In view of the interest which is being taken in the effect of wind on the propagation of sound it may be worth while to recall the form which Döppler’s principle assumes when a wind is blowing.

If the observer is moving with velocity \( v \), the source of sound with velocity \( v \), and the wind with velocity \( V \), all measured in the same direction, then in the case of sound waves moving in the opposite direction and originating at the source with frequency \( f \) the observed frequency is

\[
r_n = \frac{c - v}{c - V + v}
\]

where \( c \) is the velocity of sound in still air.

This result may be obtained with the ordinary form of Döppler’s principle either by reducing the air to rest by subtracting the wind velocity \( V \) from \( u \) and \( v \), or by regarding the velocity of sound in the moving air as \( c - V \).

To prove the formula analytically let us neglect the variation of air-density and wind-velocity with altitude and assume that the wind is blowing steadily in a direction parallel to the axis of \( x \) with velocity \( V \), then the velocity potential \( \phi \) of sound waves propagated through the air satisfies the partial differential equation:

\[
\frac{\partial^2 \phi}{\partial t^2} - c^2 \frac{\partial^2 \phi}{\partial x^2} = 0
\]

This equation may be transformed into the ordinary wave-equation for still air by writing \( x' \) in place of \( x - V t \). The solution corresponding to sound from a moving source which is at the point \( \xi(t), \eta(t) \) at time \( t \) is

\[
\phi = \frac{1}{c^2} \gamma f(t)
\]

where \( \gamma \) is defined by the equation

\[
[x - \xi(t) - V(t - t_0)]^2 + [y - \eta(t)]^2 + [z - \zeta(t)]^2 = c^2(t - t_0)^2,
\]

and \( \gamma \) is the partial derivative of the left-hand side with respect to \( t \).

Putting

\[
x = \alpha + ut, \quad y = 0, \quad z = 0, \quad \xi(t) = \alpha + Vt, \quad \eta(t) = 0, \quad \zeta(t) = 0,
\]

where \( \alpha, \alpha, u, V \) are constants so as to have the case of a source and observer moving along the same straight line with different constant velocities, we find that

\[
t = \frac{t}{v - \alpha} + \frac{u}{v - \alpha} + \frac{c}{v - \alpha}
\]

For sound of frequency \( f \) we may write \( f(t) = A \sin(\nu t + \epsilon) \) and the observed frequency is seen to be given by formula (1). The wave-length is also

\[
\lambda_0 = \frac{2\pi}{\nu (c + \epsilon - V + v)}
\]

It should be noticed that if \( u = v \) the observed frequency is the same as the natural frequency whatever be the velocity of the wind. If \( v = V \) the observed wave-length is the same as the natural wave-length. In actual practice the horizontal wind velocity may be different at the locations of the source and observer owing to vertical motion of the air, eddy motion, and friction. An exact mathematical treatment of the general problem is difficult.

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1 See, for instance, S. Fujisora, in Bull., Central meteorol. obs'y, Japan, Tokyo, (1912), 2, no. 1.
but if $U$ is the wind velocity near the observer and $V$ the wind velocity near the source of sound, the empirical formula

$$v_o = c - U + u$$

may be fairly accurate. It may be worse while to test this formula experimentally.

In the case of an overhead source of sound the theory is naturally complicated and is much more so when the variation of air density and wind velocity are taken into account. Experiments with sound produced in a moving aeroplane may indicate whether the above variations of atmospheric conditions with altitude have any appreciable effect on the observed frequency.

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**PROPAGATION TO GREAT DISTANCES OF THE SOUND OF CANNONADE AT THE FRONT.**

By G. E. Biggs.


A cannonade produces various noises from the mouths of the guns and from the explosions of the shells. Some of these noises can reach great distances, 200 to 300 kilometers, but it is not agreed how they reach them.

It is thus thought desirable to cite the case of an engineer, aged 52, totally deaf since the age of 6 through cerebrospinal meningitis. Placed at the side of a locomotive, he perceived only dull vibrations of the skin, while the other has a very uniform plate of the best mica obtainable (such as is used in phonographs). The resonator is tuned to the pitch for which it is to be used as a detector, and the vibrations of the mica diaphragm are detected and measured as follows: The mica disk carries a sharp steel point firmly clamped at its center. A narrow steel strip is suitably held taut at both extremities in a fork capable of adjustment, and the strip has its center in contact with the steel point, so that a slight movement of the disk and point gives the strip a corresponding twist. This twist is detected by the movement of a beam of light reflected from a small concave mirror carried by the strip.

The diaphragm may be worked backward and is then called the "phone" or standard generator. When its diaphragm is made to oscillate through a known amplitude it is possible to calculate the numerical characteristics of the spherical sound waves emitted. By the use of the "phone" and the "phonometer" the acoustic output of any sound generator of the same pitch (such as violin, cornet, or human voice) may be calculated.

Section five is on aerial sound waves of large amplitude and the discontinuity that may be expected to occur in their propagation. In the sixth section the thermodynamic estimate of acoustic efficiency is treated. By the use of resistance thermometers of iron wire one may measure the temperature fall of the air, due to the conversion of the compressed air energy into sound, was measured in the diaphone.

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**ACOUSTIC EFFICIENCY OF FOG-SIGNAL MACHINERY.**

By L. V. King.


The first section of this paper sketches the history of fog-signal experiments, dwelling specially on the work of Tyndall published in 1874 in a Trinity House report. At about the same time experiments by Duane and by Joseph Henry were conducted, and were published in 1874. The result of fog-signal tests carried out in the United States to the year 1894 were published in Livermore's Report to the Lighthouse Board of that date.

In 1901 a committee of the Trinity House carried out, at the Isle of Wight, a series of tests under the scientific direction of Rayleigh and T. Matthews. For calm weather a low note (about 180 per second) was considered most suitable; when the wind was contrary and the sea rough, it was found that a higher note penetrated farther than a low one. The physical significance of this was discussed by Rayleigh at that time. It appears surprising that while a blast is being sounded from a siren which can be heard about 8 miles away on a good day, energy is being expended at the rate of about 100 horsepower. The high note of a Scottish signal required 600 horsepower. Rayleigh raised the question as to whether these enormous powers are really utilized for the production of sound or whether from some cause, possibly avoidable, a large proportion may not be wasted.

The experience of French fog-signal engineers was summed up by C. Ribbière in 1908. This emphasized the desirability of obtaining further knowledge as to the efficiency of the fog-signal apparatus.

The second section deals with the production of sound by a special noise called the "diaphone," due in its present form to J. P. Northey. The essential feature of this apparatus is a hollow cylindrical piston, which is oscillated longitudinally by the "driving air," and so opens and closes ports which allow a series of puffs from the "sounding air." These puffs give a nearly pure tone of about 180 per second. This sound passes through a suitable horn.

The third section is occupied with the numerical relations between sound waves and their audibility as fog-sounds.

The fourth section deals with the "phonometer" due to S. G. Webster. This consists of a Helmholtz hollow cylindrical resonating chamber, one end of which is pierced by a smooth hole communicating freely with the atmosphere, while the other has a very uniform plate of the best mica obtainable (such as is used in phonographs). The resonator is tuned to the pitch for which it is to be used as a detector, and the vibrations of the mica diaphragm are detected and measured as follows: The mica disk carries a sharp steel point firmly clamped at its center. A narrow steel strip is suitably held taut at both extremities in a fork capable of adjustment, and the strip has its center in contact with the steel point, so that a slight movement of the disk and point gives the strip a corresponding twist. This twist is detected by the movement of a beam of light reflected from a small concave mirror carried by the strip.

The diaphragm may be worked backward and is then called the "phone" or standard generator. When its diaphragm is made to oscillate through a known amplitude it is possible to calculate the numerical characteristics of the spherical sound waves emitted. By the use of the "phone" and the "phonometer" the acoustic output of any sound generator of the same pitch (such as violin, cornet, or human voice) may be calculated.

Section five is on aerial sound waves of large amplitude and the discontinuity that may be expected to occur in their propagation. In the sixth section the thermodynamic estimate of acoustic efficiency is treated. By the use of resistance thermometers of iron wire one may measure the temperature fall of the air, due to the conversion of the compressed air energy into sound, was measured in the diaphone.

Section seven deals with the actual fog-signal experiments carried out near Quebec in 1913. The acoustic efficiency of the diaphone in one case was found to be nearly 6 per cent, in another a little over 8 per cent. Using his phonometer A. G. Webster had previously found the violin, the cornet, and the human voice to have acoustic efficiencies of about 0.05 per cent, 0.1 per cent, and 1 per cent, respectively.