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Collective excitation modes in the intermediate and superconducting states of doped and undoped indium and lead

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Abstract. Ultrasonic attenuation was studied in pure In, In + 0·003 at. % Pb, pure Pb and Pb + 0·003 at. % In in the intermediate states (for the magnetic fields 0·7 H_c and 0·9 H_c) and superconducting states, for frequencies varying from 9·9 to 29·7 MHz, in the temperature range 4·2 to 1·4 K. Collective excitation modes were observed in both the states for all the samples. There exist two distinct phases in the intermediate state but only one phase in the superconducting state in all the samples. The first phase was dependent on the magnetic field and independent of the concentration and nature of the dopant. The second phase was independent of the magnetic field and dependent essentially on the concentration of vacancies and marginally on the concentration of the dopant. The origin of the two phases has been discussed.

Keywords. Collective excitation mode; superconductivity; indium; lead; ultrasonic attenuation.

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1. Introduction

The BCS theory (Bardeen and Schriffer 1957) explain superconductivity on the basis of single-electron phonon interaction. The rapid drop in ultrasonic attenuation of superconductors below the transition temperature follows from the BCS theory by postulating single-electron phonon interaction. Besides the concept of single-electron phonon interaction, the possibility of collective excitation modes in the excitation spectrum of superconductors was postulated by Bogoliubov (1957) and Anderson (1958). Anderson and Bogoliubov showed that there are low frequency collective excitation modes for the electrons in the superconducting state which correspond to pressure waves in a neutral Fermi gas. The concept of a pressure associated with the superconducting state was first considered in regard to the electromagnetic stresses at the boundary of a superconducting region. A change in volume δV of the superconducting phase, which involves no change in free energy density f changes the total free energy F by an amount

$$\delta F = -(f_n - f_s)\,\delta V.$$

The normal material is converted into superconducting material in δV. There is an effective pressure $P = -\delta F/\delta V$. Collective type excitation modes for the electrons in the superconducting state can be produced under the influence of the effective pressure P. Ultrasonic attenuation studies by Claiborne and Einspruch (1960) in Nb-Zr alloys,