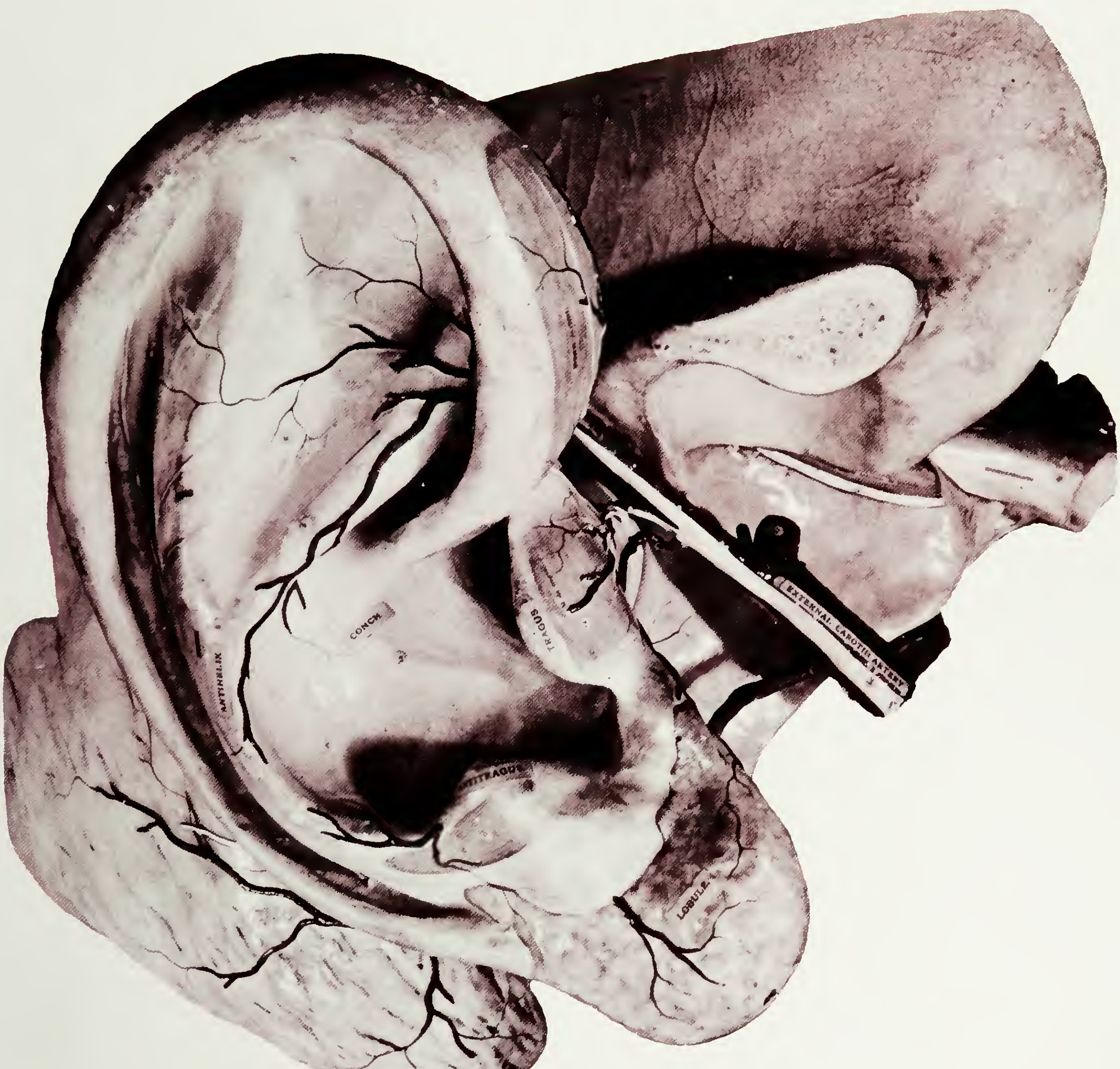
EARLY AUDITORY STUDIES

ACTIVITIES IN THE PSYCHOLOGY LABORATORIES OF AMERICAN UNIVERSITIES

Audrey B. Davis and Uta C. Merzbach



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ABSTRACT

Davis, Audrey B., and Uta C. Merzbach. Early Auditory Studies: Activities in the Psychology Laboratories of American Universities. *Smithsonian Studies in History and Technology*, number 31, 39 pages, 36 figures, 1975.—The last quarter of the nineteenth century was a formative period for experimental psychology. American pioneers in the field joined their Continental colleagues in basing the "new" psychology on the methods, apparatus, and experiments of physics and physiology. Hermann von Helmholtz, claimed by both fields, was a pilot in their new endeavors.

Auditory studies reflect this general pattern. Specialized equipment used in the psychology acoustics laboratory ranged from models of the anatomy of the ear, mechanical models to explain the functions of the ear, sound producers, receivers and measurers, to analyzers and synthesizers. Discussion of the role of the instruments in posing and answering subject-related questions of the psychologist leads to further questions on the development of the intellectual and physical institutions of psychological research.

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Preface

The following work is based on a paper entitled "Soundings Then and Now: Audition and the First Fifty Years of Experimental Psychology in American Laboratories," presented at the annual meeting of the History of Science Society in December 1972. It is an outgrowth of a collecting program in the National Museum of History and Technology, Smithsonian Institution, aimed at bringing together a representative selection of laboratory equipment in psychology. Until now emphasis has been placed on items used prior to 1930.

Of the illustrated objects, those in the National Collections were donated by Cornell University, Skidmore College, Union College, the University of Maryland, and the United States Military Academy.

We wish to acknowledge the assistance of D. J. Elliott and Anita Kordela in the preparation of the manuscript.

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ACTIVITIES IN THE PSYCHOLOGY LABORATORIES OF AMERICAN UNIVERSITIES

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Psychophysics, Physiology, and the Rise of Scientific Psychology

In 1860, the 59-year old Gustav Theodor Fechner published his *Elemente der Psychophysik*. In 1867, the 25-year-old William James wrote home from Berlin:

> It seems to me that perhaps the time has come for psychology to begin to be a science—some measurements have already been made and more may come of it . . . Helmholtz and a man named Wundt at Heidelberg are working at it, and I hope I live through this winter to go to them in the summer. (Perry, 1935, 2:1)

James lived, but he did not go to Helmholtz; and as time went on he increased his distance from the man named Wundt.

Whether or not they communicated in person, whether or not they followed the Germans in their thinking, the American pioneer experimental psychologists of James' generation studied Hermann Helmholtz (Figure 1) and tended to follow the experimental paths outlined by Wilhelm Wundt or Hermann Ebbinghaus, Carl Stumpf, or G. E. Müller. When we look at work in hearing and acoustics performed in American laboratories of experimental psychology before 1930, we find that the majority of experiments form part of two traditions that may be identified either with Wundt or with Stumpf, and that both of these take Helmholtz as their measure.

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Helmholtz's *Tonempfindungen*

In Helmholtz's classic *Lehre von den Tonempfindungen*, published in 1863, his aim was to "connect the boundaries . . *of physical and physiological acoustics* on the one side, and of *musical science and esthetics* on the other" (Helmholtz, 1954:1). The links are tones and the sensations of tones. He divided acoustical studies into the physiological, the physical, and the psychological parts. The physical deals with the motions of elastic bodies; the physiological deals with the ear, including the question of how the excitation of the auditory nerves gives rise to the sensations of sound; and the psychological with the perceptions of sound, that is, with "mental images of determinate external objects" (Helmholtz, 1954:4).

Helmholtz's book is divided into three parts: He begins with a discussion of the physical and physiological aspects of audition and arrives at his famous "resonance theory of hearing" through a physical analysis of the nature of partials, in which their relation to tonal quality is emphasized. The second part is devoted to the study of beats and combination tones, which includes Helmholtz's contribution to theories of consonance and dissonance; here physiological theory is brought into correspondence with the musical rules for the formation of chords. The final part deals with music, taking up the question of tonality after an introductory discussion of

FIGURE 1.—Hermann von Helmholtz (1821–1894). (SI photo T56571)

musical scales. Trying throughout to interrelate the physical, physiological, and psychological aspects, he states that the musical consequences "must be to the physiologist a verification of the correctness of the physical and physiological views advanced" (Helmholtz, 1954:5).

English-speaking students of the subject read Helmholtz's revised versions of the book in two translations by A. J. Ellis that appeared in 1875 and 1885 (Helmholtz, 1954). These bound a decade worth noting, since it marks the founding of the first American laboratories of experimental psychology.

The Decade 1875–1885

In 1875, William James, teaching physiology at Harvard, added to his course offering a graduate course on "The Relations between Physiology and Psychology" and obtained support for related laboratory work. In 1876, the American nation celebrated its Centennial with an exposition at Philadelphia: The French exhibition featured the acoustic apparatus of Rudolph Koenig (Figures 2–4), of which the jury, in awarding it a gold medal, declared, "There is no other [exhibit] in the present International Exhibition which surpasses it in scientific interest" (Philadelphia, 1880:489). Among the American exhibitors, Alexander Graham Bell astounded the multitudes by a demonstration of his newly patented telephone. Invention is the mark of this decade: Edison's phonograph of 1877 can be followed by a yearly listing of audiometers, microphones, graphic sound recorders, hearing aids, and the like. Meanwhile in 1878, G. Stanley Hall obtained what is cited as the first doctorate in psychology at Harvard with a thesis on "the muscular perception of space" worked out in Bowditch's physiology laboratory under William James. In 1879, Wundt's famous laboratory of experimental psychology was formally opened in Leipzig. Here, as James McKeen Cattell noted, "The students come from all quarters (. . . except from England); there are nearly always Americans and Russians, and often Scandinavians, Czechs, Greeks and Frenchmen" (Cattell, 1888:39). Within a year of its formal founding, Hall went to. the Leipzig laboratory to do postgraduate work. In 1880, too, Cattell went to Germany and heard Hermann Lotze as well as Wundt, to whom he returned in 1883, becoming his assistant. That was the year Hall founded the laboratory at Johns Hopkins, an event that marks the beginning of a phenomenal growth. By 1888 there were five formal psychology laboratories in the United States: at Harvard, at The Johns Hopkins University, and at the universities of Pennsylvania, Indiana, and Wisconsin. After another five years, there were twenty, and by the turn of the century this number had doubled. The *American Journal of Pyschology* appeared in 1887, only four years after the start of Wundt's *Philosophische Studien.*

FIGURE 2.—R. Koenig's acoustic apparatus at the International "Centennial" Exhibition in Philadelphia in 1876. Note the large forks in the case on the left, the tonometer and the siren "telephone" in the center case. (SI photo 74–3810–10)

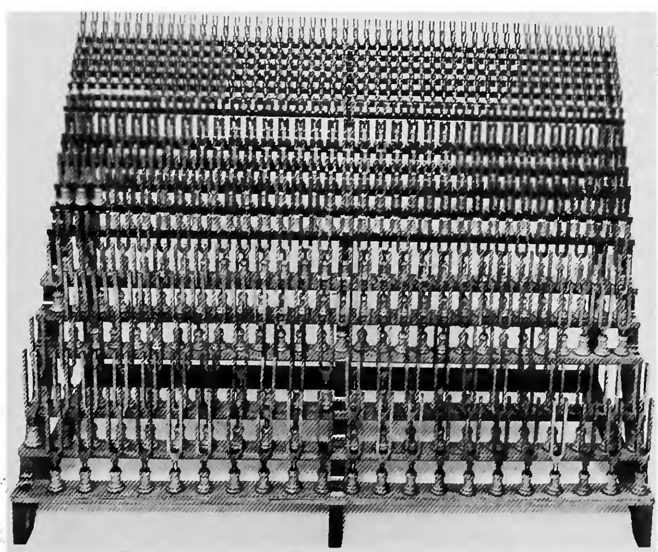


FIGURE 3.—Tonometer exhibited by R. Koenig in 1876. This set containing over 650 forks was purchased for the United States Military Academy at West Point after the Centennial Exhibition. (SI photo T70524; USNMHT 217544)

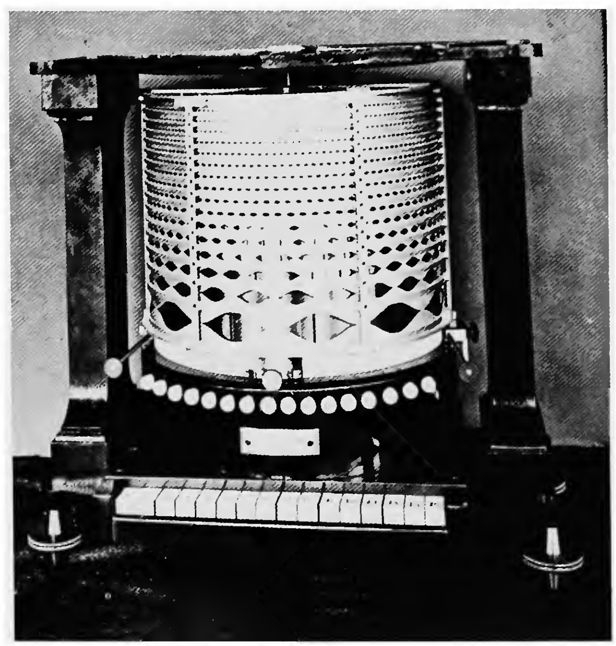


FIGURE 4.—"Telephone" siren exhibited by R. Koenig in 1876. (SI photo 74–3804–17)

The Inheritance of Physiology Prior to World War I

American laboratories of psychology showed the influence of the German laboratories where most of their directors had been trained. Yet Edward B. Titchener and other experimental psychologists reminded the young instructor in psychology of the essential characteristic of the American as contrasted with the German laboratory. The latter was a research laboratory. Introductory laboratory courses at best exposed the student to experimentation by a series of demonstration lectures or exercises; further training consisted of serving as "experimental object" for a senior person, the experiment depending on the research being conducted at the time. This approach furthered research, but did not necessarily provide the student with an understanding of experimental techniques. The function of the New World laboratory was to meet both needs, that of the researcher and that of the student. The sophomore student—at Cornell, at least—took a general introductory course of lectures and demonstrations. This prepared him for the laboratory drill-course, with only interspersed lectures in his junior year. After a systematic course in his senior year, the graduate student was prepared to enter into research work (Figure 5).

In the minds of the American laboratory psychologists, the distinction between the American and the European approach was to be an important one; self-consciously, they were to repeat it again and again. Thus we find Carl Emil Seashore reiterated the distinction in his 1930 autobiography when paraphrasing Titchener. As examples he cited the more factually oriented laboratory course patterned after the first American course of Sanford, but especially the training course furthered by Edward Scripture, Titchener and, later, himself. Here, according to Seashore and like-minded American psychologists, lay the real advantage that the American student possessed over his European counterpart, who had

FIGURE 5.—Auditory apparatus in the psychological laboratory at Cornell University, ca. 1900. (SI photo 74-7027)

obtained his basic training in some science other than psychology. Unlike even Sanford's course, the drill-courses were

> not primarily informative but intensive in fundamental drill exercises. Titchener's four-volume *Experimental Psychology* is the highest embodiment of that principle. It is to the discredit of American psychology that these monumental exercises of Titchener were driven into innocuous desuetude by the paper and pencil ravages and extreme forms of objective psychology. In the present status of psychology this type of laboratory training has been crowded to the wall. Failure to maintain the requirement is accountable for much of the slush and trash in the output from American psychologists of today (Seashore, 1930:262).

During the first decade of American laboratory effort in psychology, audition was not one of the primary research frontiers. The physiological nature of hearing, as one of the five senses, was discussed in terms of the dominant theory, which was that of Helmholtz. These discussions were of interest, because a number of problems had grown out of increasing familiarity with the detailed structures of the ear, once microscopic evaluation of the inner ear structure—so essential to its understanding—had become technologically feasible after 1830.

American students could learn the essentials of the anatomy and physiology of the ear from George T. Ladd's textbook of experimental psychology published in 1887. In 1881, Ladd had gone from Bowdoin to Yale, where he did laboratory work in physiological psychology that resulted in the founding by 1892 of the Yale Psychological Laboratory, directed by Scripture. Ladd's book, the first American textbook in physiological psychology, brought together the work of a number of physiologists, most of them German and not all in agreement. These in-

FIGURE 6.—Model by Auzoux of the human ear: middle ear bones and inner ear parts are magnified seven times. (SI photo 73–0410; USNMHT 21892.01)

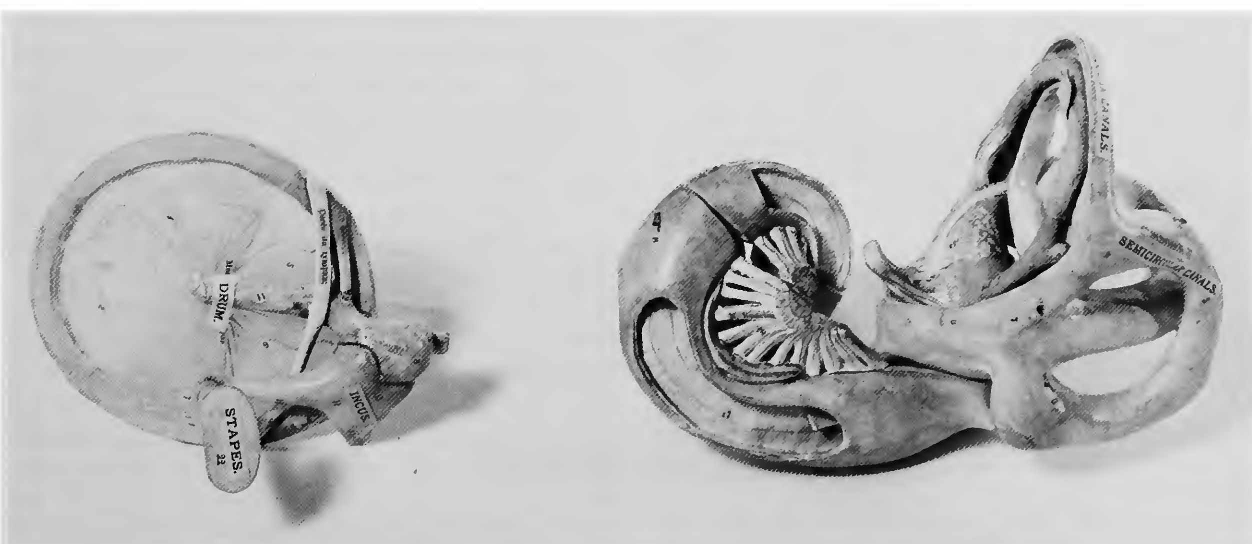


FIGURE 7.—Auzoux model parts: middle ear bones and tympanic membrane. (SI photo 73–0408; USNMHT 21892.01)

cluded Victor Hensen, Jakob Henle, Nicolaus Rüdinger, Carl Stumpf, Ernst Mach, William Preyer, W. Kühne, Max Schultze, and the Swede, Gustav Retzius. While Ladd accepted the idea that the study of sound for psychologists is a "wholly subjective affair" (Ladd, 1887:315), he summed up in text and illustration by sectional drawings the three major parts of the ear—external, middle, and inner.

The primary function of the external ear or external auditory meatus is protecting the tympanic membrane (Figure 6). The middle ear or tympanum is an irregular cuboidal chamber situated in the temporal bone and containing three small bones, which transmit sound vibrations to the inner ear (Figure 7). These bones (ossicles), called the malleus (hammer), incus (anvil), and stapes (stirrup), translate the sound waves having greater amplitude but a lesser degree of intensity into a motion that has a smaller amplitude and greater intensity. This rectified motion passes through the oval window into the inner ear or labyrinth composed of the vestibule, semicircular canals, and the cochlea (Figure 8). "It is in the labyrinth that the acoustic waves transmitted by the tympanum are analyzed and changed from a physical molecular process to a nerve-commotion, by the special end apparatus of hearing" (Ladd, 1887:189). The cochlea, the most complex part of the labyrinth, is about one-fourth inch long and coiled like a snail's shell. Ladd remained skeptical about the function of the intricate parts of the cochlea. For him the manner "in which the auditory hairs, the stone and cells of the vestibule and ampullae, and the rods of Corti, the fibres of the basilar membrane, and the conical hair-cells of Deiters, in the cochlea, actually discharge the required functions" was not known. (Ladd, 1887:195).

FIGURE 8.—Auzoux model parts: cochlea and semicircular canals. (SI photo 73-0409; USNMHT 21892.01)

Theoretical Issues

Traditionally the functions of the ear have not been understood as well as those of the eye. For example, in 1805 the association between studies of sense organs and an understanding of the physical principles underlying their functions was noted with expectation for a new understanding of the ear's functions. Anthony Carlisle (1805:198) cited the value of the anatomy of the eye to the advancement of optics and speculated that the same benefit might accrue to acoustics from a study of the ear. Helmholtz, himself, mirrored this approach, for his major studies on vision preceded those on audition. Psychologists depending on the research pattern of the anatomists and physiologists, were more certain of the functions of the eye in vision than of the ear in hearing. Helmholtz extended and united several major research results, relating them to the ear. The fundamental studies he brought together included Ohm's law of auditory analysis, Müller's doctrine of specific energies of nerves and the discovery of the arches within the inner ear by Corti (Wever, 1970:25–26).

According to Ohm, a listener has the ability to extract and hear the simple harmonic components of a complex periodic sound stimulus. This statement is summed up by Ohm's law. Fourier analysis expresses its mathematical equivalent, and a system of resonators its physical equivalent. Resonance, the vibration of materials, such as piano strings and tuning forks in response to sound waves, was a prominent physical characteristic crucial to all explanations of sound transmission. Consequently, analogies between the vibration of the tuning fork, the instrument that provided the purest tones, and the vibration of structures within the ear stimulated an explanation underlying the function of the ear in transmitting sound waves to the brain (Békésy and Rosenblith, 1951:1094). Indeed Ohm's law was the *raison d'être* of resonance theories, encouraging Helmholtz and others to seek resonating bodies within the complex structures of the inner ear (Boring, 1926:177).

Helmholtz attributed the ability to distinguish between qualitative sensations of pitch and tone to the presumed physical distinction between the endpoints of the nerve fibers. Johannes Müller's theory of the specific energies of the nerves had laid the difference in perception of the five basic senses at the door of the various nervous arrangements which received them, rather than the actions which excited them. For Müller, therefore, all forms of stimulation of the optic nerve produced some form of light and likewise all stimulation of the auditory nerve produced the sensation of sound (Helmholtz, 1954:148–149).

According to Helmholtz, analysis of sound occurs within the inner ear. At the time Helmholtz was developing the resonance theory of hearing and making it known, beginning with a public lecture in 1857 and then, in his book published six years later (Helmholtz, 1863), some of the intricate structures of the cochlea were being unveiled (Figure 9). These studies, though incomplete, exposed enough to convince Helmholtz that proper structures exist to let individual parts of the ear vibrate independently in response to each intensity and tone perceived by the ear. The vibrating structures within the cochlea had been identified with the strings of a piano or harp since the eighteenth century. Hence the theory became the "harp or piano theory" of hearing. Still, Hensen, who in 1863 showed that the basilar membrane is graded to pitch by expanding in size from beginning to end of the cochlea duct, remained skeptical and allowed that the ear might function altogether independently of this theory (Ladd, 1887: 196). Hensen's careful measurements of cochlear structures forced Helmholtz to modify his theory in later editions of his treatise (Wever, 1970:32).

Although Helmholtz did not observe precisely which parts of the ear vibrate sympathetically with individual tones, the elaborate structures of the cochlea, and specifically, Corti's arches appeared most suited for containing independently vibrating elements (Helmholtz, 1954:145). These are located on the surface of the basilar membrane and were discovered by the Marquis Alfonso Corti in 1851 in Kölliker's physiology laboratory. The basilar membrane divides the cochlea into two elongated cavities: the *scala vestibuli* and *scala tympani.* Helmholtz's description of the ear depended on Kölliker's claim for

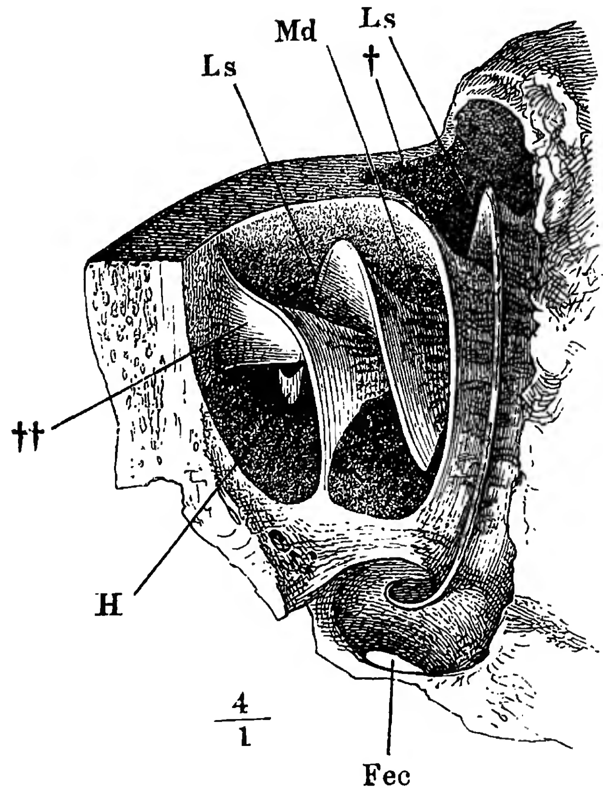


FIGURE 9.—Diagram of section of inner ear showing cochlea. (From Helmholtz, *Tonempfindungen*, 1870:211; SI photo T67012)

"having found the terminations of the auditory nerves everywhere connected with a peculiar auxiliary apparatus, partly elastic, partly firm, which may be put in sympathetic vibration under the influence of external vibration and will then probably agitate and excite the mass of nerves" (Helmholtz, 1954:142). He accounted for the degree of tone received by a one to one ratio between the incoming amount of tone and the response of the nerve.

A vibrating tuning fork displayed several responses to sound that specifically related to the ear. One was its ability to prolong its vibrations a long while after being set into motion through sympathetic vibration (Helmholtz, 1954:142); another was the change in its vibration frequency from that of the sounding body to that of the natural vibration of the fork after the original sound had ceased. No part of the ear was believed to vibrate as long as a tuning fork. The upper limit of sustained vibration within the ear was demonstrated by the duration of musical intervals recognizable by the ear (Helmholtz, 1954:143).

This action of the nerve fiber in response to the degree of stimulation it receives should have been ruled out by the discovery of the "all or none" principle of nerve reaction in 1902. In that year, Gotch (Wever, 1970:115) observed that a motor nerve fiber, no matter to what degree it is stimulated, reacted fully, provided a certain basic or threshold degree of stimulation was present. As we shall see, this principle was first applied to the theory of hearing by psychologists around 1922 (Boring, 1926:158), and at that time led to one of the cardinal criticisms of the Helmholtz resonance theory, although other problems with the resonance theory had become apparent earlier.

To justify these main theories, experimental psychologists availed themselves of one of the standard accoutrements of the physiological and anatomy laboratory: models.

Physical Models

Caspar Wistar in 1790 solved the problem of demonstration to a large class at the University of Pennsylvania by using enlarged models of body parts. He began with an enlarged wax model of the bones of the ear (Haviland and Parish, 1970:67). More generally, enlarged models of the ear were available for teaching the anatomy and relationship of its parts from the first half of the nineteenth century. Ear models manufactured in France by Louis Thomas Jerôme Auzoux were the finest. This anatomical model maker, following in the footsteps of a long tradition of model makers that include Guilio Zumbo, Guillaume Denoues, José de Flores, and Felice Fontana (Ratier, 1845) perfected the detailed life size model of the human body, as well as enlarged models of selected organs. In the course of a life devoted to this project, conceived while he was a medical student, Auzoux set out to provide accurate detailed models to be used in place of the actual organs. The latter were difficult to obtain and often repulsive to students. He developed models he termed *clastique* (clastic) from the Greek term Klao meaning "to break." This description was apropos as the models were composed of molded pieces of anatomically distinct parts, which could be easily separated and recombined. After perfecting a mannikin of the body he produced greatly enlarged models of the ear, eye, heart, brain, and other organs difficult to study and preserve (Ratier, 1845:11).

Auzoux seems to have first introduced an enlarged model of the ear in 1839. In April of 1844, a report of the Royal Academy of Medicine in Paris lists the ear as new (Blandin, 1843–1844:3). At the same time George Dexter of Albany, New York, published a catalogue of anatomical models, which he offered to import and sell. Among the items he advertized was an ear model containing the inner, middle, and outer parts. It was offered in two sizes: one in which the temporal bone measured 0.6 m (2 ft) in width sold for $35, and a smaller model measuring 0.3 m (1 ft) across the temporal bone sold for $25 (Dexter, 1844:66). Perhaps the greatest recommendation for these models came from Rudolph Koenig, who listed them for sale in his earliest catalogue along with his very carefully made acoustical equipment. These models ranged in size from 30 to 60 cm (Koenig, 1865:52).

From their inception, early American psychology laboratories were equipped with these gigantic French ear models (Figure 10). Measuring up to ten times life size, they formed a portion of model collections that included the other sense organs, brains, and various additional parts of human and animal bodies (Harvard, 1893; Baltimore, 1888). Auzoux made most of these in his firm, which flourished throughout the nineteenth century. By mid-century, over fifty craftsmen and laborers were employed in its factory

FIGURE 10.—Auzoux model showing temporal bone surrounding ear structure. (SI photo 73-0409; USNMHT 21892.01)

located near Paris (Ratier, 1845:22). In his one volume abridged edition of psychology for beginning students, William James singled out the largest Auzoux ear model for use in the laboratory (James, 1892:47).

Also important to the study of sensory psychology was a second major type of model, a mechanical analogue or "mechalogue" constructed to illustrate the mechanical principles believed to underlie the function of the specific parts of the ear. Perhaps the first of these was the Helmholtz wood and leather model of the inner ear bones and membranes. Helmholtz's construction provided a superb example of a functional model displaying the motion of the three bones of the ear. In magnifying the movement of these tiny bones and the connecting membranes, Helmholtz offered insight into his theory of the motion of the ossicles. Inspired by the challenge left by Bernard Riemann and wanting to complete in greater detail a section treated cursorily in his *Tonempfindungen*, Helmholtz had studied ear bones before stating his theory (Helmholtz, 1868:1, 2). To prove and to teach his theory, he constructed a middle ear bone model measuring 80 by 120 mm, copies of which were made available through his assistant, Sittel in the Heidelberg physiological institute laboratory (Helmholtz, 1868:45). By flexing the membrane covering the tube leading to the ear drum substitute, one can readily observe that the three bones are joined as a single lever forcing inward the membrane representing the oval window to which the stirrup bone is attached. The lever attached to the stirrup bone magnifies its motion. On a larger scale, these models were manufactured by R. Jung of Heidelberg (Figures 11, 12). His catalogue of August 1890 advertizes one for 42 marks (Jung, 1890:56). By 1899 the Cambridge Scientific Instrument Company (1899:117) sold an improved model described as increasing "the action of the air" by the installation of an india-rubber membrane over the mouth of the tube. On striking the membrane the air moves the leather diaphragm and the bones are moved.

Model designing ingenuity was also brought to bear on mechanical models intended by emphasis of selected and enlarged parts to elucidate and simplify the complex functions of the cochlea within the inner ear. Anatomical differences in various parts of the cochlea played an important role in support given the resonance theory. When observation of the ear failed to confirm the theory sufficiently, as when James observed in 1892 that "the keyboard of the cochlea does not seem extensive enough for the number of distinct resonances required" (James,

FIGURE 11.—Helmholtz model of middle ear bones and tympanic membrane made by R. Jung of Heidelberg. View of membrane. (SI photo 73-0411; USNMHT 300427.161)

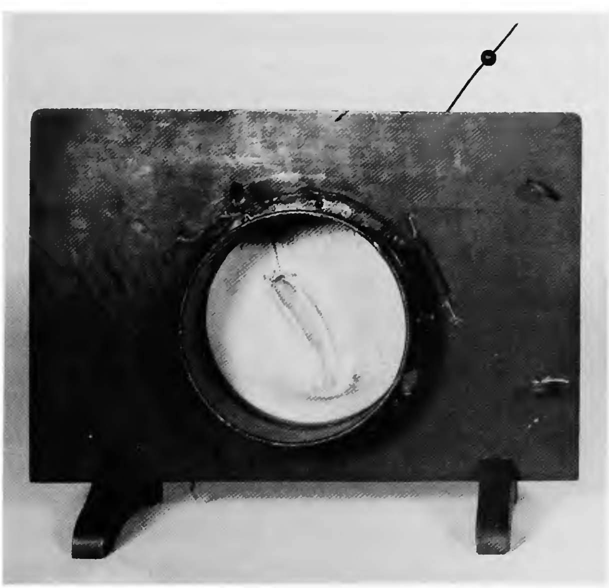
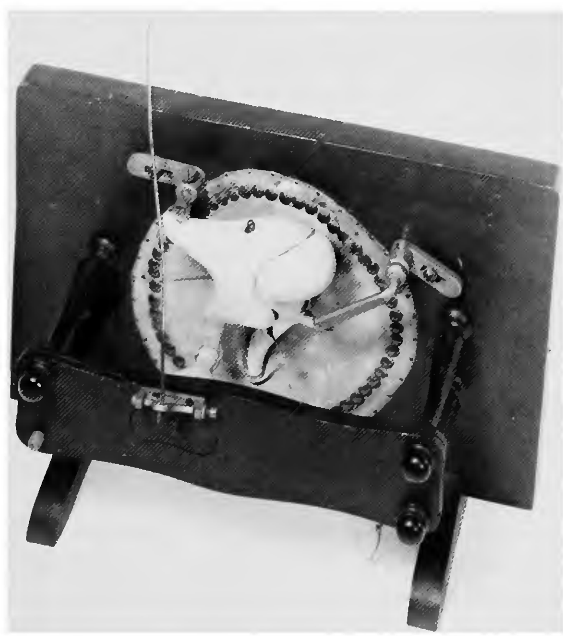


FIGURE 12.—Helmholtz model of inner ear bones and tympanic membrane made by R. Jung of Heidelberg. View of bones with lever attached. (SI photo 73-0412; USNMHT 300427.161)



1892:57), "mechalogues" of the cochlea were proposed in an attempt to by-pass and clarify the difficulties arising from knowledge of the ear's complex anatomy.

Finally, at the beginning of the century, psychologists wishing to broaden their knowledge of the ear could turn to the models prepared for the otology student. This type of model displayed pathological conditions of the ear drum. One of these models was constructed by F. Davidson of London in 1903. Essentially it was a model made of pliable material formed in the shape of the outer ear with auditory canal and ear drum. To learn the condition of the ear drum, the student was expected to peer into it with an otoscope (a magnifying instrument for viewing the ear) as he would into the ear of a patient. A variety of ear drum replicas made to resemble various diseases were mounted on discs that could be inserted into the top of the auditory tube and viewed through the otoscope (Ball, 1903:1584).

As time passed, anatomical models became secondary to apparatus associated with the laboratory of the physicist. In part, this reflects a drawing away of many American psychologists from physiology. The first generation of American psychologists had been trained in the laboratory of the anatomist and physiologist. Once established in their own laboratories they emphasized their independence. In part, and notably in the case of audition, this had to do with the state of knowledge.

At the turn of the century, it was obvious to authors of experimental psychology textbooks that the physiology of hearing had yet to make its mark. Some, as Lightner Witmer of the University of Pennsylvania, looked upon the unevenness of physics and physiology in psychology as the outcome of the nature of the senses. He regarded auditory perception as being better analyzed and explained if studied in relation to the physical stimuli that brought them about (Witmer, 1902:108). He gave up further effort to link physiological events with tone sensations. Others, such as Seashore or Kline, simply felt that physiology had no business in the experimental psychology laboratory: "The anatomy and physiology of man as related to psychology receive no formal consideration here (in the experimental course). The student is referred to standard works on physiological psychology for such study" (Kline, 1927:3). There were exceptions to this attitude, especially among those, like Shepard Ivory Franz or Karl S. Lashley, who devoted themselves to clinical psychology, or those like Walter S. Hunter, who turned to comparative psychology. However, in the laboratory of experimental psychology, there was to be more receptivitity for the experiments and the tools of the physicist than the physiologist.

The Inheritance of Physics Prior to World War I

The early psychology laboratories had been called laboratories of "psychophysics." Even William James used this term for his 1880s laboratory, though in time he sharpened his criticism of the Leipzig tradition, noting in 1890:

> The simple and open method of attack having done what it can, the method of patience, starving out, and harassing to death is tried; the Mind must submit to a regular *siege*, in which minute advantages gained night and day by the forces that hem her in must sum themselves up at last into her overthrow. There is little of the grand style about these new prism, pendulum, and chronograph-philosophers. They mean business, not chivalry (James, 1950, 1:192-193).

Experimental Apparatus

It is easy to look at auditory apparatus in the American laboratories as a subset of the acoustic apparatus of the physicist. The most widely used instrument was the tuning fork, which reigned supreme in most areas of auditory experimentation: There were giant forks for low threshold determinations, and tiny ones for measuring the upper limit of hearing. There were sets of forks for reproducing certain chords and there were sets giving a fundamental with harmonics or other overtones. There were sets for pitch discrimination and sets for reproducing vowel sounds. There were sets reproducing the tempered scale and sets reproducing the scale "of the physicist"—the even scale. Hugo Muensterberg in his 1893 inventory of apparatus at Harvard listed three different auditory sets in addition to a giant fork: one for harmonics, one for beats, and one for vowel sounds; besides these, there were general purpose forks for recording vibrations and marking time.

In general, auditory apparatus can be divided into easily defined categories: sound generators, amplifiers, analyzers, transmitters, recorders and reproducers, measurers, and receivers (Figure 13).

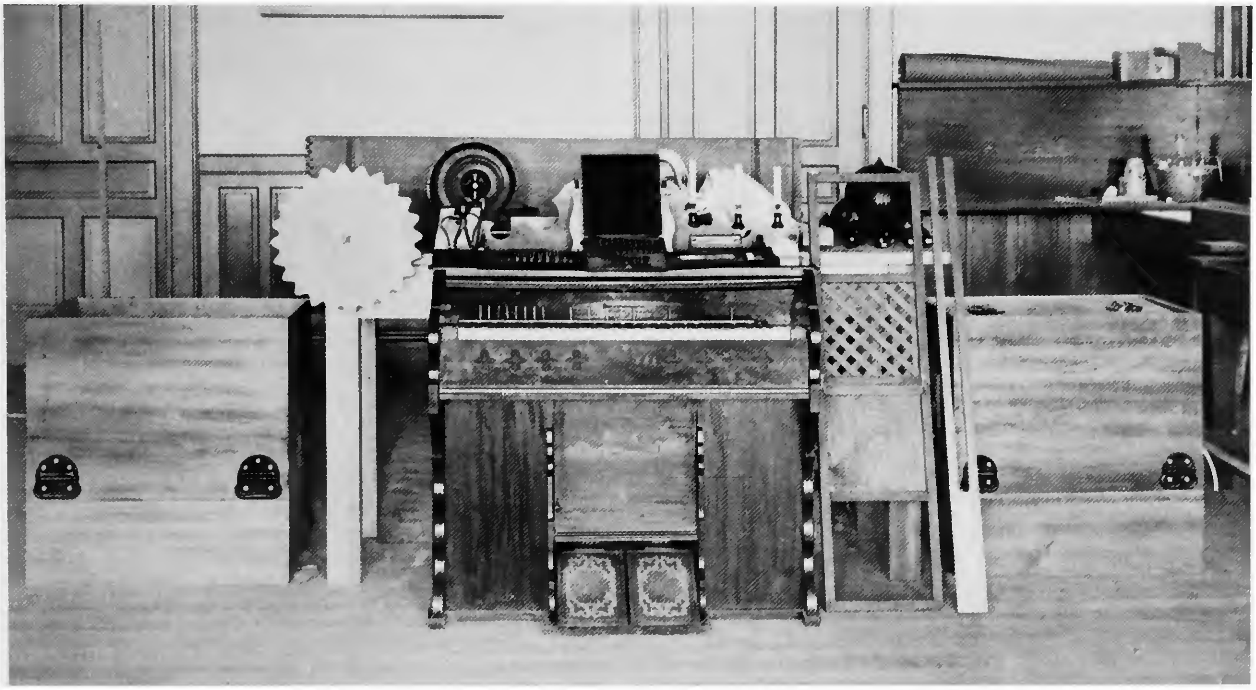


FIGURE 13.—Ensemble of auditory apparatus at the Psychology Laboratory at Clark University ca. 1893. (SI photo TPY 74–05–25)

The holdings of psychology laboratories reflect their specific orientation. There was a host of traditional and new sound generators: stretched strings and organ pipes, sirens and tuning forks, bells, whistles, and a variety of musical instruments. Sound amplifiers were more restricted; there were basic funnel-horns, resonator boxes and resonators—indicators of dependence on resonance-theories. Sound analyzers were limited to devices such as Helmholtz's "clang-analyser/synthesizer"; there was no sign of the analogue devices intriguing to mathematicians and physicists concerned with Fourier analysis. Recorders included tuning forks, with attachments for graphic recording or manometric flame combinations, such as the apparatus made famous by Koenig. Sound reproducers were notably scarce in the early laboratories, although there were specialized devices, such as the Helmholtz vowel apparatus. The phonograph made a remarkably late appearance in the laboratory of the psychologist. Of sound measurers there were a number; these were mostly sound generators to which appropriate scales had been attached. Some notable ones, in the area of intensity measurements, were of relatively recent origin. Finally, among sound receivers, the human ear stood out in solitary splendor. Eventually, telephone receivers became more common as accessories to complex pieces of laboratory apparatus. However, it was mainly on a theoretical basis that the telephone served as a guide to the analysis and specification of the functions of the ear. Thus, among the topics that made up the laboratory drill-course, the "telephone theory of hearing" so occupied the attention of experimentalists that Titchener included it in examination questions for his course.

Theoretical Questions

The telephone theory offered the first important criticism of Helmholtz's theory of resonance. It was announced by the English physicist, William Rutherford, in 1886 at an evening lecture of the British Association for the Advancement of Science held in Birmingham. Few physiologists or physicists adopted the theory immediately, so that Rutherford published another version of it in 1898 with more success (Wever, 1970:77). Drawing on the anatomical conclusions of Retzius he determined that the basilar membrane in the cochlea was merely a supporting

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structure for the organ of Corti rather than a source or support of resonating fibers (Rutherford, 1898). Rutherford's theory, that individual fibers do not possess unique resonating qualities, was based on his own suggestive experiments and on Julius Bernstein's discovery in 1867 of the incredible speed of nerve conduction. Rutherford only became aware of Bernstein's impressive evidence after he had published his 1887 paper. As Helmholtz's assistant, Bernstein had used a differential rheotome to observe that the electrical charge which accompanies the transmission of a nerve impulse lasts only 1/1400 of a second. (0.0007 sec). Therefore 1400 perfectly discrete impulses can be transmitted in each second over a single nerve fiber, in this case the sciatic nerve of a frog. Rutherford (1887:355) concluded that the number of impulses was underestimated though considerably greater than those he managed to detect with his crude measuring equipment.

Rutherford (1887:5) next suggested that a single hair cell, nerve fiber, and sensory cell are capable of resonating, and therefore transmitting, the whole spectrum of tones. Like the telephone, cochlea structures vibrate to all frequencies and transmit all sounds, transforming them into nerve vibrations. Comparable to sound vibrations being transformed into electrical vibrations in the telephone, the nerve vibrations are then carried to the brain for analysis. Rutherford (1898:358) also recognized new compelling evidence for the resonance theory provided by W. von Bezold, and S. Moos and H. Steinbrugge who investigated deaf individuals. They found that specific tone deafness could be correlated with specific areas of degeneration in the cochlea. Subsequently, debate centered on the resonance and telephone theories, often treating them as rival and exclusive explanations of hearing.

Threshold Determination

Another auditory topic taken up in the psychology laboratories was the traditional threshold determination. The five most frequently measured thresholds involved the upper and lower frequency or "hearing of highest and lowest tone," the lowest intensity, and the least noticeable differences in pitch and intensity. Frequency threshold studies initially came from the domain of physical acoustics; intensity studies were of particular interest to clinicians; "least noticeable differences" appeared to be the special province of the psychophysicists. A favorite of early psychophysicists—as well as otologists—these experiments have remained a standard topic in the basic drill course (Woodworth, 1972).

The most popular device for testing the lower tone limit was a giant tuning fork (Figure 5). One made by Koenig ranged from 16 to 24 cycles; to obtain this variation sliding weights were attached to the prongs. The fork was sounded by striking it with a hard-rubber mallet, or, lacking that, with the fist—preferably gloved. Physicists of the eighteenth and early nineteenth centuries had conducted such tests using organ pipes or stretched strings. Following Felix Savart, the spoked wheel came into vogue for these tests in the 1830s and 1840s (Figure 14). Except for some experimentation with harmonium reeds (Preyer, 1876), the major instrument used for testing the least audible tone after 1870 was the tuning fork. In the late 1880s, Appunn brought forth his lamella, a steel blade ranging from 4 to 24 cycles, which was attached to a table by a clamp with fiber jaws; this was to be the only noticeable competitor to giant forks in most psychology laboratories up to the 1920s.

As in the instance of the lowest tone, the first major tests of the highest audible tone were conducted using organ pipes and spoked wheels. The pipes proved quite inadequate, a fact not surprising if it is recalled that one with a mere 7.5-cm (3-in) diameter produces 2048 cycles. The spoked wheel, and, following it, a variety of sirens (Figure 4), were more adequate; Savart in 1830 had obtained the classic result of 24,000 vibrations per second as the upper threshold, simply by finding a limit when his 720-tooth wheel ran at 33 revolutions per second. Alternately, Savart had used a set of short cylinders, a method that later found favor through the set produced by Koenig. Thus the Harvard 1893 inventory lists the standard Koenig set of 22 cylinders designed to produce tones from 4096 to 32,768 cycles (Figure 36). These were made by tuning the lower cylinders through difference tones, then computing the requisite length of the higher ones. In the late 1890s Schwendt observed that the cylinders above the 16,000 cycle range were somewhat too long; Koenig showed how the error could be compensated for by recomputing.

Forks for testing the upper frequency threshold first came to attention in the experiments conducted by C. Desprez in the 1840s. He claimed a limit of 36,850 cycles. His forks were made by Marloye, the predecessor of Koenig; Koenig's later forks were con-

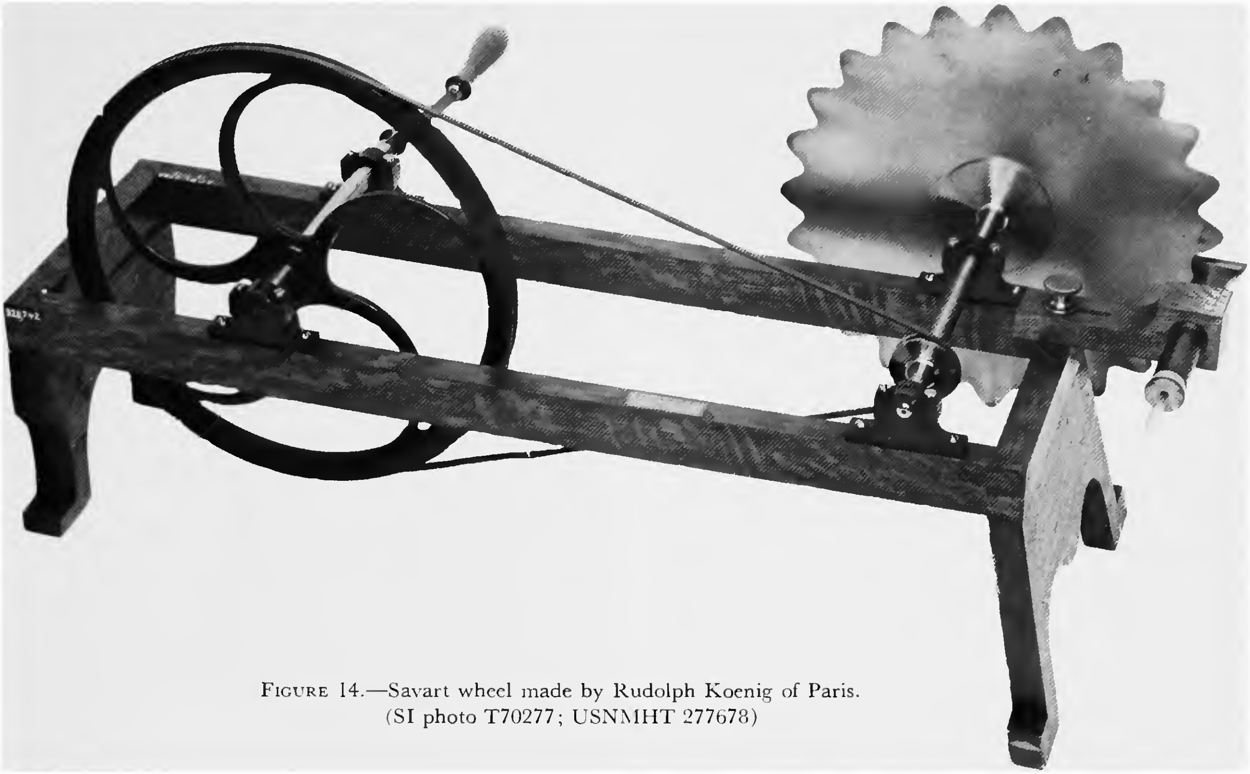


FIGURE 14.—Savart wheel made by Rudolph Koenig of Paris. (SI photo T70277; USNMHT 277678)

sidered equally reliable. His best set of 18 forks, selling for 900 francs in 1889, ranged from 4096 to 21,845.3 vibrations. Koenig stopped at that limit because he did not want to be reproached for "entering into the domain of fantasy" (Koenig, 1889:23). He found that most ears were not sensitive to the vibrations of the highest cylinders of the set and that in the case of elderly people (himself) the upper limit seems to drop to about 16,389 vibrations.

Until the 1890s, high forks made by Appunn were widely acclaimed and were acquired by several psychology laboratories. Preyer may have boosted these forks to fame in the well-known study (Preyer, 1876) in which he obtained an upper limit of 40,960 vibrations; the result was cited by Helmholtz (1954) without criticism. However in the 1890s, Melde, Stumpf and Meyer conducted tests that showed the Appunn forks—as well as Appunn pipes—to be wrongly calibrated. Following a flurry of discussions in the *Annalen der Physik* these forks gave way to the Galton whistle after the turn of the century.

Francis Galton presented his whistle in London in 1876. In its original form it consisted of a small tin "organ-pipe" of variable length; a micrometer screw permitted adjustment of the length of the air column in the pipe. Well known are the stories of Galton having built one of these pipes into his walking cane so that he could observe discreetly the auditory limit of animals in zoos and on the street.

Like other instruments of Galton's, his whistle was sold in England by the Cambridge Scientific Company. Their description (1899:110) of the whistle in 1899 is of interest:

> [It is] of very small bore with an arrangement for varying its length by an adjustable plug. It is sounded by squeezing air out of a small india-rubber bag. The whistle always makes two sounds at the same time, the high musical note best described as a very shrill squeak and the noise made by the air leaving the mouth of the whistle. To apply the test the whistle is sounded and the length of its pipe shortened, until a point is reached when the squeak becomes inaudible.

An appropriate scale allowed the experimenter to read off the length of the whistle in millimeters.

This type of whistle was also obtainable from Koenig in France, Hawksley in England, and Edelmann in Germany (Figure 15); yet, in 1898 Sanford cautioned psychologists and their students that unless extreme care is taken the instrument does

FIGURE 15.—Galton whistle made by Max Edelmann of Munich. (SI photo 74–7138; USNMHT 300427.196)

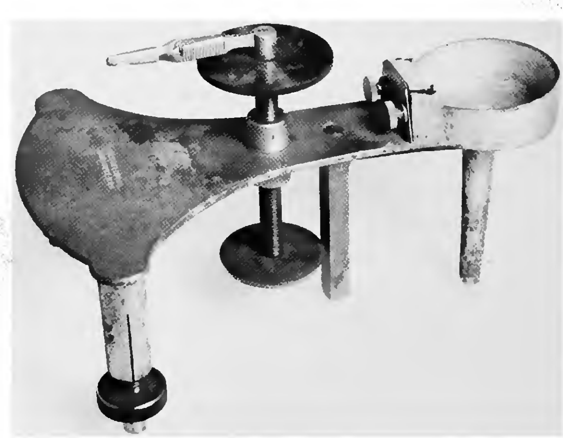
little but confirm that some hear tones that others do not. Harsh criticism of an apparently popular device that had been in use for a generation was prompted by contemporary experiments. Sanford was reacting to the varying results obtained by psychologists using the Galton whistle in the 1890s. In 1894, Scripture and Smith at Yale recorded frequencies to 53,000 cycles; during the same year Zwaardemaker in Holland reached a high of 20,480. In 1897, in Berlin, Stumpf and Meyer stopped at 20,000, while the otologist Bezold obtained values of over 55,000. Scripture and Smith had used a whistle obtained from Koenig; Stumpf and Meyer criticized them for applying an invalid method in calibrating their whistle. Stumpf and Meyer found it necessary to explain that their value of 20,000 cycles reflected the physical limitations of the experiment rather than the physiological limits of the ear; Stumpf, Meyer, and Bezold had used a whistle produced by Edelmann (Titchener, 1905b:44–45).

The problem that was to plague the users and manufacturers of the Galton whistle for two more decades was the same that had been at the root of previous controversies over Koenig's cylinders and Appunn's forks: A common difficulty was how to tune objects to frequencies that exceed the limits of hearing. The situation was to be substantially improved with techniques made possible after the development of electronic apparatus.

Experiments dealing with intensity thresholds traditionally had been conducted either by varying the distance of the subject from a sound source of fixed intensity or by varying the intensity of the sound itself. Accordingly, all instruments for measuring intensity, called acoumeters, fell into two basic classes: those emitting sounds of fixed or of variable intensity.

For testing the lower intensity threshold, the distance variation method was in vogue throughout most of the nineteenth century. Even Titchener used the traditional pocket watch test in his course, though supplementing it with an experiment utilizing the new acoumeters developed in the 1890s (Figure 16). These instruments all operated on the same basic principle. An object is dropped at a specified height at a given distance from the observer. The intensity of the noise produced when the object made contact with the receiving surface was usually measured as the product of the weight of the falling object multiplied by the height of fall. Depending upon the sophistication of the experimenters, attention was paid to other factors, such as the materials composing the object, and the receiving surface. A favorite acoumeter in American psychology laboratories was that described by Lehmann (in Hansen and Lehmann, 1895). It consisted of a three-legged platform, approximately 15 to 20 centimeters (6 to 8 in) long and adjustable in height by three set screws. At one end of the platform was a small trough. At the center of the platform, an adjustable vertical millimeter screw carried a pair of forceps. The object to be dropped was attached to the forceps, which were positioned so that the object fell into the trough when the forceps were opened. The platform was originally made of wood, later of metal. The trough was usually padded, and a variety of objects was dropped, the standard items being small pieces of copper, glass, and cardboard.

FIGURE 16.—Lehmann acoumeter made by C. H. Stoelting of Chicago. (SI photo 74–8027; USNMHT 311423.05)



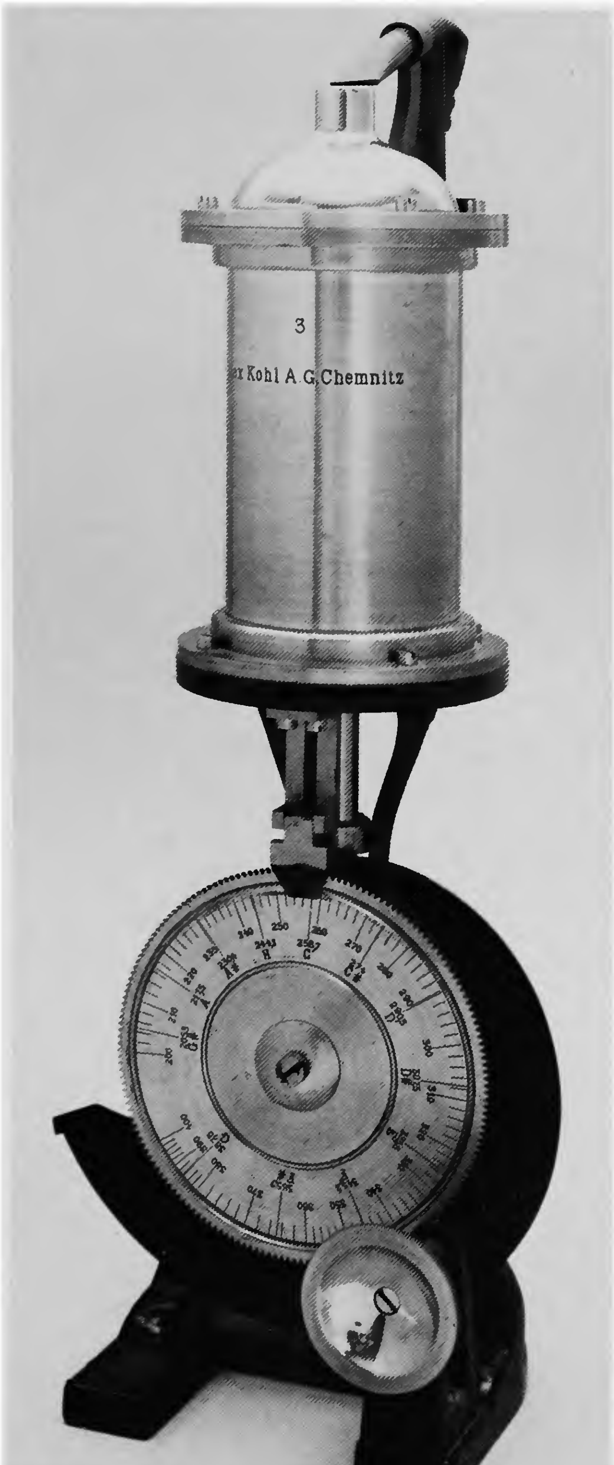


FIGURE 17.—Stern variator, designed to produce tones ranging over 200 vs, made by Max Kohl A. G. of Chemnitz. (SI 72–7048; USNMHT 300427.116)

Following the example set at Leipzig, pitch discrimination experiments were initially conducted with tuning forks and harmonicas or often reed instruments. Sets of weighted forks were soon preferred, though an organ-pipe based device of Galton's found some use in the 1890s, and the more expensive Stern variator gained favor among psychologists and physicists (Figure 17). Its usefulness depended on a well-regulated air supply. One of the few significant contributions to apparatus made by an American laboratory psychologist, Guy M. Whipple of Cornell, was a gasometer that furnished a regulated air supply.

Loudness discrimination studies were usually conducted with a sound pendulum of the type developed at Leipzig (Figure 18). Auditory work at Leipzig concentrated heavily on psychophysical measurements, with prime emphasis on testing the Weber-Fechner law. According to Weber, the least noticeable difference in sensation is proportional to the ratio of the change in stimulus to the stimulus ($Se = kSe/St$). Fechner modified this statement to say that sensation is proportional to the logarithm of the stimulus ($Se = c\log St$). In the 1880s these relationships were tested for auditory sensations at Leipzig, with less than conclusive results. The apparatus consisted

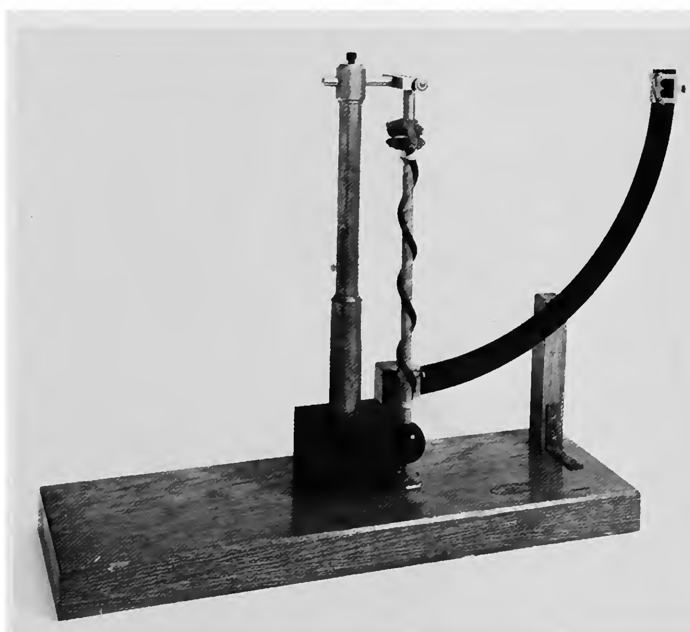


FIGURE 18.—Sound pendulum, designed to measure the intensity of the sound produced as a function of the angular distance transversed by the hard-rubber ball. (SI photo 72–7051; USNMHT 300427.009)

largely of devices that allowed the dropping of an object with specified shape and mass down a known height; the problem was to determine whether the intensity of the sound was in direct proportion to the weight and height of the object dropped. Other experiments included study of the least noticeable difference in pitch: apparatus consisted of tuning forks, harmonicas, or other reed instruments. A different class of studies dealt with auditory memory and fatigue, with special attention devoted to the effect of rhythmic combinations.

Resonance and Clang Analysis

After these psychophysical experiments a group of essentially "Helmholtzian" experiments followed. These included the analysis of clangs (the study of overtones) frequently conducted with the monochord; determinations of combination tones carried out with a set of interference tubes, a harmonium or an Appunn tonometer (Figure 19); studies of beat phenomena carried out with tuning forks and resonators; studies of pitch and clang-tint (*Klangfarbe*) using musical instruments, interference tubes, or piston whistles. Two related devices closely associated with the names of Helmholtz and Koenig are the resonator and the clang-synthesizer.

Resonators were a "must" on most inventory lists. A resonator is a hollow device, with an opening at one end, funnel-shaped at the other (Figure 20). It is "tuned" to a specific frequency so that as the surrounding air is set into vibration at that frequency, the resonator vibrates sympathetically. It reinforces the sound to which it is tuned.

By the end of the nineteenth century, three basic forms of resonators were in use: spherical "Helmholtz" resonators; cylindrical "Koenig" resonators; and, less frequently, conical "Appunn" resonators. Although Helmholtz (1954:372) had begun his investigations with glass resonators—"at first I em-

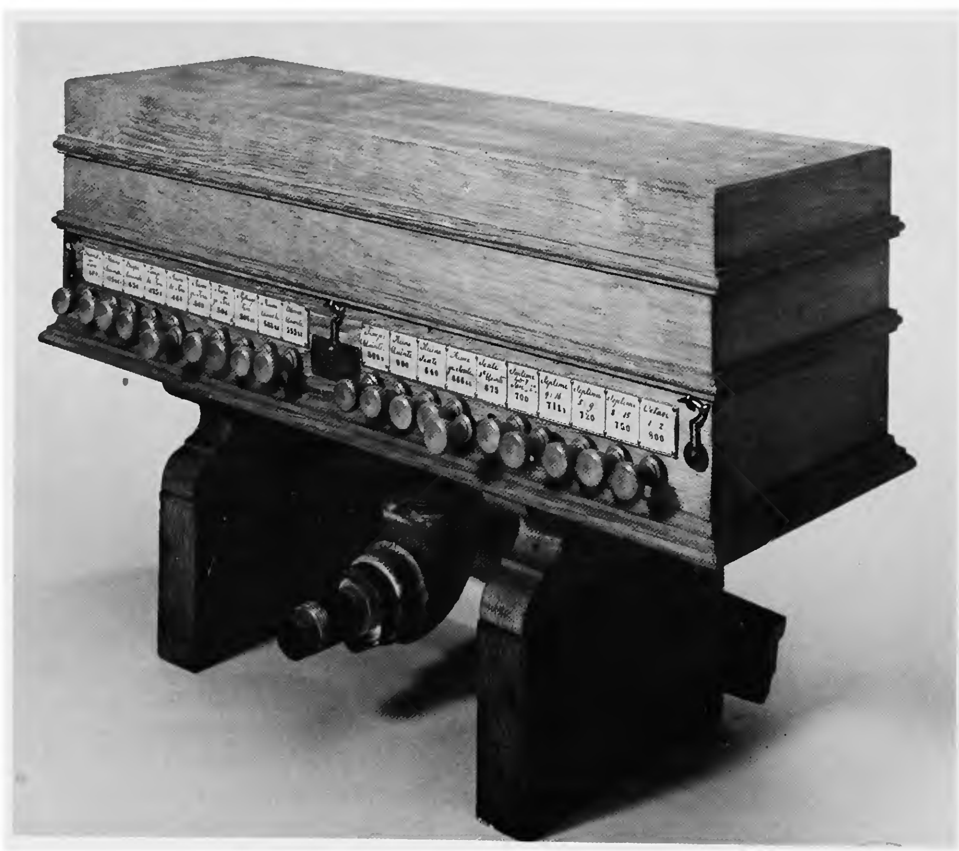


Figure 19.—Chord tonometer made by Appunn. (SI photo 72-7058; USNMHT 300427.112)

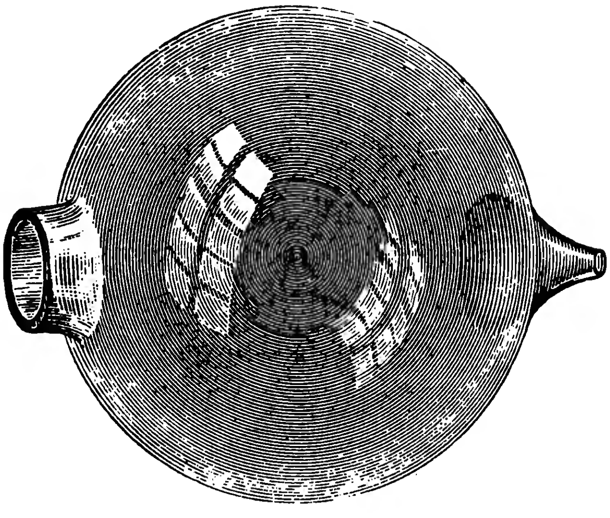


FIGURE 20.—Glass resonator, maximum diameter 79 mm. (From Helmholtz, *Tonempfindungen*, 1870:73; SI photo T67018)

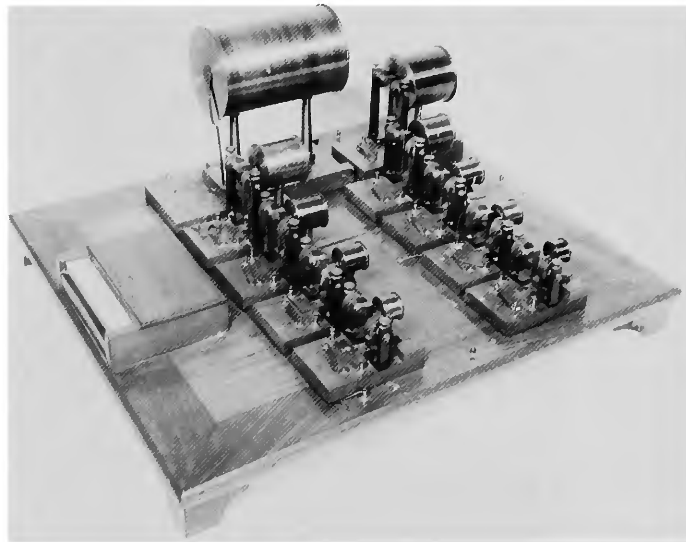


FIGURE 21.—Clang-synthesizer made by Rudolph Koenig of Paris. (SI photo 73-407; USNMHT 300427.009-109)

ployed any spherical glass vessels that came to hand, as the receivers of retorts"—most resonators were of brass. They could be "tuned" on the basis of Helmholtz's formula for the frequency as a function of the area of the orifice and the volume of the interior. Helmholtz noted the importance of these dimensions in another context: Narrower openings produce greater reinforcement, calling for closer agreement between the tone to be heard and the tone of the resonator: "It is just as in microscopes; the greater the magnifying power, the smaller the field of view" (Helmholtz, 1954:374).

Koenig's cylindrical resonators were "universal." They were made of two cylinders that fit into each other and could be "tuned" by adjusting this fit. This made it possible to reinforce various partials of the given fundamental to which the cylinder was tuned. This was in contrast to Appunn's conical resonators which simultaneously reinforced all partials of their fundamental.

Resonators were used most easily to reinforce sounds by holding the funnel-shaped opening against the ear. They were also used as parts of special purpose devices. Among the most striking of these was Helmholtz's synthesizer (Figure 21). In the major form produced by Koenig toward the end of the century this consisted of a set of ten forks providing the ten harmonic overtones of 128 cycles as the fundamental. These are mounted on a board and hooked to an electromagnetic fork of 128 cycles, which serves as interrupter. Each of the ten forks is placed in front of a resonator tuned to its frequency (Figure 22). A keyboard attached to the mounting board controls the opening and closing of the resonators. A string from the key pulls the cover off the corresponding resonator.

Originally the device had been used by Helmholtz to demonstrate his theory on vowel frequency. It had been acknowledged that there is a pitch differentiation to vowels so that they appear to rise in the order U–O–A–E–I; this appears to be implicit even in the eighteenth century "talking machine" of von Kempelen. Earlier in the century, Helmholtz theorized that the open mouth acts as a resonator, reinforcing partials defined by the fundamental. Following closely the path outlined by Robert Willis and Charles Wheatstone, Helmholtz thought he had found confirmation for his theory in the synthesizer when it allowed him to imitate vowels by reinforcement of the appropriate partials. Subsequently, the synthesizer found more general use in reinforcing a variety of tonal combinations.

Musical instruments had always furnished a convenient means to the study of tones—especially their pitch, quality and combinations (Figures 23, 24). Helmholtz had singled out the harmonium (a bellows-operated reed organ) for pitch studies: "on account of its uniformly sustained sound, the piercing character of its quality of tone, and its tolerably distinct com-

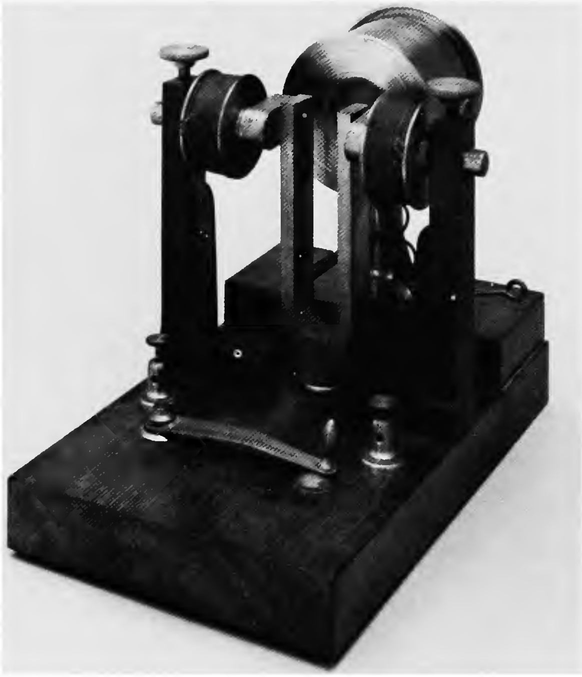


FIGURE 22.—Clang-synthesizer component: fork and resonator. (SI photo 72–7044; USNMHT 300427.104)

FIGURE 23.—Bellows organ, rear view. Note similarity to instrument shown on left in Figure 35. (SI photo T60507D; USNMHT 266154)

FIGURE 24.—Laboratory organ. (SI photo 72–11344; USNMHT 306749.16)

binational tones [it] is particularly sensitive to inaccuracies of intonation" (Helmholtz, 1954:316). He also noted that harmonia in "just intonation" lent themselves well to studies of mathematically precise tone relationships. In other words, he advocated the use of evenly tuned harmonia instead of tempered instruments. Numerous such "enharmonic" instruments were built in the nineteenth century to provide examples of chords that arise in the discussion of musical ratios. Of these, the so-called "harmonical" designed by Ellis became the favorite of American psychologists. Aside from basic studies on pitch discrimination and tonal combinations, they used it especially to show the existence of partials and to demonstrate the relationship of beat frequency and pitch.

The Ellis Harmonical was built by Moore and Moore of London. Tuned to A at 440 cycles, it had a basic range of four octaves starting with the "Great Octave," that is, C at 66 cycles. A special device furnished a fifth octave so that the highest note sounded was C with the frequency of 2112 cycles. Each octave was divided into 12 parts; the intermediate notes were in fixed ratios to C, namely 9:10, 8:9, 5:6, 4:5, 3:4, 2:3, 5:8, 3:5, 4:7, 5:9, 8:15, 1:2. We find a characteristically judicious assessment of the instrument in correspondence between Sanford and Titchener in 1895. Titchener had apparently asked for Sanford's comments about the relative merits of available instruments. Sanford expressed little enthusiasm for the "melodeon." He did not recall having had any experience with it, but was dubious because it struck him as being an "old instrument." Of the harmonical he noted that "it is not necessary for the course—everything mentioned can I think be shown without it. It is a little better in some cases because it is tuned in perfect intonation and because it has between the c and d digitals an interval of a "comma," but these are not essential. Any 5 octave reed instrument would do . . ." (Ithaca, 1895:14/23/545). Sanford added that he did not know what other laboratories used, except for Harvard which had the Ellis (Figure 36).

Sound Localization

Sound localization was another topic widely studied in American university laboratories. Two questions occupied the researcher. One dealt with the accuracy of estimating sound direction; the other one dealt with the nature of the mechanism whereby the observer determines that direction. A variety of sound cages and sound helmets were used for these experiments, to be replaced by earphones after 1920. However, earphones were not new, even the pseudophone having appeared prior to 1880. A widely used sound cage, favored by Titchener, among others, consisted of an iron base; two semicircles made of brass wire, one rotating vertically, the other, slightly smaller, horizontally; a head clamp; and a telephone receiver attached to the midpoint of the horizontal semicircle. Graduated scales could be attached so that as the circles and the telephone receiver were moved about, the precise location with respect to the observer could be measured (Figure 25). These experiments confirmed that left-right localization was much better than up-down or front-rear determination: a result that otologists had obtained with simple watch tests in the nineteenth century.

Tonal Fusion

Yet another group of auditory experiments pertained to tonal fusion. Although experimentally closely related to the Helmholtzian studies of consonance and overtones, and philosophically a part of associationist tradition, the theory of tonal fusion that determined subsequent laboratory studies was established by Carl Stumpf. Following Stumpf, this phenomenon was defined as "that relation of two sensations in consequence of which . the total impression approaches more and more closely to that of a single sensation, and is analysed with greater and greater difficulty" (Titchener, 1901b: 329). The standard experiment was designed to measure this change in impression, or "scale of fusion degrees." Recommended experimental apparatus consisted of a reed organ, which, in practice, frequently turned into a set of mouth harmonicas; however, organ pipes, tuning forks, and a variety of musical instruments from pianos to violins were used at one time or another. A sequence of single notes and double notes was sounded; the observer wrote down which was which, indicating doubtful impressions. According to Stumpf, the degrees of fusion ranged from the octave to the fifth, the fourth, the major and minor thirds and sixths, to other intervals. For intervals above an octave, the degree

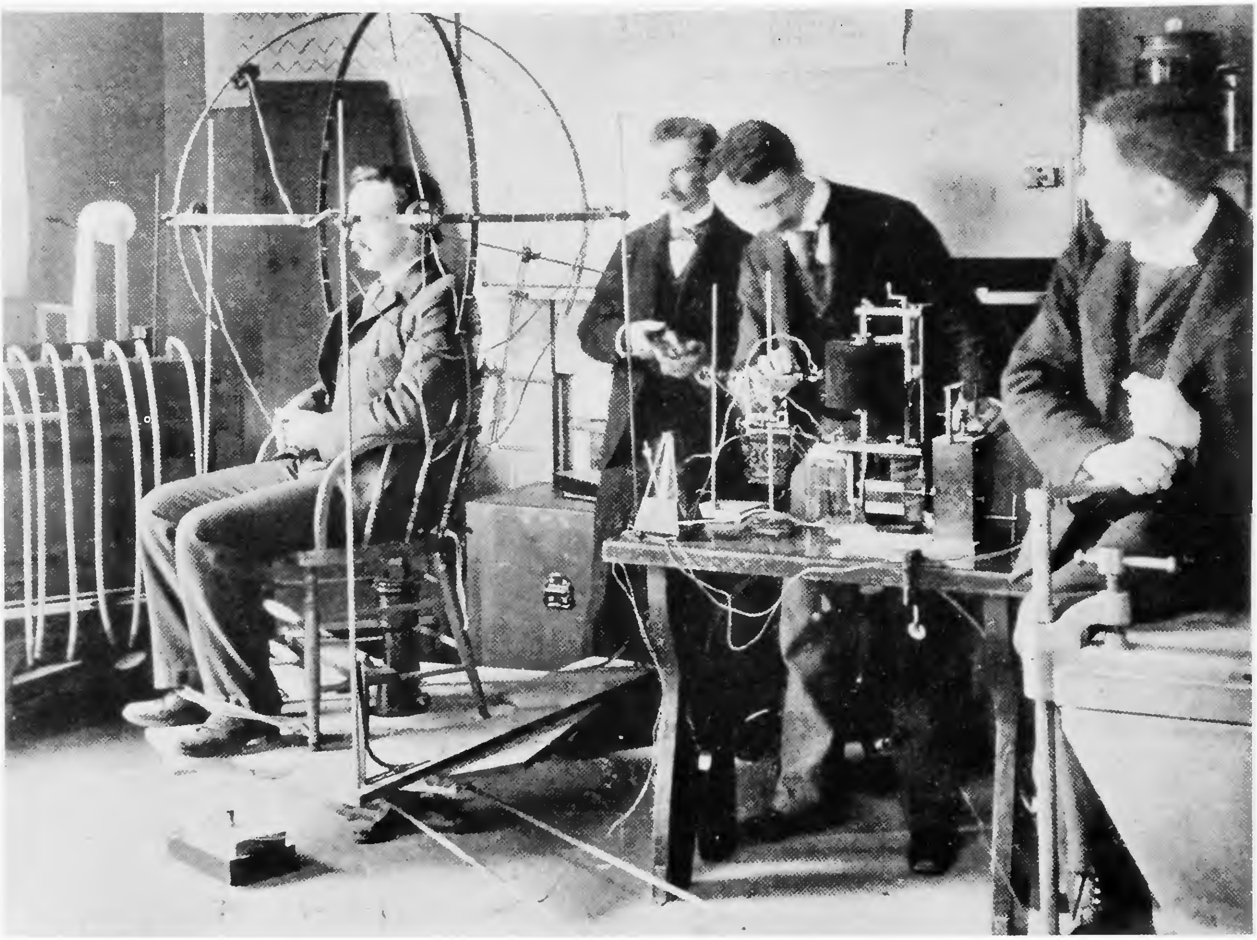


FIGURE 25.—Laboratory room at Harvard University, ca. 1893, showing equipment and subject arranged for experiment on the influence of dizziness on localization of sound. Subject is seated in a sound cage. (SI photo TPY74A1)

of fusion was thought to correspond, so that a twelfth would rank the same as a fifth.

Tonal fusion experiments were among the most inconclusive in the area of audition. There was disagreement about everything, from the question to what extent musical training or ability affected the results, to the question whether the phenomenon exists at all. After Pratt's devastating critique of these experiments in 1934, they practically disappeared from the experimental laboratory.

Transition to the Post-World War I Period

It may appear surprising to begin a discussion of the first fifty years of American psychology laboratories with emphasis on instruments and experiments that predate the turn of the century and involve European makers and scientists. Were not the twenties a period of tremendous technological development in areas that are important to the study of hearing? Did not American inventors of the nineteenth century produce important devices, such as the telephone and the phonograph that have scarcely been mentioned? Have not applications of electrophysical techniques changed basically the methods and approach of psychologists concerned with audition?

With few exceptions, apparatus in American university psychology laboratories was largely that found in inventory lists at Harvard and Cornell of the 1890s. Most of the apparatus was imported. Of 70 manufacturers listed by Muensterberg at Harvard in 1893, only 19 were American; 24 were German, 10 French, 7 English, 4 Swiss, and the rest were divided among Ireland, Scotland, Sweden, Italy, Holland, and Bohemia. The two manufacturers specializing only in acoustic apparatus were Koenig and Appunn, working in Paris and Hanau, respectively. American laboratories continued to import their equipment until World War I, offering different explanations for doing so. Titchener noted that the apparatus used in the elementary courses is "almost wholly American just as the research apparatus is preponderantly German in origin" (Titchener, 1898:321). Others emphasized the originality of their equipment. Thus, A. P. Weiss, with apparent satisfaction, called attention to the unique apparatus contrived by him in the laboratory of Max Meyer in conjunction with his 1916 Missouri thesis on sound intensity. He constructed his own equipment (Figures 26, 27) because "the physicists who are best prepared to design the apparatus are not interested in the problem of tone intensity as it presents itself to the psychologist" (Weiss, 1916:1). Similarly, when Walter Miles, a clever apparatus designer, was a student in Seashore's laboratory in 1909, instructors and students collaborated in building equipment for their experiments.

Our preoccupation with what appear to be only nineteenth-century European prototypes is justified when we look at a 1930 catalogue of the Stoelting Company, or the identical 1936 edition. Since the turn of the century this firm had steadily intensified its efforts on behalf of psychology. Stimulated by the reduction of imports after World War I, it had become the leading supplier of psychological apparatus

FIGURE 26.—Laboratory room at the University of Missouri showing tone-producing arrangement designed by A. P. Weiss, ca. 1916, as it appeared in his thesis (1916).

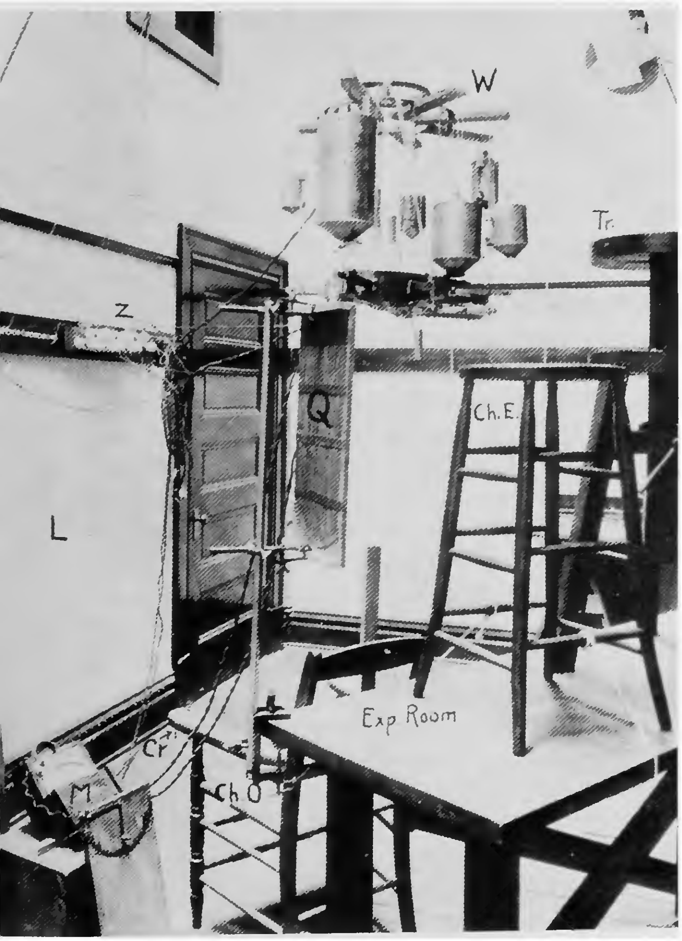
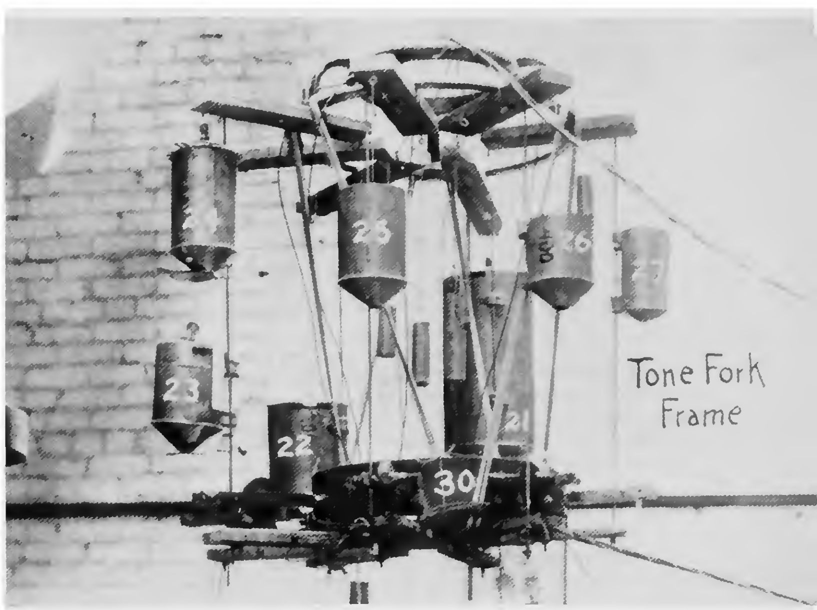


FIGURE 27.—Tone fork frame showing resonators and tuning forks at the University of Missouri, ca. 1916. (From Weiss, 1916)



in the United States, and a major exporter, particularly to the Far East. In the foreword to its catalogues, the manufacturer acknowledged the cooperation of experimental pioneers like J. R. Angell, B. T. Baldwin, Bergstrom, Jastrow, Sanford, Scripture, Seashore, Titchener, and Whipple, as well as their assistants, students, and successors in the field.

The Stoelting section on audition contained 78 lot numbers. Of these, 24 were tuning forks or sets of forks, with 5 accessories; there were 7 Stern variators, 5 Appunn-type tonometers, 5 sound hammers "à la Leipzig," 3 resonator sets, 4 whistles (including the two basic Galton whistles), 4 sound cages or accessories, 2 acoumeters, other traditional pieces such as a lamella, a set of Quincke's tubes, Koenig's difference-tone apparatus, and miscellaneous accessories, such as stoppers and tubes. The only items that represented more than a minor modification or refinement of a nineteenth-century piece of apparatus were two sets of tunable bars, first described by Paul Thomas Young in publications of 1918 and 1922. The bars arose out of work he had done as a graduate student at Cornell, where he obtained his Ph.D. in 1918; the second type was described as "without doubt the best piece of apparatus available for the demonstration of difference-tones" (Stoelting, 1936: 32). The only instruments in that catalogue new to our discussion were Seashore's audiometer and tonoscope, the related stroboscopic disk of Gray, the phono-projectoscope developed by Metfessel and Tiffin at Seashore's school, and Dorsey's phonelescope.

Apparently, we should accept Boring's statement of 1938 that "really not so very much happened in the sixty years after Helmholtz" and that one "can see how much of the psychology and physiology of hearing has been learned within the last decade and also how little of it was the product of the preceding half century" (Stevens and Davis, 1938:vi–vii). This would also lead us to reject the conclusions of historians who have told us that new movements in psychology "introduced new kinds of experiments demanding design, technique and apparatus different from the 'brass instruments' of the earlier pre-1914 workers" (Thomson, 1970:298).

Caution is essential, however. The First World War and the period following it did mark a change. The change in audition reflects similar changes in psychology and other disciplines in this country. To introduce these matters, it will be well to scrutinize the work of two men who span the period. They received their Ph.D.s in psychology in 1895 and 1896 and continued their productive endeavors until their deaths in 1949 and 1967, respectively. The two men are Carl Emil Seashore and Max Friedrich Meyer.

Max Friedrich Meyer

Max Friedrich Meyer was born in Danzig on 15 June 1873. In 1892 he matriculated in the Theological Faculty of the University of Berlin, although his basic interests appeared to lie in physics. After hearing Ebbinghaus, he changed to the Philosophical Faculty in 1894, the year Stumpf came to take the chair of psychology in Berlin. He worked closely with Stumpf for the next four years. In 1896 his doctoral dissertation, approved jointly by Stumpf and Max Planck, was published; it contained the first version of his theory of hearing, which was expressed mathematically. The theory began to assume its better-known mechanical formulation in the next two years, during which the young scholar published eight more papers, some jointly with Stumpf. In 1898 he and Stumpf parted company; apparently the main reason was his rejection of Stumpf's concept of fusion and particularly Stumpf's notion of musical dissonance and consonance.

Exiled from Stumpf's laboratory, Meyer was on the move for the next two years. After visits in London and New England, including an appointment without pay with G. Stanley Hall at Clark, he obtained a position as professor of psychology at the University of Missouri in 1900. There he remained until 1929. He had but one Ph.D. student, A. P. Weiss; but over the years a number of men who were to distinguish themselves in experimental psychology joined him as students or assistants. The list begins with R. M. Ogden, who acknowledged Meyer's influence in his well-known 1924 work on hearing. It ends with O. W. Mowrer, who, as an undergraduate doing a questionnaire study on the status of women that included some questions on extramarital relations, precipitated the controversy that resulted in Meyer's suspension and formal dismissal in 1930.

Meyer contributed to general psychology, educational psychology, the psychology of music education, and questions of laboratory instruction in psychology. He devised apparatus that included a quartertone harmonium, a sequence of testing devices, and an improvement of Scripture's "strobilion" for recording vibrational patterns. He is best known, however, for two contributions: his pioneering work, *The Fundamental Laws of Human Behavior*, which, published in 1911, guaranteed him notice as a "pre-Watsonian" behaviorist; secondly, his theory of hearing and the models devised to demonstrate it, which is of particular interest here.

According to Meyer (1907) hearing takes place in the cochlea; it is here that the auditory nerve endings receive their stimulus. He regarded the fluid in the cochlea as being inelastic and incompressible because of the short length of the tube; "to speak of tone waves travelling in the lymph up and down the tube is like speaking of a horse race which is to take place within a dog kennel" (Meyer, 1907:2). Meyer rejected the notion of describing the basilar membrane as composed of stretched strings that serve as resonators for various frequencies because they are under different tensions. Such a notion develops from the belief that the basilar membrane is under a constant tension. Meyer observed that organic membranes placed under continuous tension will break or yield to such tension. Thus, while he accepted the possibility of the basilar membrane being capable of resistance, Meyer rejected the possibility of its being under "permanent" tension, thereby also rejecting the assumption that there are resonators in the inner ear.

Meyer assumed that a bulging to and fro of the partition (the organ of Corti) causes a shock in the nerve fibers terminating in that portion of the partition, and that given a rapid sequence of such shocks, the frequency of these shocks determines a process, which he speculated may be chemical. He said that a tone is perceived that "occupies a definite point in the tonal series of sensations of hearing" proportional to the frequency of shocks received (Meyer, 1907:17). In other words, the frequency of the shocks determines the pitch and quality of the tone perceived (Meyer, 1907:32).

Meyer also hypothesized that the intensity of the tone perceived is a function of "the number of nerve ends which receive shocks in a definite frequency" (Meyer, 1907:32).

To reduce the mathematical complexity of the mechanical process taking place in the cochlea and to compensate for the lack of physiological data, Meyer made several "provisional assumptions." These allowed him to provide rational descriptions of a variety of auditory phenomena, notably the nature of difference tones, which, like Stumpf, he treated as

FIGURE 28.—Hydraulic model of the cochlea constructed by Max Meyer in 1964, after one built in 1928. Wooden frame 863 × 165 × 63 mm. (SI photo 72–11336; USNMHT 259279.01)

"subjective." In contrast to Stumpf, he accounted for subjective tones through localized functions of the inner ear.

Meyer retained and explicated his theory for a period of nearly 60 years. Starting about 1928, he turned from thought-models to specific mechanical models to illustrate the theory (Figure 28). These did not, however, eliminate the major problem, which was the failure of either Meyer or anyone else to submit his hypotheses to repeated scrutiny in light of accumulating physiological data unknown at the turn of the century. The problem that was of growing concern to him, namely that of being misinterpreted, was a by-product of this fundamental omission.

Carl Emil Seashore

Carl Seashore, a very different man, was born in Mörlunda, Sweden, in 1866, as Carl Emil Sjostrand. His parents emigrated to this country and settled on a farm in Iowa when he was three. His college years were spent first at Gustavus Adolphus College in Minnesota and later at Yale. Except for two postdoctoral years at Yale, one year at the National Research Council in Washington, D.C., and his last year spent at the home of a son in Idaho, Seashore lived and worked in Iowa for the rest of his 83 years.

Seashore entered Yale and psychology when—in his words—the latter was " 'pure' and knocked feebly at the doors of Science for admission" (Seashore, 1930:260). He entered Yale "on the day" that the psychological laboratory was founded and signed up for the laboratory course. Ladd introduced him to psychology, Schopenhauer, and Scripture, and he remained a student of Ladd's for four years, lauding his qualities as a teacher long after he had come to disagree with his system. Seashore reacted negatively to Scripture's laboratory, in which the experiments seemed to him "nearer to telegraphy than to psychology" (Seashore, 1930:260). He changed his mind rather quickly, and after the departmental upheaval at Yale, which lost not only Ladd and Scripture to American psychology but also most of the Yale graduate students of the period, Seashore emerged as the only one of Scripture's students who remained in experimental psychology. He was, and considered himself, Scripture's student; yet, characteristically, he submitted his thesis, done under Scripture, to Ladd.

Seashore's two mentors typify two styles in psychology: the one is represented by Ladd, the "Sully of America" (Boring, 1957:524), the philosopher-psychologist who excelled as a teacher and writer of textbooks; the other, by Scripture, exponent of the "new" psychology who tried to pry his students away from books and turn them to the laboratory techniques that would let this new science reach the precision of physics. Early exposure to such contrasts caused Seashore to ride multiple tides and maintain distance from dominant dogma. In his autobiography he noted (1930:285) with some satisfaction:

> Trained in structuralism of the Wundtian type, I rapidly adjusted myself to functionalism and enriched my point of view by absorbing freely from all new movements. In this attitude I faced the French school of abnormal psychology, the English group of psychical researchers, Hall's school of child study, the group of animal experimenters, the Freudian and other forms of psychoanalysis, the statistical methods as applied particularly to mental tests, the various brands of behaviorism, paper-and-pencil psychologies of various sorts, the Gestalt psychology, and the recent neurological and philosophical approaches to the theory of psychology.
>
> I owe a great deal to each and all of these and their sequels and variants but I give allegiance to none. As a rigorous experimenter I continue to plod along with the feeling that this point of view and not my particular brand of it, is the point of view of psychology. If what there is of system in my teaching deserves a name, it is the name eclectic.

Seashore went to the University of Iowa in 1898 as an assistant professor. In 1902 he had become a full professor; in 1905 he was made head of the department of philosophy and psychology; in 1908 he ascended to the deanship of the Graduate College, where he remained until he retired as Dean-Emeritus. He regarded being dean at a graduate school as doing applied psychology. Many of his major contributions were in applied psychology—and this is particularly true of his notable achievements in audition.

Seashore first became prominent in auditory work through his development of apparatus. In his first year at Iowa, Seashore, with the help of Charles Bowman, then a physics instructor at Iowa, produced an audiometer. It was a hearing meter of varying intensity in which the stimulus tones were generated electrically. This was the same type that was to be used widely in testing the hearing of pupils throughout American schools, and that was sold and advertised by the Stoelting Company as the "Seashore audiometer" for decades.

Up to the time of Seashore, hearing meters in which the intensity of the sound can be varied remained obscure. However, such hearing meters, particularly those with electrical resistances to vary the intensity existed as early as 1878. In that year, A. Hartmann, working in the laboratory of Emil Dubois-Reymond in Berlin, devised an instrument of this kind. At the same time, similar independent efforts were underway in England. The name "audiometer," now commonly applied to hearing meters in which "the stimulus tones are generated electrically" (Bunch, 1941:1100), appears to have been used first in an 1879 account of a current balance developed for audiological purposes by D. E. Hughes in England.

Seashore's audiometer (Figure 29) consisted of (1) a box into which was built an induction coil, a resistance coil, a galvanometer, as well as a battery and the necessary switches and terminals; and (2) a telephone receiver. The secondary coil was wound in 40 sections, each of which was connected with a set of corresponding spring terminals. By moving a sliding carriage along these terminal contacts, any number of these sections could be included in the circuit. Since the induced current is a linear function of the number of turns in the secondary coil, this

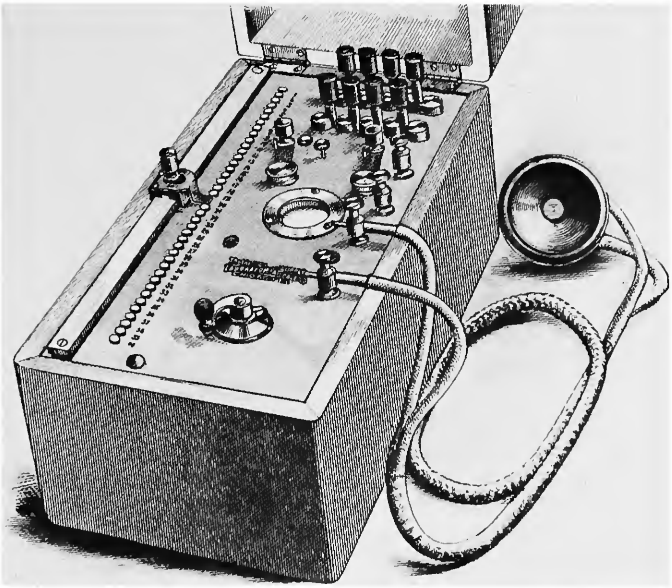


FIGURE 29.—Seashore audiometer. (From Seashore, 1899)

enabled the operator to vary the energy emitted by the circuit, which was connected to the telephone receiver and transmitted as a series of clicks. Varying the resistance and observing the galvanometer reading through a peephole on the box enabled the operator to standardize the readings.

A distinctive feature of the Seashore audiometer was the calibration of the scale. Since, by the Weber-Fechner law, stimulus and sensation are in a logarithmic ratio, so that SE=clog ST, Seashore let the number of coils in each section increase logarithmically, so as to provide "psychologically equal" steps in the increase of sound intensity. Thus, the increase in stimulus equalled the corresponding increase in sensation.

An optional feature allowed use of the instrument in tests where a tone is preferred to a click. This accessory consisted of an electric tuning fork attached to the box by a double contact; this connection permitted the fork's tone to be introduced into the circuit for transmission to the receiver. Its intensity could be varied just as that of the ordinary click.

Seashore introduced his audiometer with the advice that "it is adapted to the needs of the psychological laboratory, the school room and the aurist's office" (Seashore, 1899:156). The instrument's success in all three areas confirmed his aim.

In 1902 Seashore presented another instrument destined for long periods of use. This was the tonoscope, a device for translating vocal vibrations into visible form (Figure 30). Based on the principle, and named after, the stroboscope, the tonoscope was designed primarily to study singing. It was based on a configuration first used by Scripture in a laboratory set-up designed in the 1890s.

The 1902 tonoscope consisted of an electric tuning fork, a vacuum tube, a stroboscopic screen, a manometric capsule, a telephone receiver, and the necessary auxiliary switches, circuits, and battery. It was designed to measure the pitch of a tone produced by the singer. It would produce a tone, and then compare that one to the singer's tone by projecting the vibrations of both upon the screen.

The tonoscope appeared in several different versions over the years; later models expanded its use from recording speech or musical tones of the human voice to transcribing music, speech or other sound patterns from phonographs and other recording devices (Seashore, 1914). The tonoscope was applied by musicians, clinicians, and psychologists alike, and became a touted example of the value of applied psychology in music (Seashore, 1912).

Seashore was responsible for the development of numerous other instruments, designed by himself and by students at Iowa. One example is a sound perimeter created in 1903 to improve upon the existing gadgets invented for the study of sound localization. Seashore's early interest in this field proved useful. During World War I he served as chairman of the Committee on Acoustic Problems and consultant on the detection of submarines.

Seashore's continual applications of his inventions and investigations are symbolic of one of the aspects of the psychology of the 1920s. Seashore's students and others of their generation were to go out and become resident psychologists in medical schools, music schools, public schools, record companies, and industrial research laboratories. They remained psychologists working on auditory problems. But they were "mission-oriented" and they no longer published primarily in the *American Journal of Psychology*, the *Psychological Review*, or the *Journal of Experimental Psychology*. Instead, their work appeared in publications like *Laryngoscope*, *Musical Quarterly*, *Lyre*, *Eugenics*, *Genetics and the Family*, *The Transactions of the American Otological Society*, and eventually, the *Journal of the Acoustical Society of America*.

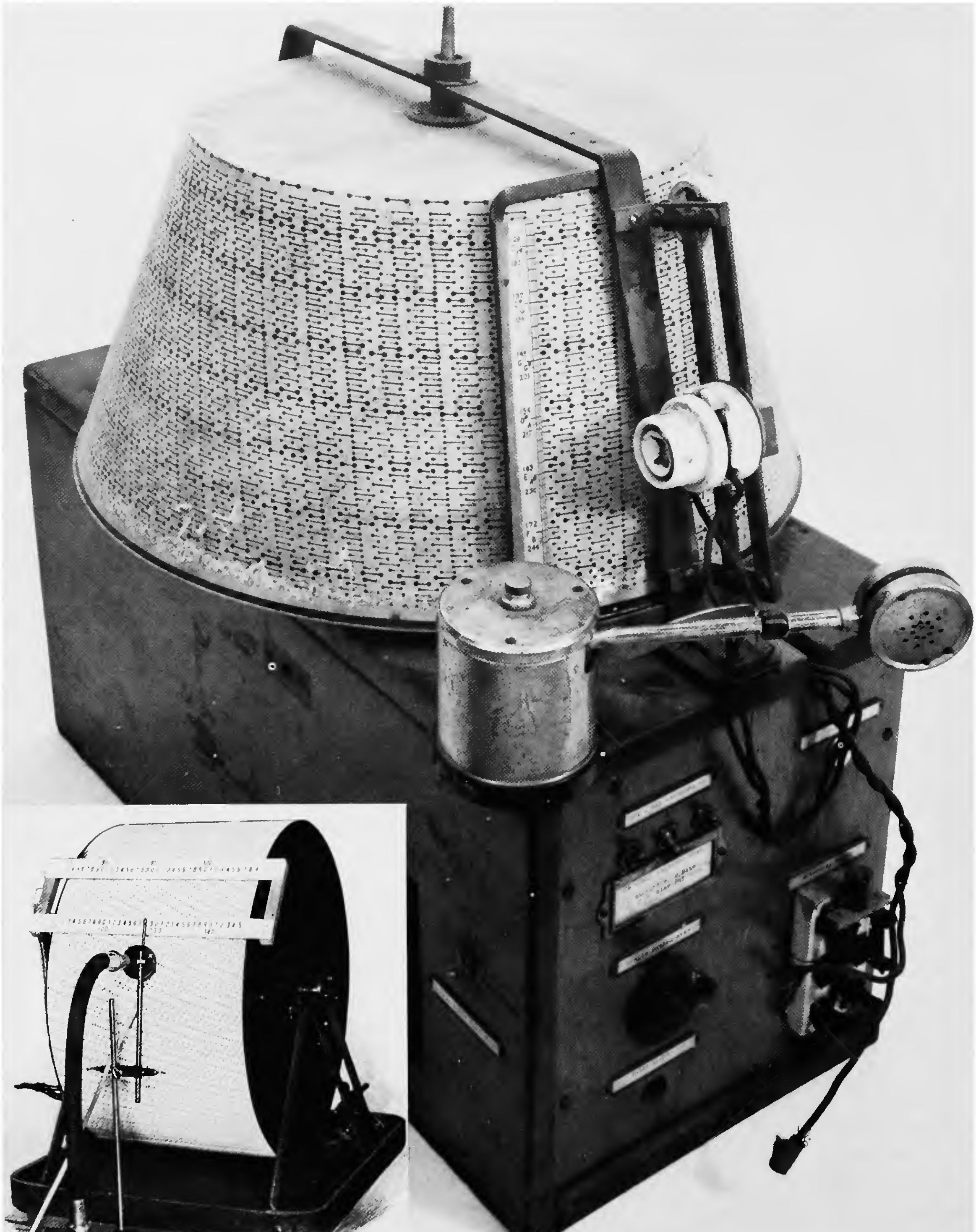


FIGURE 30.—Early version of the Seashore tonoscope. Top of drum diameter 31 cm. (USNMHT 306749.17; inset from Seashore, 1914)

The Background of the Twenties

If psychologists trained in audition were going into the outside world, what was the world offering in return? Again, the chief contributions came from the domains of the physicist and of the physiologist. Among physicists there were two groups who conducted research in acoustics that interested the psychologist. One group worked in the university, represented by the work of Wallace C. Sabine and Dayton C. Miller between 1900 and 1920. The other group worked in industry, and is best represented by the research teams at the Western Electric Research Laboratories between 1920 and 1930.

Applied Acoustics

Wallace Clement Sabine laid the twentieth-century scientific foundation of architectural acoustics. His classical paper on reverberation was published in 1900, when he was 32 years old. As a rigorous experimenter he called to the attention of psychologists the danger of testing "laws" rather than investigating phenomena. To stress the importance of boundary conditions, he singled out the failings of two of the most revered psychologists. Wundt and Muensterberg had neglected boundary conditions when they simply assumed the law of variation of intensity of sound with the inverse square of the distance: "It makes one wonder how they were able to draw any conclusions from their measurements" (Orcutt, 1933:291).

Dayton C. Miller's results of special interest to psychologists centered on recording, composition, and decomposition of sound waves. Aside from providing visible characteristics of sound waves generated by an assortment of instruments, they had special significance to those who drew upon Ohm's law.

Mechanical harmonic analyzers and synthesizers provided data for Miller. These devices, developed on the basis of nineteenth-century prototypes invented by James and William Thomson, are mathematical analogue calculators. A synthesizer sums up the components of a sound wave; an analyzer breaks out the elementary components of the wave, an operation mathematically equivalent to computing the Fourier coefficients in its trigonometric expansion. As input, both machines use a graph of the simple or compound wave. To obtain such a graph Miller developed the "phonodeik." This instrument focused the vibrations of the given sound wave onto a diaphragm from which they were transmitted graphically onto a moving film.

As a result of World War I, such men as Miller and Sabine participated in acoustic research for the War Department. Among other things, at Sandy Hook Proving Grounds, New York, in 1919, a method of electric-spark photography of the waves generated by bullets in flight was developed on the basis of their prior contributions. There, also, basic studies on shell shock were conducted in collaboration with physiologists.

Among the research scientists and engineers motivated by the requirements of the Great War were teams from the Western Electric Company. They had helped to develop a string galvanometer, based on the principle of the Einthoven galvanometer, that was intended for use in France and later adopted at Sandy Hook. They designed microphones to study sounds emitted by large guns, and continued researches in telephony. In the 1920s they were prepared to propagate basic research in electronic audiometry.

C. C. Bunch and L. W. Dean at Iowa had developed the pitch-range audiometer in 1919. In November of the same year, two groups of researchers—K. L. Schaefer and G. Gruschke, B. Griessmann and Schwartzkopf—demonstrated before the Berlin Otological Society two instruments designed to test hearing acuity. Both were built with vacuum tubes. Their designs were characteristic of the two basic types of electronic circuits used in most electronic audio devices for the next two decades. Neither of the two devices was developed commercially for some time, although the second was to be manufactured under the name "Otaudion." In the United States, J. Guttman in 1921 described an "electric acoumeter," which was an electronic device. At the same time J. P. Minton and J. G. Wilson developed their audio-oscillator. However, it was a series of audiometers developed at the Western Electric Company's Research Laboratory that marked the beginning of regular commercial production of these devices. It climaxed the breakthrough made possible with the development and application of the vacuum tube.

The first of the Western Electric audiometers was the Model 1-A (Figure 31). It was presented publicly

FIGURE 31.—Edmund P. Fowler in his sound-proofed room with the Western Electric 1–A audiometer. (SI photo 74–6750; USNMHT 256198.01)

at the 1922 meeting of the American Laryngological, Rhinological and Otological Society by Harvey Fletcher and Edmund P. Fowler. For this presentation they produced threshold curves of various types of deafness. Fowler and Wegel also presented the device to the American Otological Society that year with a discussion of the now-classic audiogram chart.

The 1–A was a pure-tone generator that had a range from 32 to 16,384 cycles, or 9 octaves; it could be set to produce any one of 20 tones within that range and at varying intensities. Although this first device was produced only in a limited quantity, it was used in some of the more important studies of the twenties, including R. L. Wegel and L. E. Lane's famous work on masking. Masking had been studied by A. M. Mayer in the 1870s. In 1876 he called attention to the difference in the masking effects of low and high sounds, observing that a sound of low pitch can mask one of high pitch totally, but that the converse does not hold. Using the 1–A's capability of generating pure tones and controlling the intensity, Wegel and Lane were able for the first time to make precise the variations in the amount of masking between tones of lower and higher pitch than the masking tone (Figure 32).

The 2–A Model (Figures 33, 34) was a smaller, portable version of the 1–A, having a frequency range varying seven octaves (from 64 to 8192 cycles), which was divided into eight positions, corresponding to the 8 c-notes of the range. Like the 1–A it could be set at varying intensities, thanks to an attenuation potentiometer. It had the advantage of selling at less than half the price of the 1–A, which cost over $1500.

A different type of audiometer was represented by the 3–A model. This relatively simple device generated a buzzer-sound and had adjustable intensity control. The 5–A also was a buzzer audiometer. Yet another type of audiometer was represented by the 4–A. This was essentially a phonograph with multiple ear phones and was widely used to conduct hearing tests on school children. The phonograph played a sequence of numbers in the most widely used test, usually spoken alternately by male and female voices.

The Western Electric scientists went beyond laboratory experimentation. They collaborated with university physicists: Harvey Fletcher in the summer of 1925 delivered lectures on "the physical aspects and measurement of speech and hearing" at the University of Michigan (Bell Laboratories, 1925:50). They collaborated with physiologists: Out of such work came the development of the electrical stethoscope. Last but not least, they provided an important impetus to those like C. C. Bunch who, coming out of the laboratory of the psychologist, had gone to work among physiologists, and now conducted studies comparing and utilizing new apparatus in the service of both fields (Figure 35). By the 1920s physiologists had considerable material to offer to the psychologist, and psychologists were once again receptive to it.

Applied Physiology

American psychologists, although aware of its limitations, had continued to rely on the resonance theory. Boring and Titchener claimed (1920:101):

> The historian of science must always regard it with admiration since for combined range and detail and directness of correlation it is still without a rival; and indeed, as a model of

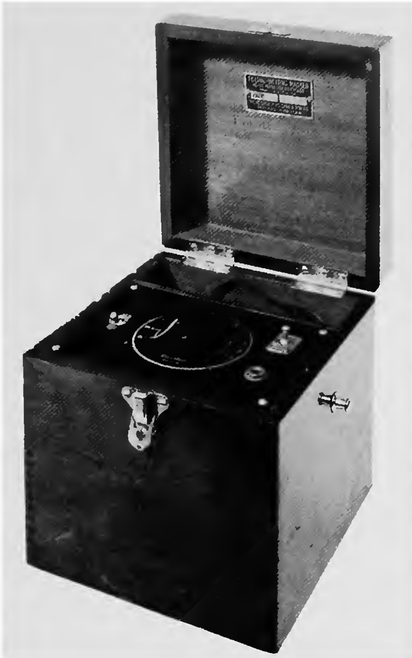


FIGURE 32.—Pilling-Witting masker made by George P. Pilling & Son Co. at Philadelphia. 205 × 210 × 210 mm. (SI photo 72–11349; USNMHT 306749.04)

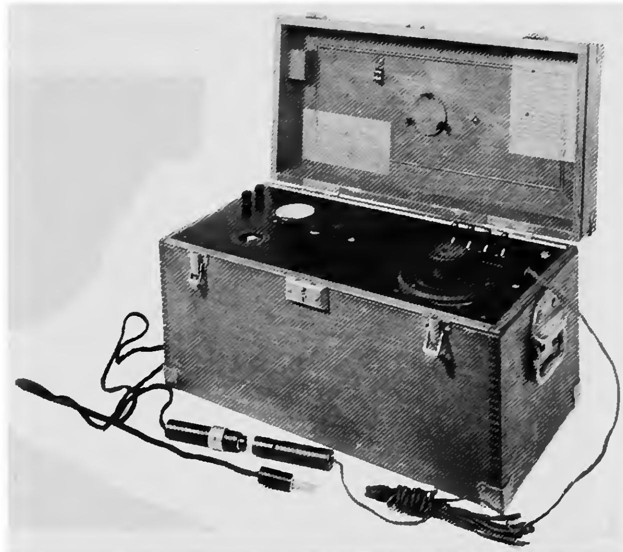


FIGURE 33.—2-A audiometer made by Western Electric. 510 × 255 × 275 mm. (SI photo 72–11333; USNMHT 306749.12)

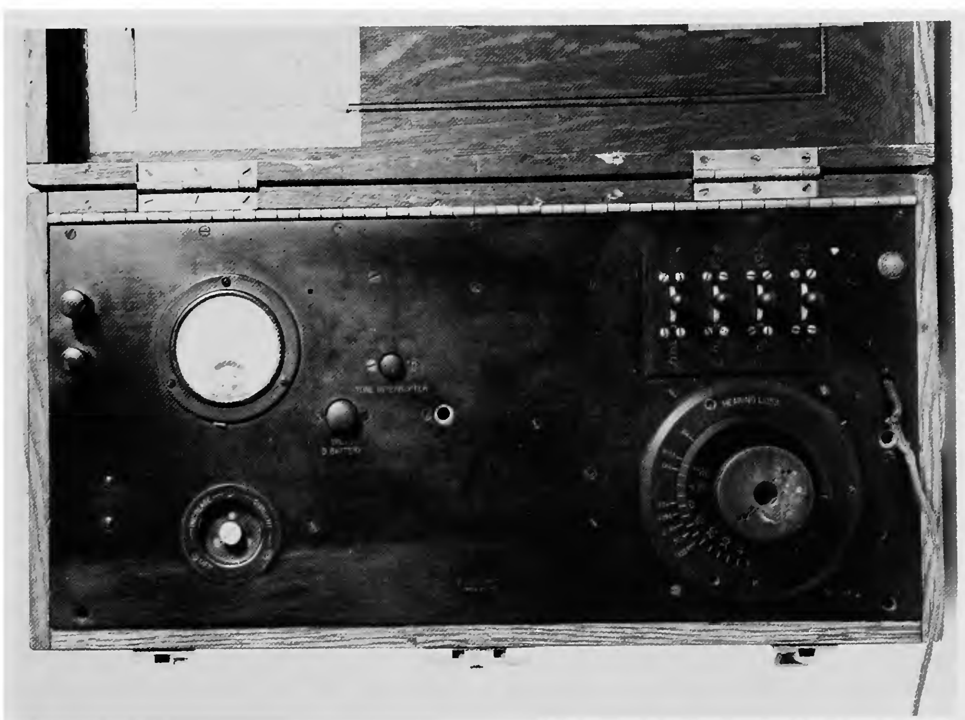


FIGURE 34.—Close up of control panel of 2-A audiometer. (SI photo 72–11334; USNMHT 306749.12)

FIGURE 35.—Dean Carl E. Seashore. (From *University of Iowa Studies in Psychology*, 12 (1928))

what a theory "ought" to be, it will probably figure for many years to come—with the more or less emphatic warning that it need not be believed—in textbooks of physiology and psychology.

Model makers especially continued to seek ways of testing and demonstrating its validity, at the same time that new experimental evidence paved the way for renewal of another basic theory—the telephone theory of William Rutherford.

Early debate over the function of the various components of the cochlea had revolved around the issue of whether or not it was the seat of auditory analysis. Where are vibrations transformed? Two most likely sites were the cochlea and the brain. Of the models built to illustrate the theories of inner ear behavior, those of Max Meyer and George Wilkinson received the most publicity and discussion during the 1920s.

The Wilkinson model was designed not to support any specific existing theory, such as the resonance theory, but rather to shed light on all theories. Above all it served to illustrate the movements of stretched membranes in response to sound vibrations, studied by C. Rich Ewald thirty years earlier (Wilkinson, 1922a:53). Wilkinson assumed that the actual vibration element in the cochlea is the basilar membrane (Wilkinson, 1927:365). The lack of a suitable material prevented him from duplicating the spiral curve form of the cochlea and basilar membrane (Wilkinson, 1930b:834). His model consisted of a brass box $5 \times 5.5 \times 6.5$ cm divided into two chambers, an upper or "scala vestibulae" and lower or "scala tympani" separated by a flat brass plate containing the "basilar membrane." The top of the upper chamber is provided with a glass window, through which the movements of the membrane may be observed. Rubber membranes cover the openings representing the round and oval windows which are secured by rubber washers. A small wooden plunger, the "stapes," is attached to the lower (larger) membrane. At the back of each chamber are small holes closed by screws, "filling holes," through which fluid can be introduced by means of a syringe with a fine nozzle, to fill the chambers. The most difficult and troublesome parts to represent in the model were the basilar fibers, which were made of a phosphor-bronze ribbon $\frac{1}{80}$ mm thick and carefully placed with controls to regulate their tension. The transverse sectors of the "basilar membrane" in the model were thrown into sympathetic vibration by touching the "stapes" lightly with a vibrating tuning fork (Wilkinson, 1922b:459).

The essential feature of the theory of cochlea function of Wilkinson is that the fibers of the basilar membrane are differentiated by length, tension and mass, just like the strings of a muscial instrument (Wilkinson, 1927:370). The scale of the model was not pertinent to the law of vibrating strings. Hence the model and the cochlea could be expected to follow the formula for vibrating strings as derived by Fourier (Wilkinson, 1922b:451). E. W. Scripture took exception to the Wilkinson model. He voiced his disapproval in a short letter to the editor of *The Lancet* in 1922 pointing out some properties of the human voice that seemed to contradict a resonance theory of hearing (Scripture, 1922:779–780).

By the mid-twenties so many theories of hearing (Wever, 1970:41, Boring, 1926:157) had appeared that dismay appeared rampant among experimentalists. The psychologist of the period wished "to clean his slate of theory and to start afresh from a thoroughgoing study of the sense-organ, biological, anatomical and physiological" (Boring and Titchener, 1920:102).

In the next few years, those who accepted this challenge could not match in deed what was asked in word. The best a trio of physiologists and several psychologists could do was adopt and improve an exciting twentieth-century electrophysical technique. They sought evidence for a current in the auditory nerve of a decerebrate cat of the same frequency or sound presented to the ear. At first, Forbes, Miller, and O'Connor (1927) used the method of F. J. J. Buytendijk, who had reported on it in 1911 in *Akademie van Wetenschappen* (Amsterdam; 13(2):649–652), but failed to record responses in frequency higher than 200 cycles per second. Psychologists Ernest Glenn Wever and Charles W. Bray (1930:377), taking on the role of the physiologist, who usually provided fresh evidence for auditory theories, set out to improve this experiment. They attached an electrode to the exposed auditory nerve, added an amplifier to the circuit and hooked it up to a telephone receiver in a sound proof room. Their contribution to the experiment was to install a telephone receiver, which made it possible to hear currents of a much higher frequency. They proved that sound applied to the ear of the animal produced effects in the acoustic nerve, which corresponded to the frequency of the original sound stimulus. Sounds including the voice were discriminated quite plainly on the receiver-recorder. Responses continued until after death, they grew fainter and ceased in approximately a quarter of an hour.

Wever and Bray, unable to arrive at a single theory suggested by their findings, proposed four, which they labeled as follows: (1) the resonance telephone theory; (2) the nonresonance telephone theory (the telephone theory of the type outlined by Boring, 1926); (3) the resonance volley theory; (4) the nonresonance volley theory. Wever and Bray conceived the Volley principle as an alternative to the telephone theory of frequency transmission. By the Volley principle they meant the serial interplay between fibers responding to sound vibrations. "A given fiber when stimulated . . . responds and then remains inactive for a time until it is again stimulable. The fiber will respond to a constantly maintained stimulus with a regular series of impulses of lower frequency than the stimulus but in synchronism with the individual waves of the stimulus" (Wever and Bray, 1930:376). The fibers may be out of synchronization with each other, but they are synchronized with the exciting frequency. Thus by 1930 physiological evidence was conducive to a blending of auditory theories, a state of affairs still shared by present day physiologists, psychologists, and physicians, though on a more refined level. Subsequent explanations centered on how the inner ear fibers and the nerve fibers react to sound vibrations.

Conclusion

In the 50-year period between the last edition of Helmholtz's *Tonempfindungen* and the publication of the experiments of Wever and Bray, audition in psychology passed through a well-defined phase.

Helmholtz had brought to the subject a masterful combination of scientific method, theory, experimentation, and technology. He had approached the field as physicist, physiologist, and psychologist. To each of these three disciplines he left a base on which to build.

Laboratory psychology was in its infancy. Its promoters were successful in cutting it loose from philosophy. In seeking to establish its identity as a science they had to broaden a narrow line of demarcation between physics and physiology. As American laboratory psychology developed, it bore the scar of a reaction against its early dependence on physiology. Problems arose, particularly in audition, where much depended on adding to our physiological knowledge of hearing.

The psychologist wishing to further the study of audition and to leave upon it the distinctive stamp of psychology could choose among the following four avenues of approach:

1. The Path of Method: He could pursue the subject in a laboratory setting applying the techniques and equipment of the physicist to a method that he could call his own. This was the course followed by Titchener and other laboratory psychologists using introspection.

2. The Path of Theory: He could pursue the subject hypothetically, applying physical laws to

the phenomena of auditory perception. By providing for a range of options to cover the possibilities left open by insufficient physiological evidence, he could establish a logically valid theory. This was the course followed by Max Meyer.

3. The Path of Applications: He could pursue the subject eclectically, selecting practical problems to which existing experimental or theoretical techniques could provide clues, if not solutions. This was the course followed by Seashore.

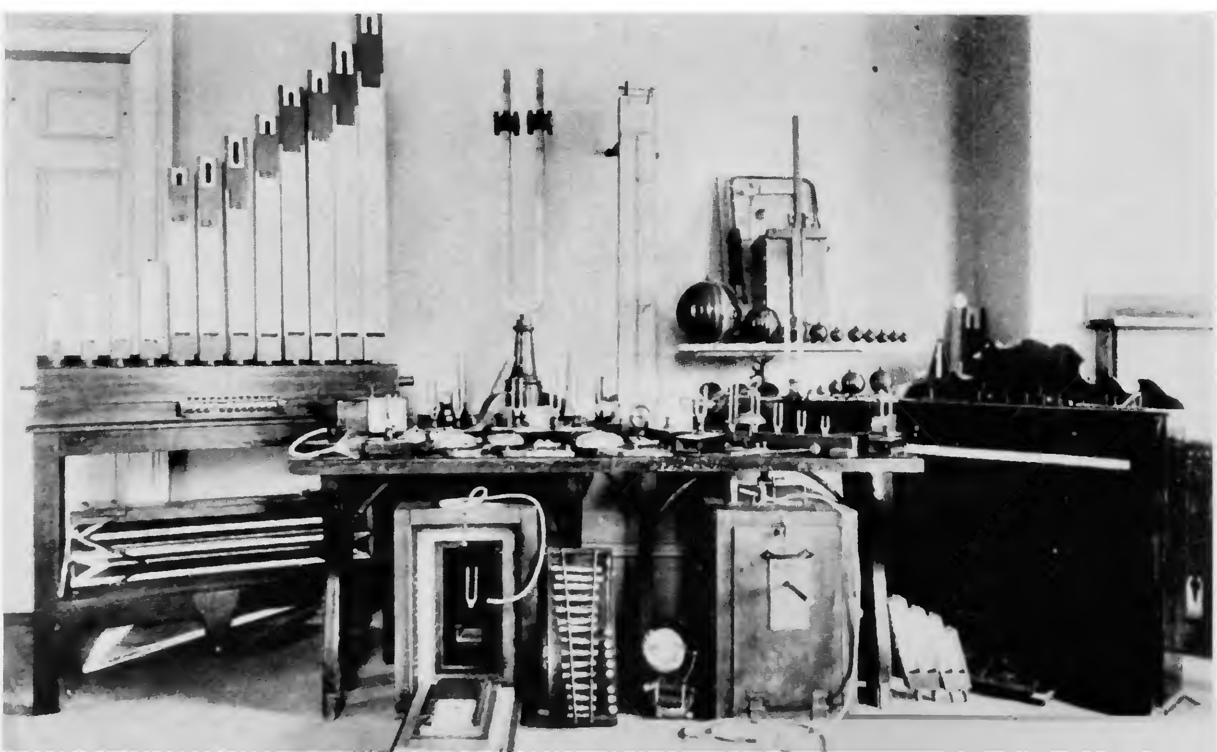
4. The Path of Experimentation: He could pursue the subject experimentally, applying physiological techniques to the study of the ear and the phenomena of auditory perception. This was the course followed by Lashley, Hunter, Bunch, and others who turned to clinical or comparative psychology.

There should have been a path of technology, but this path was blocked to the psychologist working in his own laboratory. He came upon it, if at all, indirectly by collaborating with the engineer in an industrial laboratory or the clinician in a state laboratory. It was the road that led to new frontiers. But it was costly, and these were no longer the days when one could rely on the munificence of a King Maximilian of Bavaria to underwrite an apparatus for vowel construction, as had Helmholtz, or make history as a Bell or an Edison on the basis of invention and entrepreneurship alone. In the industrial society of the twentieth century scientific advances based on technological breakthroughs have been made with the support of either government or industry. A discipline that had just found its own reason for being, and was striving hard to convince the rest of the world of it, was not in a position to win such support.

In the game of "mirror, mirror on the wall, who is the most psychological of them all?" Titchener and his fellow introspectionists may well have scored highest; their method was distinctive even if their apparatus was not. But in that game of practicality, which Titchener refused to play, it was Seashore who saw success: By keeping before the eyes of the public the usefulness of his subject, he was able to convey upon a whole discipline a prestige that was sorely needed if that discipline was to obtain its share of the forthcoming pie.

While Seashore in psychology and Sabine in physics were making themselves useful in the wings, electrophysiology took center stage in the field of audition. But being in the wings gives access to the entrances. Thus, by 1930 psychologists, as well as physicists, could join with their colleagues in physiology in reaping the benefits of the technological advances of the preceding decades. In 1961 a physicist named Békésy won the Nobel Price in Physiology for work done in audition. It was not unexpected that his recent home-base, a psycho-acoustic laboratory, also won renown—and support—for work done by psychologists, much of it under contract to the government of the United States. The laboratory was at Harvard—where William James had related physiology to psychology and allowed psychophysics to enter.

FIGURE 36.—Harvard University Psychological Laboratory, ca. 1893. (From Harvard University 1893)



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The following reference list is extremely selective. Inclusion has been restricted to items that either were cited in the text or provide guides to further reading and study. Boring 1942 and 1957 provide general guidance to the history of psychology and the history of the study of auditory phenomena within psychology. Students interested in the nineteenth-century background cannot afford to ignore Fechner 1860 and 1877, Wundt 1883 and 1902–1903, and Helmholtz 1954, or other editions of these major classics. Detailed nineteenth-century references to instruments and apparatus are found in Auerbach 1909 and Titchener 1901a, b and 1905a, b. Subsequent apparatus developments, with selected references to the literature can be pursued via Zimmermann 1912 and 1928, and Stoelting 1936. Harvard University 1955 is an excellent guide to twentieth-century work in audition and contains topical indexes.

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