it once rather quickly, "G.W." settled down to a more leisurely perusal. It happened that I then moved to a position at the end of the desk. I was therefore able to see that, as he reread the letter reporting the calculations, a more and more sour look was appearing on "G.W.'s" face. He presently picked up the slide rule that always lay on his desk and began using it, looking from the letter to the slide rule again and again. At the conclusion of his comparisons he turned toward me and said, "You know, that answer should have been 62 miles." At this mention of essentially the accepted height of the E-layer, Cohen and I came awake with a start. We carefully watched "G.W." backtrack through the calculations and come to the conclusion that, in 1912, he had taken the answer from the wrong end of the slide rule.

Professor Pierce was kind enough to inscribe and initial the correction in the margin of his carbon copy of the erring letter and give it to me as a souvenir, with permission to publish an account of the happening "sometime when de Forest and I are both dead."

A probable result of this error was that the world waited a dozen years for Professor E. V. (later Sir Edward) Appleton to measure the height of the Kennelly–Heaviside layer or E-layer, as it was named by Appleton. His method was essentially that of 1912 but with better scientific control of the variables. It is an interesting footnote that both Appleton's paper in 1924 and the paper by Breit and Tuve reporting the first pulse measurements of layer height in 1925 were titled as *proofs of the existence* of an ionized layer.

[1]Professor Cohen has given a brief account of this episode on p. 267 of his book *Science, Servant of Man: A Layman's Primer for the Age of Science* (Little, Brown, Boston, 1948, 1949; Sigma, London, 1949). I am grateful for the help of Professor Cohen in criticizing my version of this anecdote. He has corrected my dates and contributed useful editorial and background information. I am especially interested to be told that de Forest was one of the few candidates to complete his work for the Ph.D under Willard Gibbs.

Acoustic demonstrations in lecture halls: A note of caution

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A number of papers in this Journal and elsewhere[1] have described demonstrations of acoustic interference using two or more loudspeakers as sound sources. Sometimes a note of caution is added, pointing out that the interference pattern may be altered if one "gets too close to the walls of the lecture room." It is the purpose of this note to point out that the effect of reflections of sound at the surfaces of the room is often underestimated.

Particularly popular are demonstrations of Young's interference between two small loudspeakers in the front of the room separated by a wavelength or two. The students are asked to move their heads from side to side to hear the minima and maxima in the sound field, which of course they have no trouble detecting. Occasionally a student is puzzled because similar maxima and minima are detected when he moves his head toward and away from the source as well. Also, the distance between maxima and minima seldom agrees with the spacing predicted by simple two-source interference theory.

There are at least two simple ways to view the effects of the walls on the sound field. One is to think of the room as a "hall of mirrors." Plastered walls typically reflect 85–95% of the sound incident on them, which is comparable to the optical reflection from an ordinary mirror. A geometry for a simple rectangular room is illustrated in two-dimensional projection in Fig. 1. Sound reaches the observer from the directions of dozens of images of the sources. The intensity of each "sound ray" is of course determined by the distance travelled as well as the number of boundaries crossed. It is quite obvious that unless the primary path from the source to observer is much shorter than all the secondary paths, the many image sources will contribute substantially to the observed interference pattern.

Another approach, which leads to a similar result, is to consider the *near field, far field,* and *reverberant field* of the radiating source. In the near field, the sound intensity is strongly influenced by the directional characteristics of the radiating source. In the case of loudspeaker sources, this is determined by the size of the cones, the type of baffles, etc. In the free-field part of the far field, the direct sound dominates, and the intensity follows the inverse-square law rather closely. In this free field, the simple theory of Young's experiment is valid. In the reverberant field, the sound is diffuse (that is, sound arrives from many directions), and the intensity does not depend upon distance from source to

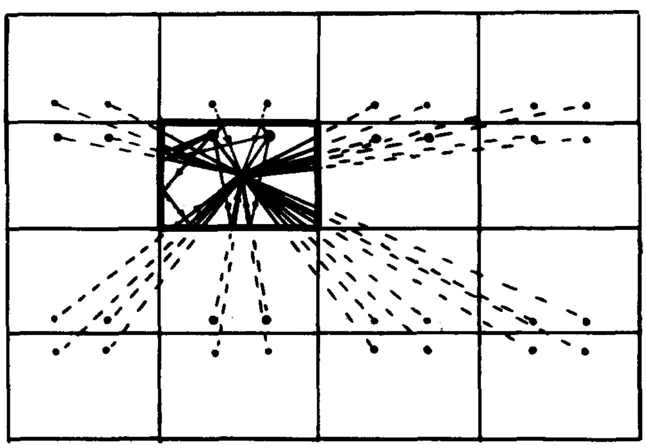

Fig. 1. Two-dimensional projection illustrating some of the sound "images" of two loudspeakers in a rectangular room. The three-dimensional pattern includes reflections by the ceiling and the floor, and greatly increases the number of images which may contribute.

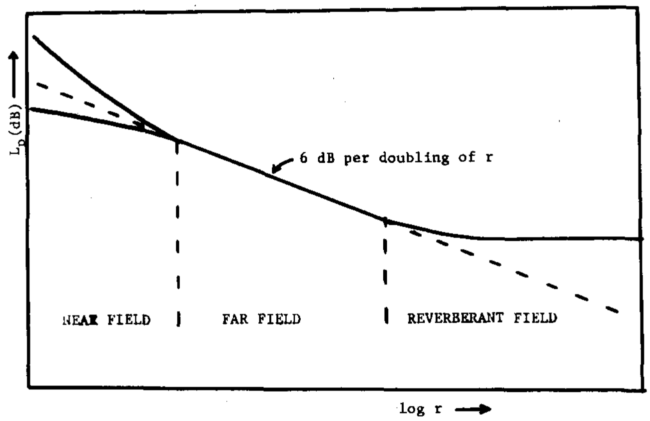

Fig. 2. Variation of sound pressure level L_p with distance from the source r in a typical large room. In the free-field region, intensity varies as $1/r^2$, so L_p decreases 6 dB each time r is doubled. In the near field, L_p depends upon the geometry of the source.

observer, as shown in Fig. 2. The distance from the source at which the transition from free field to reverberant field takes place is determined by the character of the room. In an anechoic chamber, the free field extends practically to the boundaries; in a reverberation chamber nearly the entire room is a reverberant field. Obviously, physics lecture halls lie somewhere between these two extremes.

The sound intensity in the direct field may be written $I = WQ/4\pi r^2$, where Q is a directional factor ($Q = 1$ for a nondirectional source), W is total radiated power, and r is distance from the source. The corresponding mean-square pressure is $|p|^2 = W\rho c Q/4\pi r^2$, where ρc is the acoustic impedance of air. For the reverberant field, the mean-square pressure is $|p|^2 = W\rho c(4/R)$, where R is a "room constant" defined as $R = S\overline{\alpha}/(1 - \overline{\alpha})$, S being the total surface area and $\overline{\alpha}$ the average absorption coefficient of walls, ceiling, and floor.[2] The sound pressure level is thus given by

$$L_p = L_w + 10 \log(Q/4\pi r^2 + 4/R) \text{ dB},$$

where L_w is the sound power level of the source.

For a "typical" medium-size lecture hall of dimension $30 \times 30 \times 20$ ft and $\overline{\alpha} = 0.15$, $R = 8000$; the direct and reverberant levels become equal when $r \approx 13$ ft. For a student seated 25 ft from the source, the mean-square pressure of the reverberant sound is roughly four times (6 dB) greater. $\overline{\alpha}$ varies with frequency, of course, since most wall materials are more absorbant at high frequencies. Contributions by people and furniture may be a substantial part of the total absorption in the average lecture hall.

If the source emits a single frequency, we can think of a room full of standing waves fed by reflections, and a two-source interference pattern fed by direct sound. The relative strength of these patterns is determined by the location of the observer in the room. The distance between nodes may be quite different from the free-field half-wavelength.

It is instructive to have students probe the room with a sound level meter or a microphone connected to a voltmeter or oscilloscope. After they observe standing wave ratios of 10–20 dB, one can question the importance of selecting stereo components which are "flat to ±2 dB," and usually stimulate a lively discussion.

[1]See, for example: H. Blum, Am. J. Phys. **42**, 413 (1974); S. H. Vegors, Jr., *ibid.* **43**, 1103 (1975).

[2]T. F. W. Embleton, in *Noise and Vibration Control*, edited by L. L. Beranek (McGraw-Hill, New York, 1971), p. 226.

Does the displacement current in empty space produce a magnetic field?

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It is now over a hundred years (1861) since Maxwell[1] introduced the displacement current ($\epsilon_0\dot{\mathbf{E}} + \dot{\mathbf{P}}$), and over 70 years since Einstein[2] introduced the theory of special relativity, which made the theories of the luminiferous ether "superfluous." There is still confusion in many introductory textbooks on classical electromagnetism about the role of the displacement current in empty space.

When the displacement current in empty space is first introduced, many authors interpret the equation

$$\text{curl}\mathbf{B} = \mu_0\epsilon_0\dot{\mathbf{E}} \tag{1}$$

by making statements such as: "A changing electric field produces a magnetic field."

In the 19th century, the ether was treated as a special type of dielectric, and it was believed that the roles of the $\epsilon_0\dot{\mathbf{E}}$ and the $\dot{\mathbf{P}}$ terms were similar. Nowadays the $\epsilon_0\dot{\mathbf{E}}$ term is not associated with the displacements of elements of the ether. The quasistatic case was considered by French and Tessman[3] and by Purcell,[4] who pointed out that, in the quasistatic limit, it does not matter whether or not the displacement current in empty space ($\epsilon_0\dot{\mathbf{E}}$) is included when the Biot–Savart law is applied, provided the integration is over the whole of space. Whitmer[5] showed that, in the presence of dielectrics, the $\dot{\mathbf{P}}$ term in the Biot–Savart law did contribute to the magnetic field. This is to be expected in contemporary theories since the $\dot{\mathbf{P}}$ term is associated with the movements of charges on the atomic scale inside dielectrics.

The Biot–Savart law is not applicable at high frequencies when retardation and radiation effects are important. At high frequencies it is convenient to use the vector potential. The displacement current in empty space ($\epsilon_0\dot{\mathbf{E}}$) should *not* be included in the expression for the retarded vector potential (Lorentz gauge).