Indian J. Phys. **70A** (6), 669–673 (1996)

IJP A
— an international journal

The temperature dependence of elastic constants and sound velocity in heavy fermion system

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Abstract :

Here, we consider the electron-phonon interaction in the Periodic Anderson Model(PAM) and have studied the influence of various model parameters namely the position of 4f-level E_0', the electron-phonon coupling strength $f_1(q)$ and $f_2(q)$,the effective coupling strength $f_1^2(q)N(0)/W(q)$ on the temperature dependence of the sound velocity and elastic constant in HF systems. The analysis of the results obtained are in good agreement with the general features observed experimentally for some HF systems.

Key Words : Heavy Fermion System, Periodic Anderson Model, Electron Phonon Interaction, Sound velocity, Elastic Constant.

PACS Nos. : 74.70.Tx, 71.10.-w, 62.20.Dc

1 Introduction

In recent years a lot of interest has been developed to heavy fermion (HF) systems. These are the intermetallic compounds for partially filled f-electrons of Ce,Yb and U which form a highly correlated electron system at low temperature and show many interesting anomalies of electronic and lattice properties [1,2,3]. There exist experiments where some heavy fermion system show elastic anomalies related to the valence instabilities at low temperature [3]. The most prominent effect of these are the softening of the elastic constant, temperature dependence ofthe thermal expansion, strong softening of phonon energies below the Kondo temperature. The elastic constants and sound velocity anomalies are usually related to the instability of the valence which is indirectly caused by the change of the mixing interaction and the origin of this change is due to the extreme volume dependence of the systems Kondo temperature T_K, which are again dependent on volume strain associated with the lattice. Moreover, the anomalies do not depend on the details of the electronic band structure as its effect is realised over a wide temperature range $0 < T < T_K$.

In this paper, we have used the Periodic Anderson Model(PAM) for the half filled band and introduced electron-phonon interaction in the normal state of the HF system. The sound velocity and the elastic constant are calculated to explain the experimental anomalies seen at various temperature.

2 Formalism

We consider the model system with the Hamiltonian

$$H = H_0 + H_{e-p} + H_p \tag{1}$$

where

$$\begin{aligned} H_0 &= \sum_{k\sigma} \epsilon_K c^{\dagger}_{k\sigma} c_{k\sigma} + E'_0 \sum_{k\sigma} f^{\dagger}_{k\sigma} f_{k\sigma} + v_0 \sum_{k\sigma} (f^{\dagger}_{k\sigma} c_{k\sigma} + c^{\dagger}_{k\sigma} f_{k\sigma}) \qquad (2) \\ &+ U/2 \sum_{i\sigma} n^f_{i\sigma} n^f_{i-\sigma} \\ H_{e-p} &= \sum_{kq\sigma} [f_1(q)(f^{\dagger}_{k+q\sigma} c_{k\sigma} + c^{\dagger}_{k+q\sigma} f_{k\sigma}) + f_2(q) f^{\dagger}_{k+q\sigma} f_{k\sigma}] \star (b_q + b^{\dagger}_{-q}) \qquad (3) \\ H_p &= \sum_q w_q b^{\dagger}_q b_q \qquad (4) \end{aligned}$$

The notation used in the above equations are same as described in our earlier paper [6]. The Fourier transformed phonon Green functions were evaluated to express the phonon self energy which is given by

$$w^2 - w_q^2 - 4\pi w_q \chi_{qq}(w) = 0 \tag{5}$$

The velocity of sound and elastic constant were evaluated at long wave length limit and given by the equation

$$(v/v_0)^2 = (C/C_0) = [1 + 4\pi/w_q\chi_{qq}(w)], \tag{6}$$

where v and C are the sound velocity and elastic constants respectively. The zero subscript corresponds to the bare values of these quantities.

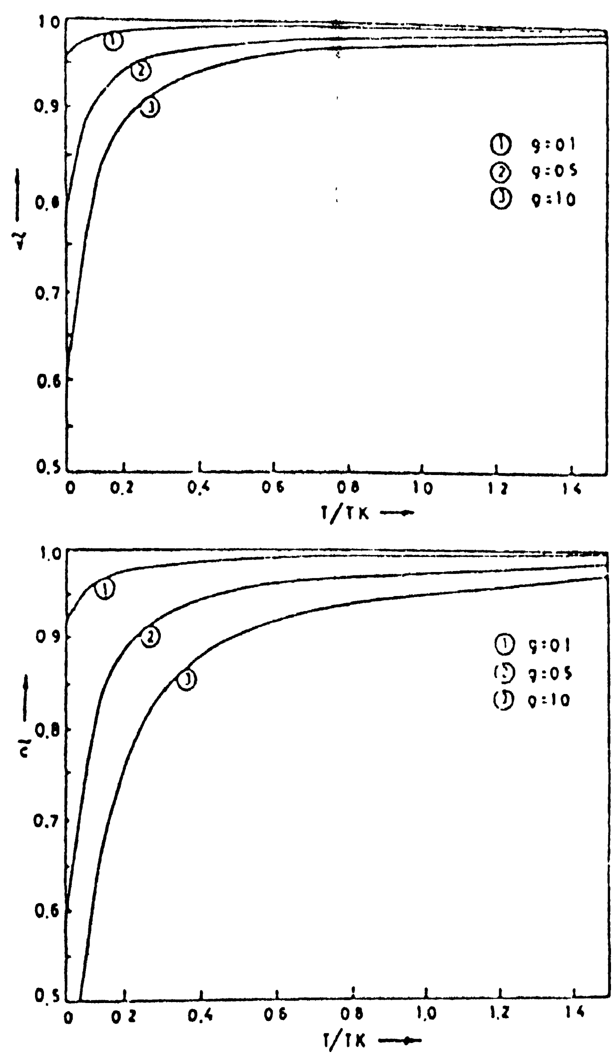

Fig.1 The temperature dependence of the longitudinal elastic constant and sound velocity (in arb. unit) for various values of g= 0.1,0.5,1.0. The values of r and d are 0.01 and 2.0 respectively.

After parameterizing different quantities in equation (6) as evaluated $\tilde{v}(= v/v_0)$ and $\tilde{C}(= c/c_0)$ numerically for different temperatures and for different parameters r, g, d which are same as defined in our earlier paper [6].

3 Results and discussion

In the present calculation we discuss the role of volume dependence of bare hybridisation γ_0 and bare 4f energy E_0' and the effect of the temperature on the longitudinal sound velocity and elastic constant. We have evaluated the equation (6) numerically for $\tilde{v}(= v/v_0)$ and $\tilde{C}(= C/C_0)$ as a function of the temperature $\tilde{T} = T/T_0$ where T_K is the Kondo temperature for the different parameters r, g, d. However, we have repoted here the variation of g only. The initial parameters are set by considering different values of these for which uniform softening of phonon energy occurs as observed experimentally. The set of different parameter fixed in the process are r=0.01, g = 1.0, d=2. The two plots of fig 1 refers to variation of $\tilde{v}$ and $\tilde{C}$ with respect to various values of g = 0.1, 0.5, 1.0. It is seen that the velocity and elastic constant increases with temperature and reaches a maximum value at high temperature. As g valueis increased the velocity decreases more rapidly at low temperature which implies electron - phonon coupling with hybridisation term produces more softening.

4 Conclusion

It is concluded that the variation of velocity of sound and elastic constant shown in the paper agrees well with the experimental observation for the compounds $CeCu_6, CeRu_2Si_6$ [7]. We don't see any deep in 'he analysis which may be assumed to be due to the local screening effect [7].

Acknowledgement: One of the author (PN) gratefully acknowledges the Department of Science and Technology, Govt. of India for their financial assistance through the major research grant No-SF/S2/MO1/93.

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