Heavy Fermion System and Its Anomalous Behaviour "A Theoretical Study"

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Abstract: In this paper we try to study theretically the anomalous behaviour such as thermal (Elastic constant), electrical (resistivity) and impurity effect of heavy fermion system on account of electron and phonon interaction. We used here the Zuvarev type double time temperature dependent technique to develop the spectral density and self energy which then used to get the elastic constant and resistivity of the system by using dimension less parameter 'd'- the f- level location, 'r'- potency of electron interaction with phonon, 'g'- coupling constant, 'b'- the inverse temperature and 'x'- the the fermi level. The results found is quite good agreement with the experimental result.

Keywords: elastic constant; Zubarev technique; spectral density; self energy.

1. Introduction

Heavy fermion systems represent an interesting group of materials recognized for their unique electronic characteristics, which emerge from the intense interactions between conduction electrons and localized magnetic moments, typically associated with rare earth or actinide elements. These systems often feature f-electrons which significantly influence their unusual low temperature behaviours. At very low temperature, heavy fermion compounds can exhibit a variety of extraordinary phenomena including unconventional superconducting prooerty, non-Fermi liquid character, quantum critical point etc. [1,2]. The effective mass of electrons in these materials can become significantly enhanced, sometimes by orders of magnitude, leading to term "heavy fermions" [3]. The interplay of localization of electrons in the f-state and delocalization of the conduction electrons gives clues about complex ground states and phase transitions, making heavy fermion systems a rich area of study in condensed matter physics. For a HF material, the value of Sommerfeld Coefficient γ exceeds 400 mJ/ f atom mol K^2 which is much greater than the value for an ordinary metal [4]. This owes for enormous electron density at the Fermi energy level occurring due to robust interaction of electrons and phonons. In heavyfermions both γ Gruencien parameter and the Pauli susceptibility χ_0 is larger by few orders. Landau theory [5] of Fermi liquids helps in understanding the highly correlated electronic state at low temperature.

Heavy fermions exhibit strangely enormous specific heat at lower temperatures for such larger values of γ. Furthermore γ strongly depends on temperature below 10 K for heavy fermion compounds as opposed to the temperature independent γ for normal metals [4]. Understanding these systems has significant implications for both fundamental physics and the development of advanced materials. Many heavy fermion systems, including UBe_{13}, $CeCu_2Si_2$, U_2Zn_{17}, UCd_{11}, $CeAl_3$, and $CeCu_6$exhibit temperature-dependent resistivity that peaks at a temperature T* that is often lower than 40K and is then sharply decreased. The formation of a strong coherence across many sites is responsible forthe resistivity decline in certain heavy fermion systems beyond the characteristic temperature T*. In these systems, additional electron-phonon interaction is essential for changing the low-temperature transport characteristics.

It is found that when temperatures fall below the characteristics temperature T*, the alterations in the sound wave velocity are significantly influenced by the specific characteristics of the density of states of quasiparticles [6,7]. In polycrystalline $CeAl_3$, low temperature studies of shear and longitudinal elastic constants reveal that the elastic constants strongly soften at low temperatures, and that softening is much more pronounced [8]. Connection between elastic deformation and phonons with q=0 to the collective behaviour of electrons band plays a significant involvement in strongly correlated HF system for the superconducting behaviour including $CeCu_2Si_2$ as observed experimentally [9]. Investigations on elastic constants revealed that at very low temperatures Heavy fermion compounds especially UPt_3, $CeAl_3$ display a significant decrease or drop of longitudinal elastic constant, whereas the transverse modes reach a peak [6,10,11]. However, in other systems such as $CeCu_6$ and $CeRu_2Si_2$, such a drop or minimum is either not evident or absent. These observations suggest that the interaction between heavy electrons

and the longitudinal microscopic phonons is the key component to the atomic configuration to heavy fermion state. The explanation of this variation of elastic constant with temperature changes studied by coupling of electrons with phonon which involves Ruderman–Kittel–Kasuya–Yosida interaction along with conduction electrons scattering in a metal due to impurities (magnetic). This explained the various phonon anomalies related to elastic constant using the framework of Gruineincen parameter coupling [12].

Again, impurities can have significant effects on heavy fermion systems, which are characterized by the presence of strongly correlated electrons that exhibit enhanced effective mass. Alloying with conduction band (CB) impurities the corporal belongings are significantly altered the normal state of HFs as demonstrated by certain recent experimental observations [13-16]. As with the substitution for Au or Ag in place of Cu in $CeCl_{16}$, the cell volume expands leading to higher values of 'γ'(specific heat coefficient) and 'χ' (magnetic susceptibility) as the concentration of conduction band impurities rises. In contrast, replacing Cu with Al reduces the cell volume resulting in lower values of γ and χ. These various occurances offer significant insights into the microscopic reasons for the constancy of the usual phase. Again, it provides evidence about impurities over the renormalization of energy of phonon and the interactions between electrons and phonons.

2. Formalism

The study of heavy fermion materials has presented significant challenges for physicists due to the wide range of ground state properties they exhibit. Initially explaining these anomalies proved to be a significant challenge for physicists. However, it is now possible to investigate many of the mysteries surrounding the HF systems because of the development of several theoretical models. Some of theof the effective models include: (i). Anderson Model with Single impurity (ii) PAM-Periodic Anderson Model (iii). KLM-Kondo Lattice Model (iv). Hubbard Model (v). Dynamic Mean Field Theory (DMFT).

To get the solution of Periodic Anderson Model and Hubbard Model various approximate schemes have been developed. Some techniques are (i). Green Function Technique (ii). Hartree Fork Approximation (iii). Gutzwiller variational Approximation (iv) Methods of Slave Bosons and Fermions.

The technique of decoupling the retarded Green's function was initially used by Hubbard to develop an approximation scheme for the solution of Hubbard model and PAM [17]. Hubbard applied the concept of two time Green functions in his initial studies of the correlation effects [18,19], which is especially useful when there is a significant particle interaction and no small parameter is involved in this interaction.

3. Methods

Among those theoretical models the PAM (Periodic Anderson Model) has been a valuable framework for understanding a number of characteristics of these systems. To explore the phonon anomalies in heavy fermion systems, we follow Fulde [20] and analyzethe mechanisms of coupling between electrons and phonons with the help of Periodic Anderson Model (PAM). Here in our calculation, we have followedZubarev technique for Green function reliant on dual time and temperature which can be defined by taking the average of T the product of operators [19] given as

$$G(t, t') = \ll A(t); B(t') \gg_a$$

$$= i\theta(t - t') < [A(t), B(t')] > \quad (1)$$

where, $\theta(t) = \begin{cases} 1 & for\ t > 0 \\ 0 & for\ t < 0 \end{cases}$

which can give the motion equation as

$$i\frac{dG(t-t')}{dt} = \delta(t - t') < [A(t), B(t')] > + \ll \frac{idA(t)}{dt}; B(t') \gg \quad (2)$$

[….] the anti-commutator for fermions and commutator for bosons and <….> represents the thermodynamic average of the operator.

Here the model Hamiltonian has been represented by the combination of the Host electron Hamiltonian denoted as (H_0), Hamiltonian for coupling of electron with phonon ($H_{e\text{-}p}$) and Hamiltonian for interaction of phonons (H_p)given as

$$H_0 = \sum_{k\sigma} \varepsilon_k C^{\dagger}_{k\sigma} C_{k\sigma} + E_0 \sum_{k\sigma} f^{\dagger}_{k\sigma} f_{k\sigma} + \gamma_0 \sum_{k\sigma} \left(f^{\dagger}_{k\sigma} C_{k\sigma} + C^{\dagger}_{k\sigma} f_{k\sigma} \right) + \frac{U}{2} \sum_{k\sigma} n^f_{i\sigma} n^f_{i,-\sigma} \quad (3)$$

$$H_{e-p} = \sum_{kq\sigma}\begin{bmatrix} f_1(q)\left(C^{\dagger}_{k+q,\sigma} f_{k\sigma} + f^{\dagger}_{k+q,\sigma} C_{k\sigma}\right) \\ +f_2(q)\left(f^{\dagger}_{k\sigma} f_{k\sigma}\right)\end{bmatrix} \quad (4)$$

$$H_p = \sum_q w_q\, b^{\dagger}_q b_q \quad (5)$$

Therefore, the model Hamiltonian takes the form,

$$H = H_0 + H_{e-p} + H_p \quad (6)$$

Where $C_{k\sigma}$ & $f_{k\sigma}$annihilation operator for electron in conductionband and f- level and $C^{\dagger}_{k\sigma}$&$f^{\dagger}_{k\sigma}$creation operators for electrons in conduction bandand f- levelhavingmomentum 'k' and spin 'σ'.ε_k and E_0represents the energy of the electron in conduction band and f- level respectively.

Using Zubarev method for Green function [19], the components of the Green functions under fourier transformation and using Kronecker delta function representation, we have calculated the self energy of phonon for q = 0 the static limit and with temperature value finite, as well as neglecting the Coulomb correlation term of the f-levelat normal state,

$$\chi(k,q,\omega)=\chi(0,\omega,T) = \frac{\mathcal{N}(\varepsilon_f)}{\pi}|f_1|^2 \int d\varepsilon_k \frac{2(\varepsilon_k - E_0)^2}{D(y_1-y_2)}\left\{\left(\frac{f_1}{f_2}\right)\frac{2\gamma_0}{(\varepsilon_k - E_0)} + 1 + \left(\frac{f_1}{f_2}\right)^2 \frac{{\gamma_0}^2}{(\varepsilon_k - E_0)^2}\right\} T_y \quad (7)$$

Here,

$$\mathrm{D} = \left\{\left(\varepsilon_f - E_0\right)^2 + 4{\gamma_0}^2 - \omega^2\right\}$$

$$y_1 = \frac{1}{2}(\varepsilon_k + E_0) + \frac{1}{2}\sqrt{(\varepsilon_k - E_0)^2 + 4{\gamma_0}^2}$$

$$y_2 = \frac{1}{2}(\varepsilon_k + E_0) - \frac{1}{2}\sqrt{(\varepsilon_k - E_0)^2 + 4{\gamma_0}^2}$$

and $T_y = -4\, exp\, \frac{(\varepsilon_k - E_0)}{2kT}\, sinh \sqrt{(\varepsilon_k - E_0)^2 + \frac{4{\gamma_0}^2}{2kT}}$

Further the electron self-energy $\chi(k,q,\omega)$ is calculated for small wave length limit by taking $\omega \to \omega + i\eta$. The real and imaginary part has been obtained using the dimensionless parameters r = $\left(\frac{f_1}{f_2}\right)$ where f_1 represents interaction strength of phonon with hybridization band and f band electron, g = $\frac{\mathcal{N}(\varepsilon_f)}{\omega_q}|f_1|^2$ is the effective coupling constant,$\mathcal{N}(\varepsilon_f)$denotes the fermi level density of states , U'=U/γ_0 localized Coulomb repulsion, $W' = W/\gamma_0$width of the band, d = $\frac{E_0}{\gamma_0}$ position of f level, b = $\frac{\gamma_0}{2kT}$ temperature inverse, x = $\frac{\varepsilon_k}{\gamma_0}$ the fermi level.

$$Re\ \chi\ (k,q,\omega) = \left[\left\{\frac{\{4-c^2+(x-d)^2\}\{(x-d)\}}{\{(x-d)^2+4-c^2-4t^2c^2\}\{(x-d)^2+4\}^{1/2}}\left[\frac{r^2}{(x-d)^2} + \frac{2r}{(x-d)} + 1\right] e^{-(x+d)b} \sin h\,\{(x-d)^2+4\}^{1/2}\right\}\right] \quad (8)$$

and

$$\mathrm{Im}\ \chi(k,q,\omega) = \int\left[\frac{2ct(x-d)^2}{\{[c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}]\{(x-d)^2+4\}^{1/2}}\sinh[b(x-d)^2+4]^{1/2}\right]dx + \int\left[\frac{2ct(x-d)\,2r}{\{[c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}]\{(x-d)^2+4\}^{1/2}}e^{-b(x+d)}\sinh[b(x-d)^2+4]^{1/2}\right]dx + \int\left[\frac{2ctr^2}{\{[c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}]\{(x-d)^2+4\}^{1/2}}e^{-b(x+d)}\sinh[b(x-d)^2+4]^{1/2}\right]dx \quad (9)$$

On further solving we get the renormalized phonon frequency as,

$$\left(\frac{\omega}{\omega_0}\right)^2 = 1 + \frac{4\pi}{\omega_0}\,\chi\,(0,\omega) \quad (10)$$

The phonon excitation spectrum is influenced by various model parameters via the response function of electron that subsequently varies spectral density. Therefore, the theoretical calculation gives spectral density as

$$S(q,\omega) = -2\ Im\ D_{qq'}(\omega + i\eta) \quad (11)$$

For long wavelength limit (q=0) the final form of $S(q=0,\omega)$ is written as

$$S(q=0,\omega) = -2\ Im\ D_{00}(\omega + i\eta) = \frac{2\left\{\left(\frac{\eta}{\omega_0}\right)^2 - \left(\frac{4\pi}{\omega_0}\right) Im\,\chi\,(q=0,\ \omega)\right\}}{\pi\omega_0} \left[\left\{\left(\frac{\omega}{\omega_0}\right)^2 - 1 - \left(\frac{4\pi}{\omega_0}\right) Re\,\chi\,(q=0,\omega)\right\}^2 + \left\{\left(\frac{\eta}{\omega_0}\right)^2 - \left(\frac{4\pi}{\omega_0}\right) Im\,\chi\,(q=0,\omega)\right\}^2\right]^{-1} \quad (12)$$

As the reduced elastic constant $(\hat{C})$ is proportional to the real part of $\chi\,(k,q,\omega)$,

$$\hat{C} = \frac{C}{C_0} = 1 + 4g\ \mathrm{Re}\ \chi(k,q,\omega) \quad (13)$$

Where C is the elastic constant associated with the interaction and C_0 is the elastic constant of the bare electron.

The resistivity ρ is inversely proportional to τ the relaxation time that is reciprocally proportional to imaginary part of $\chi(k,q,\omega)$ is and we can relate ρ as directly proportional to imaginary $\chi(k,q,\omega)$. Replacing ω by $\omega + i\eta$ in the imaginary part of $\chi(k,q,\omega)$. Calculation has been done for static limit at finite temperature with long wave legnthneglecting f – f correlation term (U) in the normal state. Here we consider upto γ_0^2, η^2 and $\gamma_0\eta$ in the expression as these are very small quantities to avoid complesity in our calculation. The final form of Im$\chi(k,q,\omega)$ comes as the following form as in eqn (11)

$$\text{Im}\,\chi(k,q,\omega) = \int\left[\frac{2ct(x-d)^2}{\{\{[c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}\}\{(x-d)^2+4\}^{1/2}}\sinh[b(x-d)^2+4]^{1/2}\right]dx + \int\left[\frac{2ct(x-d)\,2r}{\{\{[c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}\}\{(x-d)^2+4\}^{1/2}}e^{-b(x+d)}\sinh[b(x-d)^2+4]^{1/2}\right]dx + \int\left[\frac{2ctr^2}{\{\{[c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}\}\{(x-d)^2+4\}^{1/2}}e^{-b(x+d)}\sinh[b(x-d)^2+4]^{1/2}\right]dx$$

Therefore, the resistivity is calculated as

$$\text{Resitivity}(\rho) = 1 + 16gIm\chi(k,q=0,\omega) = 1 + 16\int\left[\frac{2ct\,(x-d+r)^2e^{-b(x+d)}}{\{\{c^2-t^2-(x-d)^2+4]^2-4c^2t^2\}\{(x-d)^2+4\}^{1/2}}\sinh[b(x-d)^2+4]^{1/2}\right]dx \quad (14)$$

4. Results

We have parameterized the various terms in equations (10) and (12) to make them dimensionless. The phonon response function and self energy for electron and phonon are numerically calculated. Hybridization strength is taken as the reference level for all energies in this system. Calculation has been done taking the various dimensionless parameters as mentioned earlier. Two of the most important characteristics in HF systems are the hybridization constant 'γ_0'and 'd' thef-level location with respect to Fermi level. Setting zero to the Fermi level d=E_0/γ_0 represents the position of the f-level. The negative value of d occurs when the fermi level lies above the f-level. Here in eight figures results of the numerical evaluation for various dimensionless parameters has been shown. The first two figures show how temperature affects reduced phonon frequency$\tilde{\omega}$ by varying localization of the electron in f- state to the Fermi level electron state (d) and effective coupling constant (g).while the next two plots between 'S' spectral density against reduced frequency with the varation of temperature at different b and g has been shown.Similarly, the next two figures shows the reduced elastic constant ($\hat{C}$) at different temperature by changing the g and d values and figure seven and eight illustrate how resistivity changes with temperature for various d and g values as 0.01 and 0.001 for 'r'and 'g'respectively. Fig. 1 displays the relation between phonon frequency$\tilde{\omega}$ and b with d (= 0, -3, and -5). In this picturethe phonon softening decreases with the the f-level proceeding towards the fermi level.

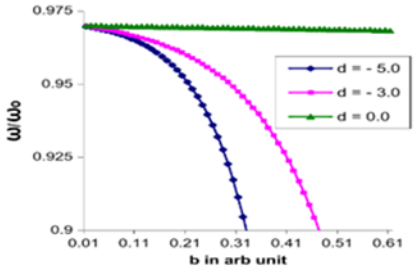

Fig. 1: The curve between ω/ω$_0$~ b withaltering the values of d (= 0, -3 and -5) atg = 0.001 and r= 0.01.

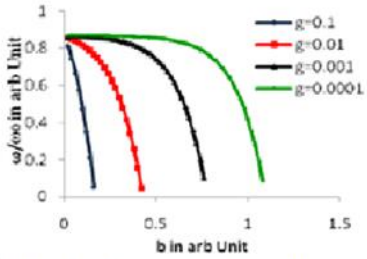

Fig. 2: The curve of ω/ω$_o$~b altering the values of g 0.1, 0.01, 0.001and 0.0001 with r= 0.01, d=-3at excitation frequency value 0.87

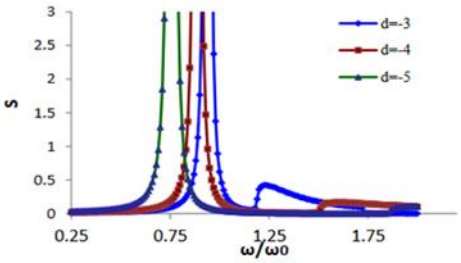

Fig. 3: Variation of S ~ ω/ω$_0$ for various d values (d = -3, -4 and -5) with g = 0.001, r = 0.01 and b = 0.6.

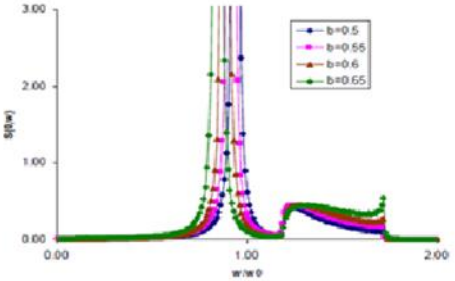

Fig. 4: Plot of spectral density S(0,ω) versus ω/ω$_o$at different values of b=0.5,0.55,0.6 and 0.65 with d=-3 g=0.001&r=0.01

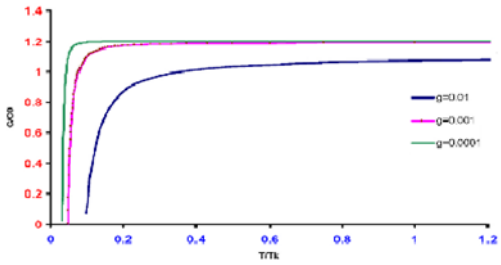

Fig.5: Plot of ?? (= C/C₀) ~ temperature T (= T/Tk) for various values of g (= 0.01, 0.001 and 0.0001)

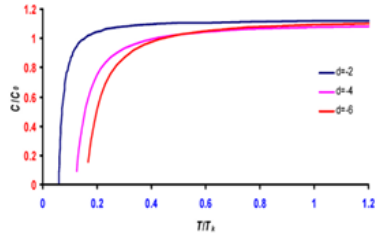

Fig:6 shows the plot of?? for d = 2, 4, and 6 with temperature and for constant values of r = 0.01, g = 0.01, and c = 0

In Fig.3 the variation of the spectral density function

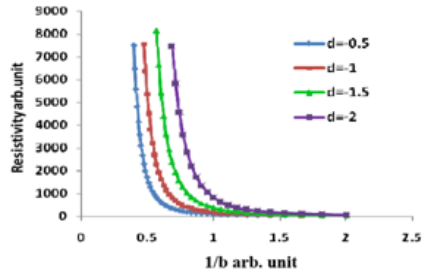

Fig. 7: variationof resistivity ~temperature for d=-0.5,-1 and -1.5withg=0.1

'S' to that of reduced frequency ω/ω₀gives the result

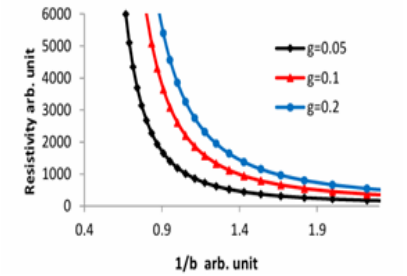

Fig. 8: Plot of resistivity versus temperatute for different g values (=0.05, 1.0 and 0.2) with d= -1

how the position of the f-level with values d= -0.3, 0 and 0.3 changes at constant system parameters as mentioned.

Fig. 4 illustrates how temperature affects the change of Sto that of$\tilde{\omega}$atb = 0.5, 0.55, 0.6 and 0.65 and with g = 0.001, r = 0.01 &d = -3.

In Fig. 5, $\hat{C}$ (the reduced elastic constant) versus temperature at various g= 0.01, 0.001 and 0.0001 while keeping r at 0.01, d at 2 and c at 0. The data indicates that, the the reduced elastic constant ($\hat{C}$) increases with decrease in g- values.

Fig. 6 shows the curve of $\hat{C} \sim {}^{T}/_{T_k}$ at d = 2, 4, and 6with r = 0.01, g = 0.01, and c = 0. The effect of the f-level position on the elastic constant is depicted in The results indicate that the elastic constant decreases with increasing distance between the f-level and the fermi level.The variation of the resistivity with the temperature parameter 1/b in the fig.7. a set of curves are plotted for varying the values of the d (=0.5, -1, -1.5 and -2) at g =0.1 with other parameters fixed. In the figure 8, a set of curves are plotted with d=-1 and varying the values of parameter g (=0.05, 0.1, and 0.2). The resistivity increases with the icrease of 'g'values.

5. Discussion

In rare earth compounds, electron-phonon coupling produces intriguing low-temperature phenomena in several physical propertiesrelated to elasticity and vibrations. The hybridization of 4fstates with conduction electron states results in low energy electronic states that differ significantly due to localize many body states, leading to a wide range of lo temperature electrical and thermal anomalies [21]. Considering experimental results for the resistivity, specific heat and susceptibility of heavy fermions, it is evident that theirphysical properties differ significantly from those of normal metals. For Heavy fermion compounds both the electron correlation and the interaction between electron and phonon is significant for the anomalous behaviour shown at low temperature by these systems. Studies on ultrasonic attenuation & sound velocity, elastic constant, Kondo volume collapse, and anisotropic Fermi surface, etc. have suggested some evidence for significant electron-phonon coupling [21,22,23]. Therefore, here we try to analyse the self-energy and spectral density along with elastic constant and resistivity of heavy fermion system taking into account the electron-phonon (e-p) interaction. Following Periodic Anderson model (PAM) and Zubarev technique, the theoretical results show the various behaviour as

follows. The reduced phonon frequency $\frac{\omega}{\omega_0}$ ~ b is plotted, with f-level positions (d =0, -3 and -5) and fixed parameters of r = 0.01 and g = 0.001 reveals a turn down in phonon softening as the f-level shifts nearer to fermi level.

In fig. 1 it is observed that phonon softening becomes more pronounced as the f-level shifts towards the core i.e. d = -3 and -5. Fig-2 compares phonon response curves across temperatures for varying values of 'g' with all other system parameters held constant. It shows that, at an excitation frequency of 0.87, phonon softening increaseswith higher b values, indicating a temperature decrease. Fig.3 With system parameters constant the variation of the spectral density function varies as 'd' takes the value (-0.3, 0 and0.3). The shifts in the peak position are clearly evident. The figure.4 shows the curve for g = 0.1, 0.01 and 0.001. The results indicate that phonon softening is more significant for the higher effective coupling constants at g=0.1 & 0.01 while it is less pronounced g=0.001. Additionally, as significant that a larger g correlates with a greater $f_1(0)$, which reflects a stronger coupling of electron with phonons in the hybridization band. In HF compounds, the value of f_1 higher normally w.r.t f_2 [24]. Fig. 5 the reduced elastic constant is illustrated for various g values: 0.01, 0.001 and 0.0001 while keeping r at 0.01, d at 2 and c at 0 suggests that as the interaction of electron and phonon increases with the hybridization band enhances the softening of the phonon particularly at lower temperatures. Fig. 6 suggests as the f- level becomes farther from the Fermi level results from phonon softening due to the reduction in interaction of electron with phonon. The plot shows the resistivity dependence on low temperature behaviour similar to that observed in the experimental plots for certainHFcompounds such as UBe_{13}, $CeCu_2Si_2$, U_2Zn_{17}, UCd_{11}, $CeAl_3$ and $CeCu_6$ [25]. In fig.7 the value of resistivity increases with decrease in temperature at lower temperature with a notable peak at extremely low temperature and then it decreases as T approaches zero which indicates that when the exchange of momentum between the electrons becomes more the effect of change of values of d on resistivity gets enhanced. From fig. 8, it is suggested thatsince 'g' is related to the electron density at Fermi level, higher values of g results instronger interaction between conduction band electrons and localized spins as well as with phonons. As a result, the resistivity curve moves upward with increasing g.

6. Conclusion

HF systems are primarily influenced by the intense electronic correlations, with the 4f and 5f electrons significantly shaping their uniquecharacteristics. Various experimental and theoretical analyses indicates the tough hybridization of electrons between conduction electrons and strongly correlated 4f electrons that produces the Fermi level with larger density of states which enhances the effective mass of these HF systems.Even if the electronic correlation is significant and the influence of the electron-phonon interaction (e-p) is crucial in understanding some of the unusual behaviours at low temperature such as elastic constant, ultrasonic attenuation, etc.The observations like a significant drop in the longitudinalelastic constant at extremely low temperature and extremely large magneto-striction below the characteristic temperature in $CeAl_3$, $CeCu_6$ and$CeCu_2Si_2$ and a pronounced ultrasonic absorption peak in UPt_3 indicate the importance of the interaction of elastic strains and long wavelength phonons with quasiparticle bands in these systems. The electron phonon (e-p) interaction is the cause of the temperature dependent resistivity in few HF systems is studied here, the resistivity is evaluated numerically for static limit at (q=0). The results so obtained are found to shows an increase with decrease in temperature which is in the line with the experimental results of the HFmaterials like UBe_{13}, $CeCu_2Si_2$, U_2Zn_{17}, UCd_{11}, $CeAl_3$ and $CeCu_6$ [25]. As distance of the relative separation between the location of Fermi level and f-level ('d') acts the key role in these systems, and resistivity variation with temperature for different values of electron-phonon interaction (EPI) strength of the phonons ('r') with the hybridization band electrons has been presented. The results are found to be in the line with the experimental facts.

7. Future Aspects

In future, we intend to broaden our research to examine how impurities affect heavy fermion systems and influence electron-phonon interactions. We also plan to explore how different impurity concentrations alter the anomalous behaviors and theoretical characteristics of heavy fermion systems.

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