Conclusions

The results of this investigation may be summarized[10] as follows:

(1) The observed hyperfine structure in the arc spectrum of columbium can be accounted for by attributing mechanical and magnetic moments to the columbium nucleus.

(2) The quantum number of nuclear spin of columbium is given by $I=9/2$.

(3) Approximate values of the nuclear g-factor and nuclear magnetic moment of columbium are $g_I=0.83$, $\mu_I=3.7$ nuclear magnetons.

In conclusion the writer wishes to express his sincere thanks to Professor H. E. White, who has guided him throughout this investigation. He also wishes to acknowledge the help of Professor F. A. Jenkins in interpreting intensity data, and the cooperation of Doctor N. S. Grace, with whom the work was first undertaken.

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[10] See also S. S. Ballard, Phys. Rev. **46**, 233L (1934).

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An Experimental Determination of Ultrasonic Absorption and Reflection Coefficients in Air and in Carbon Dioxide

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Ultrasonic absorption coefficients in air and in carbon dioxide have been measured, as well as the coefficients of reflection in these gases at a solid boundary. In the frequency range between 88 and 1000 kc/sec. the absorption in air was found to increase with the square of the wave-length as required by classical theory, but for CO_2 the absorption constant of the classical theory rises to a sharp maximum at about 98 kc/sec. The reflection coefficient (brass reflector) was found to decrease with increasing frequency for both gases, the decrease being of the order of twenty percent at the higher frequencies. Measurements on an impure sample of helium are included.

The method developed by Hubbard[1] for determining ultrasonic absorption and reflection coefficients by means of the acoustic resonator interferometer has been used in this investigation. The source of ultrasonic waves was in each case a vibrating piezoelectric quartz plate, which acted as a source of plane waves, the wave-length of which was small compared to the diameter of the source. The quartz plate was not self-oscillating but was forced to vibrate at one of its natural resonance frequencies by an external source of periodic electromotive force applied to the plate. This plate closed one end of a tube and thus radiated ultrasonic waves into it. The other end of the tube was closed by a piston, the position of which could be changed by a micrometer screw. The reaction of the vibrating column of gas in the tube upon the quartz plate, as in all work with the acoustic interferometer, varies cyclically with the position of the piston, reaching maximum values as the piston passes through resonance positions, in which standing waves are set up. Hubbard has shown that the gas column and crystal may be regarded as a single mechanical system, the impedance of which varies periodically with reflector distance. These variations can be measured quantitatively and from them can be calculated the coefficient of absorption in the gas as well as the reflection coefficient at the surface of the piston. If no energy were absorbed then the reaction of the gas column on the quartz plate would be the same for all sets of standing waves produced as the piston moves away from it. Since, however, energy is absorbed in the gas the resonance reaction diminishes as the piston recedes from the source until, at sufficiently great distances, there should be no reaction and hence no system of standing waves. The experimental work consists, in a given case, in measuring the reaction for a series of reflector distances. From these readings the coefficients of absorption and reflection are evaluated.

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[1] J. C. Hubbard, Phys. Rev. **38**, 1011 (1931); **41**, 523 (1932).

Experimental Procedure

The quartz plate, holder, the tube and piston form the sonic interferometer. The interferometer used in this investigation was specially designed to enable pressure and temperature variations to be made in the gas being measured, the whole instrument being gas tight. In order to move the piston within the enclosure by the micrometer screw outside, a metal bellows was used. By using a long one the desired motion of 25 mm was obtained without putting enough force on the screw itself to change its calibration. This long bellows also had the advantage that heat conductivity along it was small when it was immersed in a temperature bath. The design has the further advantage that the whole apparatus may be assembled and tested in place and then the cap screwed on the lower end and sealed, either with a rubber gasket or wax. A drawing of the interferometer is given in Fig. 1.

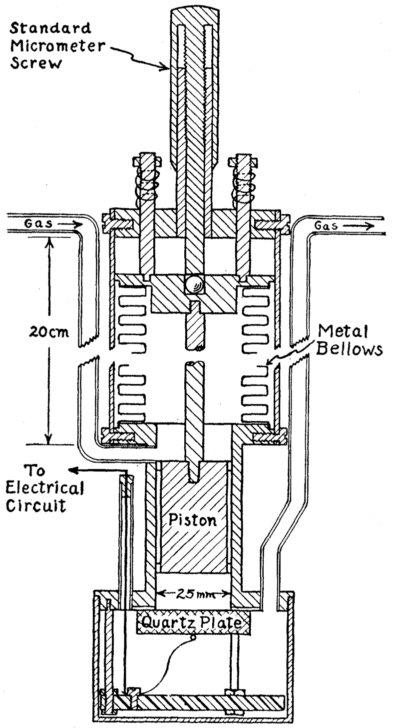

FIG. 1. Drawing of the ultrasonic interferometer in section.

The quartz plates were of the type usual for thickness vibrations, with either circular or rectangular faces. Gold electrodes were evaporated on both faces of each plate and a plate when in use in the interferometer was held against the end of the tube by a spring which also served as a lead to one electrode, the other electrode being in electrical contact with the case of the instrument which was grounded. In a few cases for low frequencies the plates were turned on edge. Slots were cut in the face on which the quartz plate rested as well as in the side of the piston to allow free flow of gas. An arrangement of springs, shown at the top of the drawing, was provided to prevent the collapse of the bellows when low pressures were used.

Since the quartz plate was forced to vibrate at one of its natural resonance frequencies it was necessary to apply to the electrodes an alternating current, the frequency of which was as constant as that usually produced by quartz crystal oscillators. However, it was not practicable to use such an oscillator because of the amount of labor which would be involved in providing exactly tuned plates for all the driving frequencies. In designing an electric oscillator for the purpose advantage was taken of the work of Dow[2] whose "electron coupled" oscillator has a frequency stability comparable to that of an oscillating crystal. In the oscillator used in these experiments the tuned circuit consisted of a precision condenser which had been carefully calibrated and a stable inductance coil, a small radio receiving, four electrode vacuum tube with indirectly heated cathodes, being used for the generation of oscillations. Its output was amplified by a two-stage amplifier and fed into an untuned output coil. The filaments were heated from the lighting mains and the plate potentials were obtained from heavy-duty dry batteries, the whole system being carefully shielded. A small micrometer vernier condenser was connected in parallel with the precision condenser and with these the frequency could be adjusted to within a cycle of the desired value. Frequency stability was extremely satisfactory, the drift usually being so small that no adjustment was necessary during the course of a set of measurements.

While frequency measurements of great accuracy were not needed for the absorption measurements, the oscillator permitted them to

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[2] J. B. Dow, Proc. I. R. E. **19**, 2095 (1931).

be made by a simple method, apparently not generally used. Taking the frequencies of radio broadcasting stations, by law, within 50 cycles of assigned values, as standards, the oscillator could be set to known frequencies using the precision condenser. Then, knowing the change in capacity necessary to change the oscillator from the known to the unknown frequency, the unknown frequency could be computed. Outside the broadcasting range intercomparison of harmonics may be used. Values are reproducible by this method within 0.1 kilocycle.

The circuit by which the output of the oscillator was applied to the quartz plate was called the driving circuit and it was also used to make the necessary measurements. It consisted of an inductance, capacity, and thermocouple in series, the quartz plate being shunted across the condenser and the inductance loosely coupled to the output coil of the oscillator. The thermocouple was of the separate heater vacuum type and had a heater resistance of 105 ohms. The capacity and inductance had such values that the natural period of the circuit was equal to that of the desired resonance frequency of the quartz plate, the capacity preferably being small.[1] The thermocouple, shunts and galvanometer were calibrated in place, using direct current. In some measurements a vacuum tube voltmeter was used in place of the thermocouple but because of calibration difficulties it was not used in the final measurements.

Only natural crystal frequencies having large acoustic reactions are of use in acoustic interferometry. Such frequencies were located by slowly varying the frequency of the electromotive force applied to the driving circuit. The resulting current observed in the driving circuit is sharply reduced at passage through a resonance frequency of the quartz. This reduction occurs over a very narrow frequency range, and is called a *crevasse* of the crystal. Each quartz plate has many crevasses corresponding to different modes of vibration, but few modes of vibration give rise to vigorous acoustic reaction. Since a system of standing waves in the tube is indicated by an increase in the minimum crevasse current it was only necessary to vary the position of the piston to determine whether such waves were present at a given frequency. The crystal was systematically explored in this way and a crevasse was selected which had a large acoustic reaction and a desirable frequency and which had no close neighbors so that no spurious frequencies or modes of vibration were present.

It is then necessary as a requirement of the the theory of the method, to adjust the frequency of the driving circuit to that of the chosen crevasse of the quartz plate, thus making the crevasse symmetrical, that is, making the curve plotted with current as ordinates and frequency as abscissas symmetrical with respect to the minimum point. This was done by trial and error methods.

For the determination of the ratio of the absorption coefficient in the gas to the reflection coefficient at the surface of the piston it is necessary to measure three currents for each of several sets of standing waves. These currents are (1) the maximum current at resonance of the driving circuit with the quartz plate disconnected, (2) the minimum current with the quartz plate connected and resonating but without a system of standing waves (piston at anti-nodal position), and (3) the increase in this minimum current when a system of standing waves is set up by moving the piston to a nodal position. The first two currents were approximately the same for all the measurements but the last current decreased as the piston receded from the quartz plate. From these sets of values it is possible to compute the ratio of the absorption coefficient to the reflection coefficient. In addition it is necessary to measure the width at half-amplitude of one of the current maxima obtained when the current is plotted against the piston position. Knowing this and the half-wave-length the two coefficients can be separated.

The actual computation is a long process which often requires more time than the measurements. The complete equations are given in the original paper describing this method and will not be repeated here. In making this computation the corrected equations given by Hubbard[3] were used.

RESULTS

Measurements have been made on dry, CO_2-free air and on dry commercial carbon dioxide.

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[3] J. C. Hubbard, Phys. Rev. **46**, 525 (1934).

In addition two measurements were made on an impure sample of dry, CO_2-free, helium. The gas to be measured was allowed to flow through the interferometer for several hours in order to wash out other gases and it was also allowed to flow slowly while the measurements were being made.

The results obtained are given in Table I. The values of the velocity are reduced to 0°C, but they are not very reliable, since in many cases measurements were made for only a few wave-lengths near the source. They will perhaps be useful in giving a clue as to the purity of the gas. For example, if air is the impurity in the helium, the velocity measurements indicate the presence of 5 percent by volume of air. The reflection coefficient is the fraction of incident energy reflected at the surface of the brass piston and is practically unity at audible frequencies. The absorption coefficient μ is defined by $I_x = I_0 e^{-\mu x}$, where $\mu = A/\lambda^2$, by the classical theory of acoustic absorption, A being a constant determined by the coefficient of heat conduction and viscosity of the gas, was well as by the gas density and specific heat. The behavior of A as determined by experiment is a test as to the presence of the type of acoustic dispersion discovered by Kneser.[4] As he has shown, it is to be expected that for a polyatomic gas there will be a characteristic frequency range in which a given energy state, such as a vibrational state in the case of CO_2, passes from participation in energy exchanges at lower frequencies to non-participation at the higher, corresponding to an apparent increase in the ratio of specific heats. For CO_2 this region lies mainly between 100 and 600 kc, but its position is extraordinarily affected by the presence of certain gas impurities.[5] This type of dispersion implies a region of extra-classical absorption[6] and accordingly a maximum of the experimentally determined value of A. Such a maximum, but of greater than theoretical value, was found for CO_2 by Grossmann[7] in the neighborhood of 100 kc. The absorption coefficients for CO_2 have been plotted as a function of frequency in Fig. 2. For purposes of comparison the corresponding values obtained by Grossmann, Pielemeier,[8] and Hubbard are also given on the

TABLE I. *Results of velocity, absorption and reflection coefficient measurements in dry, CO_2-free, air; dry CO_2-free, helium (impure); and dry carbon dioxide (commercial).*

(1) Gas; (2) frequency (kc/sec.); (3) temp. °C; (4) velocity at 0°C m/sec.; (5) reflection .coefficient; (6) absorption coefficient = A; (7) $\alpha = \mu/2$.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Air	252.1	27.2	332.0	0.92_6	0.0015_3	0.040_9
	531.3	25.8	333.8	0.86_4	0.0012_7	0.147
	589.4	28.9	332.4	0.88_0	0.0006_1	0.087
	1000.8	27.6	334.2	0.75_4	0.0008_6	0.35
He	251.9	29.1	824.5	0.95_2	0.0051	0.021_6
	1000.8	28.5	837.6	0.91_5	0.0038	0.242
CO_2	88.90	25.4	262.4	0.99_8	0.069_5	0.365
	97.95	28.5	262.4	0.96_9	0.090	0.57
	120.8	23.9	264.3	0.99_9	0.057_3	0.55
	188.7	28.6	264.2	0.98_5	0.032_6	0.75_4
	213.6	23.8	267.5	0.89_3	0.029_4	0.86_3
	251.9	28.3	265.2	0.96_4	0.019_6	0.80
	531.3	27.8	267.3	0.82_1	0.005_8	1.04

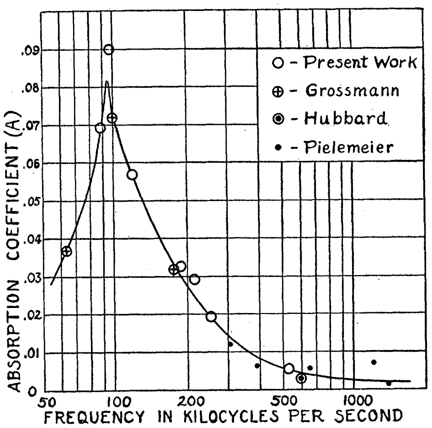

FIG. 2. Absorption coefficient A plotted as a function of the frequency.

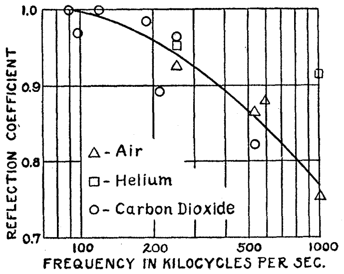

FIG. 3. Reflection coefficient plotted as a function of the frequency.

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[4] H. O. Kneser, Ann. d. Physik **11**, 777 (1931).

[5] W. T. Richards and J. A. Reid, J. Chem. Phys. **2**, 193 (1933).

[6] H. O. Kneser, Ann. d. Physik **16**, 337 (1933).

[7] E. Grossmann, Ann. d. Physik **13**, 681 (1932).

[8] W. H. Pielemeier, Phys. Rev. **34**, 1184 (1929).

graph. The agreement of the results by the present method with those of Grossmann, obtained by a direct method, is interesting and seems to give considerable support to the validity of interferometric methods in this range of frequencies. The magnitude of A at the maximum at 98 kc/sec. for CO_2 is considerably greater than that of Grossmann and is still farther from the theoretical value.[6] The values of A for air and helium are of a smaller order of magnitude and are much more affected by the errors of measurement.

Reflection coefficients have been plotted as a function of frequency in Fig. 3. It was found by Hubbard that reflection coefficients in this frequency range are less than unity by much more than would be expected on the dynamical theory of sound. The present experiments show that this decrease from expected values is not only very considerable but that the reflection coefficients decrease rapidly with increasing frequency. No detailed explanation of this phenomenon has been attempted, but it seems reasonable to suppose that the same increase with frequency of temperature gradient in the acoustic wave which accounts for the increase with frequency of acoustic absorption due to heat conduction[9] may also be the cause of irreversible heat losses at the reflector. On this view it would be reasonable to expect a decrease of reflection coefficients with increasing frequency.

The author wishes to express his thanks to Professor J. C. Hubbard for suggesting the problem and for much help and encouragement in its solution.

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[9] K. F. Herzfeld and F. O. Rice, Phys. Rev. **31**, 691 (1928).

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Electrical Resistivities of Single and Optically Mosaic Zinc Crystals

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The Voigt-Thomson symmetry relation is accurately checked for two sets of strain-free zinc single crystals made from two lots of Evanwall zinc. The principal electrical resistivities in micro-ohms/cm^3 are: $\rho_0=6.218$, $\rho_{90}=5.882$ with the ratio, $\rho_0/\rho_{90}=1.0554$ for one lot (E.W.R.) and $\rho_0=6.161$, $\rho_{90}=5.842$, $\rho_0/\rho_{90}=1.0548$ for the other (E.W.B.). The resistivity is changed by slight strains due to application of micrometer calipers to the crystals, the change being a decrease in four cases out of eleven. Severe strains, in general, increase the resistivity. The effects of repeated anneals on strained crystals are complex, the most important conclusion being that high temperature anneals (at about 400°C) are not effective in restoring the initial resistivity of all orientations. A final low temperature anneal (at 190°C for 84 hours) is however completely effective. Optically mosaic specimens have abnormal resistivities, either greater or less than single crystals of the same orientation. Such specimens are very strain-sensitive, the resistivity rising markedly after a strain and falling for a subsequent anneal. This effect may be repeated several times on a specimen. The ambiguous results of previous observers may be explained either as strain effects or as due to the presence of optically mosaic specimens.

INTRODUCTION

THE necessity for a redetermination of the resistivity of single crystal castings of zinc as a function of orientation,[1] in spite of several previous determinations,[2] will be evident upon reading the paper on this subject by Tyndall and Hoyem.[2f] None of the previous determinations have really offered a complete and definite experimental check of the Voigt-Thomson symmetry relation[3] for the resistivity when all of the

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[1] The angle between the main crystallographic axis and the length of the specimen.

[2] a. Grüneisen and Goens, Zeits. f. Physik **26**, 235 (1924); b. P. W. Bridgman, Proc. Am. Acad. Sci. **60**, 305 (1925); c. P. W. Bridgman, Proc. Am. Acad. Sci. **61**, 101 (1928); d. P. W. Bridgman, Proc. Am. Acad. Sci. **63**, 352 (1928); e. L. A. Ware, Phys. Rev. **35**, 989 (1930); f. Tyndall and Hoyem, Phys. Rev. **38**, 820 (1931); g. Goens and Grüneisen, Ann. d. Physik **14**, 164 (1932).

[3] This well-known relation states that the resistivity of zinc crystals is a linear function of the square of the cosine of the orientation.