SOCIETA' ITALIANA DI FISICA

RENDICONTI

DELLA

SCUOLA INTERNAZIONALE DI FISICA
«ENRICO FERMI»

LXIII CORSO

Nuove Tendenze dell'Acustica Fisica

SOCIETÀ ITALIANA DI FISICA - BOLOGNA (ITALY)

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RENDICONTI
DELLA
SCUOLA INTERNAZIONALE DI FISICA « ENRICO FERMI »

LXIII Corso

a cura di D. Sette
Direttore del Corso

VARENNA SUL LAGO DI COMO
VILLA MONASTERO
5 - 17 AGOSTO 1974

Nuove Tendenze dell'Acustica Fisica

1976

SOCIETÀ ITALIANA DI FISICA
BOLOGNA - ITALY

PUBLISHER: SOCIETÀ ITALIANA DI FISICA - BOLOGNA

SOLE DISTRIBUTORS: NORTH-HOLLAND PUBLISHING COMPANY -
AMSTERDAM - NEW YORK - OXFORD

ISBN NORTH-HOLLAND 0 7204 0489 4

ITALIAN PHYSICAL SOCIETY

PROCEEDINGS

OF THE

INTERNATIONAL SCHOOL OF PHYSICS « ENRICO FERMI »

COURSE LXIII

edited by D. SETTE

Director of the Course

VARENNA ON LAKE COMO

VILLA MONASTERO

5th - 17th AUGUST 1974

New Directions in Physical Acoustics

1976

NORTH-HOLLAND PUBLISHING COMPANY, AMSTERDAM - NEW YORK - OXFORD

Preface.

D. Sette

Istituto di Fisica della Facoltà d'Ingegneria dell'Università - Roma

Recent years have witnessed a genuine flourishing of research in acoustics. The close connection of acoustics with other fields of physics has always given acoustics a strong interdisciplinary character, so that specialists in other branches of science have traditionally entered into an involvement into acoustic research.

The summer course of the E. Fermi School of the Italian Physical Society, *New Directions in Physical Acoustics*, has been conceived as a place for presenting and examining the physical aspects of a part of the current interdisciplinary research in acoustics.

The proceedings are openend by an essay on the *Historical Development of Physical Acoustics and Future Perspectives* by the distinguished scholar Lindsay.

The material of the course can be grouped in three main areas: 1) sound propagation and the structure of matter, 2) propagation in fluctuating media of large dimensions (air, ocean), 3) nonlinear acoustics and surface waves.

In a large number of cases the interpretation of experiments on sound propagation requires the consideration of the co-operative collective nature of the molecular processes involved. Montrose's contribution on *Correlation Functions in Molecular Acoustics* gives the basic notions on time correlation functions, the elements of the linear theory for both cases of the response of an equilibrium system to external forces (Kubo method) and of the relaxation to equilibrium of a perturbed system (Mori theory). The results of this theoretical treatment are applied to sound propagation in dense fluids in the context of linearized hydrodynamics; the various kinds of relaxations are discussed. Some aspects of collective mode dynamics in fluids which are related to the study of sound propagation are pointed out, especially where they are closely connected with molecular dynamics.

Yip's lecture, *High-Frequency Short-Wavelength Fluctuations in Fluids*, is in a sense an application of Montrose's more general treatment to the nature of the sound processes which give rise to dispersion and absorption in the different regions of frequencies and wave numbers, with particular attention to the high-frequency and short-wavelength range. Three different regions are considered: 1) the hydrodynamics region where wavelengths are large compared with the mean free path, and frequencies small compared with collision frequency; 2) Knudsen region, where $\boldsymbol{k}$ and ω are very large, the effects of free-molecule flow predominate and sound propagation in the traditional sense does not occur; 3) kinetic, or transition, region where $\boldsymbol{k}$ and ω are of the orders of magnitude of the mean free path and the collision frequency. The third is naturally the most interesting both from the theoretical point of view and because of the striking experimental findings. In the lectures the kinetic model (simplified transport equations as an approximation to the Boltzmann equations) is used to extract normal-mode solutions for dilute gases and to show the existence for them of continuum modes in addition to the familiar discrete modes. The latter (among which the two sound modes) can disappear at sufficiently large $\boldsymbol{k}$ and ω. The analysis of the experiments of GREENSPAN and of MEYER and SESSEN in monoatomic gases is used to show the roles of the discrete and continuum normal modes.

In dense fluids the existence of significant spatial correlation among molecules give rise to restoring forces which allow collective motion even in the absence of collisions, *i.e.* even when the frequency of oscillation becomes large compared with the collision frequency. These collective modes which occur in the high-frequency region, called the collisionless regime, constitute the zero sound. The existence of such modes in a neutral classical fluid and its connection with the normal sound modes are discussed. The collective modes in liquids at short wavelengths ($\boldsymbol{k}$ comparable with the inverse intermolecular spacing) are considered by using a generalized viscoelastic description of density and current fluctuations.

The scattered light which emerges from a transparent medium illuminated by a monocromatic beam of light carries in its spectrum information on the dynamics of the scattering centres (molecules) and can be used to extract information on the acoustical modes of the density fluctuations and on the acoustical properties of the medium. The analysis of the experiments and the indications of the cases in which it confirms information also obtainable with ultrasonic experimentation are given by MONTROSE in his contribution on *Light Scattering and Molecular Acoustics*.

RUDNICK offers a thorough and up-to-date presentation of research on *Sound Propagation in Superfluid Helium*. The first part deals with a theoretical description of the various kinds of sounds and of their behaviour, while the second part is a comprehensive review of the relevant experiments carried on up to now.

The subject of *Sound Propagation in Liquid Crystals* is presented by CANDAU and MARTINOTY. The results of absorption measurements for both longitudinal and transversal waves in nematics are compared with the theoretical indications to derive various viscosity coefficients and elastic constants of nematic liquid crystals; the relaxation processes in nematic and isotropic phases are discussed and some references to recent research in smectic liquid crystals are also included.

Mason's contribution on *Acoustical Properties of Solids* examines the application of sound waves in a wide frequency range to the study of many solid-state motions such as domain wall motion, point imperfection and dislocation motion. The author examines in detail the attenuation of sound waves in perfect crystals, the effects of structure in a solid (grain, domain wall, phase transitions) and the effect of imperfections (point defects, dislocations). Some consideration is also given to fatigue in metals and to the fast-developing field of acoustic emission.

CAROME has considered the special case of *Superconducting Transducers in the* 50 *to* 1000 GHz *Range*. He discusses the use of phonon fluorescent elements and tunnel junctions as phonon sources, as well as bolometers and tunnel junctions as phonon detectors.

A very comprehensive review of the method developed in the last ten years for the *Production and Detection of Very-High-Frequency Sound Waves* has been offered by DRANSFELD. The treatment excludes the case of surface wave (see de Klerk's contribution). The production and detection of coherent phonons can be made in a variety of ways: *a*) piezoelectric methods in traditional transducers, in depletion layer transducers, in high-polymer transducers; *b*) magnetostrictive methods at microwave frequencies; *c*) electromagnetic generation at microwave ultra-sound; *d*) by scattering of light and X-rays (spontaneous or stimulated Brillouin scattering, X-ray scattering by phonons, Raman scattering by phonons, microwave-induced Raman scattering).

JOFFRIN and LEVELUT, in *Phonon Echoes*, have discussed a unique type of phonon echo experiment which looks promising both for physical application (measurements of sound absorption, of characteristic relaxation times) and for engineering applications (signal processing and memory devices). Here the term echo has to be taken with the same meaning that is applied to spin systems. A simple experiment consists in launching a pulse of coherent phonons into a specimen by means of a transducer (frequency ω_1) at time $t=0$, and in applying at time τ an electrical field of the same frequency to part of, or to the entire specimen. The nonlinear interaction between the electric field and the square of the elastic deformation creates reflected ultra-sonic waves (a reverse of the wave vector) which travel exactly in reverse of the previous waves and create an echo at the source position at time 2τ. The echo is independent of the specimen shape and of the source location.

The group of lectures related to sound propagation in fluctuating media of large dimension opens with the McCoy contribution: *Wave Propagation in Random Media*. It is concerned first with the analysis of the way in which a random medium can be statistically described *per se* and, second, with the propagation of an acoustic field; a two-point coherence function applicable to ocean studies is given special attention.

An analysis of the physical processes responsible for fluctuations of interest in sound propagation in the sea is the first part of the lectures offered by GOODMAN: *Propagation in Fluctuating Media.* The establishment and the characteristics of internal waves receive special attention in the discussion of the dynamics of the medium; turbulence plays an important role also; the sea suface behaviour and the connected capillary and gravity waves are considered in defining the dynamic properties of the sea, in the proximity of the surface. At greater depths, there exists the possibility of trapping the acoustic energy emanating from a source into a channel, allowing transmission over thousands of miles.

The results of some experiments on ocean dynamic fluctuations observed with the acoustical method are discussed. The experiments refer to propagation in the mixed layer where turbulence dominates the phenomena of fluctuations as well as to propagation to much larger depths. The reflection of waves from the sea surface is also discussed.

The third group of contributions includes Berktay's treatment of *Finite-Amplitude Effects in Sound Propagation in Fluids*, with special reference to water. The consequences of the nonlinearity of differential equations describing acoustic disturbances are examined in a lossless medium and successively in a thermoviscous medium. In the last case and with reference to sinusoidal boundary conditions the development of a « weak shock » wave form, the conservation of the « saw tooth » form and the saturation of the fundamental component of particle velocity at a given range are discussed. The analysis is then applied to the monochromatic radiation from a transducer.

Special attention is given to the parametric acoustic arrays where nonlinear interactions of sound waves are used to produce low-frequency acoustic waves. The parametric transmitters which use two monochromatic primary waves in order to produce a wave at the difference frequency are shown to produce a low-frequency source with beam width of the same order as those of the primary transducers and a level suitable for sonar applications.

Stephens' contribution is a brief review of the last-decade interest on finite wave propagation in solids. After reference to a few positions of the higher-order elasticity theory, the nonlinear effects in wave propagation, resulting either from large wave amplitude or from induced as well as local nonlinearities of the medium, are discussed. Theoretical and experimental results are presented. Harmonic generation in piezoelectric crystals, optical-acoustical interaction in photoconducting piezoelectrics, nonlinearity in surface waves are considered. Research on surface waves in liquids, acoustical streaming, nonlinearities in cochlear hydrodynamics, scattering of sound by sound and on the relation between macrosonics and nonlinear effects in crystalline solids is also reviewed.

The great interest that surface waves have recently provoked for their many valuable applications has led to a frequent presentation of the subject in terms of equivalent circuits of devices which are especially useful for engineers. This method, however, does not give much insight into the physics involved. DE KLERK has therefore developed *A Physical Approach to Elastic Surface Waves.* Both isotropic and anisotropic material are considered. An analytical method for the optimum in crystal orientations and propagation directions is presented. Moreover the effect of piezoelectric properties of the material on the action of interdigital grids on the surface and the basic principles of two surface wave devices are discussed.

A review of the present status of developments of the more interesting *Surface Acoustic-Wave Devices* is given by ATZENI and MASOTTI: interdigital transducers, delay lines, filters, oscillators, multistrip couplers, convolution using parametric interaction, interaction with light and display systems are considered in detail.

The proceedings are closed by a contribution by WANG on *Acoustics in Space*; the acoustical chamber developed for manipulating and controlling a liquid system in a zero-G environment is becoming an important tool for space research and technology.

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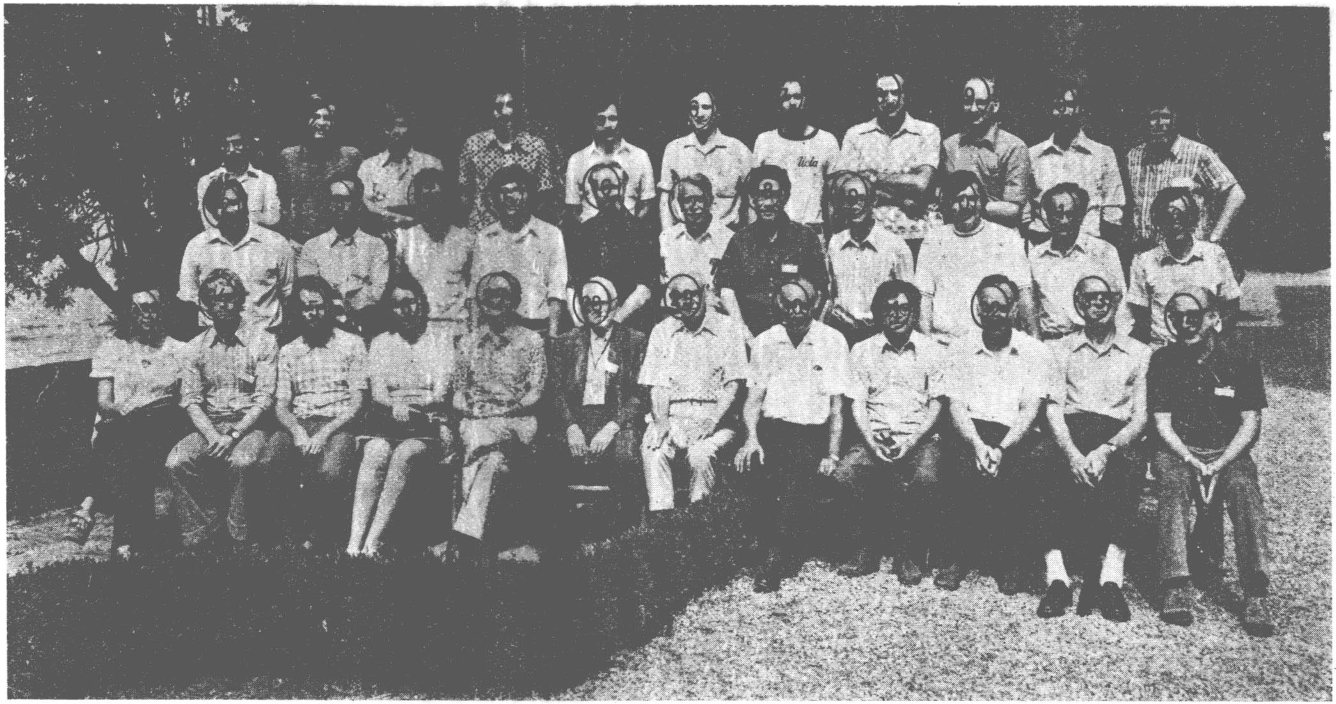

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12. J. Krüger
13. C. Luponio
14. A. Bracco
15. T. G. Wang
16. R. Goodman
17. J. de Klerk
18. S. M. Lee
19. S. Yip
20. C. Montrose
21. R. Piązza
22. Schellino
23. M. Cutroni
24. B. Nilsson
25. S. Gasse
26. B. Lambert
27. J. L. Hunter
28. R. B. Lindsay
29. W. P. Mason
30. D. Sette
31. I. Rudnick
32. H. O. Berktay
33. R. Cook
34. E. Carome

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INDICE

S. Yip – High-frequency short-wavelength fluctuations in fluids.

C. J. Montrose – Light scattering and molecular acoustics.

I. Rudnick – Physical acoustics at UCLA in the study of superfluid helium.

S. Candau et P. Martinoty – Absorption des ondes ultrasonores longitudinales et transversales dans les cristaux liquides.

W. P. Mason – Acoustical properties of solids.

E. F. Carome – Superconducting transducers for use in the 50 to 1000 GHz range.

K. Dransfeld – Production and detection of very-high-frequency sound waves.