

Phonon, magnon and electron contributions to low temperature specific heat in metallic state of $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ manganites

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MS received 19 June 2012; revised 21 August 2012

Abstract. The reported specific heat $C(T)$ data of the perovskite manganites, $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, is theoretically investigated in the temperature domain $3 \leq T \leq 50$ K. Calculations of $C(T)$ have been made within the three-component scheme: one is the fermion and the others are boson (phonon and magnon) contributions. Lattice specific heat is well estimated from the Debye temperature for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ manganites. Fermion component as the electronic specific heat coefficient is deduced using the band structure calculations. Later on, following double-exchange mechanism the role of magnon is assessed towards specific heat and found that at much low temperature, specific heat shows almost $T^{3/2}$ dependence on the temperature. The present investigation allows us to believe that electron correlations are essential to enhance the density of states over simple Fermi-liquid approximation in the metallic phase of both the manganite systems. The present numerical analysis of specific heat shows similar results as those revealed from experiments.

Keywords. Oxide materials; crystal structure; specific heat; phonon.

1. Introduction

The colossal magnetoresistance (CMR) manganites are compounds of chemical formula, $\text{R}_{1-x}\text{D}_x\text{MnO}_3$, with R being the rare-earth materials and D the doping materials such as alkaline earth, transition metals or non-metals, etc. CMR effect is caused by the temperature dependent phase transition from a paramagnetic insulator to a ferromagnetic metal. Thus, for temperature slightly above this phase transition, an applied magnetic field not only restores the magnetic order as it does in all types of ferromagnetic materials but also gives rise to metallic conductivity. The coincidence of the ferromagnetic–paramagnetic phase transition with the metal–insulator transition is generally believed to be associated with the double-exchange mechanism. Besides a technological interest in CMR effect, doped manganites are fascinating materials in that they exhibit a wide variety of unusual physical properties, which makes them considerably more complex than conventional transition metal ferromagnets (Tokura and Nagosa 2000; Salamon and Jaime 2001; Das and Dey 2007).

The systematic study of thermodynamic properties of solids has become one of the fascinating fields of condensed matter physics in the recent years. Thermodynamics play an important role in explaining the behaviour of manganites, as

many properties are attributed to ‘electron–phonon’ interaction. As electron–phonon interaction is one of the most relevant contributions in determining the conduction mechanism in these materials (Goto *et al* 2004; Dabrowski *et al* 2005). The strong coupling between the electron and lattice is affected by the ratio between trivalent and divalent ions at A site or the average ionic radius of the ions on A site. Thus, thermal properties of this material may be taken as a starting point to a consistent understanding of more complex physical properties of the doped compounds.

Specific heat measurements are understood to be an instructive probe in describing low temperature properties of the materials. Among various manganites, hole-doped system are widely analysed experimentally due to different electronic and magnetic structure with carrier density. The specific heat for $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ -doped system reflects the first-order phase transition and the phase transition are observed below Curie temperature. Based on the temperature and field dependent measured specific heats, it affected the two basic thermodynamic parameters, one being the magneto-caloric effect, i.e. the adiabatic change in temperature and the other, isothermal change in entropy, induced by the change in external magnetic field. The magnetic transition from low-temperature ferromagnetic to the paramagnetic phase was clearly observed (Szewczyk *et al* 2005).

The observed specific heat hump near T_C is associated with magnetic ordering and broadening of the peak is presumably due to magnetic inhomogeneities and/or chemical disorders in the half-doped $\text{La}_{0.5-x}\text{Ln}_x\text{Ca}_{0.5-y}\text{Sr}_y\text{MnO}_3$

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(Ln = Pr, Nd, Sm) samples (Mansuri *et al* 2011). The specific heat of the divalent-doped manganites is also reported and it has argued that the phase transition is of second order and can be well modelled as a Peierls transition in a disordered material. The heat capacity data shows two transitions with the transition at higher T exhibiting a much larger change in entropy than the lower transition. The magnetization data infers FM transition at higher temperature and AFM transition at lower temperature (Cox *et al* 2007).

On the other hand, for the strongly correlated system, there may be another contribution arising from the renormalization of the effective e - e interactions, which can modify density of states at the Fermi energy. In order to get more insight into e - e interaction, Xu *et al* 2006 tried to separate its contribution from the specific heat for $\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3$ manganite. The unique transport behaviour in manganites at low temperature can be understood by taking into account both e - e interaction and weak spin disorder scattering including the spin polarization and grain boundary tunneling. This kind of electron-electron interaction is a general characteristics and verifies the strong correlated interaction between electrons in manganites (Xu *et al* 2006).

Subsequently, heat capacity of $\text{La}_{0.78}\text{Pb}_{0.22}\text{MnO}_3$ in the temperature range $0.5 \leq T \leq 25$ K is measured and found that samples having ferromagnetic insulating or antiferromagnetic ordering exhibits spin-wave signature in specific heat data (Ghivelder *et al* 2001). Salient features of the reported specific heat measurements include a linear term (γT) at low temperature. The contribution to electronic term (γT) was extracted from the total heat capacity and is argued that this contribution is mainly due to the electronic heat capacity and emphasized that the specific heat can be resolved into a γT contribution with a finite value of γ and a lattice contribution.

On the theoretical side, explanation of specific heat behaviour for a wide doping concentration range has, therefore, been of considerable interest. The motivation is twofold: (i) to reveal the importance of the Coulomb correlations which is significant in controlling the transport properties in manganites and (ii) to understand the role of magnons as well as electron-phonon in specific heat of the ferromagnetic metal or insulator. It is indeed essential to find out if these novel materials get their metal to insulator transition from an extremely strong interaction within the double-exchange mechanism and electron-lattice interaction or if any entirely new excitation has to be invoked.

No systematic theoretical efforts addressing the issues of Coulomb correlations, spin wave impact and lattice contribution as well as the competition among these processes have been made so far, and in the present investigation, we try to understand them and retrace the reported specific heat behaviour. We begin with the assumptions and motivate them by simple physical arguments before taking up details of numerical results obtained. The idea we had in mind was to focus attention on the subsisting mass-enhancement mechanisms in the ferromagnetic metallic regime. We employ the density of states as deduced from electronic energy band

structure calculations in order to estimate the electronic specific heat. In the case of manganites, separation of spin-wave contribution from the lattice effect is difficult without an accurate estimation of the Debye temperature. Also, it is worth to seek the possible role of phonons and magnons in the low temperature specific heat of manganites that has immediate important meanings to reveal the phenomenon of colossal magnetoresistance.

The present investigation is organized as follows. In § 2, we introduce the model and sketch the formalism applied. As a first step, we estimate the Debye temperature following the inverse-power overlap repulsion for nearest-neighbour interactions in an ionic solid. We follow the Debye method to estimate the specific heat contributions of phonons and magnons. Within this scheme for phonons, electrons and magnons specific heat, we have computed the low temperature specific heat of $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ manganites. In § 3, we return to a discussion of results obtained by way of heat capacity curves. A summary of the results is presented in § 4. We believe in giving detailed information on physical parameters in correlated electron system, as manganites can be understood by low temperature specific heat behaviour.

2. Lattice specific heat

The acoustic mode frequency shall be estimated in an ionic model using a value of effective ion charge $Ze = -2e$. The Coulomb interactions among the adjacent ions in an ionic crystal in terms of inverse-power overlap repulsion is given as (Varshney *et al* 2002)

$$\Phi(r) = -(Ze)^2 \left[\frac{1}{r} - \frac{f}{r^s} \right], \quad (1)$$

where f being the repulsion force parameter between the ion cores. The elastic force constant κ is conveniently derived from $\Phi(r)$ at the equilibrium inter-ionic distance r_0 following

$$\kappa = \left(\frac{\partial^2 \Phi}{\partial r^2} \right)_{r_0} = (Ze)^2 \left[\frac{s-1}{r_0^3} \right]. \quad (2)$$

Here, s is the index number of the overlap repulsive potential. Then we use acoustic mass, $M' = (2M_+ + M_-)$ [Mn (O) is symbolized by M_+ (M_-)], $\kappa^* = 2\kappa$ for each directional oscillation mode to get the acoustic phonon frequency as

$$\begin{aligned} \omega_D &= \sqrt{\frac{2\kappa^*}{M'}}, \\ &= 2(Ze) \sqrt{\frac{(s-1)}{M'} \frac{1}{r_0^3}}. \end{aligned} \quad (3)$$

In most of manganites, the specific heat is dominated by quantized lattice vibrations (phonons) and is well estimated by conventional Debye theory. As phonons are bosons and waves of all frequencies are in the range of $0 < \omega < \omega_m$ (where ω_m is the maximum phonon frequency) they could propagate through the crystal. The internal energy of the

crystal when the maximum energy of the phonons in the crystal, $x = \hbar\omega/k_B T$, is (Tari 2003):

$$U = U_0 + 9Nk_B T \left(\frac{T}{\theta_D}\right)^3 \int_0^{\theta_D/T} \frac{x^3}{(e^x - 1)} dx, \quad (4)$$

The specific heat from lattice contribution is obtained by temperature derivative as

$$C_{\text{Phonon}} = 9Nk_B T \left(\frac{T}{\theta_D}\right)^3 \int_0^{\theta_D/T} \frac{x^4 e^x}{(e^x - 1)^2} dx, \quad (5)$$

where θ_D is the Debye temperature and N the number of atoms in a unit cell. We shall now switch on to estimation of electronic contribution.

2.1 Electronic specific heat

The internal energy of electron gas is expressed as

$$U = U_0 + \left(\frac{2\pi^3 m V}{3h^2}\right) \left(\frac{3n}{\pi}\right)^{1/3} (k_B T)^2, \quad (6)$$

m being the mass of electron as carriers and n denotes charge density in volume V .

The temperature derivative of the internal energy yields the specific heat and is

$$C_{\text{ele}} = \frac{\pi^2}{3} k_B^2 N(E_F) T = \gamma T, \quad (7)$$

where $N(E_F)$ is the density of states at Fermi level and γ denotes the Sommerfield constant. It is evident from (6) that the electronic specific heat is influenced by the effective mass of the carriers as well as by the carrier concentration. Electron correlation effects are well known to be important for the transition-metal oxides and the importance of renormalization in mass due to electron–phonon interaction (Carbotte 1990) and electron correlations for the perovskites is assessed in the later section.

2.2 Spin wave specific heat

Spin particles as magnon obey Bose statistics and allow us for the calculation of the low-temperature thermal properties of magnetic materials. Only long-wavelength spin waves are excited at low temperature and the dispersion relation for magnon in a spin system

$$\omega(k) = \Delta + D_{\text{stiff}} k^2. \quad (8)$$

Here, the spin-wave excitation at zero field is assumed and D_{stiff} (or D) is the spin stiffness, which is a linear combination of the exchange integrals. Δ is being the anisotropy spin-wavegap (Varshney and Kaurav 2004).

The internal energy of unit volume due to magnon spin wave in thermal equilibrium at temperature T is given by (Kittel 1987)

$$U_{\text{magnon}} = \frac{k_B T}{4\pi^2} \left(\frac{k_B T}{D_{\text{stiff}}}\right)^{3/2} \int_0^{x_m} \frac{x^{3/2}}{(e^x - 1)} dx, \quad (9)$$

where $x = [\Delta + D_{\text{stiff}} k^2]/k_B T$. The specific heat is usually obtained by temperature derivative for long-wavelength spin waves, which are the dominant excitations at low temperature, as

$$C_{\text{magnon}} = \frac{k_B}{4\pi^2} \left(\frac{k_B T}{D_{\text{stiff}}}\right)^{3/2} \int_0^{\infty} \frac{x^{5/2} e^x}{(e^x - 1)^2} dx. \quad (10)$$

Henceforth, the total contribution to specific heat is

$$C_{\text{tot}} = C_{\text{phonon}} + C_{\text{ele}} + C_{\text{magnon}}, \quad (11)$$

where first term on the right side, C_{phonon} , is the phonon contribution and varies as βT^3 [$T \ll \theta_D/10$], the coefficient β is related to the Debye temperature θ_D . Second term, C_{ele} , is the fermionic contribution γT , the linear coefficient (γ) can be related to the density of states at the Fermi surface (Varshney and Kaurav 2006). Last term, C_{magnon} , is associated with ferromagnetic spin-wave excitations and vary as $\delta T^{3/2}$ in the low temperature regime. Terms with higher powers of T than T^3 are anharmonic corrections to the lattice contribution and are ignored for the sake of simplicity in the present study. Within the three-component scheme [phonon, electron and magnon], we have estimated the specific heat of $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ manganites. The calculated results along with discussion are presented in the following section.

3. Results and discussion

Any discussion of the manganites necessitates knowledge of the crystal structure and this is particularly true of the calculations reviewed here. We begin with the discussion of phononic behaviour of specific heat. There can be orthorhombic, rhombohedral and cubic phases in the entire range of doping both as a function of temperature and as a function of concentration. While calculating the Debye temperature, we take $s = 8$ and the in-plane Mn{O distance $r_0 = 2.76$ [3.061] Å (Urshibara *et al* 1995; Sekhar *et al* 2005), yielding $\kappa = 3.068$ [2.2252] $\times 10^5$ g s⁻² due to the fact that the chemical pressure induces different bond length with composition. Keeping the above fact in mind, the Debye temperature from (3) is estimated as 386 {415} K and is essential for the estimation of phonon contribution in specific heat for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ manganites. It is useful to point out that for correlated electron systems as cuprates and manganites, index number of the repulsive potential has been reported to be $s = 8$ (Varshney *et al* 2002).

The Debye temperatures (θ_D), 386 K and 415 K, yield $\beta = 0.169$ and $\beta = 0.14$ $\text{mJK}^{-4} \text{mol}^{-1}$ for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, respectively and are consistent with the reported data (Uhlenbruck *et al* 1998; Tokura and Tomioka 1999). However, we do not claim the process to be rigorous, but a consistent agreement following overlap repulsion is obtained on the Debye temperature as those revealed from specific heat data. Usually, the Debye temperature is a function of temperature and varies from technique to technique. Values of the Debye temperature also vary from sample to sample with an average value and standard deviation of $\theta_D = \theta_D \pm 15$ K. The spin-wave stiffness coefficient is evaluated following $D = 2JSa^2$, where S (average value of the spin) and J (magnetic exchange coupling parameter) are directly related as $S = (4 - x)/2$ and $J = T_c k_B / 4S(S + 1)$ (Perring *et al* 1996) to get D values as 27 and 44 meV \AA .

The specific heat behaviour of $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ are discerned in figures 1 and 2, respectively. Here, we have used (5), (7) and (10) for getting C_{phonon} , C_{electron} and C_{magnon} contributions. The lattice specific heat follows a conventional T^3 characteristic and is noticed from the curve that the specific heat from lattice contribution is lesser to that of magnon specific heat below 9 K. On the other hand, above 9 K, the magnon contribution is reduced in comparison to the lattice specific heat. Both the contributions are clubbed and the resultant behaviour is plotted along with the experimental data for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ (Okuda *et al* 1998; Sekhar *et al* 2005) in figures 1 and 2. We find consistent results of heat capacity as those revealed from experiments. The consistency is attributed to the proper estimation of Debye temperature from inverse power overlap repulsion as well as other free parameters (spin-wave stiffness, average value of the spin and magnetic exchange coupling parameter). Henceforth, a T^3 contribution from the lattice and a $T^{3/2}$ contribution from the spin wave motion

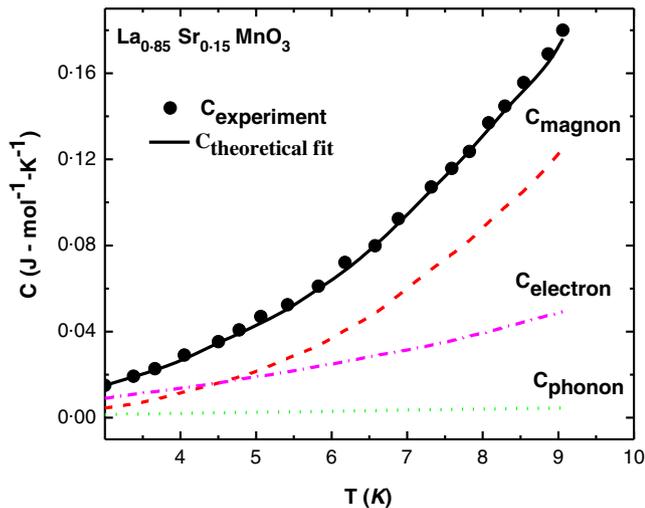


Figure 1. Variation of specific heat with temperature. Solid circles are experimental data taken from Okuda *et al* (1998).

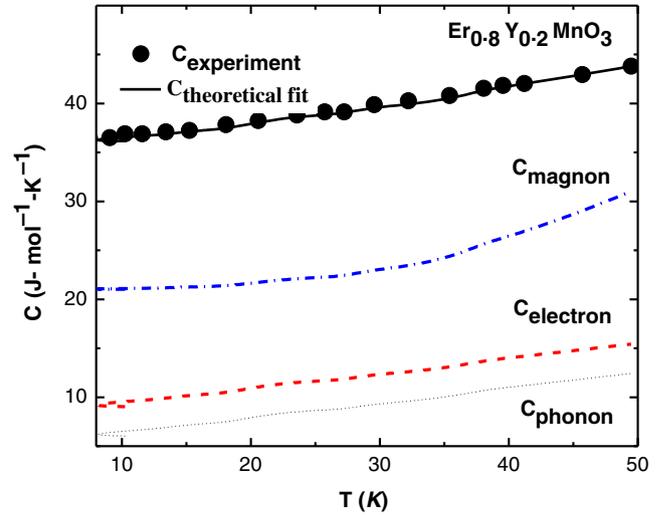


Figure 2. Variation of specific heat with temperature. Solid circles are experimental data taken from Sekhar *et al* (2005).

yield consistent interpretation of specific heat in ferromagnetic insulator (meaning insulating material in ferromagnetic states).

In an attempt to understand the observed metallic behaviour in the low temperature domain, it is important to explore the possible role of mass renormalization of carriers due to differed values of γ obtained from electron energy band structure calculation and specific heat measurements. For $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, the manganite has ferromagnetic ordering. Perhaps the dilemma in determining the magnetic specific heat of manganites is that it represents the spin-wave stiffness and anisotropy related with spin-wave gap. The stiffness is proportional to T_c and S , where T_c is the Curie temperature and S the average value of the spin whereas, anisotropy gap has been determined from neutron-scattering results and is 2.5 ± 0.5 meV for $\text{La}_{0.7}\text{Pb}_{0.3}\text{MnO}_3$ (Okuda *et al* 1998). By the above intrinsic fashion followed by these compositions, the experimental data can be fitted qualitatively by the Debye temperature of 386 and 415 K, which yields $\beta = 0.169$ and 0.14 $\text{mJK}^{-4} \text{mol}^{-1}$ for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, respectively.

We shall now address importance of the Coulomb correlations in revealing the transport properties in manganites. Using the density of states at the Fermi surface $N(E_F) = 6.9 \times 10^{37} \text{ eV}^{-1} \text{ mol}^{-1}$ and $6.88 \times 10^{37} \text{ eV}^{-1} \text{ mol}^{-1}$ from electron energy band structure calculations (Pickett and Singh 1996) for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, respectively for both ferromagnetic cubic perovskite and ferromagnetic $Pnma$ structure, we find $\gamma = 0.5$ and 1.5 $\text{mJ K}^{-2} \text{mol}^{-1}$. It is instructive to mention that the band structure studies do not incorporate the Coulomb correlations and electron-phonon interaction. Difference in γ_b and γ_{exp} necessarily points to the importance of mass renormalization of carriers and indeed significant in manganites. In fact, the

effective charge carrier mass is sensitive to the nature of interaction in Fermi-liquid description. However, in CMR materials the electron–electron interactions are apparently important. e_g electrons also interact with each other via the Coulomb repulsion. Precisely, the enhancement of γ due to electron correlations in manganites is, therefore, necessarily to be incorporated.

The importance of renormalization in mass due to electron correlations and electron–phonon interaction for the perovskites is evaluated following

$$\frac{\gamma_{\text{exp}}}{\gamma_b} = \frac{m^*}{m_e}. \quad (12)$$

Here m^* and m_e terms represent the effective mass and mass of electron, respectively. On the other hand, if we incorporate the electron–phonon coupling, electronic specific heat coefficient will take the following form

$$\gamma = \frac{\pi^2}{3} k_B^2 N(E_F) (1 + \lambda), \quad (13)$$

λ being the electron–phonon coupling strength and is characteristic of a material. Naturally, the electronic specific heat constant is directly proportional to the density of states of the electron at the Fermi level. It is worth to stress that understanding of the electronic specific heat coefficient (γ) is quite relevant as it is a direct measurement of fundamental property of metallic materials. While estimating effective mass, following (12), we find $\gamma = 7.5\gamma_b$ and $5.8\gamma_b$ is either due to Coulomb correlations or electron–phonon/magnon interaction for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, respectively. Similar enhancement in γ is reported earlier and is mainly from correlation effects in $\text{La}_{1-x}\text{Sr}_x\text{TiO}_3$ system and it becomes metallic by Sr doping (Okuda *et al* 1998).

The Coulomb correlations effect for mass renormalization is important in metal oxides. We may refer to an earlier work of Snyder and researchers, who have reported the quadratic temperature dependent resistivity of $\text{La}_{0.67}\text{Ca}_{0.33}(\text{Sr}_{0.33})\text{MnO}_3$, which points to electron–electron interaction (Snyder *et al* 1996). Furthermore, the nonlinearity in the temperature-dependent resistivity behaviour is attributed to electron–electron scattering. The resistivity behaviour follows power temperature dependence over a low temperature domain and a better argument is observed using T^2 term, which it is argued as an evidence of electron–electron scattering.

In passing, we must mention that the mass renormalization is caused by all those parameters which are not considered in band structure calculations such as electron–phonon coupling, electron–electron correlations, spin fluctuations, etc. It is not reasonable to totally exclude electron–phonon contribution to mass renormalization. Regarding the Coulomb correlations, mass renormalization is possibly due to electron–phonon interaction in manganites, although small. Indeed, the charge carriers interact with each other and with distortions of the surrounding lattice, i.e. with phonons. The

electron–phonon coupling localizes the conduction band electrons, as polarons become stronger well above the transition temperature. Furthermore, nature of polaron changes across T_c and a crossover from a polaronic regime to a Fermi liquid-like regime, in which the electron–phonon interaction is insufficient to localize electrons when T tends to zero (Millis *et al* 1995, 1996).

Besides the Coulomb correlations and electron–phonon interaction, another possibility for the carrier mass renormalization arose due to the presence of spin wave in the metallic system and is caused by spin-wave scattering at low temperature. It is worth referring to an earlier work of Fulde and Jensen (1983), who argued that electron mass, is also enhanced by interaction with spin wave in manganites. It was established that $\text{La}_{0.67}\text{Ca}_{0.33}\text{MnO}_3$ is half-metallic (Pickett and Singh 1996) at low temperature, which means that the conduction is limited to a single Mn up-spin channel of majority carriers. Mn down-spin channels are localized, consequently, the normal emission and adsorption of spin waves at finite temperatures are forbidden, since there is no conducting state at low energy to scatter into spin flips. Low temperature spin–wave scattering for the up-spin channel is primarily due to phonon or to spin conserving electron–electron processes.

Figures 1 and 2 illustrate variation of temperature dependence of specific heat for $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$, respectively. The contributions of phonon and Fermions to specific heat are shown separately along with the total specific heat. It is inferred from the plots that, at low temperature domain phonons play a significant role; electronic specific heat varies linearly with temperature and less to phononic component. It is noteworthy to comment that, in manganites, the electron contribution to the specific heat can at best be seen only at very low temperature due to its small magnitude when a comparison is made with phonon contribution.

4. Conclusions

Heat capacity is generally seen as a useful thermodynamical probe in exploring the role of phonon, electron and spin wave excitations. In order to simulate the actual situation occurring in the temperature dependent behaviour of specific heat in manganites, we have outlined the theory and analysed the available experimental data by assuming three channels to heat capacity: phonon, electron and magnon. We follow the Debye model within harmonic approximation in low temperature regime and used the Debye temperature following the inverse-power overlap repulsion for nearest-neighbour interaction. While computing specific heats we use spin-wave stiffness, average value of the spin and magnetic exchange coupling as free parameters. Developing this scheme, the present investigation deals with a quantitative description of temperature dependent behaviour of specific heat in manganites.

With the above-deduced values of θ_D , the change in θ_D with δ indicates a reduction of the lattice stiffness or increase of T^3 -term in the specific heat. Values of θ_D from the present calculation are comparable to those revealed from heat capacity data. Furthermore, specific heat increases and shows almost $T^{3/2}$ dependence on temperature and are attributed to spin-wave contribution. We found that a simple analysis head of the specific heat into T^3 contribution from the lattice and $T^{3/2}$ contribution from the spin-wave excitation yields the correct interpretation of ferromagnetic insulator.

The appropriateness of the present analysis depends on the understanding of band-structure estimation of the density of states. Fermionic component as the electronic specific heat coefficient is deduced following the density of states from electronic energy band-structure calculation. We have incorporated the Coulomb correlations and electron–phonon coupling strength while estimating the electronic specific heat coefficient γ and we believe that both of these have important implication in describing the electronic channel to the heat capacity in doped manganites. To an end, retraces of the heat capacity experimental curve in $\text{La}_{0.85}\text{Sr}_{0.15}\text{MnO}_3$ and $\text{Er}_{0.8}\text{Y}_{0.2}\text{MnO}_3$ is attributed to the assumption that the phonons in the temperature domain $3 \leq T \leq 50$ K are thermally mobile in the ferromagnetic phase of manganites and are usually the major components of specific heat. As θ_D is about 386 and 415 K in manganites, the Debye model with $T \ll \theta_D/10$ is meaningful at low temperatures. It is relevant to incorporate realistic physical parameters based on experimental observation that discerned a clear picture of the low temperature transport properties in manganites.

Acknowledgement

Financial assistance from the Madhya Pradesh Council of Science and Technology, Bhopal, is gratefully acknowledged.

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