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Measurements of Sound Absorption in Aqueous Salt Solutions by a Resonator Method*

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This paper presents the results of measurements of the sound absorption in aqueous solutions of several salts. While magnesium sulfate is the salt of primary interest in this case, some results for sea water at different temperatures, solutions of magnesium acetate, zinc sulfate, and beryllium sulfate are given. The frequency range of the measurements is approximately 50 to 500 kc. Although the resonator method used is not very precise, it is the only known laboratory method which is able to give reliable absorption measurements in water and water solutions in this low-frequency range where the sound absorption in these liquids is extremely small.

EXPERIMENTAL METHOD AND APPARATUS

THE reverberation technique for measuring sound absorption in liquids has been used and described by others, such as Mulders,[1] Moen,[2] and Tamm and Kurze.[3] As used here, the method differs in several aspects, the most important of which is the use of single resonant modes of the spherical resonator in the 30-kc–100-kc range. Tamm and Kurze[3] have recently reported their use of this technique in the 5-kc–30-kc range.

A small piezoelectric crystal transducer attached to the wall of a liquid-filled spherical resonator is used to excite one of the natural modes of the resonator until the sound intensity reaches a sufficiently high level. The transducer is then switched from the exciting amplifier to a receiving amplifier. The sound energy level in the resonator now decays exponentially at a rate determined by the energy losses in the system. A high-speed power level recorder which plots the logarithm of the decaying receiver output voltage against time, yields a straight line decay curve, the slope of which is easily measured. If the losses of sound energy at the walls and supports of the resonator are negligible, the decrease in sound level results only from the absorption of the sound in the contained liquid, and, thus, this decay rate is a measure of the sound absorption coefficient for the liquid. The decay rate, in decibels per second, divided by the sound velocity yields the plane wave absorption coefficient, in decibels per unit of distance.

In practice, for the case of pure water which has a very small absorption coefficient, the loss due to propagation of sound in the walls is not negligibly small. Energy losses also result from shearing motion at the boundary if the excited mode of vibration has particle velocity components which are tangential to the walls; this is reduced by the use of nearly spherically symmetric or radial modes of vibration in which the motion of the fluid is always normal to the resonator wall. A theoretical calculation shows that a family of these modes exists with a frequency spacing of about 5.1 kilocycles per second for the case of the 12-liter water-filled resonator. Experiment checks this spacing rather well at the lower frequencies.

Because of the high mode density in these resonators at the frequencies used, it is practically impossible to locate the desired spherically symmetric modes on the basis of frequency alone. Thus, only the lowest decay rates in each small frequency interval were used.

INSTRUMENTATION

A stable, variable frequency oscillator provides a source of signals which, after amplification, are applied through a relay operated double throw switch to the transducers attached to the resonator wall. With the switch in its second, or rest position, the transducers are connected to a high input impedance amplifier which serves as an input circuit for a model RAK-7 communications-type receiver. The audible output signal from this receiver is then recorded as a function of time by a high-speed power level recorder. Various changes in electrical connections found to be necessary (to avoid receiver overload, for example) are synchronized by a suitable arrangement of switches and relays. The resulting recordings on waxed paper tape are then placed in a slope reading device which enables direct reading of the sound level decay rate in decibels per second.

About 50 decibels of the sound level decay is also observable on the screen of a cathode-ray oscilloscope. The signal is passed through a logarithmic amplifier and rectifier, and the dc voltage from this device is displayed against a linear time base on a cathode-ray tube. The use of an attenuator in the log-amplifier input circuit and timing markers enables the calibration of this system. The visible display is helpful in locating resonant modes which have lowest decay rates; the high-speed level recorder is then used to give a more precise measurement of the decay rates.

RESONATORS

Round bottom Pyrex boiling flasks of commercial variety were converted into satisfactory spherical resonators by reducing the length and diameter of the

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[1] C. E. Mulders, Appl. Sci. Research **B1**, No. 3, 149 (1949); **B1**, No 5, 341 (1950).

[2] C. J. Moen, J. Acoust. Soc. Am. **21**, 62 (1951).

[3] G. Kurze and K. Tamm, Acustica **3**, 34–48 (1953).

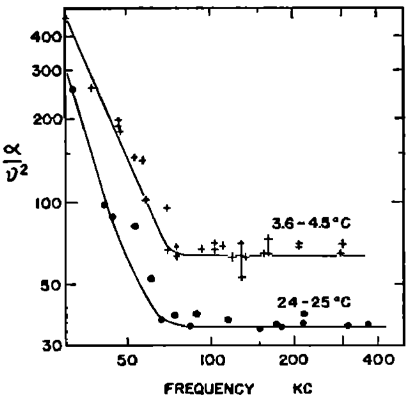

FIG. 1. Typical experimental data for pure water at two temperatures. The units for α/ν^2 are sec^2/meter$\cdot 10^{15}$.

neck in a glass-blower's lathe. A support system for the resonator consists of three pairs of 0.01-inch diameter steel wires hung from above on a ring having the same diameter as that of the resonator and held together underneath the resonator by a thin brass ring. To prevent absorption of sound by the surrounding medium, the resonator is placed in a vacuum chamber where the air pressure is reduced to about one millimeter of mercury.

TRANSDUCERS

One or more small, 45° Z-cut crystals of ammonium dihydrogen phosphate cemented to the resonator wall serve as both a sound source and as a microphone. It was found convenient to use a conducting silver paint for the crystal electrodes and for cementing on the thin lead wires.

A small disk thermistor cemented to the resonator permits measurement of the temperature of the sample, which may be varied and controlled by controlling the temperature of the vacuum chamber wall. The temperature stability of the control system (±0.5° to 1°C) is sufficient for the present investigation.

PREPARATION OF SAMPLES

The samples were compounded from distilled water and a cp grade of the salt to be studied. The natural sea water samples were filtered through a fine grade of filter paper. Growth of bacteria and other organisms in the solutions was deterred by the addition of about four parts of mercuric chloride per million parts of sample.

Before measurements of sound absorption can be made, it is necessary to degas the liquid in the resonator. This is accomplished by boiling the sample at room temperature and reduced pressure and, at the same time, irradiating the resonator in an intense sound field whose frequency corresponds to one of the radial resonant modes. The high-amplitude sound waves increase the rate of gas evolution by several orders of magnitude. A small loss of liquid as a result of evaporation during this treatment is made up afterward by addition of freshly boiled distilled water. Boiling of the liquid at atmospheric pressure without sonic excitation produces adequate degassing but results in much greater liquid losses due to evaporation and thermally induced volume changes.

EXPERIMENTAL RESULTS AND TREATMENT OF THE DATA

Figure 1 presents a typical example of the experimentally observed absorption in pure water. The apparent amplitude absorption coefficient α was calculated from the lowest observed decay rates in each frequency range.

It is to be noted that the observed values are somewhat larger than the currently accepted value due to wall losses. An approximate calculation of the wall losses assuming only spherical waves accounts for only about one-third of the discrepancy between the observed and accepted values of α/ν^2. It is believed that the remaining discrepancy is due to shear losses at the walls of the resonator and that an anomalous behavior in the absorption in water is not indicated.

It was found that the wall loss is, to within the accuracy of the measurements, independent of the value of the absorption in the liquid. It is convenient, then, to deal with the "excess" sound absorption in the solutions which is obtained by taking the difference between the observed absorption coefficient for the solution and that for water at the same frequency. For the solutions studied here, the absorption in the

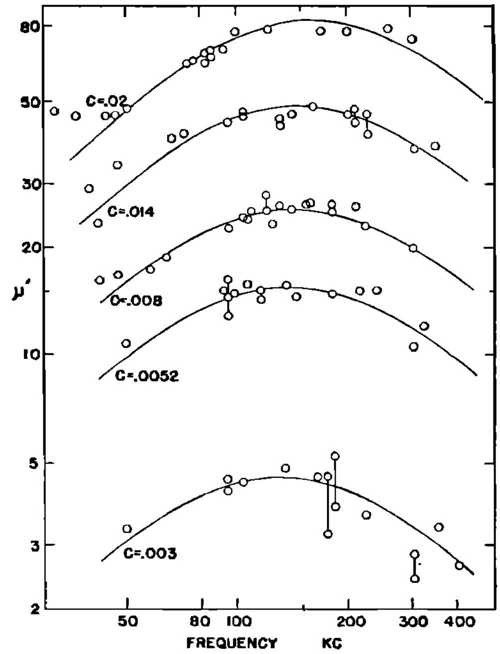

FIG. 2. Observed values of the excess sound absorption per wavelength$\cdot 10^6$ as a function of frequency for $MgSO_4$ solutions at several concentrations (in mole/liter). Temperature: 23°-25°C.

solutions was never less than the apparent absorption in pure water at the same frequency. It is estimated that the accuracy of the method as used here is about 20 percent.

In the figures that follow the excess absorption for the solutions has been plotted in units of absorption per wavelength. The curves drawn through the experimental points have the form of the familiar approximate equation for the absorption per wavelength due to a relaxation absorption phenomenon:

$$\mu' = A\nu\nu_m/(\nu^2+\nu_m^2),$$

where μ' is the excess absorption per wavelength, A is a constant, and ν is the frequency. ν_m is the relaxation frequency for the process and is the frequency for which μ' has a maximum value. The curves have been fitted to the plotted points which enables approximate determination of the relaxation frequencies and the maximum value of the excess absorption per wavelength for each solution.

TABLE I. Excess sound absorption[a] in $MgSO_4$ solutions at several concentrations. Temperature: 23°–25°C.

C mole/liter	$\mu_m'\times10^6$	ν_m kc
0.003	4.6	130
0.0052	15.5	140
0.008	25.5	140
0.01	35.5	130
0.014	48	138
0.02	80	150

[a] The quantity μ_m' is the maximum value of the excess absorption per wavelength estimated from curve fitting to the experimental data.

TABLE II. Excess sound absorption[a] in $MgSO_4$ solutions at several temperatures. Concentration: 0.01 mole/liter.

T°C	$\mu_m'\times10^6$	ν_m kc
4.5	31	51
7.9	31	65
15	34	91
20	36	120
24.5	35.5	130
35	44	250
43	44	315

[a] The quantity μ_m' is the maximum value of the excess absorption per wavelength estimated from curve fitting to the experimental data.

Figure 2 presents typical experimental data for the excess absorption in $MgSO_4$ solutions at several concentrations, and the results of curve-fitting to these data are given in Table I. Corresponding results for a $MgSO_4$ solution at several temperatures are given in Table II.

Leonard[4] has reported the absence of observable excess sound absorption in the frequency range studied here in solutions of $MgCl_2$, Na_2SO_4, and $CuSO_4$ at concentrations near 0.02-mole per liter and in NaCl

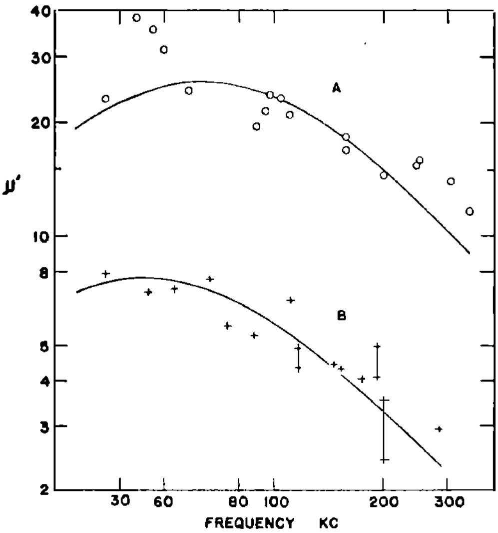

FIG. 3. Observed values of the excess absorption per wavelength·10^6 as a function of frequency: Curve A, $Mg(C_2H_3O_2)_2$ solution, concentration 0.02 mole/liter; Curve B, $BeSO_4$ solution, concentration 0.16 mole/liter. Temperature 24°C.

solutions at much larger concentrations. Since then, measurements have been made on a solution of $CaSO_4$ (approximately 0.01 mole per liter) and a solution of H_2SO_4 (0.02 mole per liter). No excess sound absorption was observed in either case. Indications of a relaxation sound absorption have been found in solutions of $BeSO_4$ at relatively high concentrations near 0.1 mole

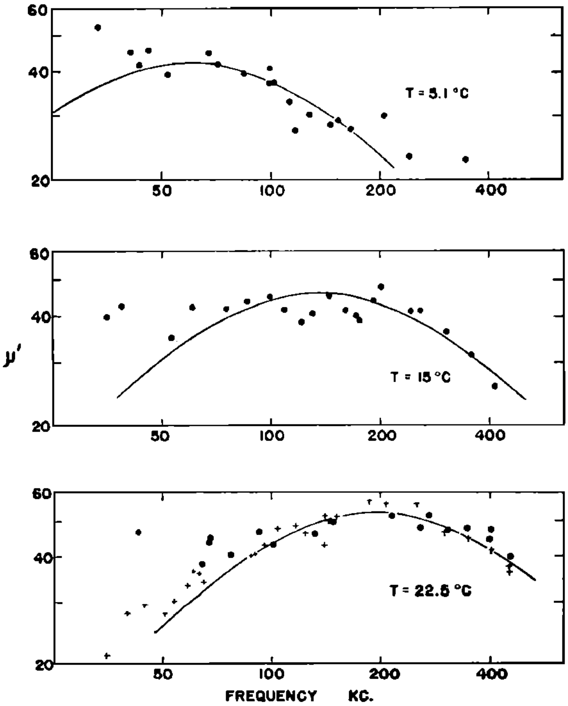

FIG. 4. Excess sound absorption per wavelength·10^6 in sea water as a function of frequency at several temperatures. ● Natural Sea Water; + Synthesized Sea Water.

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[4] R. W. Leonard, "The attenuation of sound in liquids by a resonator method," Technical Report No. 1 (Contract N6-onr27507), Department of Physics, University of California, Los Angeles (June, 1950).

per liter. In this case the relaxation frequency seems to be somewhat below 50 kilocycles, a frequency range where the wall losses in the 12-liter resonator are significantly large, so that these measurements do not permit an accurate determination of the relaxation frequency. The data of Kurze and Tamm[3] indicate that the relaxation frequency for $BeSO_4$ solution is not greater than 10 kc. A solution of magnesium acetate at a concentration of 0.02 mole per liter shows an anomalous sound absorption which is of the same order of magnitude as that for the magnesium sulfate solution. Here, the relaxation frequency seems to be near 50 kilocycles. Graphs of the results of these measurements are presented in Fig. 3.

Measurements of the sound absorption in $ZnSO_4$ solutions of concentration 0.16 mole per liter show the presence of a small excess absorption which cannot be entirely accounted for by increase in the shear viscosity coefficient. This absorption seems to be proportional to the square of the frequency over the frequency range of this equipment. The value of the ratio $2\alpha/\nu^2$ was found to be about three times that for pure water.

A rough measurement of the sound absorption in a mixture of $MgSO_4$ (0.02 molar) and NaCl (1 molar) gave a value approximately one-half of the absorption for the $MgSO_4$ solution at that concentration. This salt effect has been studied in some detail by Tamm and Kurze.[3]

Results of measurements on natural and synthesized sea water are shown in Fig. 4.

DISCUSSION

It has been pointed out recently by Barthel[5] that the concentration dependence of the sound absorption and the relaxation frequency may be quite variable, depending upon the nature of the absorbing reaction and the relative concentration of the reactants. In view of this, the present results for $MgSO_4$ cover an insufficient range of concentration and are not sufficiently accurate to enable definite conclusions to be drawn from them alone. More extensive measurements are required. Chemical data concerning $MgSO_4$ solutions, particularly those pertaining to dissociation phenomena, are not numerous and, in some cases, seem to be inconsistent.

Further experimental studies using this apparatus together with a comprehensive theoretical treatment have been made by Bies and are reported in another paper.[6]

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[5] R. Barthel, J. Acoust. Soc. Am. 24, 313–316 (1952).

[6] D. A. Bies (to be published).