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Introduction

The present chapter will serve as an overview of the material to be presented in the rest of the book. While it is hoped that the material will prove useful to all those involved in or interested in the use of ultrasound as a probe of condensed matter, a special effort is made to present the material in sufficient detail so as to be helpful to dedicated, upper-level undergraduate students and beginning graduate students. Scientists from several different disciplines are nowadays finding ultrasonic spectroscopy a useful tool, thus a strong background in solid-state physics, statistical physics, and quantum mechanics is not assumed of the readers. Brief background material is presented as needed. Several monographs have contributed to the advancement of ultrasonic spectroscopy, among them References [1, 2, 3]. The author is deeply indebted to those who have helped develop the field of ultrasonic studies of materials.

Chapter 2 deals with classical elasticity; the solid is treated as a continuum. The continuum approximation is valid for virtually all ultrasonic experiments. The present treatment of elasticity is more extensive than is usually found in books on ultrasonic techniques, but this more extensive treatment seems important if the researcher is to understand the widest implications of her/his ultrasonic research. Basic physical parameters in this chapter are stress (a two-index tensor), strain (a two-index tensor), and elastic constants (a four-index tensor, which by Hooke's Law connects stress and strain). Thus, many indices and sums over these indices appear frequently. For pedagogical reasons, it was decided *not* to use the elegant Einstein summation convention. For those new to the field, it seems better to write out the sums explicitly. The relation of elastic constants to thermodynamic potentials is derived. The condensed (Voigt) notation for stress, strain, and elastic constants is explained in detail. Coordinate transformations are treated. The form of the elastic constant matrix for each of the seven crystal systems is derived, as well as the form for the icosahedral quasicrystal. Poisson's ratio and the practical moduli – bulk, Young's, and torsion – are discussed for various crystal symmetries. It is

Cambridge University Press
978-1-107-15413-1 — Ultrasonic Spectroscopy
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Excerpt
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difficult to visualize the directional dependence of elastic constants for anisotropic materials; so, 3D representational surfaces are presented for several crystal symmetries.

Chapter 3 treats acoustic waves in solids. The first part of the chapter deals with waves in the continuum limit, the regime of ultrasonic experiments. The wave equation is derived and the Christoffel equation for plane wave propagation is found. It is shown how to calculate the wave velocities for any direction in a crystal. Solutions are given for several crystalline directions in cubic and hexagonal symmetries. Other symmetries are discussed. The Christoffel equation is valid in the continuum limit and thus is restricted to wave vectors near the center of the Brillouin zone. The second part of Chapter 3 treats lattice dynamics. To understand many properties of solids it is necessary to go beyond the continuum limit; lattice dynamics does just that. The usual 1D models for monatomic and diatomic cases are treated and the dispersion relations obtained. Much insight is gained from these models. However, it seems important to go beyond the 1D case, thus the full 3D lattice dynamics model is treated. The relevant equations are derived and force constant matrices are obtained for the face-centered cubic symmetry. A full 3D calculation is performed, demonstrating the dispersion relations in various high-symmetry directions. The last part of Chapter 3 discusses the highly simplified, but highly successful, Debye model of solids. The thermal energy and the specific heat are obtained, and it is shown how to calculate the Debye temperature from the elastic constants.

Chapter 4 deals with common experimental methods for measuring ultrasonic attenuation (or internal friction) and elastic constants (or ultrasound velocities). The material in Chapters 2 and 3 was needed before the experimental methods could be treated meaningfully. The well-known pulse-echo method is discussed. For highly accurate results it is necessary to accurately determine the time delay between echoes. This is not a trivial problem, and methods (pulse superposition, pulse-echo overlap) have been developed to solve this problem. However, several factors other than round-trip travel time usually contribute to the measured delay time. These factors are discussed in detail as well as how to account for them. The older methods were analog in nature. An important recent advance has been the development of an all digital pulse-echo system. Resonant ultrasound spectroscopy (RUS) is a resonance method dramatically different from the pulse-echo method. RUS is also discussed at length in Chapter 4. Finally, picosecond ultrasound is discussed in Chapter 4.

Chapter 5 treats the important subject of elastic constants. It starts with a review of relevant thermodynamics and statistical mechanics, culminating in the Helmholtz free energy for a harmonic oscillator. The individual lattice vibration modes are treated as harmonic oscillators, thus the Helmholtz free energy for the lattice is a sum of harmonic oscillators. A major part of Chapter 5 is concerned with using the quasiharmonic approximation to find the temperature dependence of the elastic constants. This rather lengthy calculation reveals the indirect effect of lattice expansion on the temperature dependence of the elastic constants and shows that it is of major importance. The effects of both first-order and second-order phase transitions on the elastic constants are discussed in terms of the Landau theory.

Chapter 6 is concerned with ultrasonic loss. The chapter begins with several general ideas related to ultrasonic loss: complex elastic constants and phase shifts; units of measurement of loss; Kramers-Kronig relations; and fluctuations and dissipation. Next, relaxational and resonance attenuation are discussed in general terms. Many different specific loss mechanisms are known. In general, these have been treated elsewhere. The present approach is to give a brief summary of ten of these loss mechanisms, with references to the literature and previous monographs for more detailed descriptions.