that the well-known absorption bands of cholesterol were definitely altered as a result of irradiation, that the sterol becomes more permeable to certain definite wave-lengths of ultra-violet light. This work, into which we shall not enter in detail, was first undertaken in this country, and has more recently been refined and extended by Heilbron in Liverpool, and Pohl in Goettingen. Furthermore, by means of the use of monochromatic ultra-violet light, it was shown that the uppermost limit of the antirachitic field may be placed at 313 $\mu\mu$, and that even at this point its action is feeble. When we bear in mind that the shortest rays of the sun which reach the surface of the earth rarely are less than 300 mm. in length, it is evident how circumscribed is the area of specific solar radiations. *A difference of a few millimicrons or millionths of a millimeter determines whether or not waves are specific or ineffective.*

It was soon evident that only a very small fraction of the cholesterol becomes activated following irradiation, less than one per cent. This observation raised the question in the minds of several investigators, as to whether it is truly the cholesterol which is transformed or some associated sterol—a subject which during the past year has been studied by Windaus and myself, as well as by Rosenheim and his coworkers in London. It developed that another unsaturated sterol—a sterol with 3 unsaturated bonds—is mainly concerned in the elaboration of the antirachitic factor, namely ergosterol, which heretofore has been extracted from ergot and from yeast, but which is now being found more widely distributed in nature. It would lead too far afield to discuss the moot question of the activation of cholesterol and other sterols. In brief, it may be stated that it has not been shown definitely that cholesterol, as well as ergosterol, can not be activated. In this connection, the minuteness of the amount of irradiated ergosterol required to protect an animal should be emphasized; it has been found that *1/10,000 of a milligram or 1/10,000,000 of a gram daily is sufficient to confer protection.* When we bear in mind that this infinitesimal amount is given by mouth, it is difficult to conceive that the specific antirachitic factor exerts its curative action directly and bodily on the various epiphyses throughout the body.

Parallel with these investigations on ultra-violet radiations and the sterols, which engaged the attention of the physicist and of the chemist, the question was being considered as to how these newer ideas could be brought into consonance with the well-established fact of the specific antirachitic properties of cod-liver oil. At first the two phenomena seemed irreconcilable, but, as you know, it soon was demonstrated that the activity of cod-liver oil in rickets rests on the same basis as that of foods which have been subjected to irradiation—that both are dependent on the action of a specific sterol. In passing, it should be added, however, that it has not been shown that the therapeutic activity of cod-liver oil is confined to the effect of this sterol.

In my review of this subject, it has been necessary to treat the advances in the fields of biology, chemistry and physics as if they took place consecutively. As a matter of fact, they have progressed at one and the same time, new discoveries by the physicist being made at once the basis for some newer chemical investigation and both in turn leading perhaps to interesting developments in the provinces of experimental biology or clinical therapeutics. Some of these studies have been carried out in conjunction or close cooperation with the clinic, others have been made in laboratories devoted solely to investigations in pure science. In the light of recent studies of the vitamins and hormones, it would seem that, in general, this probably will be the method—if it can be called a method—of advancement in the future. It is questioned often whether newer technics and discoveries in medicine will be evolved by the clinician in ward and laboratory, or whether, as it becomes necessary to delve ever deeper into the realms of pure science, the clinician, in spite of his modern training, will not become dependent upon the discoveries of the physicist, the chemist and others occupied with the basic sciences.

No one can answer this question with any degree of certainty. It seems probable nevertheless that for some time to come the clinician—owing to his strategic position in the broad realm of medicine—will continue to make valuable and even basic contributions to our store of knowledge, and that the recent experience in the field of rickets will from time to time be repeated in other provinces of clinical medicine. It can, however, be safely predicted that in order to gain this newer knowledge we must once more call to our aid in varying degree biology, chemistry and physics.

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ACOUSTICS OF AUDITORIUMS*

A CONSIDERATION of recent investigations led the writer logically and unexpectedly to the conclusion that good acoustics in an auditorium may be obtained by making it like the outdoor theater of the Greeks. Also, it is concluded that better acoustics appears likely if a study is made of the way in which speech and music are generated, with special consideration

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of the effect of the sound reflected from walls near the speaker or musician.

Very little was known scientifically about acoustics of auditoriums until W. C. Sabine, about 1900, began to publish the results of his work.[1] Aside from occasional minor faults or interference and resonance, Sabine concluded generally that the acoustics of a room depended mainly on the reverberation or decay of sound. He conducted an extensive and careful series of investigations which showed that the time taken for a standard sound to die out in a room depended on the loudness of the sound and on the volume of the room, and inversely on the absorption of the surfaces in the room. Most of the investigations since then have only amplified and extended Sabine's fundamental conclusions.

As a result of these efforts, auditoriums have been greatly improved in acoustical qualities, so much so that attempts have been made to specify "optimum" conditions,[2] with the hope of securing perfect acoustics. Auditoriums adjusted according to these conditions, while generally satisfactory, have not always given the expected perfect effects. In some cases, speakers and musicians have voiced objections without being able to state clearly what the trouble was.

In the meantime, within the past two or three years, several publications have appeared that yielded information from different viewpoints than those given originally by Sabine and that furnish possibilities of improving acoustic effects. That is, while Sabine investigated primarily the reverberation and decay of sound, these later studies deal more particularly with the growth of sound in a room.

For instance, Petzold[3] has shown that blurring (Verwischung) will be set up if two identical speech sounds reach an auditor with a time interval between them of .05 second or more. This would be the case if two speakers were separated about fifty-six feet and uttered the same words simultaneously. While it is practically impossible for two speakers to do this, the effect may be obtained by a single speaker who stands near a reflecting wall so that his acoustic image on the other side of the wall may be thought of as saying the same words as the speaker and at the same time. The image is really due to the reflected sound. For music, Petzold finds a shorter time limit between two sounds of .035 to .042 second, depending on the character of the music.

This conclusion of Petzold's indicates the importance of studying the reflecting surfaces near speakers and musicians to avoid blurring effects. Usually in auditoriums, the space about the performer has been decided by other requirements than acoustics. The large stage house of the modern theater gives little practical opportunity for suitable reflecting walls. In smaller auditoriums, it would be easier to design such reflectors, without the usual heavy absorbing curtains.

Such reflecting surfaces should preferably be plane, and situated not more than about twenty feet from the performer—a smaller distance would give better results—and inclined so as to reflect sound to the audience. Under these circumstances, the direct sound from the performer is reenforced without distortion by a number of images, all giving simultaneously the same sound.[4]

Not only are the auditors benefited by this arrangement, but the performer himself gets an immediate response to his effort that allows him to adjust his speech or music to get the best effect. Without this, the performer feels lost, and the resulting sound, particularly music, lacks perfection. Musicians state that they prefer to sing or play near a wall—and always with a resonant stage floor, without carpet—presumably because of the reassuring support given by such reflecting surfaces.

An experiment of this nature recently performed by the writer supports this view. A reflector, twelve by fourteen feet, was hung horizontally over a band stand, and, by means of ropes and pulleys, could be raised or lowered. When the reflector was lowered successively to positions twelve, ten, eight and seven feet above the players, the acoustic conditions were improved. The comments of the players were: "Plays easier," "Tones are more natural," "Gets better as the reflector gets lower," "Tones are smoother," etc. The resultant music in the hall for auditors was also better as the reflector was lowered.

Petzold[5] describes some uses of reflecting surfaces about orchestras and choruses. An orchestra pit, for instance, is a resonant enclosure that allows the music to be reenforced and blended beneficially before it goes out to the audience. "Sounding" boards are advantageous if they have sufficient size and if placed intelligently in accordance with acoustic principles.

Another investigator[6] obtains values of the resultant sound as it builds up and dies out at various points in an auditorium. By means of a condenser-transmitter, amplifying device and oscillograph, he obtained curves

[1] "Collected Papers on Acoustics," 1922.

[2] S. Lifshitz, *Physical Review*, 25, 391, 1925; 27, 618, 1926; F. R. Watson, *Architecture*, LV, 251, 1927.

[3] Ernst Petzold, "Elementare Raum Akustik," 1927, p. 8.

[4] F. R. Watson, "Acoustic Design of Churches," *Western Architect*, XXXVI, 178, 1927.

[5] *Loc. cit.*, Chap. 10.

[6] F. Trendelenburg, "Experimentalbeitrag zur Raumakustik," *Zts. für Tech. Physik*, No. 11, 1927.

of the resulting sound. In certain positions near the source of sound, where the reflected sound arrived some time after the direct sound, it was easy to understand the speaker. At considerable distances from the speaker the reflected sound was of more influence and the understanding of speech was difficult. He concluded that good speech understanding would be obtained only at points where the direct sound predominated.

In another connection, Petzold[7] calculated the value of the direct sound at a point 18.1 meters from the source in a room 30 x 20 x 12 meters in volume, and estimated also the added effect of the reflected sound. Neglecting interference phenomena, he assumes that the direct sound gives 10,000 "Vox" (where the Vox is the arbitrary unit of intensity of a sound produced by a special organ pipe used). To the direct sound, the beneficial reflections, that is, those that arrive quickly enough to avoid blurring the direct sound, add enough to give a total of 31,210 Vox. The resultant is then about three times as intense as the direct sound, but the loudness, as perceived by a listener, is less than this, being proportional to the logarithm of the intensity. The relative effects for auditors are the logarithms of 10,000 and 31,210, or 4 and 4.5, respectively; that is, the beneficial reflected sound contributes one half unit to the four units of the direct sound, or only one ninth of the total sound.

From these calculations, it would appear that the reflected sound could be omitted entirely without vital consequence—a conclusion that is quite contrary to the usual conception of auditorium acoustics, where the reflecting walls are supposed to be quite beneficial in increasing the loudness. Omitting the reflected sound would have the advantage of eliminating any possible blurring defects of reflection, as previously described. But this arrangement surprisingly suggests the open-air theater, such as was used by the Greeks, with no reflecting surfaces except the wall at the rear of the stage, and generally regarded as having very good acoustics.

A book[8] on outdoor theaters bears out this supposition about satisfactory acoustics. For example, we read, "Outdoor theaters differ considerably with regard to acoustic qualities, but in general it is surprisingly easy in any of them to hear what is said or sung on the stage." Regarding the Garden Terrace Theater at Yankton, South Dakota, the author writes, "The acoustic properties are a surprise to every one. At the extreme rear, 180 feet from the stage, an ordinary stage or platform voice is perfectly clear and satisfactory." In the Greek theater at the University of California, that holds an 8,000 audience, one can see and hear in every seat. Again, "The acoustic qualities of the theater (Isis Theater, Point Loma, California), like those of every other outdoor theater without exception, are spoken of as remarkable." And so on for other theaters.

An experiment by the writer furnishes a suggestive example. In an investigation on "Optimum Conditions for Music in Rooms,"[9] the fact was brought out that musicians preferred a reverberant space to play in, but that auditors found "dead" surroundings preferable for listening. What was done was first to adjust a room of approximately 6,500 cubic feet volume to give "optimum" reverberation by placing sound-absorbing material about the walls. A quartette of musicians (three violins and a cello) then played at one end of the room. They did not like the musical effects, nor were the auditors pleased. But when the absorbing material was transferred from the walls about the musicians to the end of the room occupied by the listeners, the musical effects for both playing and listening improved until, in the final stage, they were thought "perfect." This arrangement appears to imitate an outdoor theater. The "dead" conditions surrounding the listeners are repeated outdoors by the perfect absorption of the open sky, but there would be some reflection from the leaves of trees and plants.

An experiment by Sabine[10] was performed in which absorbing material was brought into a music studio until the musicians present thought the conditions were satisfactory. This was repeated in several other similar studios. Sabine then found in subsequent experiments that the average time of reverberation for rooms of this size was 1.08 seconds, thus indicating that an optimum reverberation exists for players, that is, for the generation of sound.

Lifshitz[11] conducted a similar experiment in a room of 265 cubic meters volume holding an audience of 120 persons. By varying the number of auditors he could conveniently change the absorption—due to clothing—and thus control the time of reverberation. Opinions were given concerning the acoustic effects, so that he arrived at an average optimum time of 1.11 seconds. Earlier experiments in a room of 126 cubic meters volume gave 1.03 seconds as the optimum. Averaging four values—Sabine, 1.08 sec., Watson ("Acoustics of Buildings," p. 51), 1.04 sec., Lifshitz, 1.11 and 1.03 sec.—he obtained 1.06 seconds as the

[7] *Loc. cit.*, p. 74.

[8] Frank A. Waugh, "Outdoor Theaters," 1917.

[9] SCIENCE, LXIV, 207, 1926.

[10] "Accuracy of Musical Taste," Proc. Amer. Acad. Arts and Sciences, XLII, June, 1906.

[11] "Mean Intensity of Sound in an Auditorium and Optimum Reverberation," *Phys. Rev.*, 27, 618, 1926.

optimum value for reverberation for rooms of this size. While these experiments allowed an optimum to be estimated for the reverberation or decay of sound, the writer is led to ask if the listening musicians in each case did not primarily pronounce an opinion on the generation of sound rather than the decay.

Experiments by Knudsen[12] show that speaking is better understood as an auditorium is made successively "deader" with sound-absorbing materials, thus imitating an outdoor theater. He found[13] for an open-air theater (Hollywood Bowl, Los Angeles) that a listener one hundred feet from the speaker could understand speech better than in the most satisfactory Los Angeles theater. Lifshitz (*loc. cit.*) found the same effect, but thought the speech lost its musical quality and became dry and lifeless.

The Eastman Theater, Rochester, New York, gives further information in this regard. Some apprehension was felt in designing the acoustics of this theater[14] whether or not music would be heard distinctly on the mezzanine balcony. The opening to this balcony, under the main balcony, was comparatively small and it seemed likely that only a small amount of sound would enter. Also, this space was furnished with a considerable amount of sound absorption in the upholstered seats and carpet. On completion of the theater, however, the reception of music on this floor was thought superior to other locations. Here again it appears advantageous to have conditions for listening quite dead acoustically.

From the investigations cited in this article, the writer is led to draw certain conclusions and to make suggestions for further experimental work. That is, the problem of the acoustics of auditoriums is twofold—first, a study of the generation of sound and its building-up processes, which are practically completed in one or two tenths of a second; and second, a study of the decay of sound. The latter feature has been studied extensively by Sabine and his followers, but further investigation of the growth of sound appears promising in securing important information.

The growth of sound and the decay of sound are not independent processes, because the absorption of the room affects both. What is desired apparently is to have the time of reverberation shortened sufficiently so that the successive sounds of speech and music will be given opportunity for suitable development without possibility of serious overlap and distortion.[15] Increasing the absorption allows a sound to rise more quickly to its maximum value, and also increases advantageously the rate of decay so that the field is cleared for the next sound.[16]

Further information on the relative adjustment of the growth and decay of the sound is given by the investigations of the "masking" of one tone by another. For instance, Wegel and Lane[17] showed that the masking of two tones was greatest for tones nearly alike. Also, they found that loud tones more easily masked tones of high frequency than those of low frequency. Knudsen[18] showed that noise had more effect than a pure tone on another tone. He states also, "For good hearing in an auditorium, the speech energy should be from 1,000 to 10,000 times the energy of any interfering noise." These investigations would indicate how much two sounds could overlap without serious distortion.

The various investigations discussed lead the writer to suggest the possibility of an "indoor-outdoor" theater; that is, an indoor theater that incorporates the good acoustics of an outdoor theater. An investigation should be made to improve, if possible, the stage conditions of the outdoor theater.[19] A stage with a wooden floor, a vertical rear wall, diverging side walls and a sloping ceiling gives promise of beneficially reenforcing speech and music and also of developing enough resonance so that the speaker can better judge the effect of his voice. The use of thin, resonant reflecting boards would yield some interesting effects. On the other hand, it would be instructive in an indoor theater, to have the auditorium quite dead—comparable with outdoors—but to try a stage similar to the one just described. Additional information is needed about the resultant speech effects at different points in a room; that is, a photograph of the vibrations set up by words and music of different kinds when sound-waves cross each other. Some attempts in these directions are being tried by the writer, but cooperation of others in this apparently important development appears desirable.

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12 V. O. Knudsen, *Physical Review*, 26, 287, 1925.

13 *The Architect and Engineer*, September, 1926.

14 Watson, "Acoustics of Buildings," p. 49.

15 Trendelenburg, *loc. cit.*; E. A. Eckhardt, "The Acoustics of Rooms," *Jour. Franklin Inst.*, 195, 799, 1923; E. Michel, "Horsamkeit Grosser Räume," p. 8.

16 Watson, "Acoustics of Buildings," p. 16.

17 "Auditory Masking of One Pure Tone by Another," *Phys. Rev.*, 23, 266, 1924.

18 "Interfering Effect of Tones and Noise Upon Speech Reception," *Phys. Rev.*, 26, 133, 1925.

19 R. Berger, "Die Schalltechnik," p. 61; Davis and Kaye, "The Acoustics of Buildings," chap. VII.