{\text{vn}} - \alpha_{\text{vo}})^2 \qquad (20)$$

reaches a minimum. In equation (20), α_{air} is taken from equation (19); α_{cr}, α_{vn}, and α_{vo} are computed from equations (3) to (5). The summation index (over all the points in a data set) is omitted to simplify notation. A small error in f_{vo} has a negligible effect on the evaluation of f_{vn} if the humidity exceeds 0.5 mole percent (about 20-percent RH at 20°C), but at lower humidities the effect of the error is more severe. Nevertheless, this is of little consequence in the present study because only two data sets are affected (figs. A5 and A6), and in the worst case a 10-percent error in f_{vo} results in a 22-percent error in f_{vn}.

In the driest air samples (figs. A1 to A4, A14, A21, and A27), f_{vo} shifts into the range of experimental frequencies, and relaxation in O_2 becomes the overwhelmingly dominant process. The N_2 relaxation frequency shifts to such low values as to make no detectable contribution to the sound absorption. In these figures the absorption per unit wavelength μ_{air}, evaluated from equations (8) and (19), is plotted to emphasize the O_2 relaxation peak. The data are used to best-fit f_{vo} by varying f_{vo} until the sum

$$S = \sum (\mu_{\text{air}} - \mu_{\text{cr}} - \mu_{\text{vn}} - \mu_{\text{vo}})^2 \qquad (21)$$

reaches a minimum. As in the above procedure, μ_{cr}, μ_{vn}, and μ_{vo} are given by equations (11) to (13), and f_{vn} by equation (6), even though the choice of f_{vn} is inconsequential.

The best-fitted N_2 and O_2 relaxation frequencies are summarized in tables III and IV.

Relaxation Frequency of N_2

Figure 3 shows the N_2 relaxation frequency f_{vn} plotted against absolute humidity at temperatures T of 20°C, 30°C, 40°C, and 50°C. The symbols are the results of the present measurements. The straight lines represent relationships of the form

$$f_{\text{vn}} = a_0 + a_1 h \qquad (22)$$

for the ANSI standard (eq. (6)), the best fit to the data (using f_{vo} of the ANSI standard), and the results of Zuckerwar and Meredith for binary N_2-H_2O mixtures (ref. 10). It is apparent from these figures that the measured relaxation frequencies lie between the ANSI and binary values at all temperatures. The 95-percent confidence intervals of the slope a_1, taken to be plus or minus two standard deviations, are ±29 Hz/mole percent or ±12 percent per mole percent. The best-fitted slopes are summarized in table V.

Relaxation Frequency of O_2

Figure 4 shows the O_2 relaxation frequencies f_{vo} versus humidity for the dry air samples. The circles represent data from the present measurements in the temperature interval from 10°C to 50°C, as listed in table IV. For comparison the squares represent data from Harris and Tempest (ref. 4) at temperatures of −40°C, −20°C, 0°C, and 20°C. The solid line is a plot of the ANSI relationship (eq. (7)). The measured relaxation frequencies in this range of humidity remain remarkably independent of temperature. Both the data presented here and those of reference 4 reveal a significant trend away from the ANSI standard at low values of humidity. The ANSI relationship can be made to pass through the low-humidity data points by suitable adjustment of one or more numerical constants in equation (7).

Summary

Thirty sets of sound absorption measurements in air at 1 atmosphere are presented at temperatures from 10°C to 50°C, relative humidities from 0 to 100 percent, and frequencies from 10 to 2500 Hz. The data are used to evaluate the relaxation frequencies of N_2 and O_2 for each of 30 sets of meteorological parameters. The experimentally determined relaxation frequencies reveal significant differences from those specified by the current ANSI standard, S1.26-1978.

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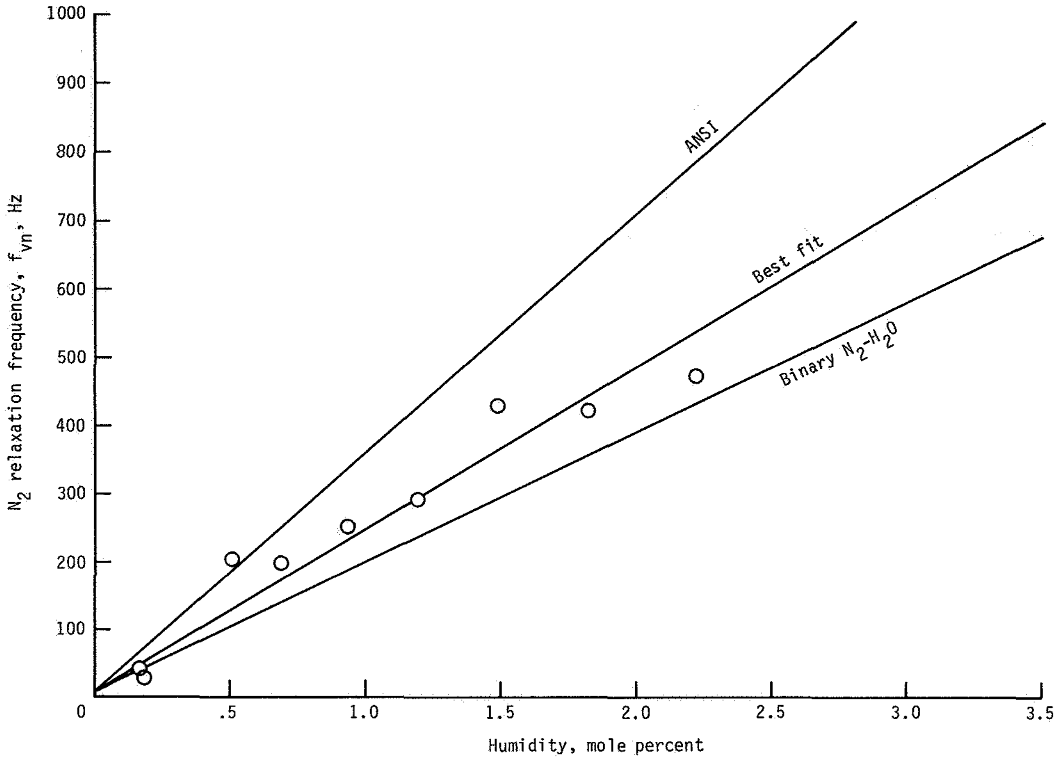
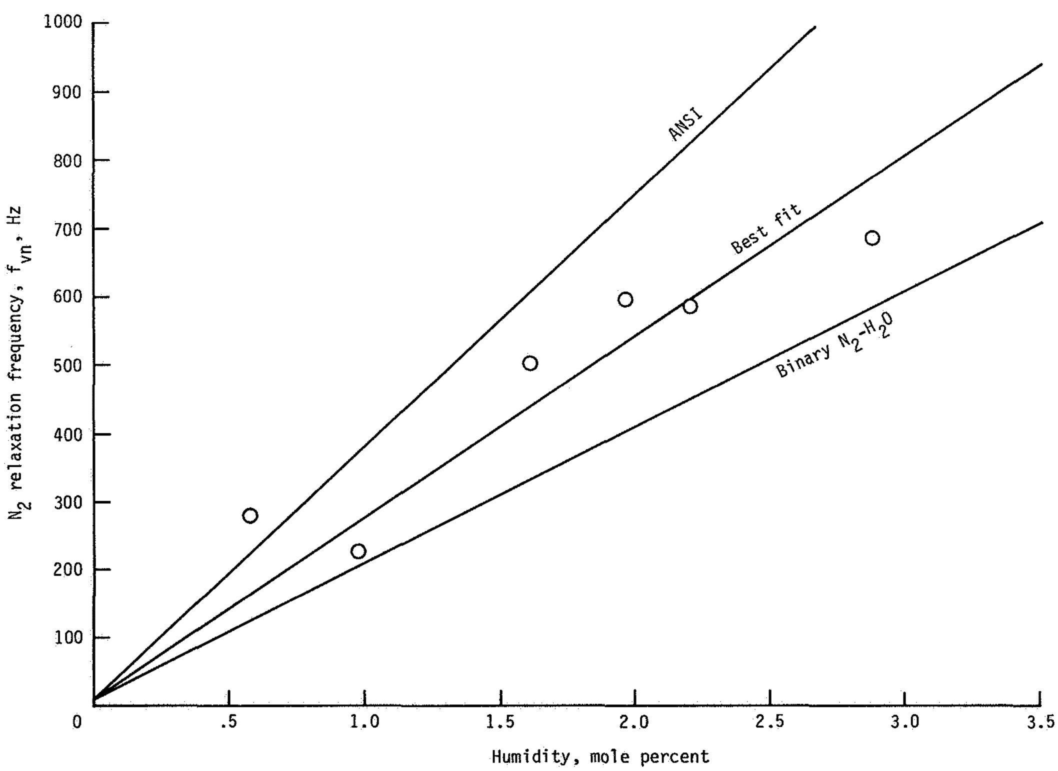
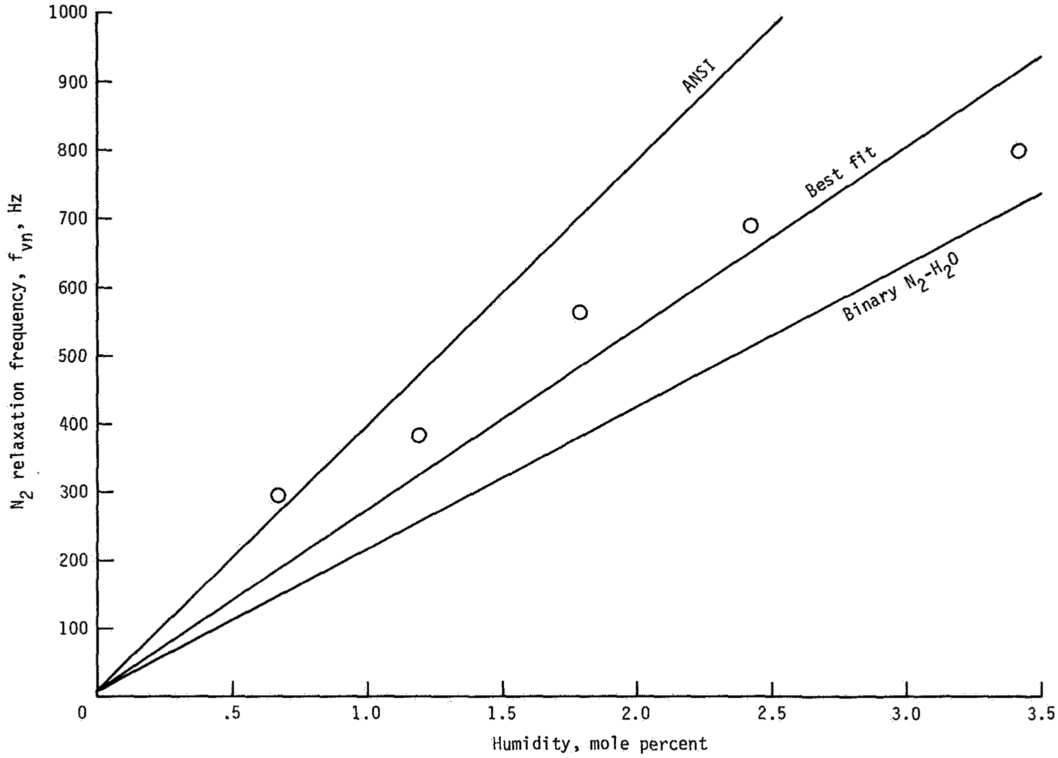


(a) $T = 20°C$.

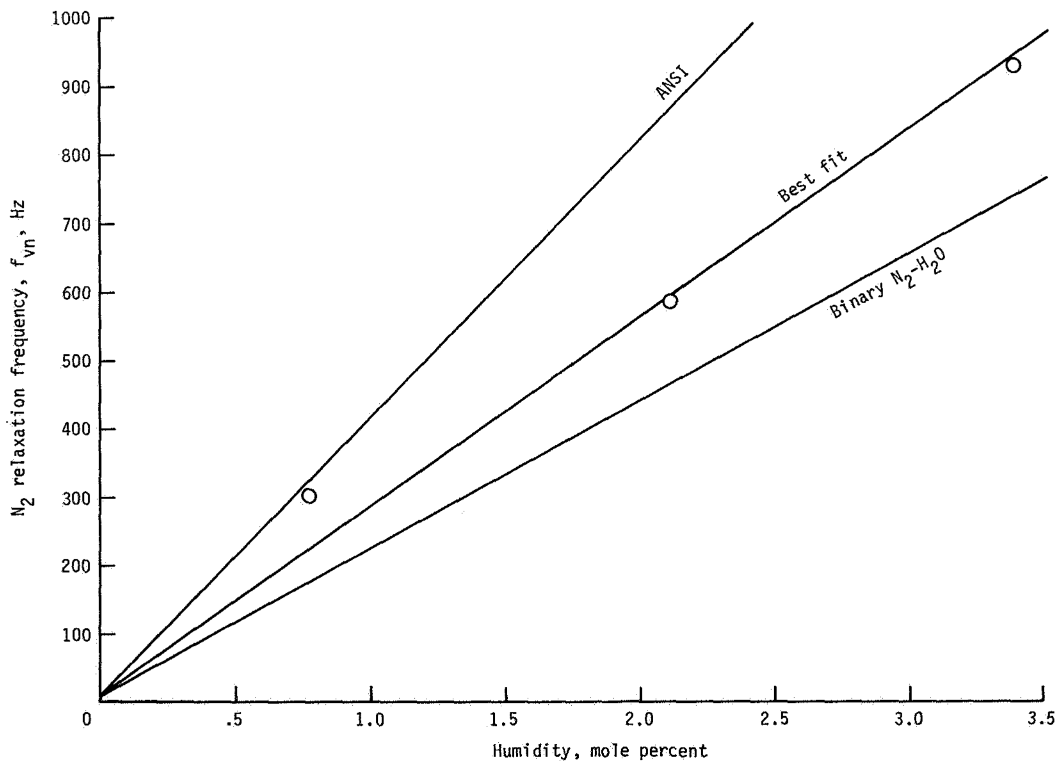


(b) $T = 30°C$.

Figure 3. Relaxation frequency f_{vn} of N_2 versus humidity. Circles are experimental data points. The straight lines represent the relationships specified by the ANSI standard (eq. (6)), the best fit to the data, and reference 10 for binary N_2-H_2O mixtures.



(c) $T = 40°C$.



(d) $T = 50°C$.

Figure 3. Concluded.

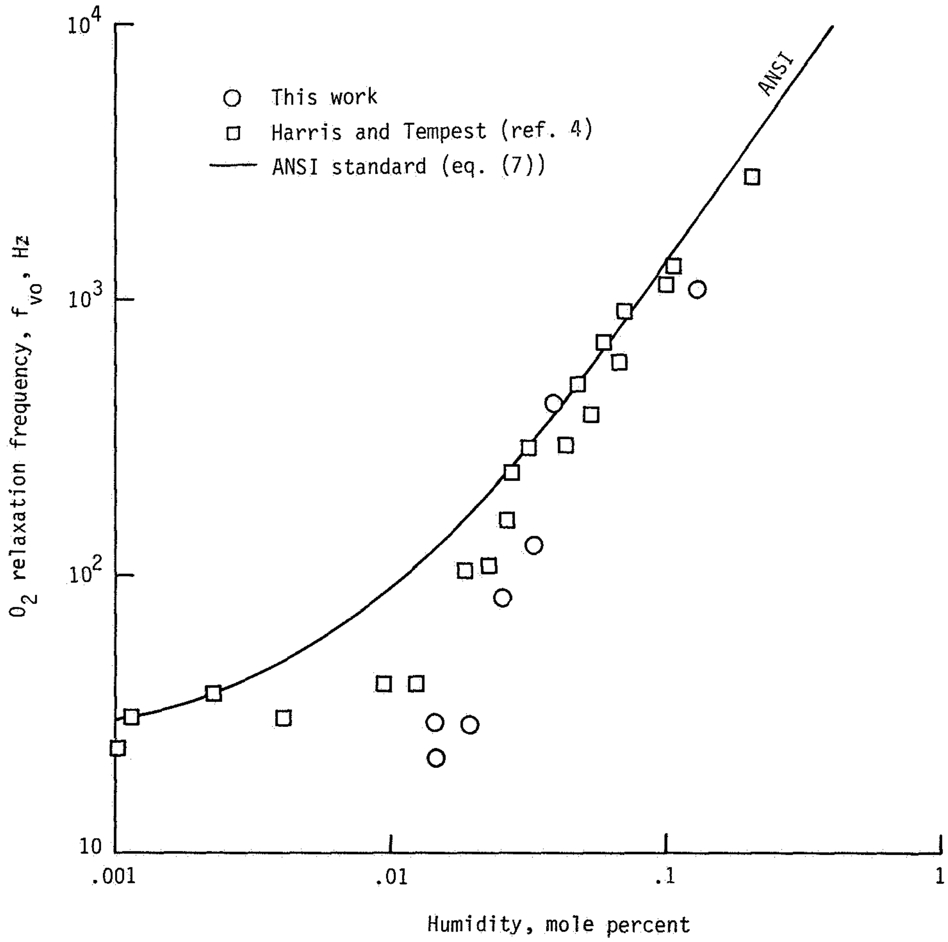


Figure 4. Relaxation frequency f_{vo} of O_2 versus humidity at low humidities.

TABLE I. COMPOSITION OF GAS SAMPLES

(a) Molar composition of test air

Constituent	Composition	
	Requested	Actual
O_2	20.9 ± 0.1%	21.0%
Ar	0.9 ± 0.1%	0.893%
CO_2	330 ± 30 ppm	348 ppm
H_2O	<5.3 ppm (dew point, −65°C)	20.6 ppm (dew point, −55°C)
N_2	Balance	Balance

(b) Molar composition of background gas

Constituent	Actual composition
N_2	89.5%
Ar	10.5%
CO_2	<1 ppm
H_2O	<2.5 ppm (dew point, −70°C)

TABLE II. SUMMARY OF METEOROLOGICAL PARAMETERS IN AIR–WATER-VAPOR MIXTURES AT 1 ATMOSPHERE

Relative humidity, percent, at temperatures of—				
10°C	20°C	30°C	40°C	50°C
1.1	0.60	0.45	0.36	0.28
2.9	7.1	13.7	9.4	6.2
9.7	7.9	24.2	16.5	17.4
	20.4	38.3	25.7	28.8
	28.3	46.0	32.9	
	35.5	52.1	47.9	
	45.8	65.5		
	65.3			
	73.5			
	91.2			

TABLE III. SUMMARY OF EXPERIMENTALLY DETERMINED RELAXATION FREQUENCIES OF N_2 IN AIR AT 1 ATMOSPHERE

Temperature, °C	Absolute humidity, mole percent	Relative humidity, percent	N_2 relaxation frequency, Hz
20	0.165	7.1	43
	.180	7.9	30
	.508	20.4	207
	.689	28.3	201
	.933	35.5	255
	1.20	45.8	295
	1.49	65.3	432
	1.82	73.5	425
	2.22	91.2	476
30	.579	13.7	282
	.976	24.2	228
	1.62	38.3	504
	1.97	46.0	597
	2.21	52.1	588
	2.88	65.5	687
40	.672	9.4	297
	1.20	16.5	385
	1.79	25.7	566
	2.43	32.9	692
	3.42	47.9	800
50	.776	6.2	304
	2.12	17.4	589
	3.39	28.8	931

TABLE IV. SUMMARY OF EXPERIMENTALLY DETERMINED RELAXATION FREQUENCIES OF O_2 IN AIR AT 1 ATMOSPHERE

Temperature, °C	Absolute humidity, mole percent	Relative humidity, percent	O_2 relaxation frequency, Hz
10	0.0146	1.11	29.7
	.0395	2.94	425
	.1304	9.74	1110
20	.0147	.60	22
30	.0195	.45	29
40	.0256	.36	84
50	.0333	.28	131

TABLE V. BEST-FITTED SLOPE a_1 IN THE HUMIDITY DEPENDENCE OF THE RELAXATION FREQUENCY OF N_2 AT 1 ATMOSPHERE[a]

Temperature, °C	Best-fitted slope, a_1, Hz/mole percent		
	ANSI (eq. (6))[b]	Binary N_2-H_2O[c]	This work
20	350	191	239
30	368	199	265
40	387	208	264
50	406	216	277

[a]See equation (22).
[b]Reference 3.
[c]Reference 10.

Appendix

Sound Absorption Versus Frequency: Plots and Tabulated Data

The sound absorption is plotted and tabulated for each of the 30 data sets listed in table II.

The sound absorption is plotted as μ, absorption per unit wavelength, in figures A1, A2, A4, A14, A21, and A27, where the air is sufficiently dry that the O_2 relaxation peak stands out prominently above the background. In the remaining figures, α, absorption per unit length, is plotted. The symbols indicate the measured points listed in the tables.

The dashed lines represent the sound absorption as specified by the current ANSI standard (ref. 3).

The solid lines represent the best fit to the data by the method of least squares. For the data sets in which α is plotted, the total absorption is fitted to the data with f_{vo} given by equation (7) and with f_{vn} as the adjustable parameter. For the remaining data sets, the total absorption is fitted with f_{vo} as the adjustable parameter and with N_2 relaxation assumed to be negligibly small.

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)
55.2	.643	598.87	.076
64.402	.686	598.865	.104
64.402	.689	607.879	-.031
73.676	.492	616.98	.131
73.676	.478	626.302	.05
82.8	.645	635.529	.222
82.8	.402	681.599	.258
92	.575	690.799	-.025
101.199	.691	700	.161
110.49	.471	799.98	.115
119.689	.54	809.089	.036
128.889	.372	818.289	.073
138.08	.587	827.5	.04
147.3	.182	901.099	.11
156.5	.357	910.299	.018
165.699	.233	919.5	.05
174.889	.419	1011.4	6E-03
184.18	.176	1020.7	-.055
193.269	.296	1029.9	-.033
202.56	.254	1103.5	.04
211.8	.311	1112.699	.042
221.089	.124	1204.699	.071
230.18	.249	1213.9	.142
239.399	.096	1287.4	.16
313.08	.024	1296.699	.078
322.379	-.012	1397.9	.024
331.58	.075	1407.199	-.061
340.799	.262	1499.099	-.022
350	.245	1499.09	.039
359.2	.338	1508.4	.144
368.379	.088	1600.3	.152
395.919	.271	1609.599	.041
405.2	.299	1701.5	-.022
414.399	.324	1710.8	.066
423.679	.297	1802.3	-.021
432.799	.321	1812	-.143
442	.303	2005.3	.096
451.2	.26	2005.199	.062
460.5	.321	2014.599	.06
469.7	.346	2097.199	.059
506.399	.223	2106.399	-.013
515.809	.256	2198.5	.124
524.94	.258	2290.699	-.187
570.99	.056	2299.8	-.015
580.4	.01	2502.3	.078
589.7	.164	2511.6	.087

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 128 Hz
(BEST FIT)= 29.7 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 14.1 Hz
(REF 10)= 11.1 Hz

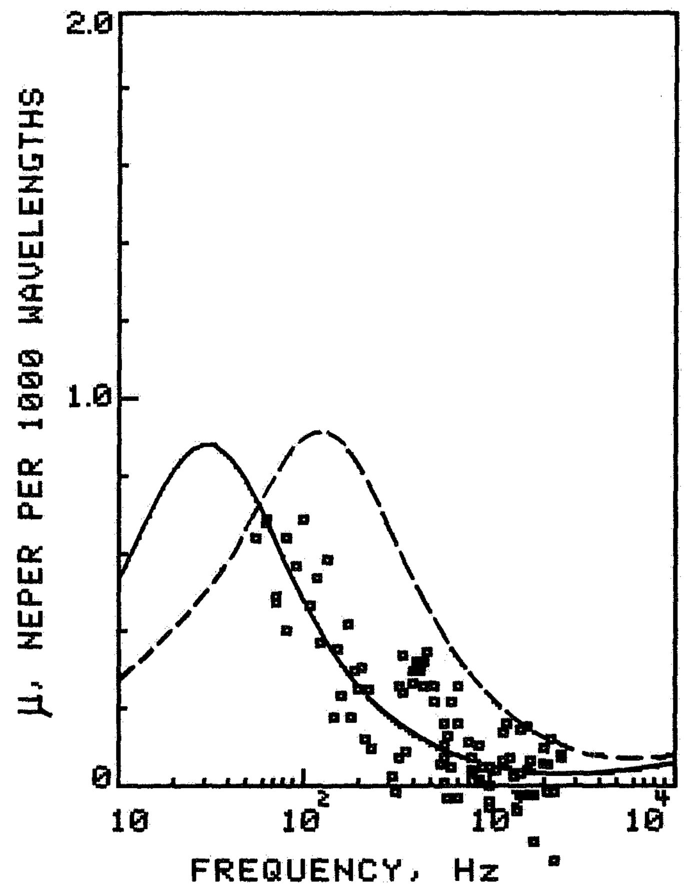


Figure A1. Sound absorption in air:

Temperature	11.1°C
Pressure	1.0097 atm
Absolute humidity	0.0146 mole percent
Relative humidity	1.1 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)
45.798	.436	634.079	.969
54.998	.433	680.079	.983
64.199	.703	689.5	.581
64.199	.664	698.629	.797
73.421	.502	800	.875
100.875	.773	809.099	.736
110.109	.71	818.4	.86
119.209	.809	827.7	.751
128.399	.76	901.5	.852
137.569	.942	910.599	.773
146.777	.671	920	.83
165.1	.655	1011.9	.739
174.28	.832	1021.299	.733
183.578	.634	1030.599	.746
192.6	.793	1104.3	.77
201.78	.854	1113.5	.659
210.969	.733	1122.8	.735
220.28	.723	1205.8	.62
229.399	.849	1215	.743
330.399	.787	1298.199	.686
339.5	1.031	1399.5	.574
348.789	.88	1408.9	.498
357.98	.986	1501	.528
367.169	.761	1510.4	.629
403.889	1.045	1455.3	.781
413.1	.977	1556.699	.421
422.299	.964	1602.8	.54
468.299	.996	1612.199	.557
477.5	.962	1704.5	.634
504.799	1.097	1713.8	.532
514.299	.95	1954.5	.426
523.5	.859	1963.699	.28
606.4	.962	2019	.453
606.403	.508	2295.1	.408
615.5	1.044	2507.1	.465
624.799	.809	2516.399	.483

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 392 Hz
(BEST FIT)= 425 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 22.6 Hz
(REF 10)= 14.6 Hz

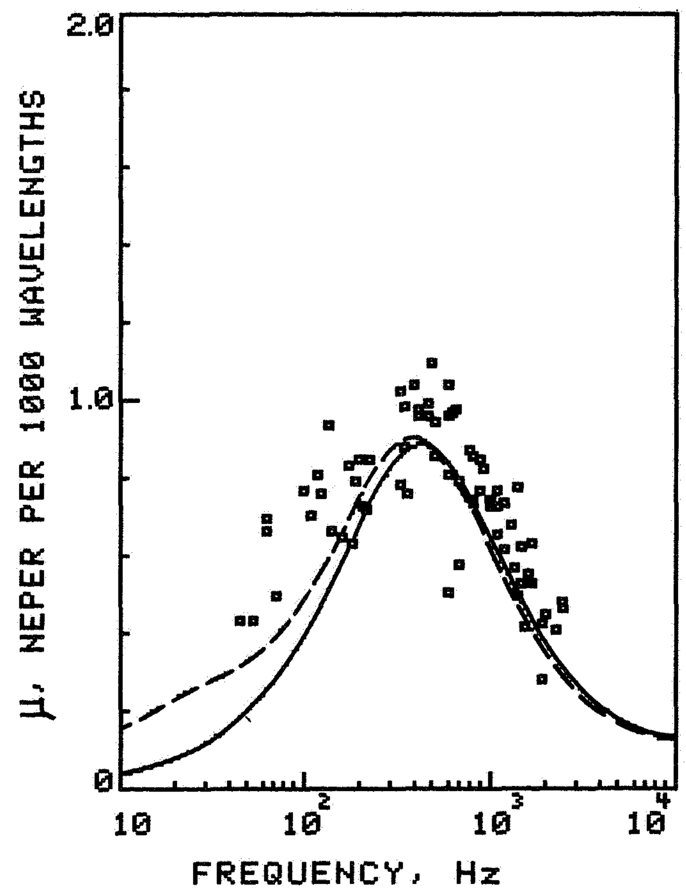


Figure A2. Sound absorption in air:

Temperature	11.3°C
Pressure	1.0166 atm
Absolute humidity	0.0394 mole percent
Relative humidity	2.9 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
36.871	.314	689.805	6.481
45.9	.303	698.995	5.837
45.903	.525	800.384	9.128
82.68	.61	809.505	7.541
101.034	1.13	818.705	11.945
110.305	1.33	901.615	13.192
119.485	.789	910.815	12.293
128.685	.931	920.014	12.902
137.835	1.598	1012.014	14.625
156.194	1.076	1021.305	13.762
165.504	.921	1030.505	13.603
174.685	1.531	1104.105	12.523
183.904	.735	1113.405	17.688
193.014	1.372	1205.505	17.451
202.193	1.464	1214.704	23.075
211.394	1.347	1297.605	10.714
229.794	1.859	1306.905	26.292
239.004	.938	1400.005	36.051
321.804	2.964	1409.505	20.804
330.985	1.541	1501.505	30.718
340.205	2.965	1510.704	21.115
349.404	3.009	1602.795	35.57
358.605	5.043	1612.105	30.993
404.475	6.314	1704.305	29.733
413.705	6.559	1713.505	34.018
422.894	6.033	1805.605	33.712
468.995	7.128	1814.805	26.756
478.175	7.122	2008.295	21.397
505.605	7.404	2017.605	14.51
514.975	8.222	2100.404	49.062
524.075	7.867	2109.605	32.328
606.995	6.129	2201.904	29.116
616.105	9.656	2211.005	62.854
625.384	8.52	2294.005	21.308
680.605	9.7	2303.105	48.631

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 2016 Hz
(REVISED)= 1110 Hz *

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 52.5 Hz
(REF. 10)= 27.6 Hz
(BEST FIT)= 37.6 Hz

* USED TO BEST-FIT THE RELAXATION FREQUENCY OF NITROGEN.

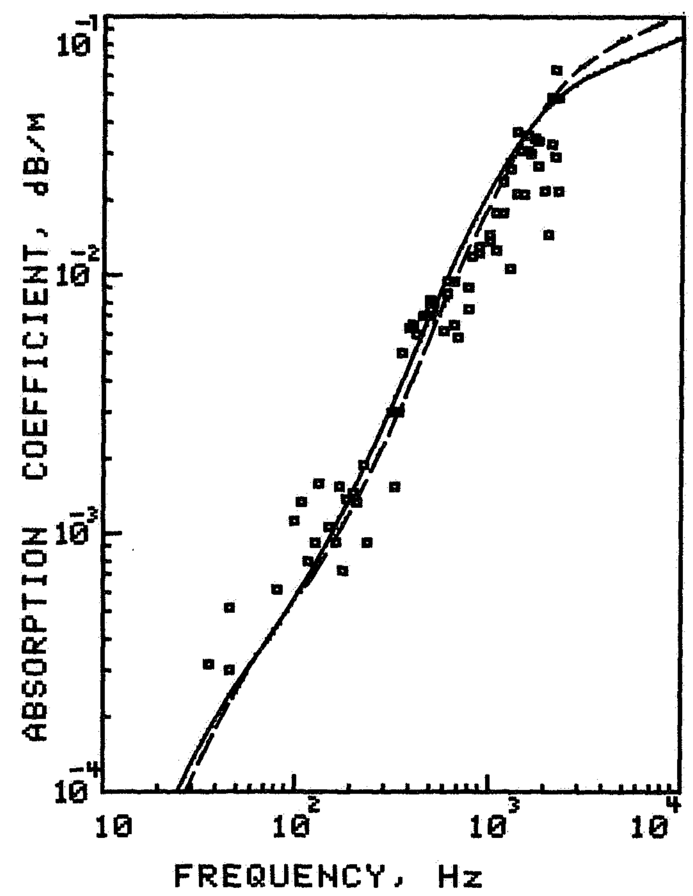


Figure A3. Sound absorption in air:

Temperature	11.5°C
Pressure	1.0009 atm
Absolute humidity	0.1304 mole percent
Relative humidity	9.7 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)
18.605	.857	625.9	.146
27.983	.906	635.2	.015
37.599	1.104	644.7	.169
46.762	1	654.099	.121
56.098	.705	682	.029
65.38	.734	691.299	.042
74.898	.466	700.7	.108
74.9	.36	812.69	.114
84.097	.448	821.99	.146
102.79	.549	887.4	.049
121.5	.449	906.179	.158
130.819	.415	989.98	.12
140.209	.28	999.4	.162
149.59	.144	1008.7	.092
158.879	.231	1092.699	.105
168.29	.074	1101.9	.144
177.6	.188	1195.199	.17
186.889	.039	1204.5	-.043
196.199	.049	1288.9	.038
205.6	.175	1298.5	4E-03
233.6	.101	1401.599	.087
317.789	.086	1411	-.05
327.1	.213	1495.3	.093
336.389	.052	1504.699	.199
355	.138	1607.71	.119
364.393	.196	1701.3	.076
411.089	.24	1832.5	-.073
420.389	.186	1954.3	.054
429.779	.2	2001.099	-8E-03
513.679	.207	2010.5	.037
523.2	.222	2113.3	.106

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 130 Hz
(BEST FIT)= 22 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 14.4 Hz
(REF 10)= 11.2 Hz

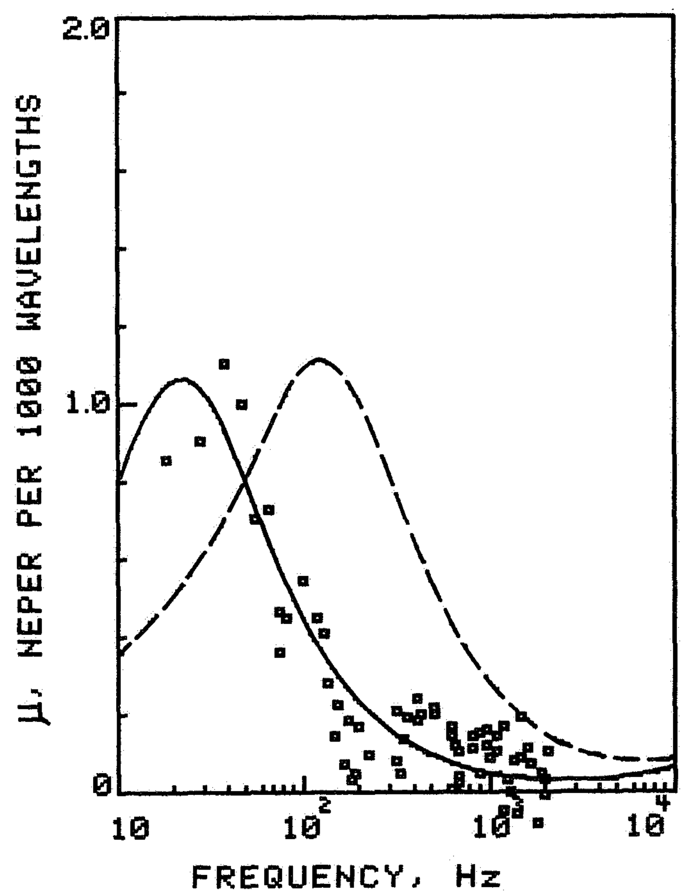


Figure A4. Sound absorption in air:

Temperature	20.6°C
Pressure	1.0193 atm
Absolute humidity	0.0147 mole percent
Relative humidity	0.604 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
37.517	.237	700.884	9.67
46.602	.16	803.695	11.986
65.28	.363	813.005	8.987
74.701	.444	822.405	11.893
83.989	.425	878.605	11.606
102.604	.561	887.905	7.653
121.302	.974	906.705	9.355
130.674	.934	990.805	14.229
139.985	.876	1000.105	8.305
149.394	.813	1009.505	13.109
158.694	.744	1018.805	10.119
168.024	.802	1093.704	14.801
177.394	.852	1103.005	15.264
186.704	1.165	1112.405	16.776
195.985	1.132	1196.505	17.141
205.394	1.146	1205.805	14.345
308.185	1.483	1289.905	23.804
317.504	2.209	1299.305	17.205
326.894	2.603	1309.105	19.557
336.205	2.842	1392.605	28.381
354.884	2.476	1402.034	21.354
364.284	3.214	1411.605	21.302
401.585	3.815	1598.405	16.995
401.583	3.991	1607.704	27.652
410.984	4.577	1701.204	30.343
420.325	4.72	1710.505	35.312
429.705	4.692	1832.005	30.126
504.294	5.504	1953.914	29.211
513.684	6.329	2009.905	20.437
523.195	5.093	2112.605	22.439
579.275	6.02	2122.005	33.694
625.905	8.782	2215.505	44.419
635.384	5.082	2308.904	26.856
654.195	8.757	2318.305	54.78
644.785	9.993	2327.704	49.666
682.085	8.681	2505.404	47.903
682.086	7.728	2514.704	39.684
691.485	9.322	2514.704	39.692

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 2879 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 67.7 Hz
(REF. 10)= 29 Hz
(BEST FIT)= 32.9 Hz

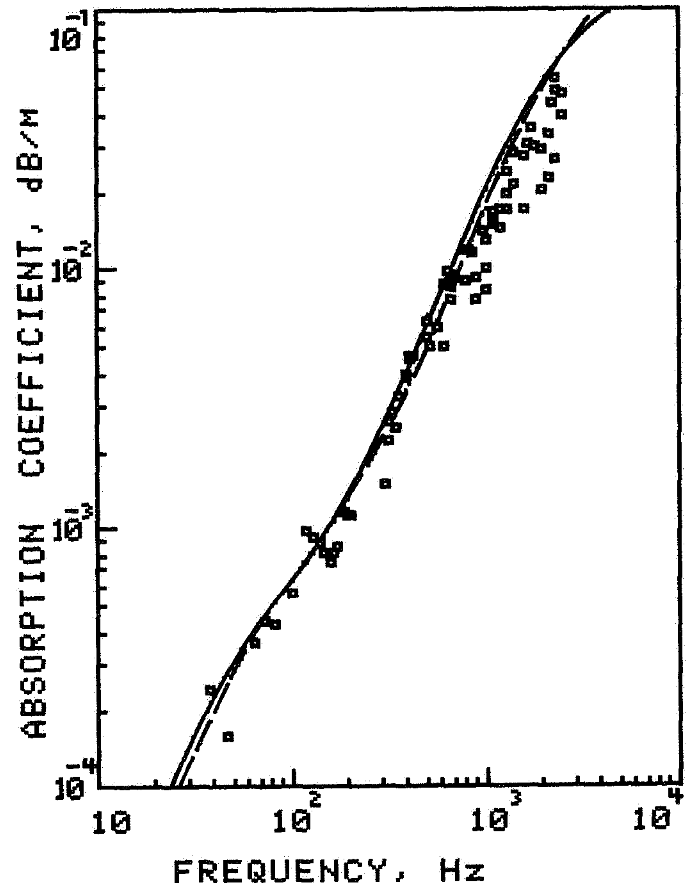


Figure A5. Sound absorption in air:

Temperature	20°C
Pressure	1.0138 atm
Absolute humidity	0.165 mole percent
Relative humidity	7.1 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
37.405	.206	813.105	8.301
46.482	.17	822.405	9.949
55.782	.286	906.805	11.048
74.581	.294	990.706	11.443
83.784	.384	1000.205	7.066
102.405	.498	1009.605	8.728
121.094	.685	1019.005	6.609
130.495	.6	1093.905	9.762
139.795	.873	1103.305	9.687
149.204	.589	1103.295	8.551
158.504	1.358	1196.784	11.971
177.185	.714	1206.204	18.901
186.585	.631	1290.305	21.221
195.805	1.011	1290.315	17.423
205.204	.719	1299.805	19.776
317.304	1.487	1299.784	19.722
326.605	2.663	1309.105	23.04
335.985	1.273	1309.095	27.456
354.585	2.029	1402.605	28.917
363.904	3.477	1412.005	19.448
401.304	4.247	1496.204	23.376
410.684	3.583	1505.505	26.057
420.084	4.499	1589.905	34.224
429.484	3.891	1589.875	31.634
513.384	6.334	1599.105	23.721
522.894	5.504	1608.305	23.319
588.505	2.099	1702.005	26.114
625.695	8.412	1711.305	21.122
635.195	3.793	2001.405	19.099
644.605	7.227	2104.305	37.165
682.005	8.878	2113.605	30.667
691.405	8.027	2207.005	62.647
700.805	9.359	2310.105	48.8
803.705	15.568	2506.204	27.86

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 3264 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 72.9 Hz
(REF. 10)= 31.2 Hz
(BEST FIT)= 35.4 Hz

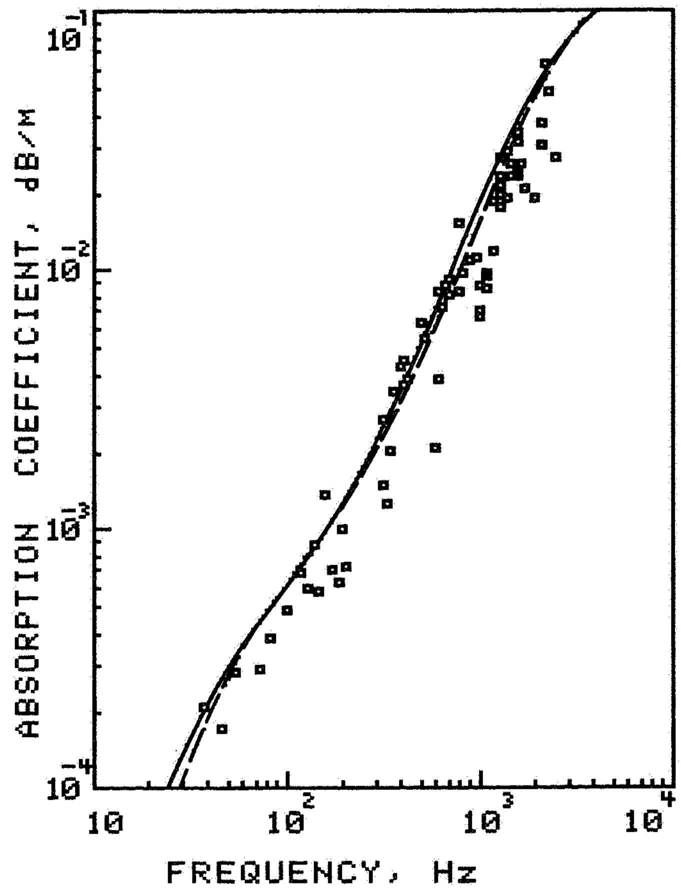


Figure A6. Sound absorption in air:

Temperature	19.6°C
Pressure	1.0104 atm
Absolute humidity	0.1803 mole percent
Relative humidity	7.9 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
46.78	.275	826.315	9.312
65.604	.646	835.705	4.402
75.004	.345	910.934	6.459
84.305	.648	920.315	6.203
103.014	.628	995.345	8.555
121.805	.76	1004.805	7.145
131.204	.857	1014.205	7.775
140.605	.89	1098.704	6.868
159.335	.95	1108.105	9.917
178.144	.963	1117.505	7.554
187.524	.722	1126.905	8.422
196.904	.922	1192.605	7.239
206.291	1.259	1202.005	13.758
309.605	2.053	1211.405	9.539
319.004	1.65	1295.905	13.86
328.384	2.724	1305.305	12.745
337.84	1.447	1314.704	9.883
356.605	2.118	1324.105	4.856
366.004	3.157	1399.305	14.239
413.004	3.533	1408.605	13.824
422.404	3.518	1493.204	6.976
431.705	3.299	1502.605	15.577
506.705	2.118	1596.405	17.823
516.205	3.671	1605.905	11.072
525.805	4.227	1709.105	19.744
582.205	6.44	1718.605	17.046
619.605	2.309	1962.905	9.298
629.005	3.394	2009.905	18.826
638.505	2.188	2103.704	13.006
648.035	5.114	2113.204	27.846
685.505	3.822	2207.204	22.718
694.905	6.556	2310.404	28.739
704.205	7.325	2319.904	22.495
807.505	6.126	2507.805	24.08
816.915	3.091		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 14070 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 189 Hz
(REF. 10)= 84.8 Hz
(BEST FIT)= 207 Hz

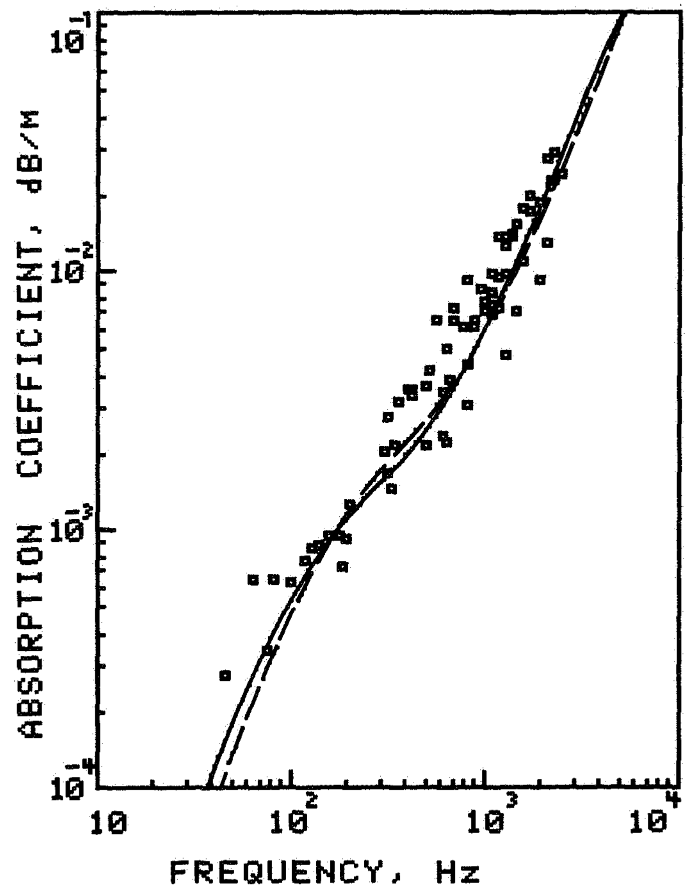


Figure A7. Sound absorption in air:

Temperature	21.1°C
Pressure	1.0104 atm
Absolute humidity	0.5078 mole percent
Relative humidity	20.4 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
46.905	.168	993.785	3.22
84.322	.341	1003.205	2.805
103.104	.635	1012.505	3.167
121.905	.658	1096.905	5.777
140.62	.531	1106.204	5.662
150.095	.492	1115.605	5.05
159.394	.803	1190.704	4.628
178.204	.883	1200.005	7.767
196.983	.772	1209.505	5.65
206.384	.874	1293.704	12.461
234.608	.701	1303.204	4.766
243.985	.919	1312.505	10.945
319.085	.814	1396.905	9.26
328.485	1.627	1406.204	11.378
337.884	.901	1415.704	10.091
356.585	1.182	1500.005	12.825
365.985	2.006	1509.405	14.904
412.984	2.405	1593.805	11.501
422.384	3.286	1612.505	8.836
431.784	2.132	1706.204	15.992
441.084	3.608	1715.704	10.857
506.684	3.993	1837.605	12.512
516.184	3.134	1847.005	6.644
525.684	2.775	2006.805	13.573
619.485	1.798	2016.105	14.341
628.785	4.579	2109.805	8.623
647.785	3.465	2109.805	9.736
685.085	2.253	2119.105	10.994
694.485	5.237	2203.605	11.125
703.905	4.81	2213.005	16.521
797.605	2.442	2316.204	11.432
806.905	3.742	2325.505	16.856
825.485	6.812	2503.904	13.185
834.505	4.245	2513.204	20.112
890.805	2.048	2513.204	20.12
909.505	3.163		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 21013 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 253 Hz
(REF. 10)= 112 Hz
(BEST FIT)= 201 Hz

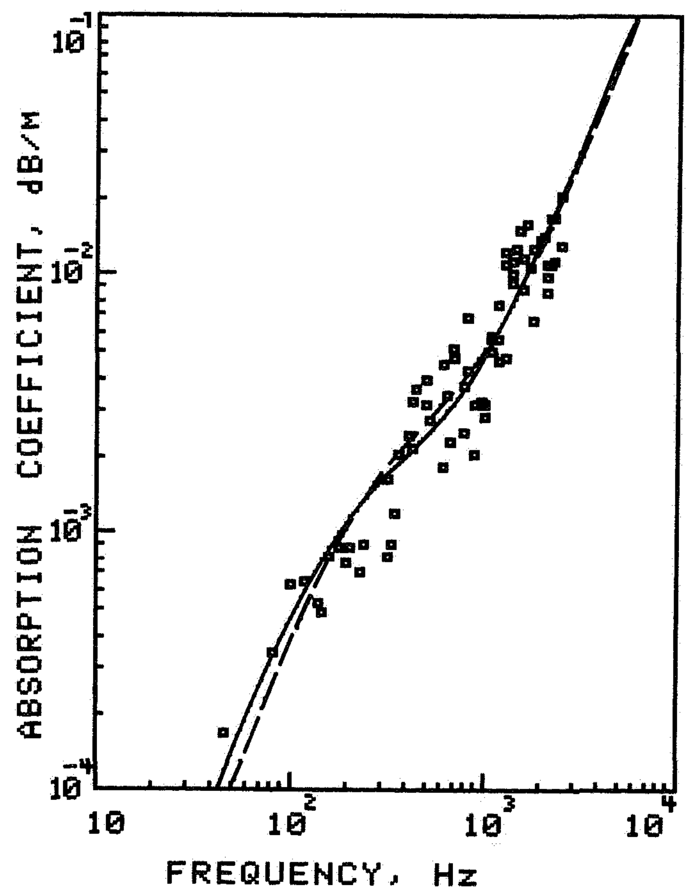


Figure A8. Sound absorption in air:

Temperature	20.7°C
Pressure	1.0104 atm
Absolute humidity	0.6884 mole percent
Relative humidity	28.3 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
46.98	.152	883.514	3.262
56.381	.104	892.895	3.945
65.807	.213	996.205	2.653
103.398	.598	1005.505	4.09
122.282	.687	1015.005	5.259
131.682	.621	1099.405	2.496
141.085	.64	1108.605	4.227
150.485	.824	1118.005	4.314
159.805	.81	1202.505	5.674
178.634	1.151	1211.905	4.869
197.485	.701	1296.505	8.963
206.884	.918	1305.805	4.22
319.774	1.792	1315.204	5.255
329.185	1.02	1390.305	4.28
338.504	1.453	1399.704	8.402
404.304	3.521	1409.105	8.593
404.304	3.155	1418.605	7.803
413.804	3.471	1503.005	6.326
423.205	2.844	1512.405	13.102
432.504	2.652	1596.905	12.559
517.184	2.688	1606.405	6.293
526.684	3.583	1709.704	11.429
582.985	4.437	1719.204	7.692
620.505	2.739	2001.305	13.613
629.805	2.955	2010.505	13.896
639.305	1.705	2113.805	19.923
648.805	2.703	2198.404	13.651
658.205	1.572	2207.704	12.662
686.315	4.599	2301.805	10.866
695.715	1.938	2311.005	19.231
705.005	4.813	2320.505	15.415
808.415	4.357	2498.904	8.665
827.105	4.878	2508.505	11.796

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 31386 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 345 Hz
(REF. 10)= 148 Hz
(BEST FIT)= 255 Hz

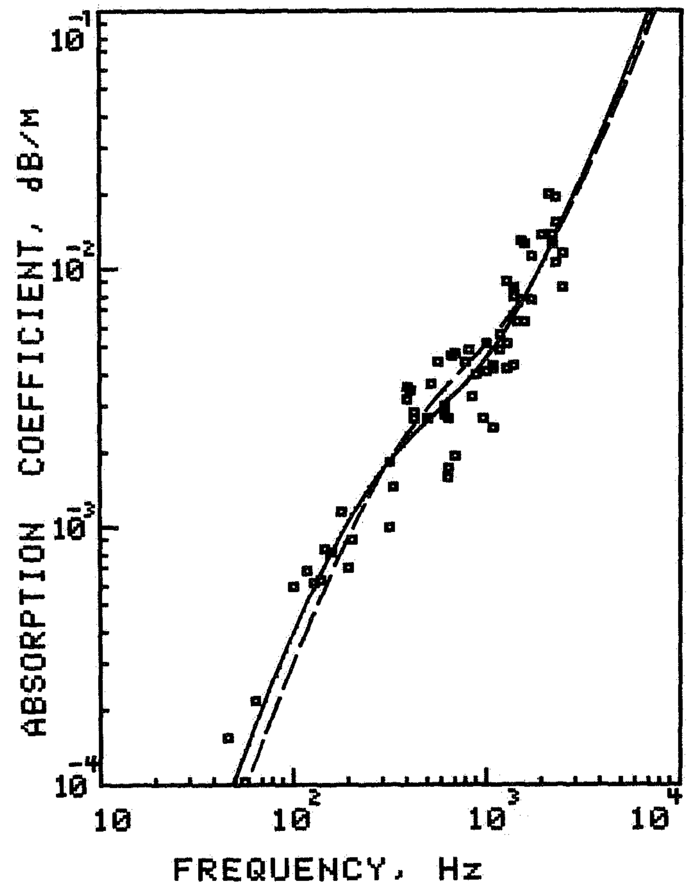


Figure A9. Sound absorption in air:

Temperature	21.7°C
Pressure	1.0261 atm
Absolute humidity	0.9333 mole percent
Relative humidity	35.5 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
47.005	.099	705.605	3.339
65.882	.228	809.105	6.897
75.305	.401	818.405	4.068
84.704	.43	827.805	7.441
103.505	.742	884.205	3.319
122.382	.81	893.495	5.105
141.204	.806	996.985	4.319
160.004	.735	1015.505	5.715
169.394	.816	1203.395	11.105
178.785	1.05	1212.704	3.401
197.694	1.108	1296.105	8.648
207.094	1.3	1305.505	5.356
310.694	.995	1314.805	3.517
329.594	1.386	1399.405	14.677
338.995	1.111	1408.704	10.233
357.685	1.621	1502.704	4.545
367.185	1.916	1596.605	11.421
414.284	2.584	1606.105	4.316
432.995	2.559	1709.305	9.88
442.394	3.719	1718.704	12.123
508.105	3.61	2010.105	11.429
517.595	2.151	2103.805	9.447
527.205	3.713	2197.805	13.721
630.495	3.024	2207.305	9.155
639.915	2.141	2301.005	7.916
649.405	3.916	2310.505	13.2
658.805	3.568	2498.404	10.965
686.805	2.568	2507.904	13.039
696.305	5.707		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 42041 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 435 Hz
(REF. 10)= 188 Hz
(BEST FIT)= 295 Hz

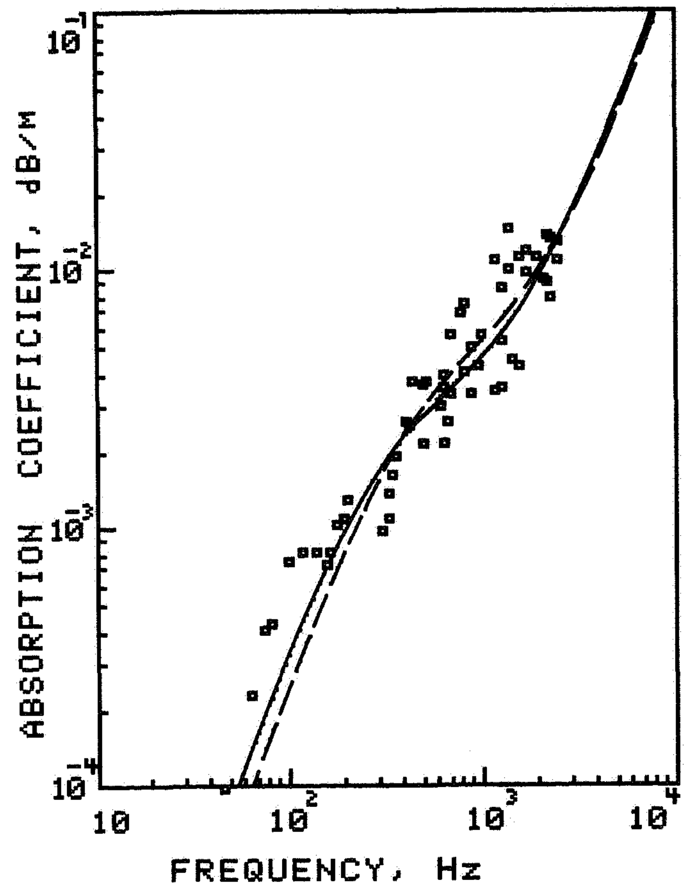


Figure A10. Sound absorption in air:

Temperature	21.8°C
Pressure	1.0145 atm
Absolute humidity	1.196 mole percent
Relative humidity	45.8 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
65.481	.152	703.005	6.743
74.88	.16	806.305	6.946
102.881	.443	815.505	3.369
121.69	.45	824.985	4.273
140.464	.654	918.785	5.13
159.115	.813	993.785	5.542
177.904	.526	1012.505	4.529
196.605	.523	1106.505	5.12
206.004	.732	1116.005	3.886
318.504	1.172	1200.305	7.137
327.805	1.841	1209.704	5.781
355.985	1.583	1294.204	7.388
365.384	2.714	1303.605	8.309
402.794	2.725	1313.005	6.864
402.794	2.359	1397.405	8.885
412.294	2.438	1416.204	8.029
421.675	3.221	1491.204	5.752
430.984	1.744	1500.505	7.157
515.305	3.571	1594.505	8.397
524.905	2.972	1603.805	6.228
618.605	2.183	1706.905	10.355
627.905	2.99	1716.505	7.609
637.384	4.839	1838.405	8.757
646.884	3.622	1960.505	7.629
656.205	3.125	2120.005	10.315
684.305	2.7	2514.105	11.773
693.705	4.337	2514.105	11.781

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 54114 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 534 Hz
(REF. 10)= 232 Hz
(BEST FIT)= 432 Hz

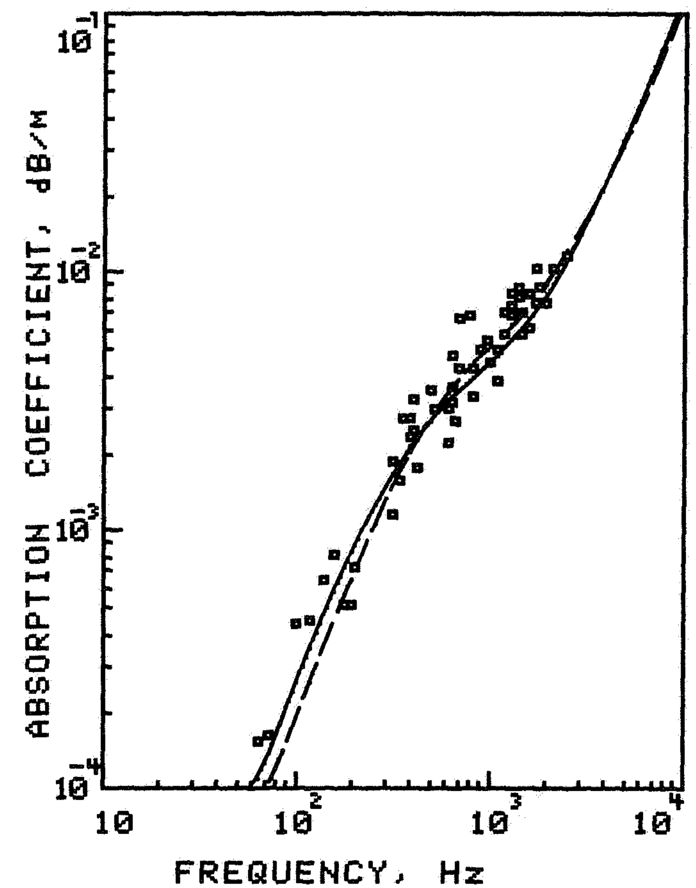


Figure A11. Sound absorption in air:

Temperature	19.8°C
Pressure	1.0036 atm
Absolute humidity	1.4922 mole percent
Relative humidity	65.3 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
65.8	.133	640.884	5.494
75.201	.241	650.285	6.552
103.474	.373	659.705	5.377
122.305	.381	706.785	6.545
131.795	.404	810.505	3.648
141.194	.593	819.805	8.201
159.985	.803	885.905	2.282
169.404	.507	904.805	6.217
178.903	.977	989.605	3.382
188.305	1.088	999.005	3.959
197.703	1.014	1008.405	7.433
207.09	1.26	1112.005	4.249
235.404	1.298	1121.405	3.201
320.205	1.494	1196.905	8.419
329.605	1.115	1206.305	6.774
339.105	1.305	1291.204	8.152
357.903	1.258	1300.605	4.236
367.304	2.991	1310.095	5.014
405.004	3.336	1404.405	10.479
405.004	2.969	1413.704	9.248
414.502	2.931	1498.605	10.604
423.904	3.09	1706.005	9.877
433.304	3.199	1715.204	9.262
508.504	3.313	1960.605	5.466
527.705	4.298	2215.105	8.064
594.005	5.886	2309.404	4.719
621.865	3.658	2328.305	7.323
631.285	4.983		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 69268 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 660 Hz
(REF. 10)= 281 Hz
(BEST FIT)= 425 Hz

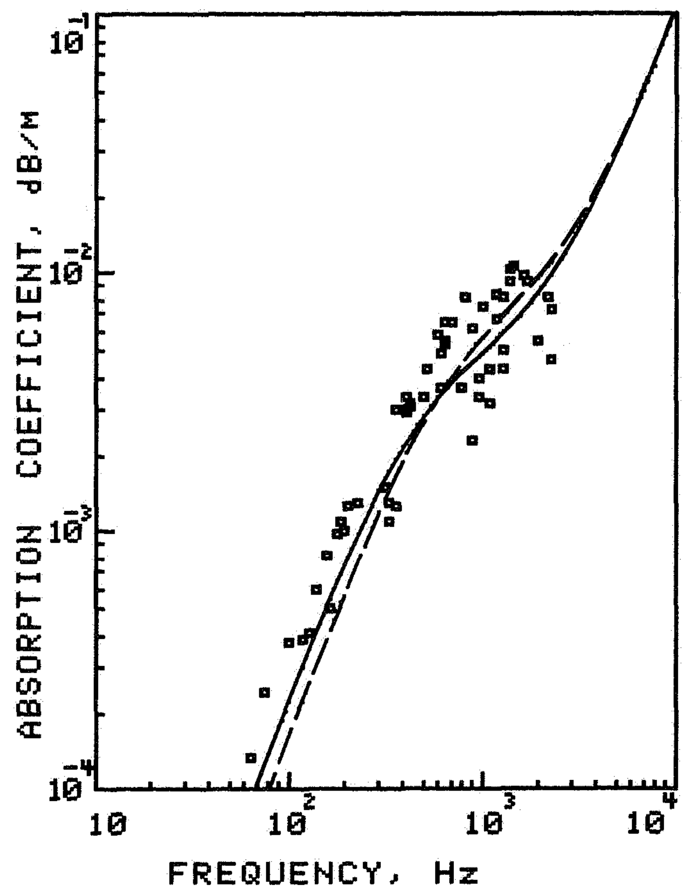


Figure A12. Sound absorption in air:

Temperature	20.9°C
Pressure	1.0172 atm
Absolute humidity	1.8242 mole percent
Relative humidity	73.5 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
84.997	.121	705.405	3.36
103.885	.398	799.505	6.18
122.796	.314	883.895	4.977
132.282	.498	893.305	3.123
141.697	.62	996.205	7.609
160.504	.867	1005.605	4.419
179.394	.662	1014.905	3.413
188.898	.497	1099.204	4.288
198.298	.458	1108.505	2.411
207.698	.73	1202.305	4.509
235.398	.756	1211.505	3.147
329.498	1.748	1296.005	10.425
338.898	1.267	1305.405	2.907
319.995	1.158	1314.805	5.667
357.594	1.109	1399.204	13.274
366.998	1.975	1408.405	8.719
413.998	2.127	1417.805	4.434
423.498	2.661	1492.704	4.458
432.798	1.82	1501.905	5.871
517.499	3.198	1511.305	8.418
526.999	3.281	1595.405	4.791
621.005	1.612	1707.704	11.213
630.301	3.317	1717.005	11.964
639.825	3.706	1960.204	11.909
639.305	4.882	2015.805	7.382
658.595	3.456	2212.204	10.243
686.605	2.997	2315.204	6.215
696.095	2.995	2324.505	17.916

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 80626 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 746 Hz
(REF. 10)= 341 Hz
(BEST FIT)= 476 Hz

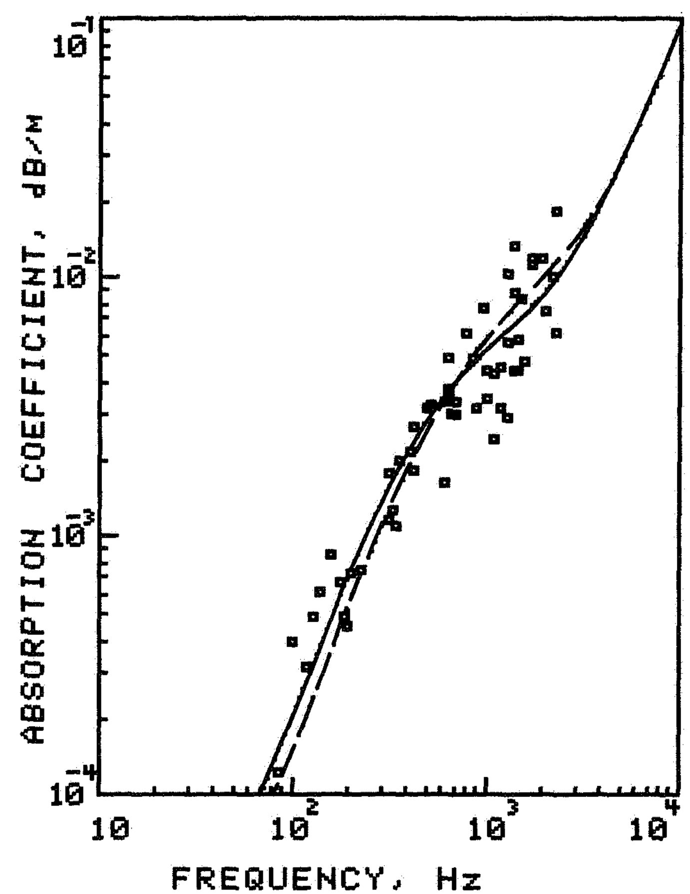


Figure A13. Sound absorption in air:

Temperature	21.8°C
Pressure	0.9458 atm
Absolute humidity	2.2223 mole percent
Relative humidity	91.2 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)
18.994	1.293	905.679	.168
28.483	1.133	915.179	-7E-03
38.178	1.171	924.67	.056
47.577	1.309	991.48	.121
57.079	.97	1000.879	.023
66.594	.877	1010.5	.057
76.186	.818	1096.199	-.12
85.687	.963	1105.8	.011
104.715	.565	1115.3	.114
114.3	.55	1191.599	.121
123.8	.689	1200.99	.148
133.325	.509	1210.699	.2
142.9	.662	1305.9	.058
152.4	.382	1315.199	-.018
161.9	.39	1496.4	-.024
171.501	.31	1505.9	-4E-03
181	.471	1515.5	.031
190.601	.25	1601.3	.124
190.6	.231	1610.9	-.178
200.009	.253	1706.199	-.045
228.701	.224	1715.699	.205
238.203	.307	1725.199	.195
314.495	.301	1715.687	.125
323.995	.129	1801.599	-.081
333.593	.091	1811.099	.064
343.089	.198	1811	-.037
400.299	.267	1811.085	.09
409.789	.286	1963.199	.019
419.399	.277	2001.4	-.032
428.902	.279	2020.5	.106
438.399	.231	2106.199	-.066
505.009	.249	2115.6	.214
524.2	.218	2125.3	-.086
591.089	0	2211.1	.166
600.778	.281	2306.3	.123
810.48	.228	2314.899	-.111
819.9	.212	2325.399	.201
829.4	-.024	2506.699	-.072
896.079	-.072	2516.199	-.03

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 172 Hz
(BEST FIT)= 29 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 16.3 Hz
(REF 10)= 12 Hz

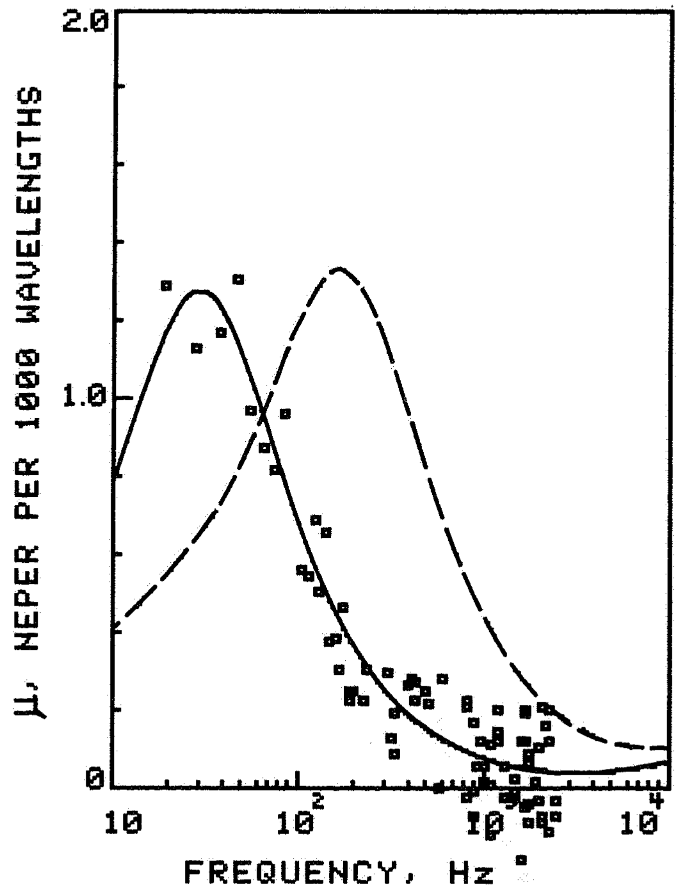


Figure A14. Sound absorption in air:

Temperature	30.3°C
Pressure	1.0138 atm
Absolute humidity	0.0194 mole percent
Relative humidity	0.451 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
38.188	.144	821.205	7.251
47.686	.164	897.705	7.798
57.287	.231	907.205	9.766
66.816	.278	916.805	6.576
76.38	.419	1002.605	8.617
85.914	.625	1012.205	6.981
105.08	.676	1098.105	9.564
114.58	.52	1107.605	7.482
124.08	1.086	1203.204	5.553
133.68	.833	1212.704	13.345
143.194	.851	1298.505	13.235
162.305	.763	1298.105	11.871
171.88	.725	1307.704	9.272
181.38	1.612	1317.204	9.067
200.481	.976	1403.105	14.993
219.528	1.452	1412.605	12.048
229.119	.976	1498.605	12.252
238.683	1.022	1508.005	17.456
305.483	1.141	1517.605	12.775
315.001	2.541	1603.505	19.311
324.605	1.35	1613.005	14.274
334.201	2.043	1698.905	21.252
391.504	4.003	1708.405	16.704
400.985	4.577	1803.905	9.458
410.484	3.695	1813.405	23.407
420.084	3.463	1994.704	11.523
429.684	5.304	2004.204	16.649
439.184	5.456	2013.905	14.103
496.415	3.796	2100.005	33.425
496.404	6.14200001	2109.204	23.435
505.904	4.681	2204.704	33.068
525.184	4.287	2214.105	24.18
601.995	9.141	2300.005	26.66
592.205	7.558	2309.404	30.266
668.505	4.611	2500.404	24.712
802.205	9.887	2509.904	16.464
811.805	9.592		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 16472 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 221 Hz
(REF. 10)= 99.2 Hz
(BEST FIT)= 282 Hz

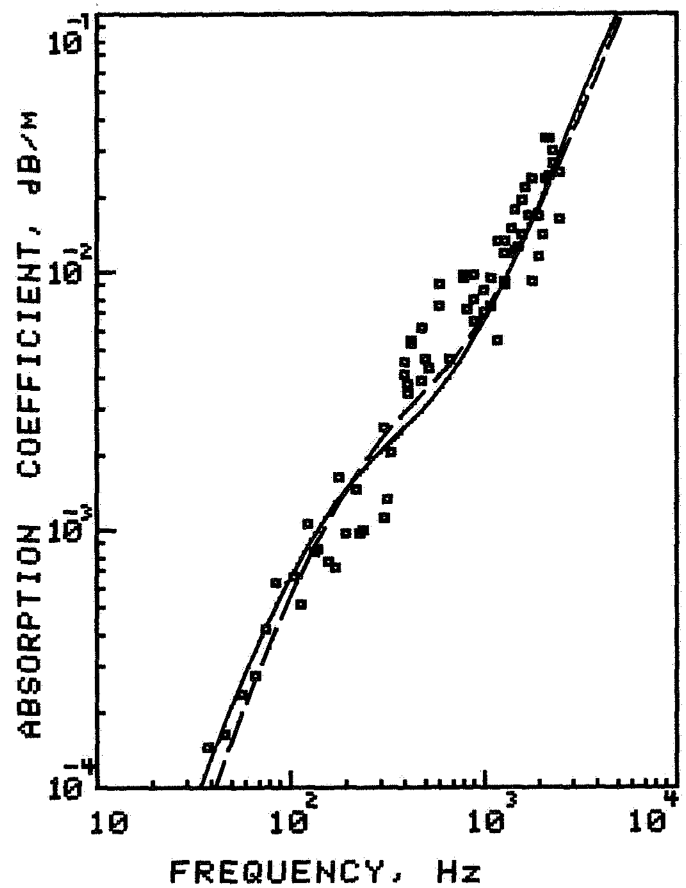


Figure A15. Sound absorption in air:

Temperature	30.3°C
Pressure	0.9934 atm
Absolute humidity	0.5789 mole percent
Relative humidity	13.7 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
47.706	.151	916.785	4.126
57.206	.319	926.285	5.298
66.805	.449	993.085	5.551
76.306	.241	1002.585	3.562
85.828	.548	1012.085	4.124
104.944	.552	1098.005	6.522
114.502	.53	1107.605	3.698
124.004	1.379	1117.204	4.995
133.615	.743	1193.605	7.512
143.105	1.043	1203.105	5.663
152.644	.879	1212.704	7.555
162.204	1.383	1308.105	5.289
171.805	1.199	1317.605	8.304
181.305	2.074	1394.005	7.043
190.904	1.188	1403.605	8.01
200.404	1.172	1413.105	13.826
219.504	1.615	1499.005	8.222
229.105	1.325	1508.505	10.672
238.605	1.362	1518.005	8.972
248.105	1.747	1604.005	7.782
257.705	1.959	1613.605	4.966
305.404	1.779	1613.614	6.131
314.985	2.253	1699.405	14.84
324.605	2.158	1709.005	15.419
334.085	2.353	1718.405	18.921
343.685	2.064	1794.805	10.107
400.904	2.619	1813.805	13.996
410.484	2.359	2024.805	12.874
420.084	2.394	2101.005	14.146
429.584	2.91	2110.605	18.303
439.184	4.285	2120.105	11.237
505.784	3.813	2206.204	17.523
525.085	4.823	2215.904	8.662
668.515	5.13	2301.805	10.764
802.285	6.805	2311.305	17.156
811.785	3.949	2321.005	20.899
907.184	5.093	2502.605	23.001

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 31505 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 360 Hz
(REF. 10)= 161 Hz
(BEST FIT)= 228 Hz

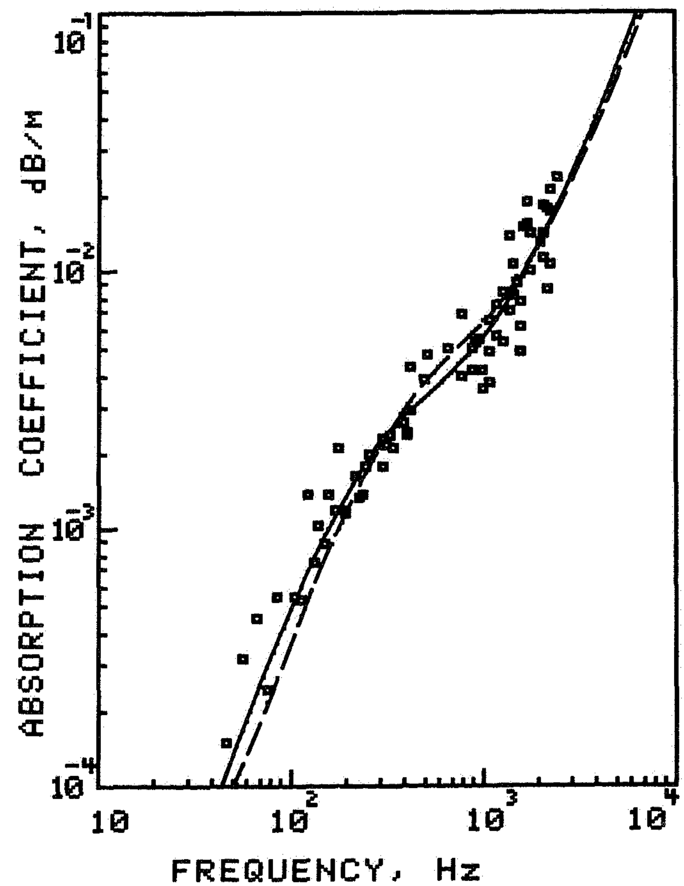


Figure A16. Sound absorption in air:

Temperature	29.8°C
Pressure	0.9744 atm
Absolute humidity	0.976 mole percent
Relative humidity	24.2 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
47.802	.148	996.914	5.212
66.941	.221	1006.505	6.105
76.418	.246	1016.105	6.763
86.104	.227	1102.305	5.143
105.204	.265	1111.905	6.216
114.804	.757	1121.605	5.677
124.405	.635	1207.805	10.001
133.98	.372	1217.305	16.276
143.504	.419	1303.704	8.766
153.105	.685	1313.204	9.934
162.68	.424	1409.005	11.225
172.28	.578	1418.605	7.423
181.78	.944	1495.305	5.837
191.394	.984	1504.905	5.419
200.985	.534	1514.405	10.59
220.185	1.137	1524.005	10.62
229.704	1.431	1600.704	12.254
239.294	.995	1610.305	9.513
248.904	1.235	1619.905	7.7
306.304	1.422	1706.005	11.098
315.904	1.519	1706.005	11.139
325.504	1.84	1715.605	14.713
335.105	2.664	1725.105	17.677
344.705	2.844	1725.095	20.659
392.605	4.339	1801.005	10.393
402.105	4.156	1801.105	6.872
411.694	4.084	1810.605	6.029
421.404	3.574	1964.005	17.112
497.984	5.859	2107.505	14.818
507.484	6.545	2203.404	20.58
526.905	4.486	2213.005	8.33
604.055	2.772	2299.105	11.532
670.905	6.179	2308.805	12.884
805.205	7.43	2318.105	22.104
814.785	6.734	2500.404	17.776
824.285	4.599	2510.005	14.345
901.105	7.334	2510.005	16.598
901.106	7.904		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 60215 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 616 Hz
(REF. 10)= 261 Hz
(BEST FIT)= 504 Hz

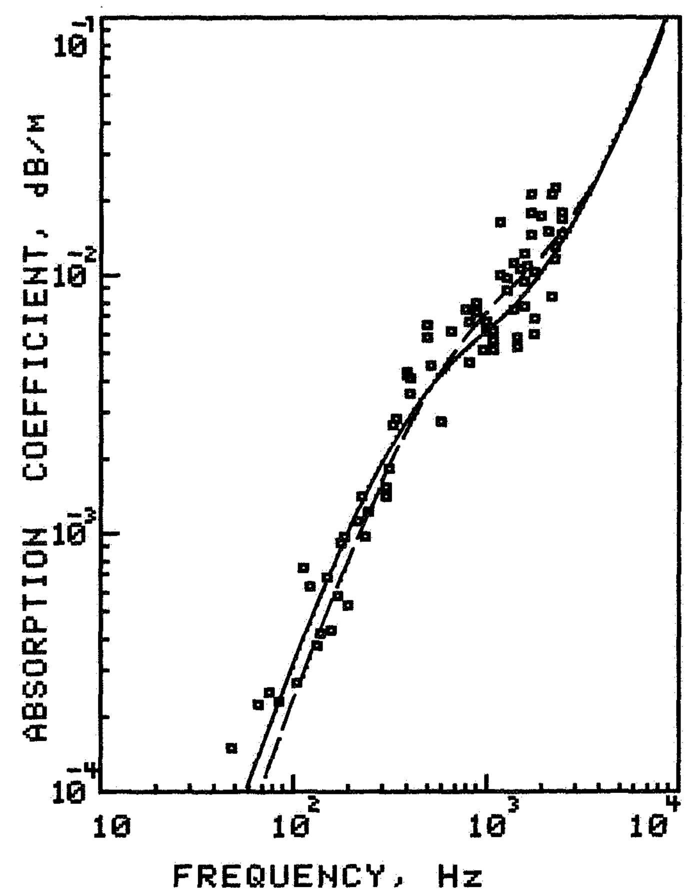


Figure A17. Sound absorption in air:

Temperature	29.8°C
Pressure	1.0179 atm
Absolute humidity	1.6153 mole percent
Relative humidity	38.3 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
86.137	.194	824.905	7.273
105.295	.246	834.485	7.093
114.905	.225	901.714	5.177
124.504	.997	911.305	3.91
143.681	.686	920.795	4.582
153.204	.359	997.414	5.761
162.805	.656	1016.705	3.746
172.396	.517	1102.914	3.848
181.985	1.206	1112.505	3.649
191.603	.64	1208.405	6.51
201.105	.558	1218.005	13.452
220.406	1.36	1303.505	7.748
230.004	.754	1313.105	5.407
239.504	.792	1418.514	14.056
249.105	1.454	1428.105	14.257
316.205	2.208	1514.305	11.988
325.804	1.263	1600.605	16.884
335.396	2.325	1610.105	6.212
345.004	1.793	1705.905	16.311
402.534	2.965	1715.605	11.76
412.094	2.78	1801.805	11.236
421.797	2.811	1811.405	10.027
431.394	3.919	2012.704	14.834
507.908	5.867	2098.904	8.247
527.308	4.267	2108.404	18.195
536.894	7.071	2204.204	18.087
671.415	6.916	2309.704	13.464
805.815	10.337	2319.005	17.89
815.415	5.771	2510.704	15.88

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 74838 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 741 Hz
(REF. 10)= 315 Hz
(BEST FIT)= 597 Hz

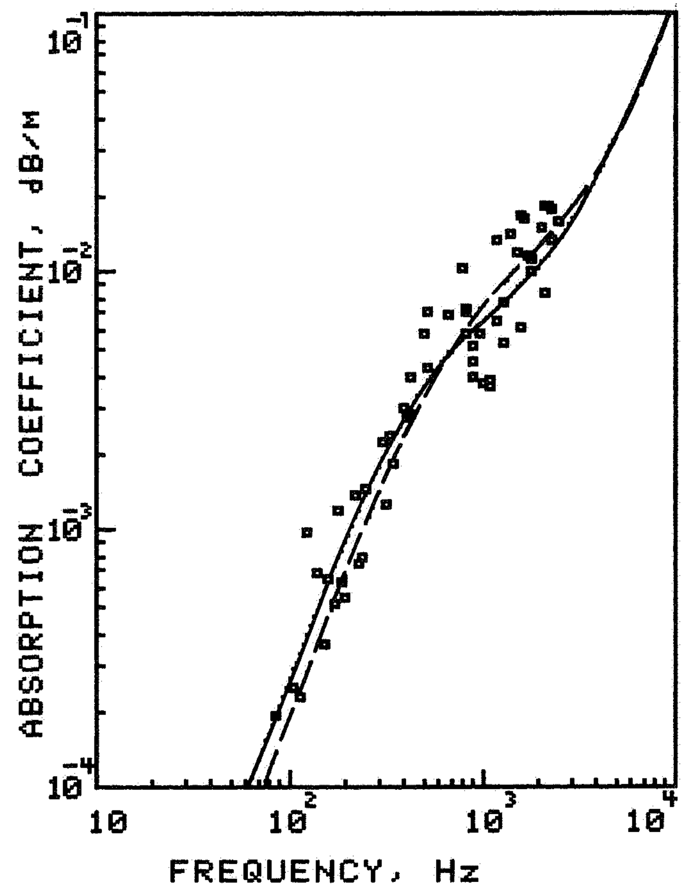


Figure A18. Sound absorption in air:

Temperature	30.2°C
Pressure	1.0091 atm
Absolute humidity	1.9655 mole percent
Relative humidity	46 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
86.205	.479	901.514	3.838
114.985	.461	911.205	3.053
124.477	.74	920.705	13.105
134.095	1.087	930.315	3.655
143.691	.756	1102.815	5.543
153.204	.534	1112.414	4.402
162.785	.659	1121.905	4.285
172.485	.372	1208.315	4.369
182.014	.707	1217.905	8.778
191.625	.644	1294.605	12.05
201.185	.669	1304.105	7.527
220.384	1.441	1313.715	7.121
229.985	.997	1400.005	17.925
239.508	1.001	1409.605	15.398
249.085	.749	1418.905	20.375
316.208	1.632	1505.405	9.096
325.808	2.162	1514.914	10.073
335.404	1.981	1601.305	10.799
345.004	1.111	1610.914	13.437
402.504	2.919	1706.704	9.828
412.014	2.209	1716.305	13.105
421.708	2.493	2012.805	12.963
507.794	5.501	2108.704	13.573
527.095	5.623	2204.704	17.311
536.905	6.252	2214.404	10.32
671.215	2.919	2310.404	18.69
805.634	13.461	2319.904	21.06
815.215	7.83	2511.904	19.815
824.714	6.309		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 85569 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 833 Hz
(REF. 10)= 353 Hz
(BEST FIT)= 588 Hz

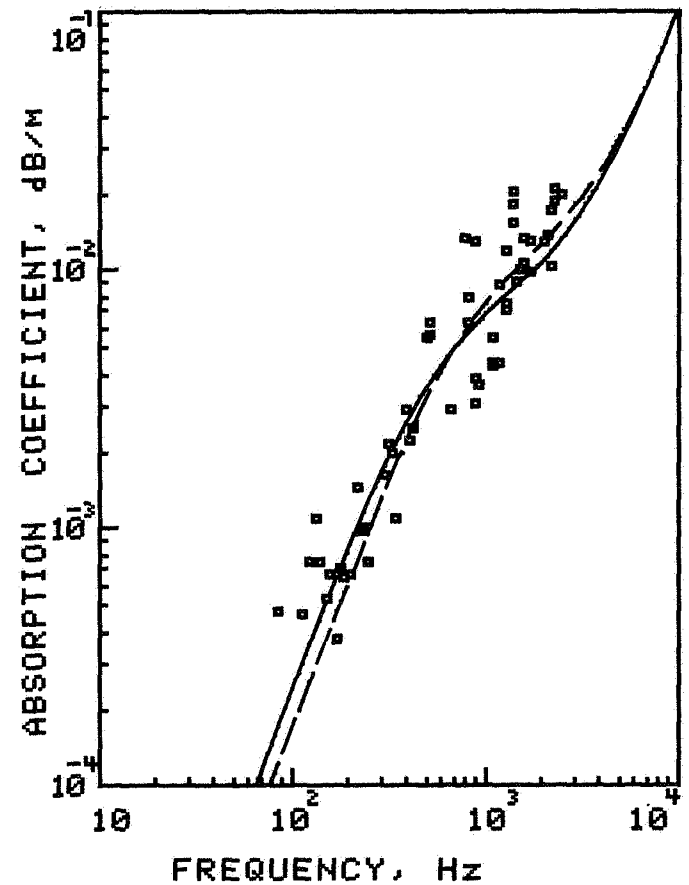


Figure A19. Sound absorption in air:

Temperature	30°C
Pressure	1.0118 atm
Absolute humidity	2.2067 mole percent
Relative humidity	52.1 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
86.28	.081	990.605	11.3
105.481	.288	1000.305	5.811
114.994	.297	1010.005	7.851
124.681	.359	1096.605	5.447
143.881	.572	1106.305	8.815
163.082	.685	1115.605	10.568
172.681	.802	1192.905	6.442
182.281	.678	1202.704	9.805
191.895	.755	1212.204	13.817
201.469	.988	1298.905	11.117
220.783	.925	1308.505	14.227
230.383	.915	1318.204	5.303
239.983	.94	1385.505	15.467
249.583	.944	1395.204	8.19
307.083	1.547	1404.805	8.778
316.783	2.338	1414.605	9.225
326.385	1.623	1491.505	10.353
336.091	2.175	1501.204	10.459
345.692	2.26	1510.704	5.752
403.383	3.892	1607.204	7.791
412.983	2.813	1616.704	12.889
422.583	2.195	1693.805	15.211
432.337	4.764	1703.505	13.385
499.384	5.078	1722.704	10.049
508.915	3.911	1809.405	13.43
528.384	4.727	1818.995	11.654
595.886	4.764	2002.005	9.874
605.795	4.853	2107.805	12.992
672.884	7.36	2117.404	10.118
894.285	8.443	2204.204	18.072
904.005	6.136	2213.704	13.256
913.605	4.464	2318.805	19.611
923.305	5.277	2511.305	15.739
981.105	5.943		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 114779 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 1081 Hz
(REF. 10)= 458 Hz
(BEST FIT)= 687 Hz

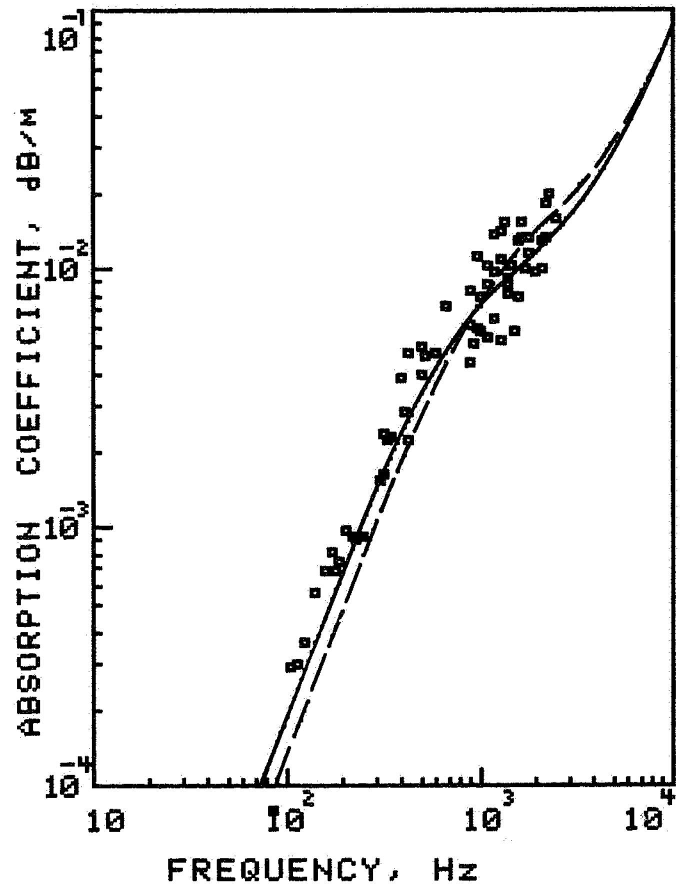


Figure A20. Sound absorption in air:

Temperature	30.7°C
Pressure	1.0084 atm
Absolute humidity	2.8806 mole percent
Relative humidity	65.5 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)
38.71	1.172	825.2	.384
48.416	1.3	903.599	.254
58.112	1.496	913.299	.297
67.775	1.363	1000.799	.23
77.5	1.355	1010.5	.327
87.203	1.546	1020.299	.332
106.676	1.361	1078.599	.242
116.28	1.476	1088.3	.206
126.077	1.434	1098	.303
135.78	1.141	1107.699	.23
145.399	1.39	1195.199	.338
155.09	1.116	1204.9	.249
164.79	1.244	1292.5	.332
174.498	1.021	1302.199	.461
184.3	.88	1311.9	.232
193.99	.972	1399.3	.289
203.6	1.101	1409.099	.395
213.3	.956	1506.3	-.029
223	.981	1515.9	.176
310.31	.559	1603.5	.385
320.1	.724	1613.199	.172
320.101	.765	1700.699	.297
329.799	.55	1710.4	.102
339.5	.826	1817.3	.226
397.799	.725	1827	-2E-03
407.41	.69	1826.99	.129
504.47	.614	2002.3	-.086
514.079	.559	2021.8	.052
523.779	.732	2099.399	.065
533.679	.564	2109.3	.118
601.789	.434	2118.8	-.035
611.789	.628	2206.399	-.026
689.079	.321	2216.1	.274
698.889	.377	2410.8	-.025
708.599	.65	2508	.087
815.5	.306	2517.899	-3E-03

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 231 Hz
(BEST FIT)= 84 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 18.8 Hz
(REF 10)= 13.2 Hz

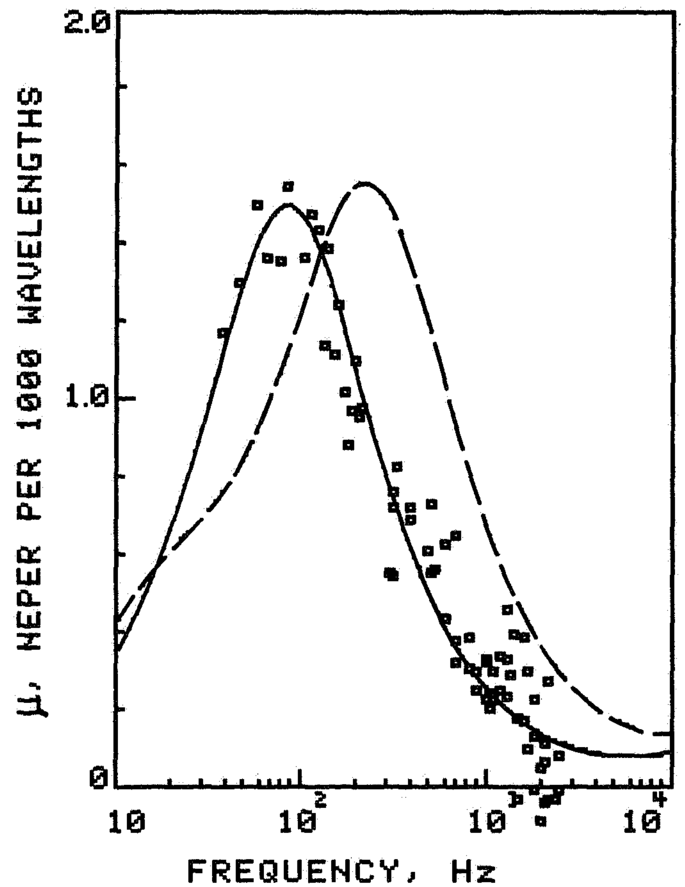


Figure A21. Sound absorption in air:

Temperature	39.6°C
Pressure	1.0077 atm
Absolute humidity	0.0256 mole percent
Relative humidity	0.356 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
48.479	.287	662.408	4.168
58.18	.213	672.105	4.274
67.88	.296	681.825	4.83
77.516	.352	701.305	4.378
87.306	.936	701.305	4.375
106.804	1.085	711.009	9.863
116.487	.745	837.705	6.558
126.204	1.057	847.405	10.046
136.004	.708	905.905	4.444
145.704	1.657	915.815	6.561
155.404	1.144	925.514	7.361
165.204	1.401	1003.405	9.286
174.905	1.232	1013.105	10.631
184.628	1.081	1023.005	11.297
194.404	1	1061.905	13.947
204.115	1.822	1071.704	10.45
213.898	1.451	1081.405	12.178
223.605	1.339	1198.505	10.6
243.118	1.971	1208.204	16.875
301.506	3.257	1295.905	16.796
311.291	1.87	1305.605	14.776
321.004	2.536	1393.405	17.923
340.498	4.009	1403.105	20.776
350.294	3.368	1500.005	19.124
398.995	5.501	1617.605	14.907
408.815	5.88	1705.305	10.853
418.504	5.243	1715.105	13.929
428.304	4.124	1812.505	40.033
438.004	5.593	1822.405	15.054
496.404	4.671	2007.505	16.834
506.105	4.573	2017.505	29.617
515.815	5.896	2105.105	32.033
525.605	6.542	2114.805	20.282
594.005	4.361	2212.404	19.892
603.985	7.612	2514.305	29.144

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 20277 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 271 Hz
(REF. 10)= 118 Hz
(BEST FIT)= 297 Hz

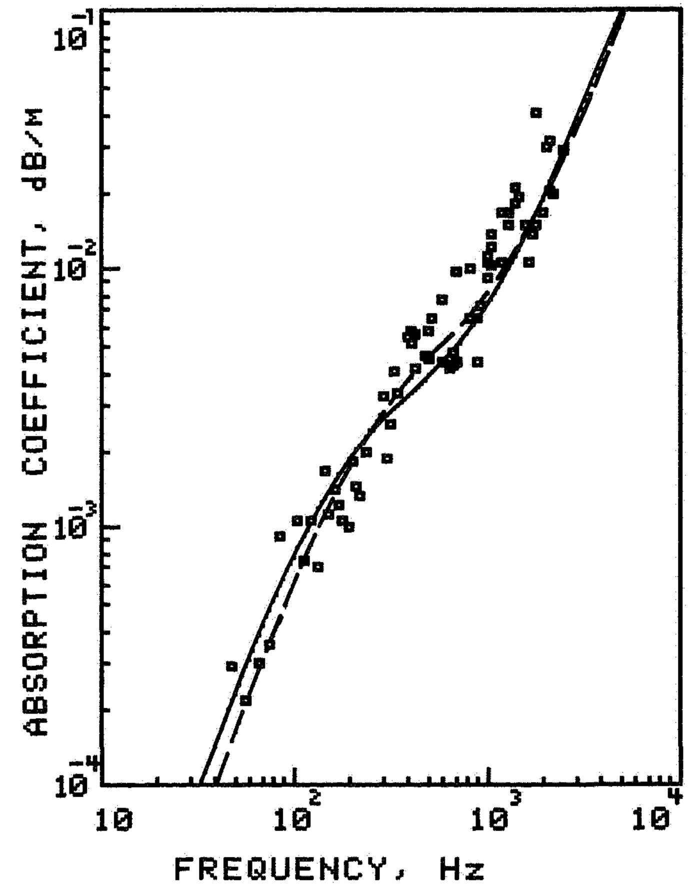


Figure A22. Sound absorption in air:

Temperature	39.6°C
Pressure	1.007 atm
Absolute humidity	0.6715 mole percent
Relative humidity	9.4 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
67.803	.28	828.305	6.838
77.476	.308	838.005	8.825
87.305	.533	906.205	5.223
106.68	.639	915.905	5.844
116.405	.423	993.914	5.909
126.104	1.187	1003.605	7.383
135.845	.673	1013.405	9.416
145.605	1.592	1091.305	10.273
155.305	.745	1101.005	4.377
164.985	.809	1110.704	8.115
174.78	1.026	1198.405	7.054
174.781	1.049	1208.105	11.042
184.595	1.207	1295.704	15.633
194.305	.873	1305.505	11.755
204.004	1.406	1315.105	14.479
213.724	1.492	1285.805	8.361
223.504	1.539	1401.22	11.606
243.004	2.185	1411.005	11.675
320.875	2.762	1498.405	10.549
330.685	2.25	1508.204	5.584
340.384	3.626	1605.405	16.698
350.185	2.444	1615.105	6.803
398.985	4.28	1624.704	13.395
408.685	5.538	1702.305	6.541
418.384	4.675	1712.005	11.583
428.184	4.039	1809.204	15.929
496.484	5.753	1818.905	16.02
506.184	5.942	1828.405	9.082
515.785	5.441	2003.605	15.818
525.585	7.094	2013.405	5.989
603.884	6.681	2023.005	24.034
613.884	6.15	2100.704	13.992
662.384	3.935	2110.505	11.481
672.285	5.076	2120.105	21.052
681.985	7.192	2207.305	10.992
701.405	4.111	2216.904	29.276
701.405	4.108	2401.805	11.534
711.205	8.307	2411.305	25.106
721.005	11.804	2508.505	28.378
818.605	13.532	2518.204	16.787

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 41917 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 478 Hz
(REF. 10)= 203 Hz
(BEST FIT)= 385 Hz

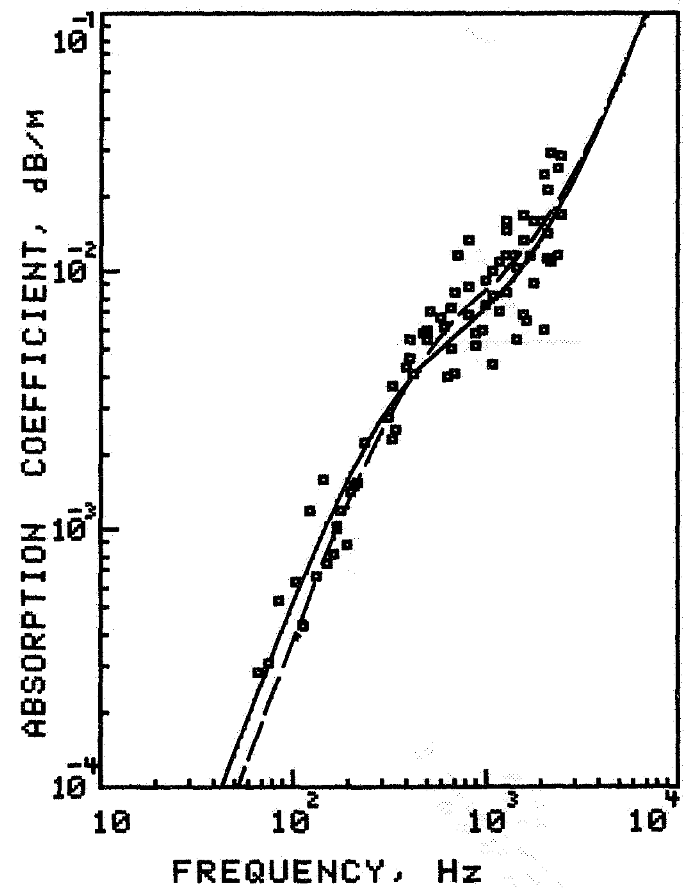


Figure A23. Sound absorption in air:

Temperature	39.6°C
Pressure	1.0132 atm
Absolute humidity	1.1944 mole percent
Relative humidity	16.5 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
68.127	.122	535.684	6.116
68.127	.1	594.205	5.317
68.129	.108	614.005	7.701
87.604	.571	701.505	6.421
107.081	.317	701.505	6.417
116.78	.35	711.305	7.947
126.581	.485	818.605	9.204
146.004	.647	906.305	8.955
155.768	.513	916.105	5.093
165.491	.648	1003.705	6.685
175.281	.607	1013.505	9.647
175.281	.57	1081.704	4.906
184.995	.763	1101.204	6.01
194.781	.55	1110.905	4.739
204.481	1.817	1098.704	11.798
214.183	.918	1208.505	4.94
223.883	.839	1218.204	13.335
243.388	1.56	1296.204	7.35
301.896	1.36	1305.905	15.726
311.583	1.577	1413.204	9.971
321.383	2.919	1608.005	6.348
331.085	2.581	1617.805	7.417
331.085	2.218	1715.204	13.941
340.784	2.905	2005.905	16.396
350.594	2.402	2015.704	7.323
399.274	4.07	2025.305	7.194
409.004	4.864	2103.204	18.747
418.684	5.175	2113.005	22.629
428.525	3.968	2122.605	14.886
496.775	5.225	2210.305	8.594
506.384	6.182	2220.005	8.626
515.985	5.993	2512.404	12.493
525.785	6.483	2522.204	16.725

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 66605 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 703 Hz
(REF. 10)= 300 Hz
(BEST FIT)= 566 Hz

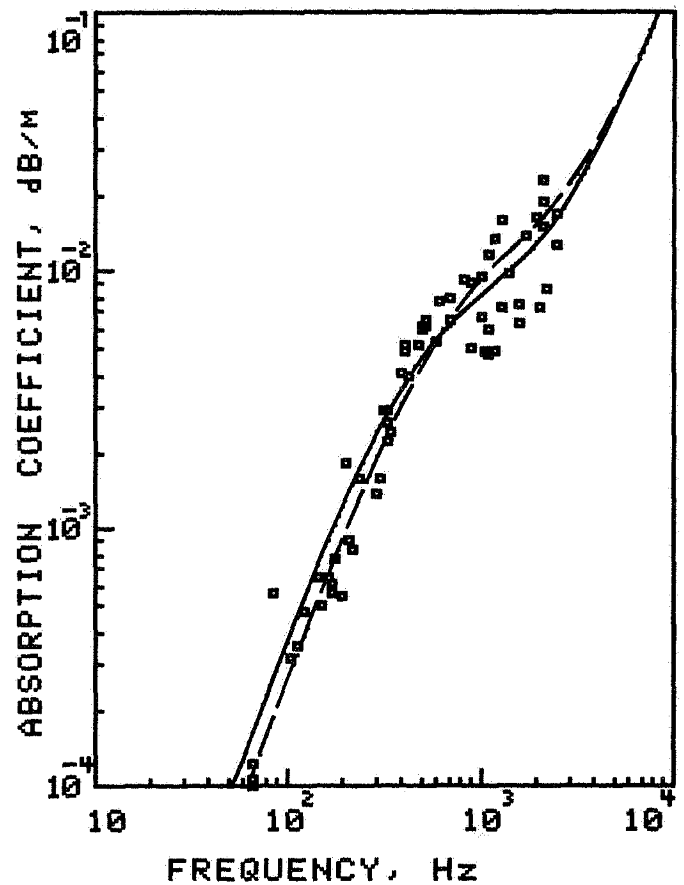


Figure A24. Sound absorption in air:

Temperature	39.2°C
Pressure	0.9989 atm
Absolute humidity	1.7913 mole percent
Relative humidity	25.7 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
87.704	.378	722.835	12.16
107.285	.454	820.755	6.15
126.806	.72	830.514	10.138
146.322	1.194	840.315	10.633
156.006	.39	909.714	11.522
165.806	.858	1007.705	9.861
175.606	.723	1017.764	6.63
175.606	.686	1066.605	6.055
185.404	.83	1076.514	9.305
195.111	.451	1106.105	11.641
204.901	.875	1115.905	9.121
214.625	.662	1194.505	11.631
224.415	1.238	1204.204	13.944
243.935	1.3	1214.005	14.354
322.024	2.03	1292.414	19.958
331.824	1.536	1302.105	13.45
331.824	1.173	1311.805	13.579
341.605	3.676	1400.005	13.129
351.404	2.26	1409.505	19.214
400.205	4.288	1497.715	14.582
409.915	4.392	1507.405	10.165
419.684	5.015	1605.204	20.682
507.402	4.741	1614.985	9.814
517.095	5.377	1624.805	11.887
526.915	4.773	1702.905	15.839
536.915	5.613	1712.815	7.761
605.515	8.375	2025.905	9.088
615.495	9.453	2104.005	12.263
674.005	6.709	2113.704	22.18
683.695	7.078	2524.605	16.436
713.005	8.085		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 95264 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 962 Hz
(REF. 10)= 402 Hz
(BEST FIT)= 692 Hz

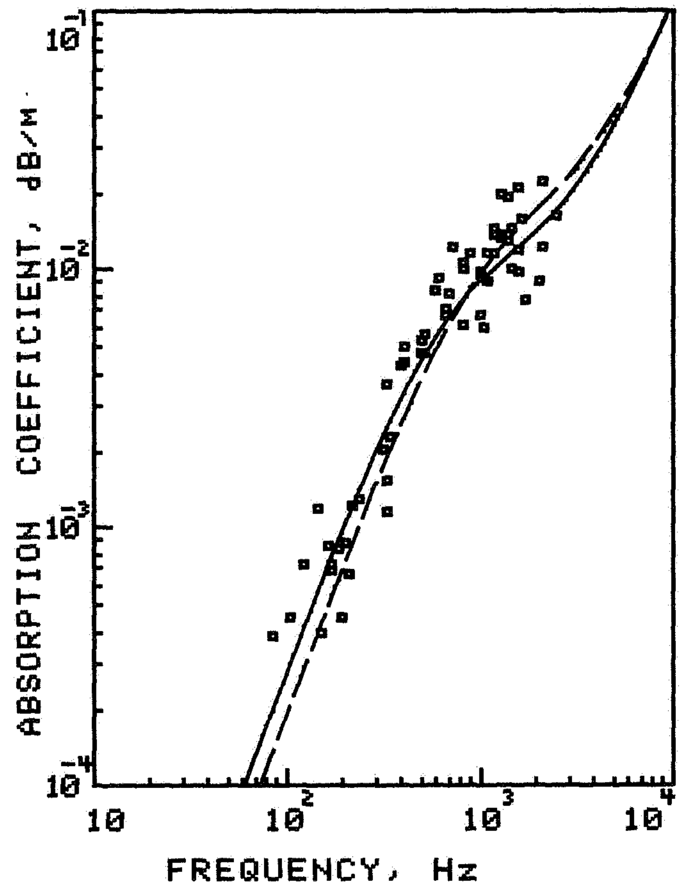


Figure A25. Sound absorption in air:

Temperature	40°C
Pressure	1.0132 atm
Absolute humidity	2.4251 mole percent
Relative humidity	32.9 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
117.009	.628	890.305	8.958
126.805	.739	900.105	7.382
136.605	.664	909.905	11.835
175.704	1.044	920.305	12.226
175.704	1.007	998.605	8.385
185.404	.98	1008.505	9.847
195.305	.817	1018.305	6.777
204.994	1.686	1067.405	14.491
214.805	1.014	1077.204	11.988
224.504	1.154	1087.005	8.079
244.024	2.062	1106.605	10.853
302.605	2.311	1116.405	10.826
312.504	1.248	1195.005	17.573
322.205	2.348	1283.204	16.76
332.014	1.778	1293.105	16.586
332.014	1.414	1302.905	16.278
341.804	3.441	1312.805	16.671
400.504	3.969	1391.315	31.178
410.304	3.873	1401.204	17.281
420.054	5.262	1411.005	17.252
420.605	5.137	1489.505	16.056
429.904	3.734	1499.305	20.474
439.605	4.985	1509.105	17.096
508.105	3.082	1518.905	20.927
517.905	4.266	1705.405	20.681
527.705	3.757	1715.105	21.906
537.505	5.997	1813.505	26.4
596.205	8.576	1823.305	27.378
606.005	3.488	2010.905	28.839
664.705	3.747	2108.005	22.903
674.505	8.643	2117.904	21.982
703.905	10.8	2206.005	32.217
703.905	10.797	2215.904	13.675
694.205	4.893	2510.805	14.299

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 138987 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 1351 Hz
(REF. 10)= 563 Hz
(BEST FIT)= 800 Hz

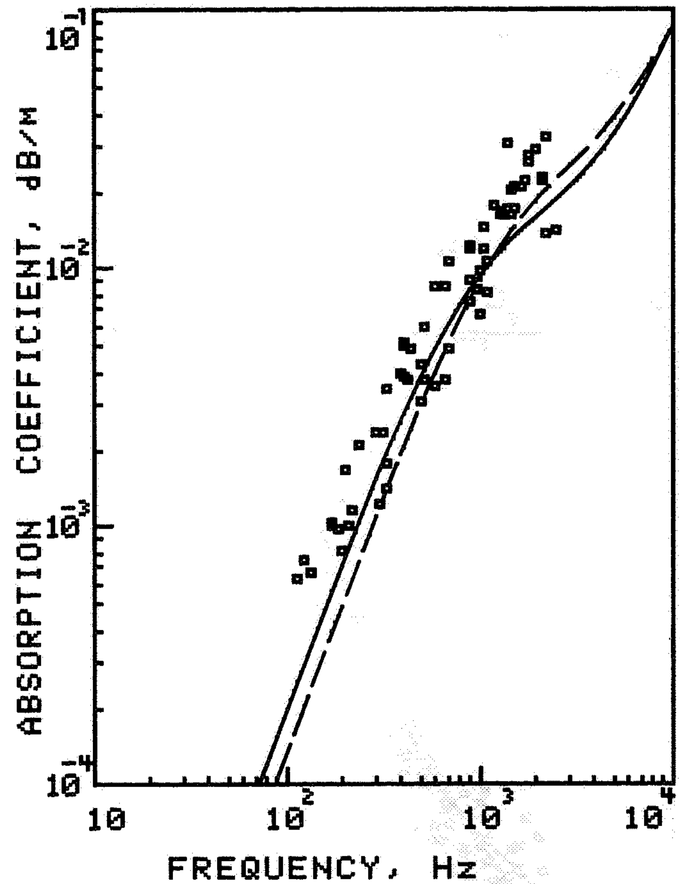


Figure A26. Sound absorption in air:

Temperature	39.4°C
Pressure	1.0125 atm
Absolute humidity	3.4181 mole percent
Relative humidity	47.9 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (NP/1000WL)
29.576	1.128	680.5	.499
29.576	1.095	690.299	.645
39.377	.956	700.099	.736
59.1	1.295	709.98	.501
68.976	1.838	828.48	.873
78.784	1.888	838.299	.59
88.664	1.945	848.2	.532
98.578	2.006	858.099	.449
108.377	1.863	907.4	.416
118.18	1.969	917.299	.39
138.002	1.843	927.299	.529
147.86	1.794	937.2	.539
157.68	1.796	996.4	.595
167.59	1.839	1006.2	.385
177.389	1.65	1016.099	.443
187.219	1.582	1026	.373
197.189	1.536	1095.199	.579
206.989	1.635	1105.099	.335
216.8	1.457	1115.099	.213
226.699	1.444	1115.101	.411
236.58	1.338	1194.199	.591
246.378	1.507	1204.099	.509
315.301	1.124	1214	.679
325.2	1.288	1303.099	.629
325.2	1.229	1313.099	.315
335.101	1.228	1392.3	.453
344.99	1.042	1412.4	.399
394.399	1.095	1491.5	.506
404.089	1.193	1501.4	.172
413.899	1.123	1649.9	.29
423.789	1.058	1659.8	.263
433.689	1.168	1709.4	.407
492.879	.973	1719.3	.2
502.779	1.103	1729.4	.315
512.5	1.08	1808.599	.215
522.299	1.016	1818.5	.363
532.099	.933	2006.699	.095
601.4	.758	2016.5	.142
611.379	.975	2204.399	-.015
660.599	.856	2214.5	.27
670.599	.814		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 316 Hz
(BEST FIT)= 131 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 22.4 Hz
(REF 10)= 14.6 Hz

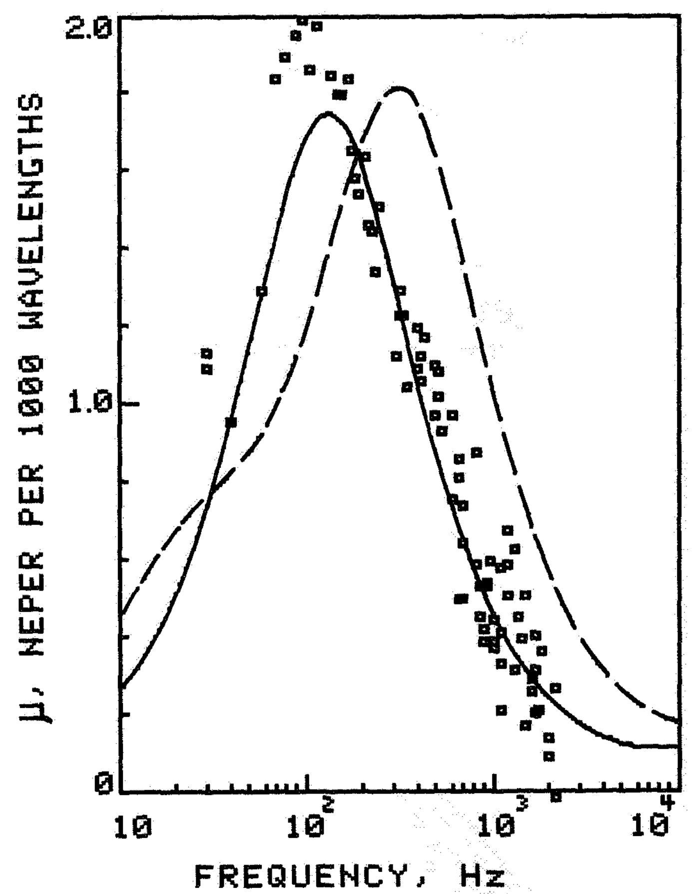


Figure A27. Sound absorption in air:

Temperature	49.2°C
Pressure	1.0111 atm
Absolute humidity	0.0332 mole percent
Relative humidity	0.282 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
39.398	.283	840.405	12.251
59.2	.351	850.315	10.315
69.099	.416	860.277	9.471
78.822	1.276	899.905	13.085
88.9	1.243	909.815	10.05
88.9	1.064	919.714	8.69
98.8	1.077	929.585	13.049
39.479	.331	988.989	13.363
98.803	1.162	998.785	16.229
108.68	1.315	1008.705	14.036
118.479	1.368	1018.605	11.43
128.487	1.977	1058.204	12.548
138.388	1.522	1068.085	14.736
148.287	2.402	1097.905	13.973
158.187	1.179	1107.704	10.591
168.004	2.017	1117.605	10.772
178.004	1.68	1186.805	18.689
187.89	2.263	1196.805	10.976
197.89	1.449	1206.704	14.426
207.69	2.076	1285.805	20.429
217.52	2.405	1295.704	13.821
227.476	3.151	1305.605	22.848
237.399	2.189	1315.405	17.379
247.217	3.58	1394.605	17.631
257.092	2.252	1404.505	27.277
306.516	4.976	1493.704	24.503
316.383	3.064	1503.405	18.236
326.284	3.696	1513.305	21.628
336.283	4.52	1652.005	13.075
346.106	5.558	1661.805	22.287
356.006	5.499	1711.105	24.157
395.585	4.817	1721.005	22.115
405.384	6.422	1809.992	19.857
415.286	7.246	1819.905	29.781
425.186	7.356	1829.905	24.048
494.486	10.443	1998.204	29.746
504.297	8.621	2007.905	23.305
533.797	8.83	2017.905	24.063
662.495	9.305	2006.905	34.649
672.497	12.68	2205.805	28.624
682.305	6.246	2493.005	31.502
711.915	9.755	2512.605	48.136

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 24809 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 331 Hz
(REF. 10)= 140 Hz
(BEST FIT)= 304 Hz

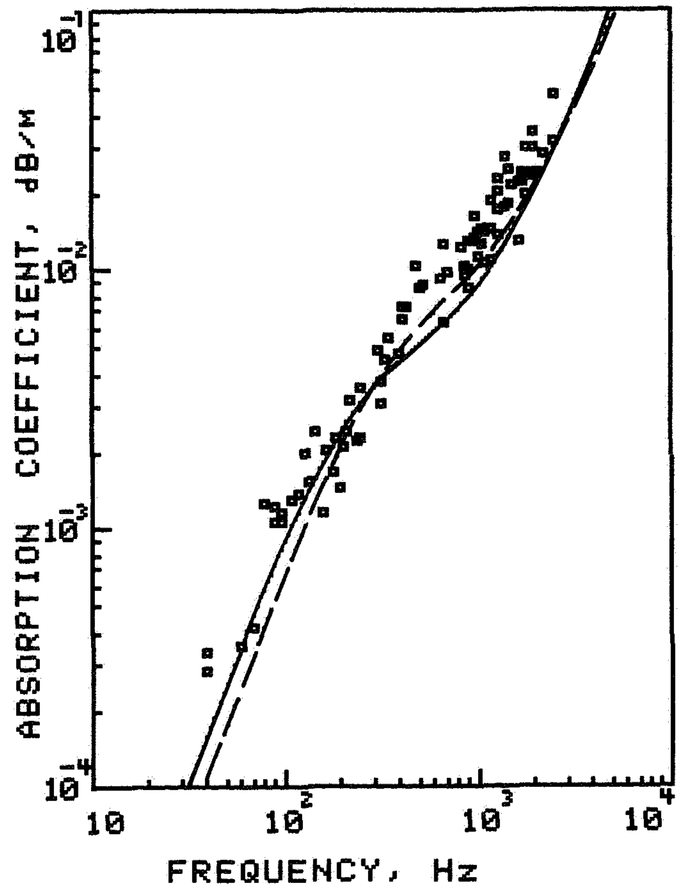


Figure A28. Sound absorption in air:

Temperature	50.2°C
Pressure	1.0234 atm
Absolute humidity	0.7758 mole percent
Relative humidity	6.2 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
39.604	.098	674.105	11.577
49.505	.177	713.705	8.842
59.401	.242	842.714	14.622
89.205	.596	852.514	9.858
89.205	.416	901.714	13.608
99.03	.572	911.514	7.321
108.982	.645	990.705	14.338
118.819	.646	1000.505	12.3
128.782	1.429	1010.505	12.841
138.682	.55	1020.405	9.802
148.585	1.307	1099.815	14.938
158.485	.716	1109.605	11.513
168.384	1.053	1119.605	10.196
178.295	.896	1198.905	19.51
188.185	1.281	1208.905	21.59
207.894	.888	1218.805	20.727
217.805	1.241	1298.105	8.981
227.785	1.597	1308.105	17.518
237.785	1.081	1318.105	11.836
247.574	2.679	1407.505	26.251
257.504	1.312	1417.405	18.243
306.985	4.552	1705.204	24.604
316.884	2.934	1715.204	13.818
326.804	3.822	1725.204	21.188
336.804	3.899	1804.805	22.998
346.705	4.833	1814.905	19.234
396.404	5.187	1824.704	23.075
406.205	5.207	1993.805	17.113
416.105	6.221	2003.905	30.947
425.995	7.297	1994.005	14.421
435.904	7.477	2202.204	31.936
495.504	6.615	2212.305	29.524
505.304	9.176	2222.204	20.413
515.105	8.834	2222.195	12.657
525.005	9.095	2510.505	18.741
534.905	7.761	2520.305	23.366
604.505	10.482	2520.295	37.109
664.105	11.941		

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 81197 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 874 Hz
(REF. 10)= 366 Hz
(BEST FIT)= 589 Hz

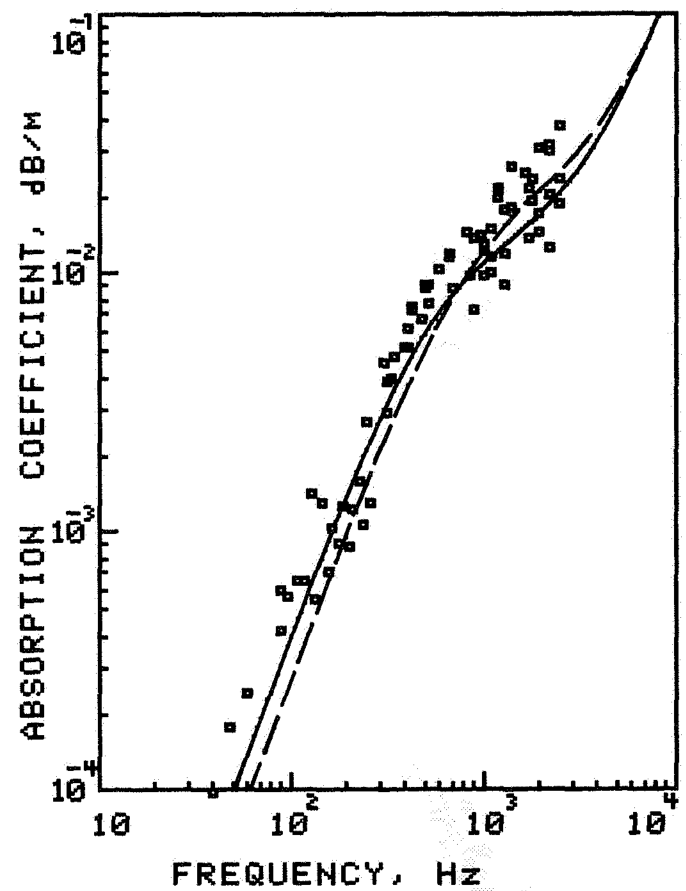


Figure A29. Sound absorption in air:

Temperature	49.8°C
Pressure	1.007 atm
Absolute humidity	2.1155 mole percent
Relative humidity	17.4 percent

FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)	FREQUENCY (Hz)	MEASURED SOUND ABSORPTION (dB/1000m)
89.704	.557	857.205	6.184
89.704	.376	907.005	8.959
109.635	.378	926.805	13.938
109.638	.368	996.605	13.277
129.605	.731	1006.505	11.376
149.49	.695	1016.505	12.55
159.404	.706	1026.405	9.018
169.404	.451	1096.005	13.5
189.305	.372	1106.005	9.435
229.105	.902	1115.905	6.822
248.994	1.208	1195.704	15.966
308.745	2.179	1205.605	14.497
318.705	1.516	1215.605	20.098
328.705	1.759	1295.305	15.199
338.705	1.49	1305.305	19.051
348.705	2.436	1315.405	16.242
358.705	2.604	1415.005	18.454
398.705	3.222	1504.805	15.809
408.544	3.323	1514.704	19.146
418.495	4.133	1706.605	31.212
428.404	5.015	1706.614	24.107
438.504	4.746	1716.704	12.54
608.105	6.711	1806.605	24.648
657.905	8.633	1816.505	33.793
667.905	7.021	1826.605	19.315
687.905	9.703	2006.605	14.515
837.405	11.664	2016.505	26.67
847.205	11.713	2205.904	18.719

RELAXATION FREQUENCY OF OXYGEN (ANSI)= 137129 Hz

RELAXATION FREQUENCY OF NITROGEN (ANSI)= 1397 Hz
(REF. 10)= 580 Hz
(BEST FIT)= 931 Hz

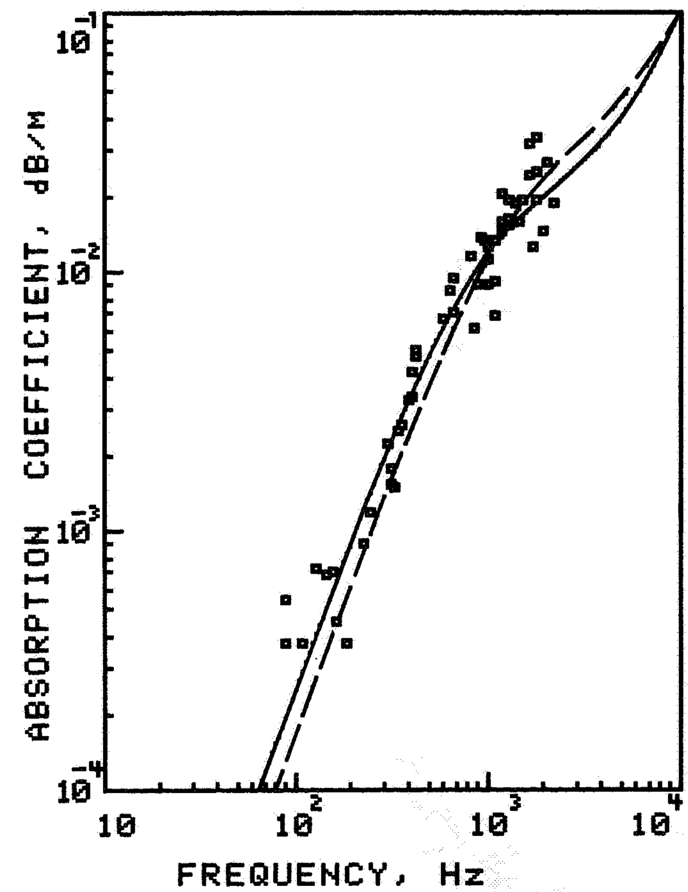


Figure A30. Sound absorption in air:

Temperature	49.1°C
Pressure	1.0091 atm
Absolute humidity	3.3865 mole percent
Relative humidity	28.8 percent

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16. Abstract
Thirty sets of sound absorption measurements in air at a pressure of 1 atmosphere are presented at temperatures from 10°C to 50°C, relative humidities from 0 to 100 percent, and frequencies from 10 to 2500 Hz. The measurements were conducted by the method of free decay in a resonant tube having a length of 18.261 m and bore diameter of 0.152 m. Background measurements in a gas consisting of 89.5 percent N_2 and 10.5 percent Ar, a mixture which has the same sound velocity as air, permitted the wall and structural losses of the tube to be separated from the "constituent" absorption, consisting of classical-rotational and vibrational absorption, in the air samples. The data were used to evaluate the vibrational relaxation frequencies of N_2 and/or O_2 for each of the 30 sets of meteorological parameters. Over the full range of humidity, the measured relaxation frequencies of N_2 in air lie between those specified by ANSI Standard S1.26-1978 and those measured earlier in binary N_2-H_2O mixtures. The measured relaxation frequencies of O_2, which could be determined only at very low values of humidity, reveal a significant trend away from the ANSI standard, in agreement with a prior investigation.

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