THEORETICAL STUDY OF RARE EARTH MANGANITES DOPED WITH ALKALINE EARTHS NAMELY $Re_{1-x}A_xMnO_3$ (where Re = La, Nd etc. & A= Ca, Ba etc.) EXHIBITING COLOSSAL MAGNETO RESISTANCE PHENOMENA

A

FINAL REPORT FOR MAJOR RESEARCH PROJECT

ज्ञान-विज्ञान विमुक्तये

File No. F 42- 765/2013 (SR)
May 2013 to April 2016

SUBMITTED TO

UNIVERSITY GRANTS COMMISSION

BAHADUR SHAH ZAFAR MARG

NEW DELHI – 110 002

BY

Dr. Sunil Panwar

DEPARTMENT OF APPLIED PHYSICS

FACULTY OF ENGINEERING & TECHNOLOGY
GURUKULA KANGRI VISHWAVIDYALAYA
HARIDWAR -249404

Annexure – VIII

UNIVERSITY GRANTS COMMISSION

BAHADUR SHAH ZAFAR MARG

NEW DELHI – 110 002

PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF SENDING THE FINAL REPORT OF THE WORK DONE ON THE PROJECT

1. **NAME AND ADDRESS OF THE PRINCIPAL INVESTIGATOR: Dr.Sunil Panwar**

2. **NAME AND ADDRESS OF THE INSTITUTION:** Department of Applied Physics,Faculty of Engineering & Technology, Gurukula KangriVishwavidyalaya,Haridwar 249404

3. **UGC APPROVAL LETTER NO. AND DATE :** F 42-765/2013 (SR) & 30-03-2013

4. **DATE OF IMPLEMENTATION:** 1st May, 2013

5. **TENURE OF THE PROJECT:** 1st May, 2013 to 30th April, 2016

6. **TOTAL GRANT ALLOCATED**: Rs. 8,11,800/-

7. **TOTAL GRANT RECEIVED:** Rs. 5,33,392/-

8. **FINAL EXPENDITURE:** Rs. 6,38,932/-

9. **TITLE OF THE PROJECT : Theoretical Study of Rare Earth Manganites Doped with Alkaline Earths Namely $Re_{1-x}A_xMnO_3$(where Re=La, Pr, Nd etc. and A=Ca,Sr,Ba etc.) Exhibiting Colossal Magnetoresistance Phenomena**

10. OBJECTIVES OF THE PROJECT: The main aim of the project is to understand the various anomalous electronic & magnetic properties of doped CMR manganites represented by a suitable theoretical model using variational method. We shall be able to use the variational techniques to investigate various anomalous observations in CMR systems for example,

i) Metal- insulator transition

ii) Maximum sensitivity to external fields at temperature close to room temperature.

In connection with the CMR phenomena, we shall study a two band model Hamiltonian and develop a suitable theoretical model for manganites in the presence of strong electron-lattice JT coupling. In this work we shall be able to study the behaviour of ground state energy, electrical resistivity, electronic specific heat, thermoelectrical power, magnetic susceptibility and Hall constant as a function of temperature for different values of model parameters like ferromagnetic Hund's rule coupling J_H between e_g & t_{2g} spins, the net effective ferromagnetic exchange coupling J_F between these t_{2g} spins and ℓ -d hybridization V_k between polarons and d-electrons of the same spin in the absence as well as presence of magnetic field.

Our overall work will be focussed on the study of role of the above model parameters to understand the magnetic/nonmagnetic ground state of these materials and the study of the magneto- transport phenomena of CMR materials.

11. WHETHER OBJECTIVES WERE ACHIEVED:

Objectives were achieved as per the project. We studied a two band model Hamiltonian and developed a theoretical model for doped CMR manganites in the presence of strong electron-lattice JT coupling. In this work, we have observed the behaviour of ground state energy, electrical resistivity, electronic specific heat, thermo-electrical power, magnetic susceptibility and Hall Constant as a function of temperature for different values of model parameters like ferromagnetic Hund's rule coupling J_H between e_g & t_{2g} spins, the net effective ferromagnetic exchange coupling J_F between these t_{2g} spins and l-d hybridization V_k between polarons and d-electrons of the same spin in the absence as well as presence of magnetic field. Finally, we have studied the magneto transport phenomena of CMR materials.

12. ACHIEVEMENTS FROM THE PROJECT:

Six Research Papers have been published in International / National Journals in context of the findings of the project. The results are also presented in different conferences/ workshops on the topic. Also one Ph.D. is going on this related topic.

13. SUMMARY OF THE FINDINGS

The project consists of theoretical study of various electronic and magnetic properties of rare earth manganites doped with alkaline earths namely $\boldsymbol{Re_{1-x}\, A_x\, MnO_3}$ (where Re=La, Pr, Nd etc., and A= Ca, Sr, Ba etc) which exhibit colossal magnetoresistance (CMR), metal insulator transition & many other poorly understood phenomena by using a simple variational method. We have considered the two band model Hamiltonian for manganites in the strong electron- lattice Jahn-Teller (JT) coupling regime. This model is constructed for the doped CMR manganites involving a broad spin- majority ($\boldsymbol{e_g}$-spins) conduction band (b-band) as well as nearly localized spin- minority($\boldsymbol{t_{2g}}$-spins) electron states(ℓ-band).Two band models involving itinerant & localized states were also suggested earlier by both experimentalists & theorists. The overall work can be described in the two categories given below:

i) A Variational description of the doped CMR manganites at zero magnetic field

Using a simple variational method, we have studied the zero field electrical resistivity $\rho(T)$, electronic specific heat $C_v\ (T)$, thermoelectric power $Q\ (T)$, magnetic susceptibility(χ_S) and Hall constant (R_H) of doped CMR manganites and observed the role of the model parameters e.g. local Coulomb repulsion $\boldsymbol{U}$, strong ferromagnetic Hund's rule coupling $\boldsymbol{J_H}$ between $\boldsymbol{e_g}$ & $\boldsymbol{t_{2g}}$ spins & hybridization $\boldsymbol{V}$ between $\boldsymbol{\ell}$ – polarons & **b** - electrons of the same spins and ferromagnetic nearest neighbour exchange coupling $\boldsymbol{J_F}$ between t_{2g} core spins on $\rho(T)$,$Cv\ (T)$, $Q\ (T)$, $\chi_S\,(T)$ and $R_H.(T)$. We find from the resistivity results that as the temperature is lowered below a critical temperature T_c (~ 200K), there is a sudden drop in electrical resistivity $\rho(T)$ at H=0 resembling with the key feature of many CMR compounds like $La_{2/3}(Pb,Ca)_{1/3}MnO_3$ &$(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ at y=0.5. This anomaly in $\rho(T)$ arises from the onset of magnetic ordering at 200K and vanishes on increasing V or J_H value. Moreover T-dependence of $\rho(T)$ is metallic-like below T_c (~ 200K), above which it shows insulator/semiconducting- like behaviour. This work has been published in the Journal of Modern Physics Letters B, Vol. 28 No. 24 (2014) 1450182 (World Scientific Publishing Company).

We conclude from our specific heat & thermoelectric power results that as the temperature is lowered below a critical temperature T_c , there is a an anomaly (sharp peak) in C_v *(T)* and C_v/T at *H*=0 resembling with the key feature of many CMR compounds $Sm_{0.15}$ $Ca_{0.85}$ Mn O_3 and $Nd_{0.67}$ $Sr_{0.33}$ MnO_3.The low temperature peak in C_v *(T)* becomes broader and shifts towards the high temperature region on increasing V_k or J_H or doping *x* value. While the low temperature peak in *Q (T)* becomes sharper and shifts towards the high – temperature region for larger values of V_k or J_H or *x* .Thermoelectric power *Q (T)* at *H*=0 also changes sign at higher temperature. This work is to be communicated soon for publication in the Journal of International repute. Also a separate paper on thermoelectric power is published in the Asian Journal of Physics, 24 No. 11 (2015) 1575 where we have given the detailed calculations on thermoelectric power *Q (T)* at high temperatures.

From magnetic susceptibility and Hall constant results, we find that the maxima of magnetic susceptibility (χ_S) occurs at 200 K followed by a sudden drop in χ_S as we decrease the temperature, resembling with the key feature of many CMR compounds like $La_{0.52}$ $Ca_{0.48}MnO_{3+\delta}$ .This anomaly in χ_S arises from the onset of magnetic ordering at 200K and decreases on increasing V_k or J_H value. While it increases with increasing J_F value and the peak at low temperature becomes more sharpened. This work has been published in the International Journal of Advanced Research in Science & Engineering (IJARSE), Vol 4,Issue 5(2015) 53 & the work on Hall Constant is to be communicated soon for publication in the Journal of International repute.

ii) Magneto transport properties of doped CMR manganites

We have developed here a simple variational method for calculating the magneto transport properties like magnetic field dependent resistivity $\rho(T,H)$ and thermoelectric power *Q (T, H)* of doped CMR manganites. Further we have studied the role of our model parameters e.g. *U, J_H, J_F &V* on $\rho(T,H)$ & $Q(T,H)$ of these materials. From the study of magnetic field dependent resistivity $\rho(T,H)$ and thermoelectric power *Q (T, H)* , we have tried to find the effect of magnetic field on these quantities. This work is published in the Journal of Solid State Communications 223 (2015) 32-36.
At present we are working on the other magnetotransport properties of doped CMR manganites. We are studying the effect of magnetic field on the electronic and magnetic properties like χ_S & R_H of CMR manganites. In connection with the above work, we have arranged many visits at IIT, Roorkee for having fruitful discussion with Prof. Ishwar Singh , Co- Investigator of this project . We are thankful to Prof. Singh for giving his valuable advices from time to time to us.

14. CONTRIBUTION TO THE SOCIETY:

The results obtained from the project work might be useful in the understanding of the CMR and related properties and potential applications in magnetic information store and low-field tunnelling magnetic sensors. A major area that has come up in the last two decades is (CMR or GMR) oxides with extraordinary physical properties & major potential for magnetic recording applications. The study of these technologically important materials will definitely boost up a new generation of magnetic devices & sensors.

15. WHETHER ANY Ph.D. ENROLLED/PRODUCED OUT OF THE PROJECT:

Yes, one student is enrolled for Ph.D. degree.

(I) **Name**: Mrs. Amit Chaudhary

(II) **Topic**: "Electronic and Magnetic Properties of Manganites Exhibiting Colossal Magnetoresistance"

16. NO. OF PUBLICATIONS OUT OF THE PROJECT:

Six papers have been published in International / National journals. A list of publications is attached as Annexure-I.

PRINCIPAL INVESTIGATOR	**Dean** **(Seal)**	**REGISTRAR** **(Seal)**

Annexure – III

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002.

Annual/Final Report of the work done on the Major Research Project.
(Report to be submitted within 6 weeks after completion of each year)

1. **Project report No. 1st /2nd /3rd /Final** Final

2. **UGC Reference No.** 42-765/2013 (SR)

3. **Period of report: from** 1st May, 2013 to 30th April , 2014

4. Title of research project. "***THEORETICAL STUDY OF RARE EARTH MANGANITES DOPED WITH ALKALINE EARTHS NAMELY*** $Re_{1-x}A_xMnO_3$***(Where Re=La, Pr, Nd etc. and A=Ca,Sr,Ba etc.) EXHIBITING COLOSSAL MAGNETORESISTANCE PHENOMENA***"

5. (a) **Name of the Principal Investigator: Dr. Sunil Panwar**

   (b) **Deptt. and University/College where work has progressed:** Deptt. of Applied Physics , Faculty of Engg. & Tech. , Gurukula Kangri Vishwavidyalaya , Haridwar

6. **Effective date of starting of the project** 1st May, 2013

7. **Grant approved and expenditure incurred during the period of the report:**
   a. **Total amount approved** Rs. 8, 11,800/-

   b. **Total expenditure** Rs. 6, 38,932/-

   c. **Report of the work done: (Please attach a separate sheet):-**

   i. **Brief objective of the project :** The main aim of the project is to understand the various anomalous electronic & magnetic properties of doped CMR manganites represented by a suitable theoretical model using variational method. We shall be able to use the variational techniques to investigate various anomalous observations in CMR systems for example,

1) Metal- insulator transition
2) Maximum sensitivity to external fields at temperature close to room temperature.

In connection with the CMR phenomena, we shall study a two band model Hamiltonian and develop a theoretical model for manganites in the presence of strong electron-lattice JT coupling. In this work we shall be able to study the behaviour of ground state energy, electronic specific heat, magnetic susceptibility and electrical resistivity as a function of temperature for different model parameters like ferromagnetic Hund's rule coupling J_H between e_g & t_{2g} spins, the net effective ferromagnetic exchange coupling J_F between these t_{2g} spins and l-d hybridization V_k between polarons and d-electrons of the same spin .

Our overall work will be focussed on the study of role of the above model parameters to understand the magnetic/nonmagnetic ground state of these materials and the study of the magneto transport phenomena of CMR materials.

ii. **Work done so far and results achieved and publications, if any, resulting from the work (Give details of the papers and names of the journals in which it has been published or accepted for publication**
Summary of work done alongwith publications is attached. (see Annexure-I)

iii. **Has the progress been according to original plan of work and towards achieving the objective. if not, state reasons :-** Yes

iv. **Please indicate the difficulties, if any, experienced in implementing the project :-** 2nd installment of grant is not released to the project. Due to the lack of funds, project could not be accomplished properly. We received only the I st installment of grant.

v**. If project has not been completed, please indicate the approximate time by which it is likely to be completed. A summary of the work done for the period (Annual basis) may please be sent to the Commission on a separate sheet :-** Completed. Summary of work done is enclosed.

vi. **If the project has been completed, please enclose a summary of the findings of the study. Two bound copies of the final report of work done may also be sent to the Commission :-** A summary of the findings of the study as well as two bound copies of the final report of work done is attached

vii. **Any other information which would help in evaluation of work done on the project. At the completion of the project, the first report should indicate the output, such as (a) Manpower trained (b) Ph. D. awarded (c) Publication of results (d) other impact, if any:-** Nil

SIGNATURE OF THE PRINCIPAL INVESTIGATOR **REGISTRAR**

Annexure-I

Summary of the work done so far along with the list of publications during May 2013 to April 2016

After the commencement of the project, academic personnel Mr. Vijay Kumar was appointed on the post of project fellow. He was trained on various many body techniques viz. Variational methods, Green's function methods, Diagrammatic perturbation methods etc.

1. Work completed

Mainly we have worked on the four problems given below:

i) **A Variational description of the doped CMR manganites at finite temperature**

Using a simple variational method, we have studied the zero field electrical resistivity ρ(T) of rare earth manganites doped with alkaline earths namely $\boldsymbol{Re_{1-x}}$ $\boldsymbol{A_x}$ $\boldsymbol{MnO_3}$ (where Re=La, Pr, Nd etc., and A= Ca, Sr, Ba etc.) which exhibit colossal magnetoresistance **(CMR)**, metal insulator transition & many other poorly understood phenomena. We have considered the two band model Hamiltonian for manganites in the strong electron- lattice Jahn-Teller (JT) coupling regime. This model is constructed for the doped manganites which exhibit colossal magnetoresistance (CMR) involving a broad spin-majority ($\boldsymbol{e_g}$-spins) conduction band **(b-band)** as well as nearly localized spin-minority($\boldsymbol{t_{2g}}$-spins) electron states(**ℓ-band**).Two band models involving itinerant & localized states were also suggested earlier by both experimentalists & theorists. We have also studied the temperature dependence of electrical resistivity ρ(T) at H=0 of these materials and observed the role of the model parameters e.g. local Coulomb repulsion **U,** strong ferromagnetic Hund's rule coupling $\boldsymbol{J_H}$ between $\boldsymbol{e_g}$ & $\boldsymbol{t_{2g}}$ spins & hybridization **V** between **ℓ** – polarons & **b** - electrons of the same spins on ρ(T) . We find from the resistivity results that as the temperature is lowered below a critical temperature T_c (~ 200K), there is a sudden drop in electrical resistivity ρ(T) at H=0 resembling with the key feature of many CMR compounds like La $_{2/3}$(Pb ,Ca)$_{1/3}$ MnO_3 &(Sm_{1-y} Gd_y) $_{0.55}$Sr $_{0.45}$$MnO_3$ at y=0.5. This anomaly in ρ(T) arises from the onset of magnetic ordering at 200K and vanishes on increasing V or J_H value. Moreover T-dependence of ρ(T) is metallic-like below Tc (~ 200K), above which it shows insulator/semiconducting- like behaviour. This work has been published in the Journal of Modern Physics Letters B., Vol. 28 No. 24 (2014) 1450182 (World Scientific Publishing Company).

ii) **Electronic specific heat & thermoelectric power of doped CMR manganites**

We have developed here a variational method for describing the zero field electronic specific heat Cv (T) and thermoelectric power Q (T) of rare earth manganites doped with alkaline earths namely $\boldsymbol{Re_{1-x}}$ $\boldsymbol{A_x}$ $\boldsymbol{MnO_3}$ exhibiting CMR & metal- insulator transition phenomena. We have also studied the temperature dependence of Cv (T) and Q (T) at H = 0 of these materials and observed the role of the model parameters e.g. local Coulomb repulsion **U,** strong ferromagnetic Hund's rule coupling $\boldsymbol{J_H}$ between $\boldsymbol{e_g}$ & $\boldsymbol{t_{2g}}$ spins & hybridization **V** between **ℓ** – polarons & **b** - electrons of the same spins on Cv (T) and Q (T). We find from our results that as the temperature is lowered below a critical temperature T_c , there is a an anomaly (sharp peak) in Cv (T) and linear coefficient of specific heat Cv/T resembling with the key feature of many CMR compounds $Sm_{0.15} Ca_{0.85} Mn O_3$ and $Nd_{0.67} Sr_{0.33} Mn O_3$.The low temperature peak in Cv (T) becomes broader and shifts towards the high temperature region on increasing V_k or J_H or doping x value. While the low temperature peak in Q (T) becomes sharper and shifts towards the high – temperature region for larger values of V_k or J_H or x .Thermoelectric power Q (T) also changes sign at higher temperature. This work is to be communicated soon for publication in the Journal of International repute .Also a separate paper on thermoelectric power is published in the Asian Journal of Physics 24 (11) (2015) 1575 where we have given the detailed calculations on thermoelectric power Q (T) at high temperatures.

iii) **Magnetic Susceptibility and Hall constant of doped CMR Manganites**

We have developed here a simple variational method for calculating the zero field magnetic susceptibility(χ_S) and Hall constant (R_H) of rare earth manganites doped with alkaline earths namely $\boldsymbol{Re_{1-x} A_x MnO_3}$ (where Re = La, Pr, Nd etc. and A= Ca, Sr, Ba etc.) which exhibit colossal magnetoresistance (CMR), metal insulator transition and many other poorly understood phenomena. These materials are well represented by a two band model Hamiltonian for manganites in the strong electron- lattice Jahn-Teller (JT) coupling regime. Further we have studied the role of our model parameters e.g. local coulomb repulsion U, ferromagnetic Hund's Rule coupling J_H between e_g spins & t_{2g} spins, ferromagnetic nearest neighbor exchange coupling J_F between t_{2g} core spins & hybridization V_k between ℓ – polorons & d - electrons of the same spins on χ_S & R_H of these materials. We find from results that the maxima of χ_S occurs at 200 K followed by a sudden drop in χ_S as we decrease the temperature, resembling with the key feature of many CMR compounds like $La_{0.52} Ca_{0.48}MnO_{3+\delta}$ .This anomaly in χ_S arises from the onset of magnetic ordering at 200K and decreases on increasing V_k or J_H value. While it increases with increasing J_F value and the peak at low temperature becomes more sharpened.

This work on magnetic susceptibility has been published in the International journal of Advanced Research in Science & Engineering (IJARSE) 4 (5) (2015) 53 ISSN- 2319-8354(E) and Journal of Indian Institute of Engineering, Management and science (JIIEMS), volume 3, Issue 1, November 2015, ISSN-2347-6184(In Press) . while the work on zero field Hall Constant is to be communicated soon for publication in the Journal of International repute.

iv) Magneto transport properties of doped CMR manganites

We have developed here a simple variational method for calculating the magneto transport properties like magnetic field dependent resistivity $\rho(T,H)$ and thermoelectric power Q (T,H) of doped CMR manganites. Further we have studied the role of our model parameters e.g. U, J_H, J_F &V on $\rho(T,H)$ & $Q(T,H)$ of these materials. From the study of magnetic field dependent resistivity $\rho(T,H)$ and thermoelectric power Q (T, H) , we have tried to find the effect of magnetic field on these quantities. This work is published in the Journal of Solid State Communications 223 (2015) 32-36.While the work on magneto thermal properties like specific heat Cv (T) is published in ESSENCE-International Journal for

Environmental Rehabilitation and Conservation, VI No. 2(2015)189-193,ISSN : 0975-6272.

2. Work in Progress

At present we are working on other magnetotransport properties of doped CMR manganites. We are studying the effect of magnetic field on the electronic and magnetic properties like χ_S & R_H of CMR manganites.

In connection with the above work, we have arranged many visits at IIT, Roorkee for having fruitful discussion with Prof. Ishwar Singh , Co- Investigator of this project . We are thankful to Prof. Singh for giving his valuable advices from time to time to us.

RESULTS:

I. Introduction:

The discovery of CMR effect in the mixed- valence hole doped manganites has attracted much attention for their scientific and technological interests. Magnetic perovskites (manganites) such as $La_{0.7}$ $Sr_{0.3}$ MnO_3 have attracted as potential magneto- resistive sensors. CMR materials with integrated electronics have attracted as high sensitivity magnetic field sensors. While the applications of these materials are well known as magneto- resistive (MR) sensors in Navigation.

The project consists of theoretical study of various electronic and magnetic properties of rare earth manganites doped with alkaline earths namely $\boldsymbol{Re_{1-x}\ A_x\ MnO_3}$ (where Re=La, Pr, Nd etc., and A= Ca, Sr, Ba etc) which exhibit colossal magnetoresistance (CMR), metal insulator transition & many other poorly understood phenomena using a simple variational method. We have considered the two band model Hamiltonian for manganites in the strong electron- lattice Jahn-Teller (JT) coupling regime. This model is constructed for the doped manganites which exhibit colossal magnetoresistance (CMR) involving a broad spin- majority ($\boldsymbol{e_g}$-spins) conduction band (**b-band**) as well as nearly localized spin-minority($\boldsymbol{t_{2g}}$-spins) electron states($\boldsymbol{\ell}$**-band**).Two band models involving itinerant & localized states were also suggested earlier by both experimentalists & theorists.

II. Work Completed: The overall work can be described in the two categories given below:

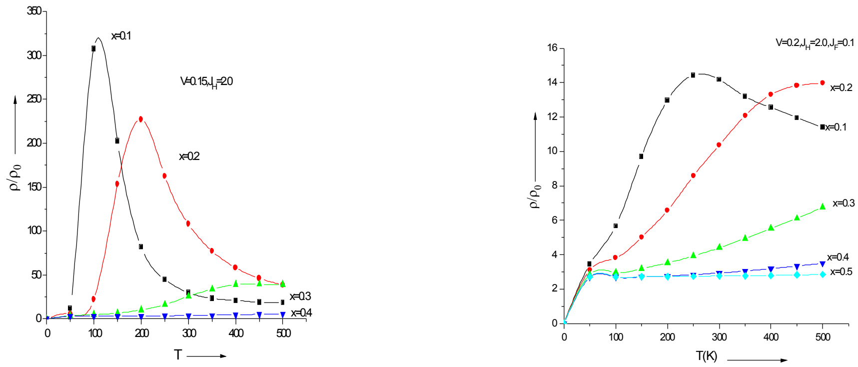
i) A Variational description of the doped CMR manganites at zero magnetic field

Using a simple variational method, we have studied the zero field electrical resistivity $\rho(T)$, electronic specific heat $C_v\ (T)$, thermoelectric power $Q\ (T)$, magnetic susceptibility(χ_S) and Hall constant (R_H) of doped CMR manganites and observed the role of the model parameters e.g. local Coulomb repulsion $\boldsymbol{U}$, strong ferromagnetic Hund's rule coupling $\boldsymbol{J_H}$ between $\boldsymbol{e_g}$ & $\boldsymbol{t_{2g}}$ spins & hybridization V between $\boldsymbol{\ell}$ – polarons & **b** - electrons of the same spins and ferromagnetic nearest neighbor exchange coupling $\boldsymbol{J_F}$ between t_{2g} core spins on the quantities $\rho(T)$,$C_v\ (T)$, $Q\ (T)$, $\chi_S(T)$ and $R_{H}.(T)$.

In our calculations, we have taken the unperturbed band of three dimensional solid represented by simple semicircular density of states $N^c{}_\sigma\ (\epsilon_k) = (2/\pi)\sqrt{(1-\epsilon_k^2)}$ (which is centred around zero energy) with band width W=2.0eV, U=5.0 ,E_{jt}=0.5,V= 0.1 & 0.2 , $\in_F$ = -0.238 eV (for x =0.3) and J_H = 1.0 & 2.0 eV. Doping x is varied from 0.1 to 0.5 .

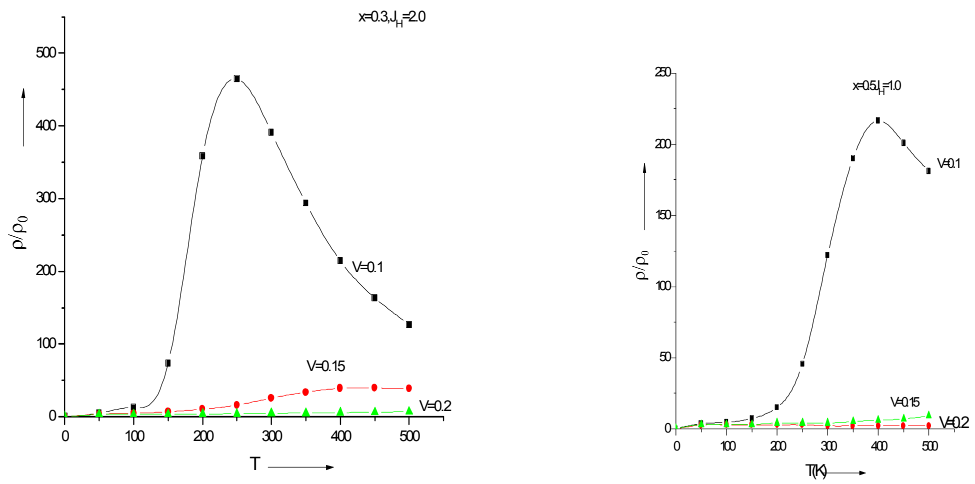
1. Temperature Dependence of Electrical Resistivity ρ(T) at H=0:

We find from the resistivity results **(Fig. 1-4)** that as the temperature is lowered below a critical temperature T_c (~ 200K), there is a sudden drop in electrical resistivity $\rho(T)$ at H=0 resembling with the key feature of many CMR compounds like $La_{2/3}(Pb,Ca)_{1/3}MnO_3$ &$(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ at y=0.5. This anomaly in $\rho(T)$ arises from the onset of magnetic ordering at 200K and vanishes on increasing V or J_H value. Moreover T-dependence of $\rho(T)$ is metallic-like below T_c (~ 200K), above which it shows insulator/semiconducting- like behaviour. The details of ρ(T) results are given below:



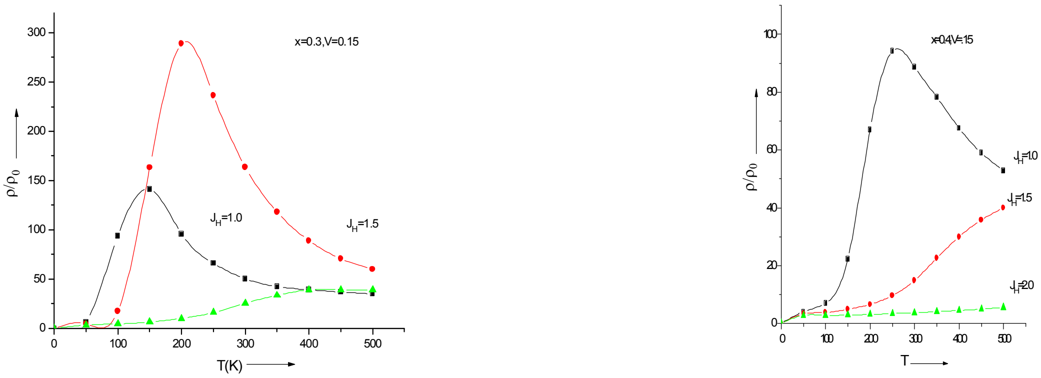
(a) (b)

Fig.1: Variation of ((ρ/ ρ_o) at H=0 as a function of temperature T(K) for different values of x at U=5,E_{jt}=0.5 , J_H=2.0 (a)V=0.15 & (b) V=0.2



(a) (b)

Fig.2: Variation of (ρ/ ρ_o) at H=0 as a function of temperature T(K) for different values of V at J_H=2.0 U=5,E_{jt}=0.5 (a) x=0.3 & (b) x=0.5 but J_H=1.0



(a) (b)

Fig.3: Variation of (ρ/ρ_o) at H=0 as a function of temperature T(K) for different values of J_H at V=0.15, U=5,E_{jt}=0.5 (a) x=0.3 (b) x=0.4

In **Figs. 1-3**, we have shown the temperature dependence electrical resistivity $\rho(T)$ of at H=0 for different values of parameters J_H, V & various doping values of x. The electrical resistivity $\rho(T)$ shown in the figures initially rises, attaining a maximum at the metal-insulator transition temperature T_{MI} ~ 200K. Then below T_{MI} down to 0K, it changes to a metallic like behaviour characteristic of the ferromagnetic phase. We would also like to point out that there exists a sharp drop in the resistivity curves at the temperatures lower than 200 K for all the cases shown in figures. This phenomenon is similar to that in many CMR compounds like $La_{2/3}(Pb, Ca)_{1/3}MnO_3$ & $(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ at y=0.5 which was attributed to the existence of ferromagnetic interaction **.**

Remarkable dependence of $\rho(T)$ on various doping values x is revealed by $\rho(T)$ curves with different x in **Fig. 1**.Surprisingly, a change of value x by factor 2 is sufficient to switch the low-T ground state of the same compound from metallic to insulating. The low-T resistivity ρ *(T)* around 200 K appears to be the most x- sensitive characteristic of the samples. For x =0.1 to 0.5, $\rho(T)$ varies systematically over the temperature range from 0 to 500 K. All the curves display the overall characteristics of metallic-like-semiconducting-like transition at T_{MI} of the order of 200 K. The peak at low temperature becomes broad & shifts towards higher temperature on increasing the value of x& J_H and even disappears at much larger value of V, J_H & x (say for x=0.4 &0.5).

It is interesting to observe that, even using such a simple phenomenological model, the results are already in reasonable agreement with the experiments namely, i) at large temperature insulating behaviour is observed even for x as large as 0.5,ii) at small temperature a metallic-like behaviour appears & iii) a broad peak exists in between. In between low and high temperatures, it is natural that $\rho(T)$ will present a peak. Thus near room temperature insulating behaviour is expected.

To conclude, the present results establish that the observed anomalies in $\rho(T)$ in the vicinity of magnetic transition temperature around 200K is solely related to magnetic precursor effect due to 4d magnetism. This observation is of relevance to the field of colossal magneto resistance.

2. Temperature dependence of thermoelectric power *(Q/Q_0)* at *H* = 0:

In **Fig. 4-6** below, we have shown the temperature dependence of thermoelectric power *(Q/Q_0)* at *H* = 0 for different values of parameter J_H , V & doping values x.

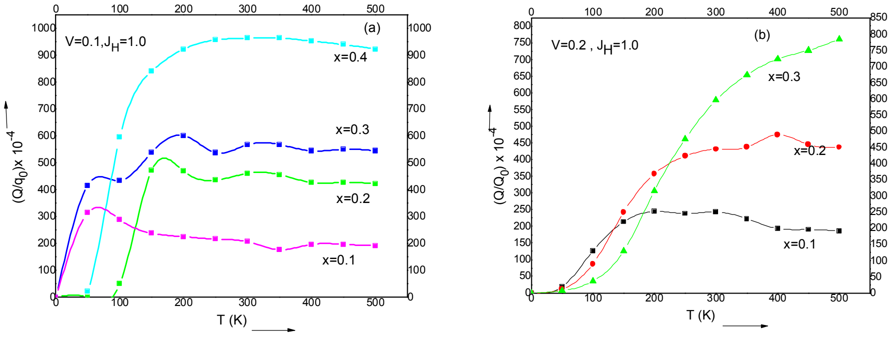


Fig. 4: Temperature dependence of thermoelectric power (Q/Q_o) for different values of $\boldsymbol{x}$ at $U = 5$, E_{jt} =0.5 & J_H = 1.0 with (a) V=0.1 & (b) V=0.2

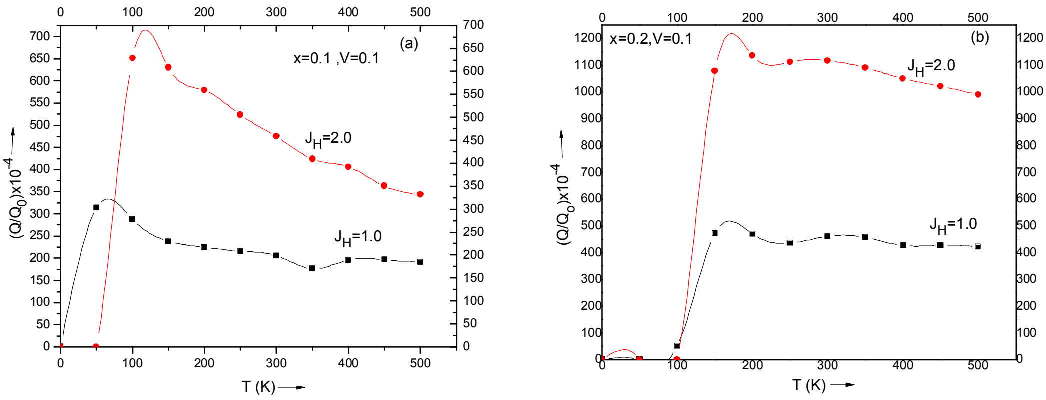


Fig. 5: Temperature dependence of thermoelectric power (Q/Q_o) for different values of $\boldsymbol{J_H}$ at U= 5, E_{jt} =0.5 & V = 0.1 with (a) x=0.1 & (b) x=0.2

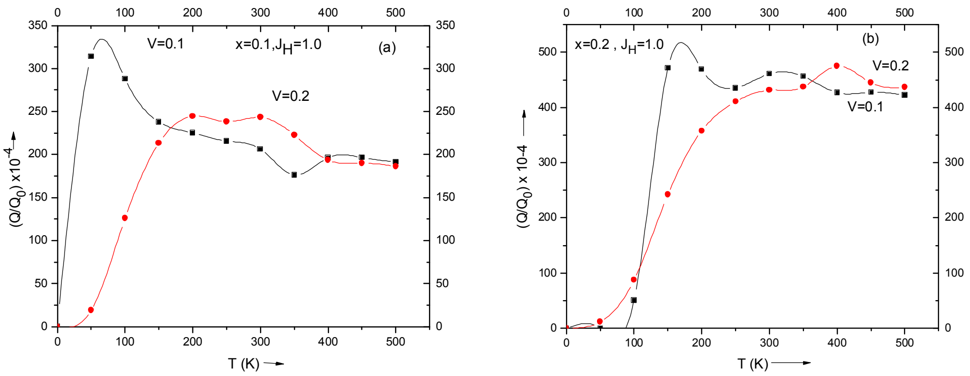


Fig. 6: Temperature dependence of thermoelectric power (Q/Q_o) for different values of $\boldsymbol{V}$ at U= 5, E_{jt} =0.5 & J_H = 1.0 with (a) x=0.1 , (b) x=0.2

In **Fig. 4**, we show the temperature dependence of $Q\ (T)$ on various doping values x for J_H=1.0 with (a) V = 0.1 &(b) V = 0.2 . $Q\ (T)$ at low temperatures increases as T increases & has a peak around 50K for x = 0.1 curve beyond that it decreases (see **Fig. 4(a)).** But as x increases, $Q\ (T)$ increases & the peak at low T becomes broader & shift towards the high temperature. Also $Q\ (T)$ remains positive in the whole temperature range.

Temperature dependence of $Q\ (T)$ on different J_H has been shown in **Fig. 5** for V = 0.1 with (a) x = 0.1 & (b) x = 0.2. Whereas $Q\ (T)$ with different V has been reported in **Fig. 6** for J_H= 1.0 with (a) x = 0.1 b) x = 0.2. In Fig. **5** also, we observe broad maxima in $Q\ (T)$ at low temperature, becomes more sharper & shifts towards the higher temperature region as J_H increases. But on the contrary in the **Fig. 6** , the magnitude of *Q (T)* decreases on increasing V_k and peak at low *T* becomes broader & shifts towards the high temperature region .This behavior of *Q (T)* shown in the above figures agrees qualitatively with some CMR compounds such as $La_{0.67}Ca_{0.33}MnO_3$ & $La_{5/8-y}Pr_y Ca_{3/8} MnO_3$ with y=0.25,0.35 & 0.42 . Broadly speaking, the behavior of Q (T) for x=0.1, V=0.2, J_H=1.0 in **Fig. 6(a)** with a broad peak at T = 250 K corresponds to CMR compound $La_{0.67} Ca_{0.33}MnO_3$.

To conclude, we have investigated zero field thermoelectric power *Q (T)* of hole doped RE manganites with doping *x*=0.1- 0.5. *Q (T)* is positive throughout the temperature range of investigation thereby representing that the charge carriers are holes. Our curves of *Q* Vs *T* plot upon lowering the temperature from 500 *K* exhibit a broad maxima near the magnetic transition temperature (T_c) as reported earlier in *Pr* – based manganites .The observed broad peak may be explained on the basis of the spin – wave theory and may be attributed to the magnon drag effect which increases with *x* or J_H value.

3. Temperature dependence of magnetic susceptibility (χ_S) at *H* = 0 :

We find from magnetic susceptibility (χ_S) results (**Figs 7-9**) that the maxima of χ_S occurs at 200 K followed by a sudden drop in χ_S as we decrease the temperature, resembling with the key feature of many CMR compounds like $La_{1-x} Ba_x MnO_3$ with x=0.02-0.35 & $La_{0.67} Ca_{0.33} Mn_{0.9} Ta_{0.1} O_3$.This anomaly in χ_S arises from the onset of magnetic ordering at 200K and decreases on increasing V_k or J_H value. While it increases with increasing J_F value and the peak at low temperature becomes more sharpened. The details of χ_S (T) results are given below:

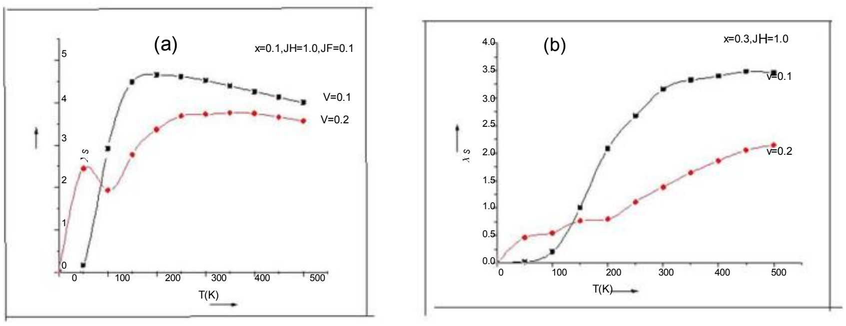


Fig.7: Variation of magnetic susceptibility (χ_S) with temperature T (K) at U=5.0,E_{jt}=0.5,J_H=1.0 & J_F=0.1 for different values of V with a) x=0.1, b) x=0.3

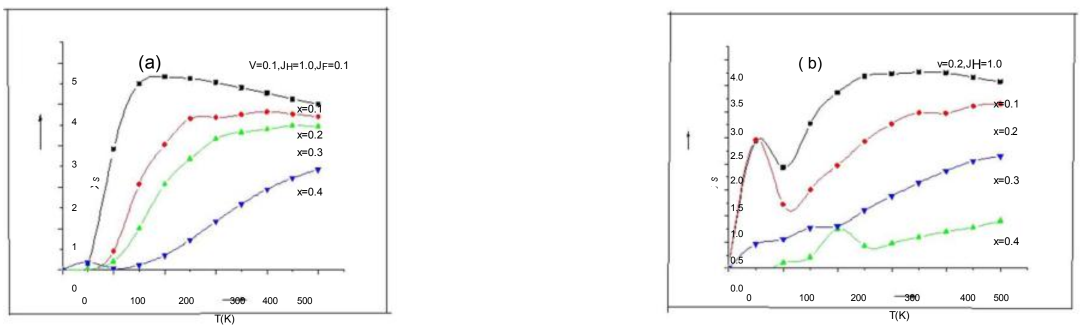
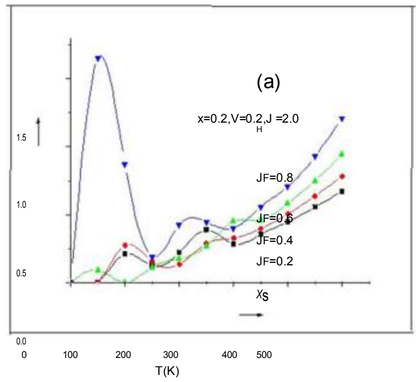


Fig.8: Variation of magnetic susceptibility (χ_S) with temperature T (K) at U=5.0,E_{jt}=0.5 J_H=1.0 & J_F=0.1 for different values of x with a). V=0.1 & b). V=0.2



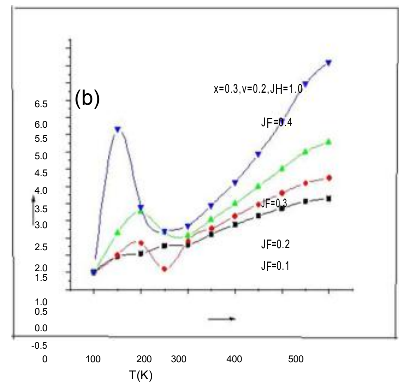


Fig. 9: Variation of magnetic susceptibility (X_S) with temperature T (K) at U=5.0, Ejt=0.5 V=0.2 for different values of J_F with a). x=0.2 & J_H=2.0 & b). x=0.3& J_H=1.0

In **Figs. 7-9**, we have shown the temperature dependence of magnetic susceptibility (X_S) for different values of parameters *V, x & J_F*. Here X_S follows a Curie- Weiss behaviour at high temperatures well above *T* * where the short-range FM fluctuations are negligible. The Curie- Weiss law is not followed towards lower temperature. At low temperature, it shows a peak at
T * ~ 200 K (**see fig.7 a**) followed by a sudden drop in X_S as we decrease further the temperature resembling with the key feature of many CMR compounds like $La_{1-x}Ba_xMnO_3$ with x=0.02-0.35 & $La_{0.67}Ca_{0.33}Mn_{0.9}Ta_{0.1}O_3$ .This sharp cusp like anomaly in X_S arises from the onset of magnetic ordering at 200 K & decreases on increasing V, J_H or doping concentration x . The ferromagnetic exchange interaction J_F enhances the X_S appreciably in the low temperature. We have seen that the results of the simple model considered here are in qualitative agreement with the experimental results of a broad class of hole doped CMR manganites.

To conclude, we have investigated here the low- field magnetic susceptibility of hole doped RE manganites with doping concentration x= 0.1 -0.5 . Our curves exhibit a PM – FM transition at a temperature *T* * which increases as x increases. Well above *T* *, the Curie – Weiss dependence of X_S (T) is observed. Upon lowering the temperature below *T** anomalous behaviour of X_S (T) which arises from the onset of magnetic ordering at *T**~ 200 K is observed.

ii) Magneto transport properties of doped CMR manganites (Figs. 10-12)

We have developed here a simple variational method for calculating the magneto transport properties like magnetic field dependent resistivity $\rho(T,H)$ and thermoelectric power $Q\ (T,H)$ of doped CMR manganites Further we have studied the role of our model parameters e.g. U, J_H, J_F & on $\rho(T,H)$ & $Q(T,H)$ of these materials. From the study of magnetic field dependent resistivity $\rho(T,H)$ and thermoelectric power $Q\ (T,H)$, we have tried to find the effect of magnetic field on these quantities. This work is published in the Journal of Solid State Communications 223 (2015) 32-36. The details of $\rho(T,H)$ & $Q\ (T,H)$ results are shown in the figures given below:

Fig. 10: Temperature dependence of resistivity $(\rho/\rho_0) \times 10^2$ for different values of h & *m at* $U=5$, $E_{jt} = 0.5$, $V=0.1$,$J_H=1.0$ & $J_F=0.1$ *with (a)* $x=0.3$, *(b)*$x=0.4$

Fig. 11: Temperature dependence of magnetoresistance (MR) ratio for different values of *h & m at* $U=5$, $E_{jt} = 0.5$, $V=0.1$, $J_H=1.0$ & $J_F=0.1$ *with (a)* $x=0.3$ *(b)* $x=0.4$

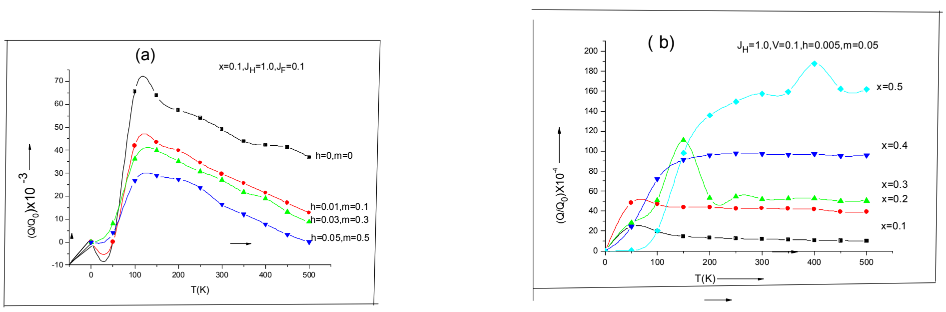


Fig. 12: Temperature dependence of thermoelectric power $(Q/Q_0) \times 10^{-3}$ at $U=5$, $E_{jt} = 0.5$, $V=0.1$, & $J_F=0.1$ with (a) for different values of h & m with $x=0.1$, $J_H=2.0$ (b) for different values of x with $J_H=1.0$, $h= 0.005$, $m=0.05$.

The temperature dependence of ρ *(T,H)* , MR ratio & *Q (T,H)* is shown in **Fig. 10-12** for different values of magnetic field parameters h ,magnetization m & doping concentration x . The parameter h is related to the physical field through $h= g\ \mu_B\ Sc\ H_{phys} / t$. Using $g=2$ $t=0.6$ eV & $Sc=3/2$, we find that $h= 0.01$ corresponds to $H_{phys} =15T$ whereas the parameter m stands for magnetization per site.

1) A magnetic field dependent Resistivity [$\rho(T, H)$]

Fig.10 shows the temperature dependence of resistivity ρ *(T,H)* for different values of *h & m* with (a) *x*=0.3, (b) *x*=0.4 & (c) *x*=0.5. In these Figures, the electrical resistivity ρ *(T,H)* for a particular value of *h & m* increases sharply with increasing temperature, until the highest ρ *(T,H)* at metal – insulator transition temperature $T\rho$ ~ 150K. Beyond $T\rho$, the ρ *(T,H)* gradually decreases .Here we also find that there is a sharp drop in the ρ *(T,H)* curves at temperatures lower than $T\rho$. This phenomenon is similar to that in many CMR Compounds which was attributed to the existence of FM interaction. The low temperature ($T<T\rho$) resistivity shows metallic like behavior & high temperature ($T>T\rho$) resistivity shows semiconductors/insulators like behaviour.

We also noticed from **Fig. 10**, that the application of magnetic field decreases the ρ *(T,H)* of these materials throughout the temperature range of our investigation & T_ρ shifts towards higher temperature side. This may be due to that the delocalized charge carriers induced by applied magnetic field suppress the resistivity which in turn leads to the local ordering of the electron spins. Due to this ordering, the ferromagnetic metallic state might have suppressed the paramagnetic insulating regime resulting in the observed increase in T_ρ under applied magnetic field. The decrease in ρ *(T,H),* due to applied field, is maximum near the ρ – peak thereby showing a peak in the MR ratio versus temperature plot (see **Fig. 11 a & b**) around T ρ~ 250 K. The resistivity data of all the curves for $T < T\rho$ could be well accounted in terms of the electron – electron & electron-magnon scattering while those for $T > T\rho$ obey the adiabatic small polaron model .

Magnetoresistance is the key property of these perovskite manganites. The MR ratio [{ $(\rho_H-\rho_0)/\rho_0$} x 100 % ; where ρ_H & ρ_0 are respectively , the resistivities in presence & in absence of magnetic fields] is calculated and plotted versus temperature in **Fig. 11** for different values of *h & m*. Large negative MR ratio is observed in all the curves at and below $T\rho$ as shown in Fig. **11 (a & b).** All curves show an increase in MR ratio at low temperatures. It keeps on increasing below a peak near $T\rho$ ~ 250K like MR variation with temperature of many CMR materials like Sb-LBMO under 0.6 T magnetic field & $La_{2/3}Ca_{1/3}MnO_3$ in a field of 10 kOe . In general, we observed that the value of MR ratio increase with increasing magnetic field H (see **Fig. 11**). The application of a magnetic field lines up the randomly oriented spins and increase the conductivity. The activation energy is thus reduced appreciably, and hence the material shows an extremely large negative MR ratio.

2) Magnetic Field Dependent Thermoelectric Power [Q (T,H)]:

Fig. 12(a) displays the temperature dependent thermoelectric power *Q(T,H)* with different values of *h & m (h*= 0.0-0.05 & *m*=0.0-0.5). It is seen that *Q(T,H)* at low temperatures increases as temperature increases & has a peak around 100 K beyond that it decreases .Also there is no change in the sign of *Q(T,H)* & it remains positive throughout the temperature range of our investigation thereby indicating that the charge carriers are holes. . It is further noticed in **Fig.12 (b)** that *Q (T,H)* increases more with increasing doping concentration *x* for a particular value of *h & m (h=0.05 & m= 0.5*). This large value of *Q(T,H)* arising from hole localization may occur due to the narrowing of e_g band. This behavior of *Q (T,H)* agrees qualitatively with some CMR compounds such as $La_{0.67}Ca_{0.33}MnO_3$ & $La_{5/8-y}Pr_yCa_{3/8}MnO_3$ with y=0.25,0.35 & 0.42 .

Fig. 12(a) also shows the variation of *Q (T, H)* with temperature in the absence & in the presence of a magnetic field. Here it is observed that with the application of a magnetic field, *Q* - values decrease at low temperature and the peak near $T\rho$ becomes broader. In the external magnetic field, the phonon- drag effect is expected to become weaker so that value of *Q (T,H)* reduces. It has previously been found that phonon drag (Q_g) and magnon drag (Q_m) contributions are present in the low temperature regions.

To conclude, from the study of field dependent resistivity *ρ(T,H)* and thermoelectric power *Q(T,H),* we tried to find the effect of magnetic field on the properties of these materials and discussed the transport mechanism using variational method . In this study the resistivity ρ *(T,H)* & thermoelectric power *Q(T,H),* decrease with increasing magnetic field and the metal-insulator transition temperature (T_ρ) shifts towards higher temperature region . This may be due to that the delocalized charge carriers induced by applied magnetic field that suppress the resistivity which in turn leads to the local ordering of the electron spins.. We have also shown the temperature dependent magneto- resistance (MR) ratio at different magnetic fields. We obtained large MR value at low temperatures. While the phonon- drag effect is expected to become weaker in the presence of external magnetic field so that the value of

Q (T,H) reduces. *Q (T,H)* is positive throughout the temperature range of investigation there by representing that the charge carriers are holes .

III. Work in Progress

At present, we are working on the other finite temperature magnetotransport properties like χ_S & R_H of doped CMR manganites. We are studying the effect of magnetic field on these properties of CMR manganites.

In connection with the above work, we have arranged many visits at IIT, Roorkee for having fruitful discussion with Prof. Ishwar Singh , Co- Investigator of this project . We are thankful to Prof. Singh for giving his valuable advices from time to time to us.

Annexure- II

List of Publications

(A)Papers Published / Communicated in Journals (2013-16)

1. **A variational theory of zero field electrical resistivity of colossal mangnetoresistive manganites ($Re_{1-x}\,A_x\,MnO_3$).**
   Sunil Panwar, Vijay kumar, Amit Chaudhary and Ishwar Singh
   Modern Physics Letters (B), Vol.28, No.24 (2014) 1450182. **(See Enclosure -1)**
2. **Theoretical study of magnetic susceptibility of colossal magnetoresistive manganites ($Re_{1-x}\,A_x\,MnO_3$); A Variational Treatment**
   Amit Chaudhary, Sunil Panwar & Rajendra Kumar
   International Journal of Advanced Science & Engineering (IJARSE), Vol. No. 4 , Issue 05 , May (2015) 53, ISSN - 2319 - 8354 (E). (**See Enclosure -2**)
3. **Theoretical study of zero field thermoelectric power in colossal magnetoresistive manganites ($Re_{1-x}\,A_x\,MnO_3$); A Variational Treatment**
   Amit Chaudhary, Vijay Kumar, Sunil Panwar, Rajendra Kumar and Ishwar Singh
   Asian Journal of Physics, 24 No. 11 (2015) 1575-1582, p-ISSN : 0971-3093 **(See Enclosure -3)**
4. **Theoretical study of magneto transport properties of colossal magnetoresistive manganites ($Re_{1-x}\,A_x\,MnO_3$); A Variational Treatment**
   Sunil Panwar, Vijay kumar, Amit Chaudhary and Ishwar Singh
   Solid State Communications,223 (2015) 32-36. **(See Enclosure -4)**
5. **Zero field magnetic susceptibility of colossal manganites ($Re_{1-x}\,A_x\,MnO_3$);**
   Sunil Panwar, Vijay Kumar, Amit Chaudhary, Rajendra Kumar
   Journal of Indian Institute of Engineering, Management and science (JIIEMS), volume 3, Issue 1, November 2015, ISSN-2347-6184(In Press) **(See Enclosure -5)**
6. **Magneto thermal properties of hole doped CMR manganites ($Re_{1-x}\,A_x\,MnO_3$): A Variational Treatment**
   Sunil Panwar, Vijay kumar and Ishwar Singh
   ESSENCE-International Journal for Environmental Rehabilitation and Conservation, VI No. 2(2015)189-193,ISSN : 0975-6272. **(See Enclosure -6)**
7. **Assessment of variation in zero field Hall constant of colossal magnetoresistive manganites ($Re_{1-x}\,A_x\,MnO_3$)**
   Sunil Panwar, Vijay Kumar and Ishwar Singh
   ESSENCE-International Journal for Environmental Rehabilitation and Conservation, VIII No. 2(2017)103-107,ISSN : 0975-6272. **(See Enclosure -7)**

8. **A variational theory of Hall effect of Anderson lattice model: Application to colossal Magnetoresistive Manganites ($Re_{1-x}\,A_x\,MnO_3$)**

Sunil Panwar, Vijay Kumar and Ishwar Singh
Solid State Communications, 266 (2017) 50-54. **(See Enclosure -8)**

9. **A variational theory of zero field electronic specific heat & thermoelectric power in colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
   Sunil Panwar, Amit Chaudhary, Vijay Kumar and Ishwar Singh
   (to be communicated)

(B) <u>Papers Presented in Conferences / Symposia</u>

1. **Electronic specific heat of colossal magnetoresistive manganite ($Re_{1-x}\ A_x\ MnO_3$)**
   Amit Chaudhary, Vijay Kumar, Sunil Panwar and Rajendra Kumar
   Presented at the National Conference on Emerging Trends in Engg. & Sciences (ETES) FET, GKV, Haridwar (2013)
2. **Thermoelectric power of colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
   Sunil Panwar, Vijay kumar, Amit Chaudhary and Rajendra Kumar
   Presented at the National Symposium on Innovation in Science and Technology for Inclusive Development, Indian Science Congress Association Chapter, GKV, Haridwar on Feb. 16 , 2014.
3. **Magnetic susceptibility and Hall constant of colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
   Sunil Panwar, Vijay kumar, Amit Chaudhary & Rajendra Kumar
   Presented at the National Symposium on Innovation in Science and Technology for Inclusive Development, Indian Science Congress Association Chapter , GKV ,Haridwar on Feb. 16 2014.
4. **Electronic specific heat and thermoelectric power of colossal magnetoresistive *manganites* *($Re_{1-x}\ A_x\ MnO_3$)***
   Amit Chaudhary , Sunil Panwar , Vijay Kumar & Rajendra Kumar *Presented at the National Symposium on Innovation in Science and Technology for Inclusive Development , Indian Science Congress Association Chapter ,CCSU ,Meerut (2014)*
5. **Electrical resistivity of colossal magnetoresistive manganites *($Re_{1-x}\ A_x\ MnO_3$)***
   Vijay Kumar ,Amit Chaudhary and Sunil Panwar
   Presented at the 2nd National Conference on Photonic & Materials Science,GJUS&T, Hisar(2014).

6. **A variational theory of transport properties of colossal *magnetoresistive manganites* ($Re_{1-x}\ A_xMnO_3$)**
   Vijay Kumar, Sunil Panwar , Amit Chaudhary and Ishwar Singh
   *Presented at the 2nd National Conference on Photonic & Materials Science ,**GJUS&T, Hisar**(2014).*
7. ***F*TIR and FT-Raman spectra,vibrational assignments and other molecular properties of 2-amino-5-chlorobenzonitrile: a DFT study**
   S.Panwar,J.K. Vats, M.A. Palafox and V.K. Rastogi
   Presented at the 5th International conference on Perspectives in Vibrational Spectoscopy held during 08-12 July 2014 at Mascot Hotel, Trivandrum, Kerala India
8. **Low temperature transport anomaly in colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
   Sunil Panwar, Amit Chaudhary,Vijay Kumar and Ishwar Singh
   *Accepted in the International Conference on Condensed Matter in Paris (CMD 25-JMC-14) Organised by **Universite' Paris** Descartes(2014) , from24-29 August,2014.*
9. **Zero field magnetic susceptibility of colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
   Sunil Panwar and Vijay Kumar

Presented at the National Conference on Recent Engineering Trends in Energy, Environment & Ecology (RETEEE - 2014), Rajshree Institute of Management & Technology, ***Bareilly****, from27-28 September, 2014.*

10. **Hall constant of colossal magnetoresistive manganites ($Re_{1-x}A_xMnO_3$)**
Amit Chaudhary , Vijay Kumar, Sunil Panwar & Rajendra Kumar
Presented at the National Symposium on Instrumentation (NSI-39), organized by Instrument Society of India, IISc, Banglore & Faculty ofEngineering & Technology, Gurukula Kangri University,Haridwar, INDIA from 15-17 October, 2014. **(See Enclosure -16)**

11. **A variational theory of zero field electronic & magnetic properties of colossal *magnetoresistive manganites* ($Re_{1-x}A_xMnO_3$)**
Sunil Panwar, Amit Chaudhary , Vijay Kumar & Rajendra Kumar
Presented at the National Symposium on Instrumentation (NSI-39), organized by Instrument Society of India, IISc, Banglore & Faculty of Engineering & Technology, Gurukula Kangri University,Haridwar, INDIA from 15-17 October, 2014. **(See Enclosure -17)**

12. **Zero field thermoelectric power of colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
Sunil Panwar and Vijay Kumar
Presented at 102nd Indian Science Congress Association, University of Mumbai, ***Mumbai*** *from 03-07 January, 2015.*

13. **Effect of magnetic field on thermoelectric power of colossal magnetoresistive manganites ($Re_{1-x}A_xMnO_3$)**
Sunil Panwar,Vijay Kumar ,Amit Chaudhary,Rajendra Kumar and Ishwar Singh
Presented at the National Conference on Emerging Trends In Physics And Materials Science (ETPMS-2015) Oraganized by Chaudhary Devi Lal University , Sirsa , Haryana from 9-10, March, 2015.

14. **Magneto transport properties of colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
Sunil Panwar,Vijay Kumar ,Amit Chaudhary,Rajendra Kumar and Ishwar Singh
Presented at the National Conference on Science & Technology for Human Development Organized by ISCA , Haridwar Chapter & Department of Ancient Indian History , Culture & Archaeology, Gurukula Kangri University, Haridwar, INDIA from March 20-21 , 2015.

15. **Magnetic susceptibility of colossal magnetoresistive manganites ($Re_{1-x}\ A_x\ MnO_3$)**
Sunil Panwar and Vijay Kumar
Presented at the National Conference on photonics and Materials science, Nov. 18-19, 2015 (NCPMS) in Guru Jambheswar university of Science & Technology, Hisar.

16. **Hall constant of colossal magnetoresistive manganites ($Re_{1-x}A_xMnO_3$) A variational study**
Sunil Panwar and Vijay Kumar
Presented at the National Conference on Impact of Rapid Advancements in Management, Science and Technology (IRAMST - 2015), Rajshree Institute of Management & Technology, ***Bareilly****, from 26-27 December, 2015.*

17. **Magneto thermal properties of hole doped CMR manganites ($Re_{1-x}\ A_x\ MnO_3$): A Variational Treatment**
Sunil Panwar, Vijay kumar and Ishwar Singh
Presented at the National Conference on Science & Technology for Indigenous Development in India. Organised by the Indian Science Congress Association: Haridwar Chapter and Faculty of Engineering & Technology, Gurukul Kangri Vishwavidyalaya, Haridwar 249 404, Uttarakhand (September 28-30, 2015).

18. **Magnetic susceptibility & Hall constant of colossal magnetoresistive manganites (Re_{1-x} A_x MnO_3) & thermoelectric power of colossal magnetoresistive manganites (Re_{1-x} A_x MnO_3)**
Sunil Panwar and Amit Chaudhary
Presented two papers in the National Symposium on "Innovations in Science & Technology for inclusive Development'', organized by Haridwar Chapter of the ISCA on Feb. 16, 2015.

19. **A variational study of Zero field Hall cnstant of colossal magnetoresistive manganites (Re_{1-x} A_x MnO_3)**
Sunil Panwar and Vijay Kumar
Presented at the 8th Conference of Indian Science Congress Association (Haridwar Chapter) on "Reaching the unreached through Science and Technology", organized by Department of Mathematics and Department of Computer Science, D.S.B. Campus , Kumaun University, Nanital during October 14-15 , 2017.

To,

DR. G.S. AULAK
UNDER SECRETARY
UNIVERSITY GRANTS COMMISSION
BAHADURSHAH ZAFAR MARG
NEW DELHI-110 002

Sub: Submission of Completion Documents as performa of Annexure- IV, V, VI, VII as well as Final Report of work done in book form (Annexure-VIII) and to release the remaining amount of our Major Research Project.

Title of Project: **Theoretical Study of Rare Earth Manganites Doped with Alkaline Earths Namely $Re_{1-x}A_xMnO_3$(where Re=La, Pr, Nd etc. and A=Ca, Sr, Ba etc.) Exhibiting Colossal Magnetoresistance Phenomena**

Respected Sir,

I am submitting herewith the following completion documents within first instalment of grant already released under Major Research Project (Letter No. F42-765/2013(SR) dated 30-03-2013).

1. Final report of work done in book form (**Annexure- VIII & III)**
2. Consolidated audited item-wise expenditure duly signed/ sealed by the Competent Authority (**Annexure-V**)
3. Consolidated Audited U.C. in the prescribed format (**Annexure-IV**)
4. Statement of expenditure incurred on field work (**Annexure-VI**)
5. Actual fellowship amount disbursed/to be disbursed to the project fellow (**Annexure-VII**)
   - Since there was no unspent balance under the released grant & hence no refund to UGC.
   - This is to bring to your kind notice that an amount of Rs. 1, 05, 540/- (Rs. One lakh five thousand five hundred forty only) has been spent[Committed Expenditure including salary of the Project Fellow] till 31-03-2016 under the Major Research Project sanctioned to me.

Therefore, I request you to kindly release the remaining amount of Rs. 1, 05, 540/- so that salary of the Project Fellow could be reimbursed.

Thanking you
With regards

Dr. Sunil Panwar
Principal Investigator &
Associate Professor
Department of Applied Physics