Chlorine was found to be effective in destroying bacterial pollution without injury to fish but did not destroy algae. Both methods have now become standard practice in sanitary engineering.

The next development grew out of the observation that mosquito larvae were killed by these traces of copper, 1 part to 10 million. Colonel Gorgas requested that we send one of our men with him to clean up the zone in the Isthmus of Panama through which we were to dig the Panama Canal. The late Karl Kellerman was assigned to the job and used the copper treatment exclusively in destroying algae and mosquito larvae when it was not practicable to use oil.

The use of copper in water supplies was followed by a study of copper in animal nutrition. The results of that study show that it is absolutely essential along with iron for haemoglobin formation in the red-blooded animals. Its absence in the diet brings on secondary anemias that result in death if copper is not supplied. A trace of copper also proved to be essential in the growth of plants. What the next chapters will be I do not know. But I do know that Nägeli's work on "frog spittle" paved the way for work of very great value to humanity many years after he had passed away.

We must encourage and support research in all fields. It is the only key to progress. Botanical research has made it possible to produce food sufficient for earth's teeming millions if they will stop fighting and intelligently use the knowledge already gained.

In conclusion, I am sorry that the last annual report of the Brooklyn Botanic Garden did not come to my attention before I prepared my address for this evening. A discussion of that report would be a forceful presentation of botany and human affairs. The Brooklyn Garden is outstanding among the gardens of this country in its public relations contacts and in its cooperation with civic agencies of city, state and nation, in educating the public to appreciate the value, to the community, of botany in its many aspects and relations. Director Gager has been selected as chairman of the subcommittee having in charge this aspect of the plans for the National Botanic Garden at Washington.

THE ABSORPTION OF SOUND IN GASES[1]

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THE experiments I shall here describe, which began with studies in architectural acoustics, have led to the discovery of important, although peculiar and unsuspected, laws concerning the propagation of sound in the atmosphere and other gases.[2] The results obtained also conform remarkably well with predictions of modern theories of the dispersion and absorption of sound in gases. In this latter connection the results exhibit a new technique for investigating the nature of energy transfers during molecular collisions.

The classical theories of Stokes and Kirchhoff on the absorption of sound in gases were based upon the effects of viscosity and heat conductivity, and until recently it has been assumed generally that these effects accounted for the observed attenuation of sound in the air and other gases. These classical theories, which require the attenuation to increase with the square of the frequency, explain, qualitatively at least, why, when listening to distant echoes of speech, we hear only the low-frequency vowels and do not hear the high-frequency consonants, which are absorbed in the air before reaching our ears. However, certain acoustical phenomena, which nearly every one must have observed in his early youth, are not even qualitatively explained by these classical theories. Thus, the sound of an approaching train or a wagon coming over a cobblestone road can be heard more distinctly and at a greater distance when a storm is gathering (usually characterized by a drop in temperature and an increase in humidity) than when the air is warm and relatively dry; and the sounds of ordinary speech can be heard at distances of more than a mile on cold, dry days. Reliable observations of such Arctic explorers as Stefansson indicate that at − 80° F. conversations as far away as five or six miles have been heard and understood, and that other sounds, as the barking of dogs or the chopping of wood, have been heard at distances as great as fifteen miles. These long distance transmissions of sound through the atmosphere are usually explained by assuming that the temperature of the air increases from the ground upward—often referred to as an inverted temperature gradient—which would cause the sound waves to be refracted downward and thus spread out essentially in two dimensions over a wide horizontal zone; whereas, under the more common condition of

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[1] At the request of the editor of SCIENCE this non-technical article has been prepared by the author of the paper presented at Pittsburgh to which was awarded the prize for a notable contribution presented at the annual meeting of the American Association for the Advancement of Science.—ED.

[2] The experiments are described more completely in papers in the April (1935) issue of the *Journal of the Acoustical Society of America*, and in previous issues of this journal.

a decreasing temperature from the ground upward—referred to as a normal temperature gradient—the sound waves are refracted upward and thus are not heard at great distances by observers on the ground. Although temperature refraction is an important factor in explaining the propagation of sound in the atmosphere, it is not sufficient to account, for example, for the observed differences of sound transmission in temperate and frigid zones, since the air may be characterized by an inverted temperature gradient in both zones; and, as we shall see, the acoustical "transparency" of the air is greatly dependent upon both temperature and humidity.

The modern theory of the absorption of sound in gases began with a paper by Jeans in 1904, and has been developed into a useful form by the contributions of Einstein in 1920, Hertzfeld and Rice in 1928, and Kneser and others since 1931. The work of Kneser,[3] the theoretical part of which was modeled after the treatise by Einstein, not only led to convenient equations for calculating the velocity and absorption of sound in gases, but was followed by an experimental study on the velocity of sound in CO_2 which gave results in good agreement with his dispersion formula.

In the simplest form of this modern theory, such as is here sufficient to account for the observed absorption in air and oxygen, it is assumed that there are only normal or non-vibrating molecules, and one kind of vibrating molecules having a characteristic frequency and a characteristic "life time" (average duration of a quantum of vibration). The theory shows that the absorption coefficient per wave-length is

$$\mu = 2\pi \left[\frac{RC_i}{C_\infty (C_\infty + R)} \cdot \frac{\omega k_{10}}{k_{10}^2 + \omega^2} \right] \qquad (1)$$

where R is the gas constant, C_∞ is the heat capacity of the gas for sound of infinite frequency, C_i is the internal heat capacity, ω is 2π times the sound frequency and k_{10} is a reaction constant which gives the number of transitions from the excited to the normal state per molecule per second. The maximal value of the absorption coefficient μ_m occurs when $k_{10} = \omega$, so that

$$\mu_m = \pi \left[\frac{RC_i}{C_\infty (C_\infty + R)} \right] \qquad (2)$$

From (2) it is seen that the maximal absorption, which occurs when $\omega = k_{10}$, is a constant which, for a certain gas, depends only on C_i and C_∞, and that the maximal absorption coefficient per unit length $m_m = \mu_m / \lambda$ (where λ is the wave-length) is proportional directly to the frequency. Further, it is evident from (1) that in order to determine the reaction constant k_{10} either for a pure gas or a gas mixture it is necessary only to determine the frequency at which the absorption is a maximum.

Before the above theory had been fully developed, the author's attempt to calibrate a new reverberation chamber revealed that the absorption in air at ordinary temperatures and humidities was very much greater than the value predicted by classical theory, and depended upon humidity and temperature in a characteristic manner. These results were obtained by measuring the rate of decay of sound in two similarly shaped rooms, having the same boundary material (painted concrete) and containing air of the same temperature and humidity, but having different "mean free paths" (the average distance the sound waves travel between successive reflections).

The success of the initial two-room experiment suggested the desirability of using smaller chambers in which the temperature and humidity of the air could be more easily controlled, and in which other gases could be investigated. Accordingly, a six-foot cubical chamber and a two-foot cubical chamber were constructed from one fourth inch steel boiler plate, strengthened with angle iron, spaced two feet on centers. The chambers are equipped with rotating paddles which keep the sound in a diffuse state. The source of tone is a high frequency loud speaker actuated by a pure sine wave alternating current from an audio-frequency oscillator. The rate of decay of sound in the chamber is measured by a specially designed reverberation meter consisting of an electrodynamic microphone, amplifier, attenuator, rotating contacts and neon lamp indicator.[4]

Figure 1 shows the results of a series of measure-

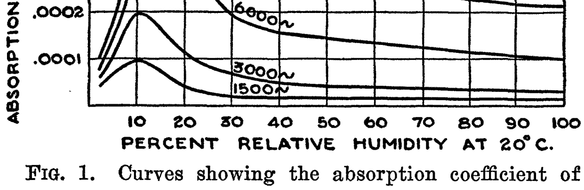

FIG. 1. Curves showing the absorption coefficient of sound in air for different relative humidities at 20° C. Note that for each sound frequency there is a certain humidity at which the absorption is a maximum.

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[3] H. O. Kneser, *Ann. d. Phys.*, 11: 761–801, 1931; *Jour. Acous. Soc.*, 5: 122–126, 1933.

[4] The apparatus is described in an article by the author in the *Jour. Acous. Soc.*, 5: 112–121, 1933.

ments on the absorption of audible sound in air for different relative humidities at a temperature of 20° C., for frequencies of 1,500, 3,000, 6,000 and 10,000 cycles. It will be noticed that for each frequency there is a certain humidity at which the absorption is a maximum. Further, the magnitudes of these maxima are proportional directly to the frequency and *not* to the square of the frequency, as is required by classical theory. Also, the magnitude of the absorption at any frequency or humidity is greatly in excess of the amount predicted by the classical theory—the observed absorption is of the order of 10 to 100 times greater than the classical absorption. For example, at a relative humidity of 18 per cent. and for a frequency of 10,000 cycles, the absorption (or attenuation) coefficient is 0.00065 per cm, or 0.020 per ft. Hence, such a plane wave would have its intensity reduced to $\frac{1}{e}$ of its initial intensity after traveling a distance $\left(\frac{1}{0.020}\right)$, or 50 feet. This is equivalent to a rate of decay of 96 db per sec., or 450 db per mile—a rate of decay which is in excess of the most desirable rate of decay for good acoustics in auditoriums, and which is so high as to exclude the possibility of using tones above, or even near, this frequency for long distance signaling in the air.[5]

Having determined the nature and magnitude of the very high absorption of sound in air containing different amounts of water vapor, the investigation was continued in the direction of ascertaining whether the oxygen, nitrogen or some other component of the air were responsible for the anomalous absorption. Accordingly, measurements were made in oxygen plus water vapor and in nitrogen plus water vapor. In these experiments we obtained the interesting result that the values of the maximal absorption (μ_m) in oxygen plus water vapor were almost exactly five times greater than the corresponding maxima for air plus water vapor; and in the case of nitrogen plus water vapor we found that there was no appreciable absorption in excess of classical absorption, and no dependence of absorption upon the concentration of water vapor.

These findings suggested that the absorption was almost, if not entirely, attributable to the oxygen in the air; and in fact, Dr. H. O. Kneser, who was then at the University of California, showed that the results were in good agreement with Eqs. (1) and (2) provided the absorption resulted entirely from energy transfers between oxygen molecules and provided further that the reaction constant k_{10} were a quadratic function of the concentration of the water vapor. Water vapor is the only gas we have worked with which, when added to oxygen, obeys this quadratic relation; for all other impurities the reaction constant is a linear function of the concentration.

The above measurements in air and in oxygen were made at a temperature of 20° C. At a temperature of 55° C., the absorption in air and oxygen, containing small amounts of water vapor, reached maxima which were approximately twice as large as those obtained at 20° C. This result is in good agreement with the predicted values based on Eqs. (1) and (2).

On the other hand, measurements in air at $-15°$ C. indicated that there was practically no absorption at this temperature—certainly not much more than the classical absorption—and there was no measurable variation of absorption with humidity.

These experiments at different temperatures and humidities explain, in part at least, why sounds are transmitted over such great distances in the cold, dry air of the Arctic, and why similar sounds are stifled in the hot desert air, which so often has just the required humidity to give maximal absorption. All problems associated with the propagation of sound in the atmosphere must reckon with this anomalous absorption. I shall mention only two typical problems: (1) for a given temperature and relative humidity of the air there is an optimal frequency for long range sound signaling, usually not more than 2,000 cycles per second; and (2) in the reproducing of sound in large theaters, and especially in the out-of-doors, selective amplification, in amount and character dependent upon temperature and humidity, should be given to the high frequencies.

The good agreement between the observed and calculated values of the absorption of sound in oxygen plus water vapor indicated that similar absorption measurements in pure or mixed gases should provide an effective means for investigating energy transitions during molecular collisions. Accordingly, Kneser and the author undertook a series of experiments on the absorption of sound in oxygen containing known amounts of gaseous impurities.[6]

The results of these experiments show that the reaction constant k_{10} for O_2 is strongly influenced both by the kind and amount of gaseous impurities, a conclusion which for other gases had been previously reached from dispersion measurements at supersonic frequencies by Richards and Reid and by Eucken and Becker.

Kneser has calculated the collision frequencies and the probabilities of transitions between excited and normal oxygen molecules for the different gaseous im-

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[5] These problems are discussed at greater length in the article referred to in footnote 4.

[6] Kneser and Knudsen, *Ann. d. Phys.*, 21: 682–696, 1935.

purities in oxygen with which we have worked.[6] From these calculations it is found that when an excited oxygen molecule collides with an alcohol molecule the probability is slightly better than 1 in 1,000 that the vibrating oxygen molecule will lose its vibrational energy. This probability of transition is of the order of 5,000 times the probability of transition in collisions between two oxygen molecules. This probability of transition decreases progressively, and in the order named, for impurities of ammonia, benzene, water vapor, acetylene, hydrogen sulfide, carbon tetrachloride, carbon monoxide, hydrogen, carbon dioxide, nitrogen, helium and oxygen. A collision between two oxygen molecules is thus seen to be the least probable type of collision for producing transitions between normal and excited oxygen molecules. It also appears that hydrogen molecules are more effective than helium molecules for producing transitions.

As yet, insufficient data are available to offer a complete explanation of the collision process. However, a number of tentative assumptions are suggested by the data obtained to date.[6]

(1) The simple impulse theory of the transfer of energy at collision is inadequate, since hydrogen, for example, is more effective than the heavier helium.

(2) If an oxygen molecule collides with a molecule having a dipole moment, the collision is more likely to disturb the nuclear vibrations of the oxygen molecule than is the case in a collision with a molecule which has no dipole moment. Thus, our data indicate that carbon monoxide is more effective than the similar nitrogen molecule.

(3) Our results would seem to support the suggestion of Eucken and Becker that a strong disturbance should be expected if the collision partners have a high chemical affinity.

In conclusion, the experiments described in this paper indicate that the measurement of sound absorption in gases provides a new approach to a number of important problems related to molecular collisions. In addition, the absorption measurements in air are of general interest to the most casual observer. They not only clarify a large number of curious problems associated with the influence of the weather on the acoustics of the atmosphere, but they have an immediate and practical application in architectural acoustics and sound signaling.

OBITUARY

HUGO DE VRIES

1848–1935

ON May 21, in the little Dutch village of Lunteren, a kindly old man in his eighty-seventh year died, and the news was cabled to all parts of the civilized world. The passing of Hugo de Vries brings to a close a life rich in achievement.

De Vries was a botanist, but his early work on turgor in plants influenced the development of chemical theory. By means of the plasmolytic method he determined the relative influence of molecular solutions of various salts and organic compounds upon osmotic pressure of the cell sap and expressed these differences in terms of his isotonic coefficients. It was upon these studies that Van't Hoff and Arrhenius based their laws of disassociation in dilute solutions which form one of the fundamental concepts of physical chemistry.

De Vries is most widely known, however, for his influence on biological thought. In 1889 he published his theory of intracellular pangenesis, in which, on the basis of extensive observations, he argued that hereditary particles corresponding to the different adult characters must be present in all cells of the organism. This is an early statement of our modern concept of the gene. In his foreword to Gager's translation of "Intracellular Pangenesis," Strasburger writes as follows: "By creative imagination Hugo de Vries predicted much in his book that gained a material basis only through the histological research of the following decades . . . he predicted phenomena which were to furnish the basis for our conceptions of fertilization and heredity but which have become actually known to us only through later works on the most intimate processes of nuclear division." His powers of prophetic imagination are also shown in an address delivered at the opening of the Station for Experimental Evolution in 1904. He urged that attempts be made to alter the hereditary particles in germ cells by application of external stimuli. He pointed out that x-rays and radium have been found capable of bringing about important changes in living organisms. "If the same holds good for our dormant representatives in the egg we may hope some day to apply the physiological activity of the rays of Röntgen and Curie to experimental morphology." It was nearly a quarter of a century before this hope of de Vries was realized.

De Vries was the outstanding figure in the biological world in the early part of this century when genetics was being born and new and revolutionary ideas were appearing in rapid succession. More than any other man he helped to lead biologists from the speculative age of Darwin into an age of experimen-