the role of memory, and the perception of instrumental timbre. The field as a whole is currently undergoing rapid expansion. This is due in large part to recent technological advances which have facilitated the generation of complex auditory stimuli with precisely controlled parameters. Given the developing interest among scientists, music theorists, who have traditionally been rationalistic in their approach, are also turning their attention to empirical issues. Thus, we see emerging a new and strong interaction between musical acoustics on the one hand and music theory on the other. It is expected that considerable advances will be made in the understanding of music perception over the next decade.

2:30

JJ2. Voice as a musical instrument. I. R. Titze (Sensory Communication Research Laboratory, Gallaudet College, Washington, DC 20002)

A comparison between voice as a periodic sound source in speech and voice as a musical instrument is made on the basis of physiological and acoustic differences. Oral acoustic output power is about 1000 times greater in maximal effort singing than in conversational speech, and vocal efficiency can be 100 times greater. This makes optimization of laryngeal and pharyngeal configurations an important performance task. Recent research demonstrates that a somewhat lowered larynx, stable respiratory and phonatory configurations based on nearly isometric contractions of opposing muscles, and formation of an upper laryngeal resonator for high-frequency emphasis (the singing formant) are key factors. Fundamental frequency control over a range of several octaves is accomplished by intrinsic laryngeal muscular contraction, but nonlinear tissue characteristics of the vocal folds can account for an amplitude tuning by pulmonary effort. The quality of the tone is dominated by two major register adjustments in the larynx, but a larger number of minor register effects are perceived on the basis of vocal tract loading. This source-system interaction, which depends on vocal tract dimensions, in conjunction with the size of the vocal folds, establishes a scaling principle for voice classification on both physiological and acoustic levels. Training of the instrument and training of the artist is an inseparable process. Evidence is yet scarce that a good singing voice, like a good violin, is structurally determined. If so, what are the key morphological elements? If not, is the quality improved by overall muscular strengthening, by differential adjustment and accurate coordination of specific muscles, or by biological adaptation of mechanical tissue properties?

3:00

JJ3. A brief history of violin research. Carleen M. Hutchins (112 Essex Avenue, Montclair, NJ 07042)

Underpinnings making possible present day violin research have been provided by such well known figures as Gallileo, Mersenne, Hooke, Saveur, Fourier, Chladni, Poisson, Helmholtz, Rayleigh, Dayton Miller, Erwin Meyer, and manufacturers of modern electronic and optical equipment. First known extensive investigations in violin acoustics were done in early 19th century France by Felix Savart. Not until early 20th century did a continuous research flow emerge. Today there is fairly good knowledge of *what* goes into the violin and *what* comes out based on extensive studies of: vibrational characteristics of bowed strings; overall spectral content of violin sounds with variations from one instrument to another; vibrations of the violin bridge; Eigenmodes of free plates; geometries of air resonances of the violin cavity; acoustical properties of suitable wood and other materials. We are beginning to understand *how* free-plate Eigenmodes affect tone quality, but we don't know *how* they relate to the coupled modes of both wood and air in the bowed instrument. We don't know exactly *how* the nonlinear bow-string mechanism activates the instrument, nor *how* vibrations of the bridge relate to those of each violin for desired tone quality; and we don't know *how* Chladni patterns of the vibrating box affect radiated sounds, nor *how* they are altered by changes in position and other soundpost variations. Also we have relatively little psychoacoustical information for correlation of subjective musician judgements with physical effects amenable to measurement and analysis. Since the early 1900s research has been done in laboratories around the world and considerable goes forward today on highly technical levels which should provide new insights into old problems. Highlights of this will be discussed. An excellent survey of currrent developments is: "The Acoustics of Stringed Musical Instruments," M. E. McIntyre and J. Woodhouse, Interdiscip. Science Rev. **3**, No. 2 (1978).

3:30

JJ4. On some aspects of mechanical reed woodwinds. William J. Strong (Department of Physics and Astronomy, Brigham Young University, Provo, UT 84602)

During the lifetime of the Acoustical Society of America, certain developments have led to an improved understanding of the physical and tonal properties of woodwind instruments. These developments include theoretical analysis, instrumentation for measuring acoustical properties, and high speed digital computing. This paper will review past work, summarize the present state of our knowledge, and offer some conjectures on the future. The content is restricted to a consideration of mechanical-reed woodwinds, although comparable things could be said about "air-reed" woodwinds. The following aspects will be discussed: (1) acceptable bore shapes; (2) theory of tone holes; (3) experimental measurement of input impedance; (4) numerical calculation of input impedance; (5) implications of input impedance; (6) reed and air-column interaction; (7) small-amplitude, steady-state vibrations; (8) medium-amplitude, nonbeating, steady-state vibrations; (9) functional modeling of arbitrary amplitude transient and steady-state vibrations; (10) tonal analysis-synthesis and spectral properties; and (11) tonal perception.

4:00

JJ5. What happens when you blow your own horn? Robert W. Pyle, Jr. (Bolt Beranek and Newman Inc., Cambridge, MA 02138)

This paper will trace the development of our understanding of the acoustics of brass wind instruments from the eighteenth century to the present. Topics to be covered include the theory of sound propagation in ducts and flaring horns, the physical attributes of brass-instrument tone, the physiology of the player, the regeneration mechanism of the player's embouchure, and the influence upon the instrument of the materials from which it is made. The sometimes remarkable empiricism of instrument makers and players will be discussed along with research by the scientific community.

4:30

JJ6. Keyboard and electronic musical instrument research: Status and outlook. Daniel W. Martin (Baldwin Piano and Organ Company, Cincinnati, OH 45202)

An acoustical review and a limited projection of the status of keyboard musical instrument research and development, both mechanoacoustic and electronic.

THURSDAY AFTERNOON, 14 JUNE 1979 ROOM 473, STUDENT CENTER, 2:00 TO 5:00 P.M.

Session KK. Physical Acoustics VI: Nonlinear Acoustics

R. T. Beyer, Chairman

Department of Physics, Brown University, Providence, Rhode Island 02912

Contributed Papers

2:00

KK1. A kinematic theory of the parametric array. Peter H. Rogers (Naval Research Laboratory, P.O. Box 8337, Orlando, FL 32856)

The absorption limited parametric array is considered as a three-phonon interaction process. By examining the kinematics of such interactions an integral expression is obtained for the difference frequency beam pattern. The expression, which is valid whether the difference frequency is generated in the primary's nearfield, farfield, or both, involves only the primary's farfield directivity function. The expression agrees with experiment and reduces to all appropriate limiting values with the "aperture factor" predicted by Moffett and Mellen [J. Acoust. Soc. Am. **60**, 581–583] arising in a natural manner. The result is obtained by integrating over all allowed (i.e., energy and momentum conserving) interactions of the primary wave phonons, with the primary wave vector distribution determined by consideration of the primary field distribution in an attenuating fluid. It is thus shown that parametric array beam patterns are independent of the nature of the interaction and can be obtained without recourse to "virtual sources." An interesting corollary is that generation of difference frequency takes place entirely at the expense of the higher frequency primary since $\omega_d(=\omega_1-\omega_2)$ phonons result from a process in which ω_1 phonons are annihilated and ω_2 and ω_d phonons are created. [Work supported by ONR.]

2:15

KK2. Parametric acoustic array in the presence of turbulence. M. S. Korman and R. T. Beyer (Department of Physics, Brown University, Providence, RI 02912)

The nonlinear interaction of two collinear ultrasonic beams in the presence of turbulence in water has been investigated. The transmitting unit was driven continuously at 3 and 5 MHz. A 1-in. diameter water jet (20 ft/s) was located with nozzle 75 cm from the beam path which intersects the flow at 90° and originates 40 cm from it. Forward scattering angles were measured in the plane of the jet and sender by a 2-MHz receiver located 185 cm from the interaction region. The energy spectrum of the turbulence had frequency components in the range of several Hertz to 2 kHz. In the presence of turbulence the difference frequency was broadened by sidebands up to ±1 kHz from the center frequency for scattering results taken in the angular range −30° to +30°. The received spectrum was asymmetric relative to the center frequency. Comparisons are made between the spectral broadening of a primary 2-MHz signal and the broadening associated with a difference frequency component (2 MHz) that exists due to the mechanisms of the parametric array. These results are an extension of earlier experiments of the authors on the scattering of sound by sound in the presence of turbulence for a crossed-beam arrangement. [J. Acoust. Soc. Am. **64**, S14 (A) (1978)] [Work supported by the Office of Naval Research.]