ridge basalts, variations in dolomite abundance and in the composition of shales, and the rise of atmospheric oxygen. Here is where Holland's uniformitarian viewpoint becomes apparent. The relative constancy of the lithium content of shales is used to discount the idea that the chemistry of the early oceans was dominated by hydrothermal fluxes and that the early oceans were buffered by large-scale interaction of seawater with ocean floor basalts. Evidence from paleosols and detrital uraninite deposits is used, along with data on the manganese content of carbonates and inferences on the availability of sulfate, to argue that atmospheric pO_2 remained at a roughly constant level of 0.02 of the present atmospheric level (4×10^{-3} atmospheres) throughout the time period from 3.0 to 1.5 billion years before the present. This interpretation contrasts sharply with that of other recent workers, who see major increases in pO_2 at 2.4 billion years and 1.7 billion years before the present. Holland suggests that the oxidant required to precipitate banded iron formations and to oxidize iron in ancient soil horizons was, in both cases, atmospheric O_2; these are just two examples of specific points about which prolonged debate is likely to flourish.

Holland's discussion of the Phanerozoic is necessarily compact but contains a nice synopsis of the mechanism by which oxygen is transferred between carbonate, sulfate, and atmospheric reservoirs. Biological innovations leading to greater productivity in the oceans and colonization of the continents are suggested as the principal cause of increases in atmospheric pO_2 since the late Proterozoic. Biological evolution is also invoked to explain the scarcity of dolomite deposits during the last 150 million years; Holland suggests that this phenomenon is linked to the decreasing abundance of intertidal and subtidal algal mats. The possible role of an impact event in causing mass extinctions at the end of the Cretaceous is mentioned briefly but enthusiastically.

In summary, many workers in the field of Earth history will probably disagree with parts of Holland's analysis, but they should all become acquainted with it. Dense with facts, cautious in its interpretations, and laced with interesting speculations, Holland's book will be a valuable reference for geochemists, geologists, and atmospheric scientists for years to come.

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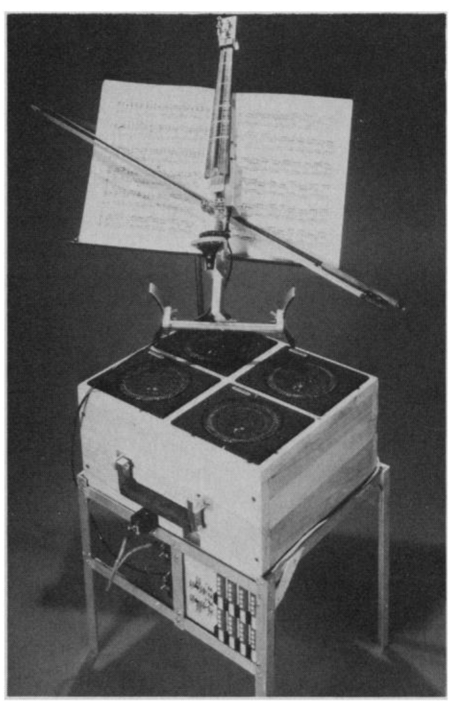
The Sound of Music

The Science of Musical Sound. JOHN R. PIERCE. Scientific American Library, New York, 1984 (distributor, Freeman, New York). xiv, 242 pp., illus., + two records. $27.95.

This lavishly illustrated introduction to musical acoustics demonstrates once again the wide-ranging wisdom, infectious enthusiasm, and unique flair for rendering the complex comprehensible that John Pierce has manifested in numerous earlier scientific books (not to mention several science-fictional entertainments under the pseudonym J. J. Coupling). Undaunted by two retirements—first from the Bell Telephone Laboratories and subsequently from the California Institute of Technology—the irrepressible Pierce continues an active interaction with the world's leading centers for computer research in music and acoustics, especially Stanford's CCRMA, and a playful exploration (with Elizabeth Cohen and Max Mathews) of new musical scales based on computer-synthesized tones whose partials depart from the usual harmonic series.

It was under Pierce's auspices at the Bell Laboratories that Mathews (to whom this book is dedicated) developed his series of increasingly powerful and versatile computer programs, culminating in Music V. Mathews's programs have enabled composers, psychoacousticians, and perceptual psychologists to generate for the first time any specifiable sound, unfettered by the limitations of existing musical instruments or physical devices. As this book attests, the worlds of music and psychoacoustics have been forever transformed.



Max Mathews's electric violin, which can simulate the sounds not only of a good violin but of brass instruments. [Photo courtesy of M. V. Mathews; from *The Science of Musical Sound*]

Not only can one now closely simulate the sounds of real trumpets, violins, bells, or drums, one can parametrically interpolate between such instruments, changing by degrees a violin into a trumpet, or a flute into a human voice. One can also synthesize completely novel sounds and, by independently varying the frequencies of the sinusoidal components and the overall amplitude envelope, produce paradoxical illusions in which a tone that seems throughout to be falling in pitch is clearly much higher at the end than it was at the beginning.

Readers can hear a number of these auditory phenomena on two thin phonograph disks that are included, along with nine informative appendixes, at the back of the book. The demonstrated phenomena are more than amusing tricks; they have influenced contemporary musical composition, and they have made it possible to determine which of the vast number of physical variables of musical sounds are perceptually salient. Thus, whereas the steady-state spectral energy distribution had been thought since Helmholtz to determine the characteristic tone quality or timbre of a particular musical instrument, Grey, Risset, Wessel, and others have shown that the temporal variations in attack and decay of the individual partials of a tone are just as important.

Pierce enlivens his presentation with illuminating historical commentaries, personal anecdotes, photographs, and "microbiographies" of contemporary notables in the fields of electronic and computer music (including Babbitt, Boulez, Chowning, Stockhausen, Ussachevsky, and Varèse) and in the fields of acoustics and psychoacoustics (including Békésy, Fletcher, Schouten, Schroeder, Stevens, and Sundberg). Particularly enlightening is his recounting of the vicissitudes of the science of architectural acoustics from its turn-of-the-century founding by Harvard mathematics professor Wallace Sabine, through the acoustical disaster of Philharmonic Hall in New York's Lincoln Center, to the salvation of that structure as the present Avery Fisher Hall by Cyril Harris.

How can something as subjective as the quality of musical sound be made a science? Of the many advances in this direction described by Pierce, I can give

Manfred Schroeder's collaborators K. F. Siebrasse (left) and D. Gottlob (right) and the dummy head through which they recorded the sounds of 20 European concert halls. [Photo courtesy of M. Schroeder; from *The Science of Musical Sound*]

only one illustrative example. Manfred Schroeder (who divides his time between the Bell Laboratories and his own institute at the University of Göttingen) together with two collaborators, D. Gottlob and K. F. Siebrasse, assessed the musical qualities of 20 major European concert halls by the following ingenious steps: In each hall they acoustically broadcast the same high-fidelity multichannel tape of Mozart's *Jupiter* Symphony previously recorded by the BBC orchestra in an anechoic chamber. They rerecorded the music through two small microphones inserted in the ear canals of a dummy human head variously situated in each hall. In an anechoic chamber back in their own laboratory they then reproduced the signals, as picked up at the dummy's ears, at the ears of a listener who could switch back and forth at will between what the *Jupiter* Symphony would be sounding like in one hall or another. They submitted listeners' preference ratings for the alternative sounds to a technique of multidimensional scaling (also perfected at the Bell Laboratories), which represented these sounds as points in a two-dimensional psychological space. They then established that the direction through this space that corresponded to greatest average preference also corresponded to the physically identifiable factors of a moderately long reverberation time of the hall and the lowest correlation between the early echoes incident at the two ears.

The correlational result was a major discovery. Old halls and churches, constrained to the short horizontal spans achievable in wood or stone, are narrow with high ceilings. The first echoes received by the two ears are therefore from opposite walls, yielding decorrelated signals and a desirably spacious sound. Modern steel-spanned halls, designed to accommodate large audiences at low cost, are wide with low ceilings. The first echoes to reach both ears are therefore from the ceiling above, yielding highly correlated signals and a disappointing lack of spaciousness. In a final brilliant stroke, Schroeder and his colleagues used "quadratic residues" of number theory to design a textured surface, with optimally scaled protrusions and depressions, that can be applied to a low ceiling to scatter the soundwaves laterally, yielding the desirable decorrelation.

Focusing as it does on the science of musical sound, this book does not concern itself much with what might be called the science of musical structure—a science that is just now burgeoning within the corner of cognitive psychology that adjoins music theory. When Pierce does touch on such matters as tonality, mode, and harmony, he notes that he is "wandering a little beyond the science of musical sound into the territory of music itself." He acknowledges that "of the harmonic language of music this book has little to say" and rightly notes that "there is more to harmony than avoidance of dissonance."

As a supplemental text, the book could nicely fill either of two pressing needs: for an exposure to relevant musical matters in a course on physical acoustics or auditory perception or for a non-mathematical grounding in relevant acoustical matters in a course on music theory or music cognition.

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