Meetings

Ultrasonics

Only recently ultrasonics was a very narrow field of specialization. The growth of the field and its present sweep are illustrated by the papers presented at the 1964 Ultrasonics Symposium held 14–16 October at Santa Monica, California, under the sponsorship of the Sonics and Ultrasonics Group of the Institute of Electrical and Electronic Engineers.

The conference was opened by R. W. B. Stephens (Imperial College, London) with a paper on the transmission of sound in liquid metals. Since the velocity of sound is a simple function of the density and the adiabatic compressibility of the medium, it can provide information on such questions as how the compressibility varies with temperature, and this information can be correlated with theories of the liquid state.

Attenuation provides information about viscous absorption and thermal conductivity. Because liquid metals are used as heat-transfer agents in nuclear reactors, their structure is now of technological as well as scientific import. There is a growing interest in the acoustical study of liquid alloys, which reveal the influence of a second type of atom on thermodynamic and kinetic properties of the liquid metal.

O. L. Anderson (Bell Telephone) pointed out that because of the precision with which the velocity of sound can be determined as a function of pressure and of temperature, it can be used to find the equation of state for solids. One does so by integrating the thermal compressibility and expansivity to get the volume as a function of pressure and temperature. Further integrations involving the specific heat give the internal energy, the free energies, and the entropy. Because of the accuracy of sonic data, Anderson believes that one can extrapolate the values of the thermodynamic variables far outside the pressure range of the experiments, so long as there is no change of phase. Moreover, from measurements on the pressure dependence of the wave velocities, one can evaluate the Grüneisen ratio, thus relating thermal properties to acoustic data. These possibilities were actually put into practice by F. Birch in 1952 in a study of the structure of the earth's interior. Anderson's talk called attention to the opportunities opened up by recent improvements in the precision with which the velocity of sound can be measured. G. Alers (Ford Motor Company) showed how measuring velocity changes as small as one part per million gives information about the electronic structure of metals.

The relation between the velocity of sound and the compressibility and density of a medium can be turned to account in industrial process control. Oleg I. Babikov (Central Designing Office for Ultrasonic and High-Frequency Apparatus, Leningrad) described instrumentation for the automatic control of such diverse quantities as the concentration of aqueous solutions, the degree of polymerization of rubber latex, and the molecular weight —or even the isomeric structure—of a hydrocarbon. There was also a report by Viktor Fridman (Scientific Institute of Chemical Machinery Design, Moscow) on the use of sonic waves in speeding up chemical reactions; the devices described operate in continuous processing at flow rates of several cubic meters per hour.

L. D. Rosenberg (Acoustics Institute, Academy of Sciences, Moscow) submitted a paper on the energetics of ultrasonic cavitation, indicating the possibility of great improvement in the efficiency of industrial processes that use high-intensity ultrasound. One suggestion was that the fraction of the sonic energy that goes into cavitation can be estimated from the readings of a radiometer before and after a thin film shields it from the sonic wind. His colleague Irena Goliamina presented a review of work on transducers made of magnetostrictive ceramic, which for industrial applications have the advantage of operating at much lower voltages than those needed with transducers operated piezoelectrically.

At the other extreme, in the range of scientific purity, was a group of papers on "microwave ultrasonics," elastic waves with frequencies exceeding 500 megacycles per second. Among the most interesting of these were those by Townes and Chiao (Massachusetts Institute of Technology) and Quate and co-workers (Stanford) on the interaction of sound waves with light.

Some 40 years ago, L. Brillouin noted that a traveling elastic wave must scatter light with a change in frequency analogous to the Doppler shift associated with reflection from a moving mirror. The process can be depicted as collision between a light quantum (photon) and a sound quantum (phonon); in the collision, momentum and energy are each conserved. If one observes the scattering of monochromatic light by the phonons that exist in a crystal because of the thermal motion of the lattice, then in any well-defined direction the conservation laws might seem to ensure that the frequency shift has some specific value. However, the phonons in question have relatively short lifetimes, as is apparent from the rapid attenuation of microwave ultrasound in most solids. The Heisenberg principle of indeterminacy implies that there is an uncertainty in the energy of the phonon; the greater the attenuation (that is, the shorter the lifetime) the greater the uncertainty in energy and consequently in momentum. When these uncertainties are taken into account, the conservation laws imply that in a given direction, the recoiling photons have a spread in wavelength. The spectral broadening is so small that heretofore it has been masked by other effects.

Townes and Chiao, in the first part of their paper, pointed out that a helium-neon optical maser, with its intense and very nearly monochromatic light, enables one to measure the spectral broadening and thus to find the attenuation. The amount of the shift in optical wavelength gives a measure of the sonic velocity, which in this domain is frequency-dependent. The authors went on to describe what can be called a sonic maser. By using a ruby laser with a very short pulse

(30 nsec) they performed a similar experiment with very much more intense light, with a focused power density on the order of a million megawatts per square centimeter. In this case, the frequency-shifted light is so intense as to materially enhance the probability that other frequency-shifting collisions will occur, a phenomenon recognized in Einstein's theory of stimulated emission. Once a certain threshold intensity is exceeded, as it is in this experiment, there is, in effect, positive feedback that results in an avalanche of phonons. In the case of compressional waves, the process may be viewed as the generation of sound waves by electrostriction of the medium (in Townes and Chiao's experiment, quartz or sapphire) under the action of the intense electric field of the incident light wave. The sonic pulse lasts about 30 nsec and has a calculated peak power of about a kilowatt; the frequency is determined jointly by the wavelength of the incident light and the line along which the observation is made; in the experiments reported, the sonic frequency was in the neighborhood of 60,000 Mc/sec.

Quate and his colleagues reported a complementary experiment, in which they observed the effect on light of a high-frequency elastic wave generated by conventional means. Measuring the fraction of a laser beam diffracted by the sonic wave, they determined the coupling constants for the photon-phonon interaction. The stage is now set for the generation of intense beams of microwave phonons through the interaction of two beams of light.

The generation of sonic waves with frequencies higher than 10^9 per second has already been accomplished for several years by subjecting a piezoelectric material to the rapidly alternating electric field in an electrically resonating cavity driven by a microwave oscillator. J. deKlerk and E. F. Kelly (Westinghouse Research Laboratories) and N. F. Foster (Bell Telephone Laboratories) gave details of a technique for depositing piezoelectric layers of cadmium sulfide onto other solids, which can then be excited at high frequency even though they are not piezoelectric. The interest in sound waves of such high frequency comes in large part from their utility as probes of the solid state. However, because they correspond to the microwave region of the electromagnetic spectrum, they will probably find use in communication and radar technology. R. Pohl (Cornell University) spoke on what may be called the spectroscopy of phonons. The scheme uses the thermal vibrations of the lattice as a source and the thermal conductivity as a measure of transparency. The dominant lattice frequency is proportional to the temperature; at 0.3°K, it is 5000 Mc/sec. For alkali halide crystals doped with CN^- ions, thermal conductivity plotted as a function of temperature has dips at certain temperatures. One of these can be interpreted as the temperature at which the rotary motion of the CN^- ion changes from libration to rotation; a dip at low frequency is ascribed to a resonance absorption associated with tunneling between two equilibrium orientations of the ion.

On the communications side, J. E. May (Bell Telephone Laboratories) discussed design considerations for the amplifying of electronic signals by means of sound waves. This amplification, startling when first conceived, is possible in semiconductors that are piezoelectric. If an electric field established in such a material is large enough to make the electrons drift faster than sound travels, then the electrons can transfer their energy to a sound wave; the effect can be more than large enough to offset the ordinary acoustic attenuation, and the result is a sonic amplifier. Though conversion of an electronic signal into a sound wave and back again introduces some loss, overall gain can be achieved. F. S. Hickernell (Motorola) described a gallium arsenide amplifier that has net gain at frequencies in the neighborhood of 100 Mc/sec. The outlook for development of this type of amplifier is good.

The symposium was enlivened by a session devoted to medical problems. It dealt chiefly with the improvement of techniques for mapping internal organs by means of ultrasonic echograms. Typically, such work employs frequencies of about 1 Mc/sec. Advances in design were put forward by G. Kossoff (Commonwealth Acoustical Laboratory, Sydney, Australia) with applications to the pregnant uterus, and by R. A. Brinker (Presbyterian Hospital, New York) with applications to the detection of brain tumors by noting displacements of the ventricles from their normal positions. An ingenious instrument for both scanning and surgery was described by D. Gordon (West End Hospital for Neurology and Neurosurgery, London), who has the distinction of being the first ultrasonic radiologist appointed as such to a hospital staff. His system is built around a focusing transducer well controlled in its position and orientation with respect to reference planes in the patient. The focus of the transducer, located by maximizing the echo from a 1.5-millimeter metal sphere, is known in position to a few hundredths of a millimeter. The device is first used as a sonar set, emitting pulses at low power, to map the subject. The result is a sequence of silhouette-like outlines of coronal or sagittal sections of the brain. A blood vessel 1 mm in diameter can be located to within about 30 μ. When the desired locus has been established, it can be irradiated with high continuous-wave ultrasonic power, which destroys localized groups of cells at the focus. The technique permits the destruction of tumors that cannot be reached without going through some organ that must not be harmed.

The meeting showed that the older phases of ultrasonics are moving into broader use in technology, and that there is an impressively expanding interplay between ultrasonics and solid-state physics. Because the methods of generating ultrasounds are different in the regions above and below about 500 Mc/sec, some feel that the field of ultrasonics will undergo fission. I believe, however, that unity of concept will win out over diversity of technique, and that ultrasonics will grow as a single increasingly well-knit body.

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Biological Nitrogen Fixation

The fundamental role of nitrogen fixation among the earth's life-dependent processes has stimulated the interest of scientists for many years. Recent successes in obtaining N_2 reduction with cell-free preparations have led to examination of this process at the enzyme level, studies which, it is hoped, will lead to an understanding of the mechanism. A group of scientists active in this field attended the 1964 Colloquium on Biological Nitrogen Fixation held at Butternut Lake, Wisconsin,