VELOCITY OF ULTRASONIC WAVES IN WATER VAPOR

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Abstract

The velocity of sound waves having a frequency of 108,600 cycles per second, has been measured in water vapor by a method similar to that used by Pierce for other gases. At a temperature of 27° C. the velocity is 432 meters per second.

SOME results by Pierce[1] for the velocity of ultrasonic waves in air showed much less than the expected variation of velocity with change of humidity. This situation suggested the desirability of making similar measurements in pure water vapor, so the present work was undertaken. More recently Reid[2] found the effect due to humidity which was expected on the basis of theory. It still seemed worth while, however, to continue the work with water vapor along the line originally planned.

Description of Apparatus

The sound chamber consisted of a cylindrical brass tube of 9.5 cm inside diameter and 25 cm in length. A plane reflector about 9 cm in diameter was moved back and forth by the calibrated screw S. (See Fig. 1) In order to

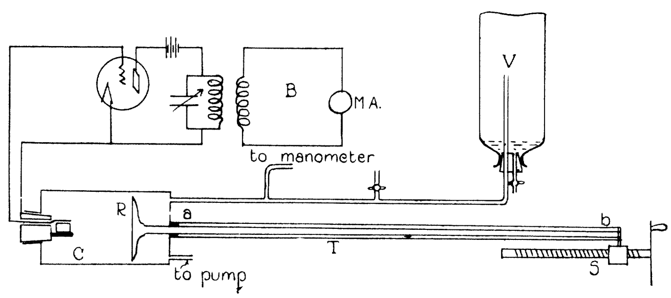

Fig. 1. Diagram of apparatus.

get an air tight joint at a, the rod carrying the reflector was enclosed in a rubber tube which was fastened to the sound chamber at a and to the rod at b. This arrangement permitted the reflector to be moved back and forth easily, the rubber being stretched or contracted to accomodate the motion of the rod. The rod was about 150 cm long. A spiral spring was placed around the rod and inside the rubber tube to keep the tube from gripping the rod when the pressure was reduced inside the chamber.

[1] G. W. Pierce, Proc. Am. Acad. of Arts and Sciences **60**, No. 5 (1925).
[2] C. D. Reid, Phys. Rev. **35**, 814 (1930).

The quartz crystal was mounted between electrodes on the end of a brass plug which was carefully ground to fit a tapered opening at the end of the chamber. The wire leading to the upper electrode of this crystal holder was insulated by filling the hole through which it passed with sealing wax. The lower electrode was not insulated from the plug so that connection to it was made by soldering a wire to the outside end of the plug.

The vapor was generated in a glass bottle *V* and pumped slowly through the chamber *C* during the course of the experiment. It was necessary to keep the pumps working continuously because the apparatus was not quite vacuum tight, the leak with the pump idle amounting to about one half centimeter of mercury pressure per hour.

The electrical circuit is fully shown in the figure and needs no detailed description. Instead of making observations on a d.c. meter placed in the plate circuit of the oscillator tube, a Weston, model 412, high frequency milliameter (2 m.a. range) was placed in a resonant circuit which was coupled loosely with the oscillator. This circuit had a resistance of over 700 ohms and consequently tuned very broadly.

The temperature of the vapor was measured with a copper-constantan thermocouple placed in front of the crystal but above the direct path of the sound waves.

Method of the Experiment

Absolute measurement of velocity was not attempted. The velocity of the waves in air was assumed to be known and the velocity in the vapor determined by comparing the wave-length in vapor with the wave-length in air. In water vapor the crystal oscillations were somewhat irregular so that high precision of measurement could not be attained easily. Also the milliameter fluctuations caused by the motion of the reflector were very slight due to the low density of the vapor. This difficulty was partly overcome by using a microscope to observe the movement of the pointer of the meter. In making measurements, the reflector was placed about 2.5 cm from the crystal face and at a position of minimum deflection, and the position read on the screw. Another position 20 half wave-lengths farther from the crystal was found and another reading taken. The settings were always made with the screw turning in the same direction.

Source of Error

It was considered likely that the greatest source of error would be the lack of purity of the vapor caused by air leakage. Consequently, extremely accurate measurement of temperature, pressure, frequency, and wave-length were not attempted.

In order that the wave-length be proportional to velocity the frequency of the crystal must not change when the nature of the surrounding gas is changed. A second oscillator was heterodyned with the crystal oscillator to give a beat note of about 200 cycles per second. Since no very appreciable change of pitch was produced by changing from air to water vapor, the frequency control was deemed satisfactory.

The screw was calibrated by comparison with a Gaertner comparator and found to be of sufficiently uniform pitch, the maximum variation from the average being about 0.009 mm. The average pitch was 2.509 mm.

Results

The wave-length in air at 22°C was found to be 3.176 mm. Considering the velocity to be 345 meters per second, the frequency figures out to be about 108,600 cycles per second.

In Table I are values for the wave-length in water vapor. These are given in terms of the pitch of the screw and changed to mm after averaging.

Table I. *Wave-lengths in water vapor.* (Average, $1.586 \times 2.509 = 3.979$ mm, Vapor pressure, 1.4 cm of mercury, Temperature, 27°C).

1.581	1.585	1.566	1.597
1.610	1.605	1.591	1.600
1.593	1.567	1.588	1.588
1.576	1.572	1.597	1.572
1.575	1.576	1.604	1.572
1.588	1.596	1.578	

With the data of Table I, we get for the velocity of sound in water vapor at 27°C.

$$V = (3.979/3.176) \times 345 = 432 \text{ meters per second.}$$

Masson gives 401 meters per second as the velocity in water vapor at 0°C. Although no factor for temperature correction is available it seems that Masson's value is considerably below the value given above. Failure to provide air-free vapor for the determination would account for the low value. Since the effect of air in the vapor is to decrease the velocity, the largest value one can obtain for the velocity would presumably be most reliable.

With the value for the ratio of specific heats and density of water vapor given by Neyreneuf[3] we get a theoretical value for the velocity of sound in water vapor at 27°C which is $V = 348(1.321/0.6143 \times 1.402)^{\frac{1}{2}} = 431$ meters per second. Neyreneuf's data were given for saturated vapor, whereas, the vapor pressure used in the present experiments was only slightly more than half that of saturated vapor. On the whole, the agreement is quite satisfactory, considering the errors involved in the measurement of the various quantities.

[3] Neyreneuf, Annals de chimie et de Physique **9**, 535, (1886).