

Some Important Features of Manganites

R. J. Singh

Physics Department, Aligarh Muslim University, Aligarh, India

Email: ranajsingh@yahoo.com

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ABSTRACT

Manganites are very complex systems because of interplay among charge, spin, orbital and lattice degrees of freedom. To come closer to the understanding of its nature, we discuss its three important features: 1) correlation between magnetization and electrical resistivity in the same temperature range; 2) detection of chemical constitution and the arrangement of Mn^{3+} and Mn^{4+} ions at different hole concentrations; and 3) how electrical current flows through double exchange in manganites. The first feature will be discussed for three-dimensional manganites. The features 2 and 3 are inscrutable in three-dimensional manganites. So they will be discussed for one-dimensional manganites and then generalized. One-dimensional solid has been discussed because it may give a see-through picture of various aspects of manganites. All the discussions will be done through a representative example of $La_{1-x}Ca_xMnO_3$, because it is the intermediate bandwidth manganite; has been most widely investigated and has the highest magnetoresistance. If two things: 1) magnetization and resistivity as a function of temperature at various magnetic fields; and 2) phase diagrams of other manganites are known, their properties can be understood by the discussion of the three features mentioned above.

Keywords: Manganites; Electrical Resistivity; Magnetization; Phase Diagram

1. Introduction

Manganites ($Re_{1-x}M_xMnO_3$), where $Re = La, Y, Pr, Nd$, etc. and $M = Ca, Sr, Ba, Pb$, etc. have claimed wide attention due to the property of colossal magnetoresistance (CMR) and tantalizing prospect of practical applications and are also important from the point of view of microscopic understanding. Manganites are very complex systems. Probably all degrees of freedom conceivable in condensed matter physics are present here e.g., lattice, orbital, spin, charge and interplay among them, crystal structure differences, crystal defects, single crystal, polycrystalline and amorphous materials, different kinds of magnetic states-ferromagnetic (FM), antiferromagnetic (AFM), canted antiferromagnetic (CAFM), paramagnetic (PM), mixture of magnetic states or spin glass, phase coexistence, phase separation, phase coherence, inhomogeneities (large and small, temporal and spatial), pseudogaps, grain size, intergrain disorder, grain surface anomalies, tolerance factor, single and multilayer compounds, small, intermediate and large bandwidths, double exchange (DE) and superexchange (SE) interactions, Coulomb and Jahn-Teller interactions, different hole concentrations, different spin stiffness constants, different substituents for Re and M in the formula unit, conductor (half metallic), insulator (half insulator), known and unknown impurities, effect of temperature, pressure, magnetic and electric fields and their directionalities and

above all CMR and what not. Large number [1-15] of theoretical and experimental works have been carried out but satisfactory answer to the properties and characteristics of manganites have not been obtained as yet.

With the help of some important experimental results given in [16,17], we have tried to understand several important features of manganites in simpler ways. These features are the following: 1) to find correlation between electrical resistivity and magnetization in the same temperature range at different hole concentrations (x -values); 2) to explore chemical constitution and distribution of Mn^{3+} and Mn^{4+} ions (which mainly decide the electrical and magnetic properties of manganites) for different x -values; 3) to understand the way the electric current flows through manganites by means of DE mechanism [18]. The first important feature e.g., correlation between electrical resistivity and magnetization will be obtained with the help of the data from three-dimensional (3-D) manganites. But the last two features seem to be more mysterious. Hence these two problems (a) chemical constitution and distribution of Mn^{3+} and Mn^{4+} in the sample will be explored through one dimensional (1-D) manganite and then generalized. In the problem (a), chemical constitution and arrangement of ions Mn^{3+} and Mn^{4+} ions in 1-D manganites will be proposed for different x -values in such a manner that their magnetic and electrical characteristics (FM metal, AFM insulator, FM insulator

and also electrical resistivity etc.) come out in the same proportion as in the phase diagram (PD) of 3-D manganite [in the present case it is compared with $\text{La}_{1-x}\text{Ca}_x\text{MnO}_3$ (LCMO)]. The important thing in the problem (b) is to show how the directions of the spins of ions (if parallel to the applied magnetic field, denoted by the symbol “u” and if antiparallel, denoted by the symbol “d”) connected by SE interaction in an 1-D chain of manganite are affected when DE jump of electrons takes place from Mn^{3+} to Mn^{4+} any where in the linear chain.

2. Resistivity versus Magnetization

Schiffer *et al.* [16] studied magnetization (M) and electrical resistivity (ρ) and magnetoresistance (MR) of $\text{La}_{0.75}\text{Ca}_{0.25}\text{MnO}_3$ as a function of temperature and magnetic field and the results were plotted in a figure. Part of this figure has been reproduced here as **Figure 1**. Khan and Singh [15] on examining this figure had indicated inverse proportionality between temperature dependence of magnetization and electrical resistivity up to the Curie temperature (T_c). This problem has been visited again here to demonstrate inverse proportionality between temperature dependence of M and ρ (ρ) in a more convincing way by superposing graphs of $1/M$ and ρ under the same magnetic field and in the same temperature range from near zero Kelvin to T_c . Above T_c upto 350 K (highest temperature in this experiment), direct proportionality between M and ρ has been observed and is

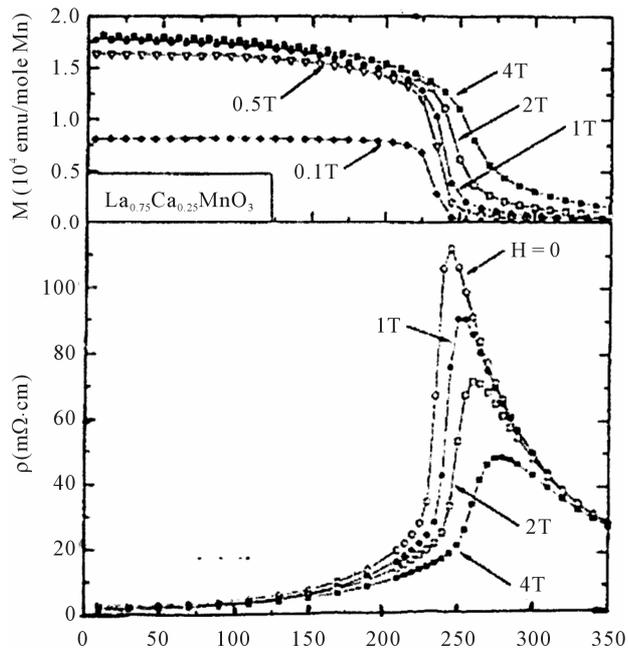


Figure 1. Magnetization and resistivity of $\text{La}_{0.75}\text{Ca}_{0.25}\text{MnO}_3$ as a function of temperature at various magnetic fields [It is a part of the figure from P. Schiffer *et al.*, *Physical Review Letters* 75, (1995) 3336-3339].

demonstrated by superposing graphs of M and ρ , both carried out under the same strength of magnetic field. Before plotting M and ρ curves together to show direct and inverse proportionality, height of both the M and ρ curves were scaled to the same magnitude as the length of both the curves was already the same. Curves between $1/M$ and ρ have been shown in the **Figures 2(a)-(c)** and between M and ρ in the **Figures 2(d)-(f)** at different magnetic fields. On close inspection of the **Figures 2(a)-(f)**, it becomes clear that at higher magnetic fields, coincidence between $1/M$ and ρ before T_c and between M and ρ beyond T_c becomes better.

First we explain inverse proportionality between M and ρ shown in the **Figures 2(a)-(c)**. It is generally agreed that electrical conductivity ($1/\rho$) is governed by Zener double exchange [18] in which the velocity of the electrons is decided by the relative direction of spins of electrons in the consecutive Mn^{3+} ($t_{2g}^3 e_g^1$) and Mn^{4+} (t_{2g}^3) ions, being maximum when spins of both the ions are parallel to each other. Thus at very low temperatures, the conductivity is maximum or the resistivity is minimum. As the temperature increases, alignment of spins is disturbed; perhaps the spins (considering classical nature of spins) start oscillating about a mean position with different phase angles. Consequently, the transport of electrons is slowed down because of the mismatching of spin directions, as a result of which resistivity starts increasing. When the temperature approaches T_c , there will be more disorder in the distribution of the directions of electronic spins; thus resistivity will go on increasing with temperature and will attain a maximum at T_c . The opposite is the case for magnetization. As temperature increases, disorderliness in the parallel orientation of magnetic moments will increase resulting into decrease of net magnetization and it will become minimum at T_c . Thus temperature dependence of M and ρ are of opposite nature.

Beyond T_c , the charge carriers in manganites are spin or magnetic polarons as concluded in [15]. In magnetic polarons, the charge carriers are surrounded by electron spins arranged in certain order. When temperature increases beyond T_c , orderliness of spins surrounding the charge carriers goes on decreasing. As the orderliness of spin environment is destroyed, their control on the movement of charge carriers is loosened and thus they can move faster resulting into the decrease of resistivity. When the orderliness of spins surrounding the charge carriers is loosened by the increase of temperature, the sum total of magnetic moments in the direction of the magnetic field will also decrease. Hence beyond T_c , both M and ρ will decrease with the rise of temperature.

On examining the **Figures 2(a)-(f)**, it becomes clear that at higher magnetic fields, there is better correlation between $1/M$ and ρ below T_c and between M and ρ be-

yond T_c . It has been noted in the last two paragraphs that any relationship between M and ρ below or beyond T_c is dependent on the strength of magnetic field and hence better coincidence between $1/M$ and ρ below T_c and between M and ρ with increasing magnetic field is explained.

Not only in $(\text{Re}_{1-x}\text{M}_x\text{MnO}_3)$ types of manganites, very

strong correlation between M and ρ has been found in bilayered manganites as $[(\text{La}_{0.5}\text{Nd}_{0.5})_{1.2}\text{Sr}_{1.8}\text{Mn}_2\text{O}_7]$. Daquan Liao *et al.* [18] noted that there are step like magnetizations and also step like resistivity jumps in the bi-layered manganite $[(\text{La}_{0.5}\text{Nd}_{0.5})_{1.2}\text{Sr}_{1.8}\text{Mn}_2\text{O}_7]$ as shown in **Figure 3**. In **Figure 3**, there are two parts, one on the left and the other on the right side. In each part,

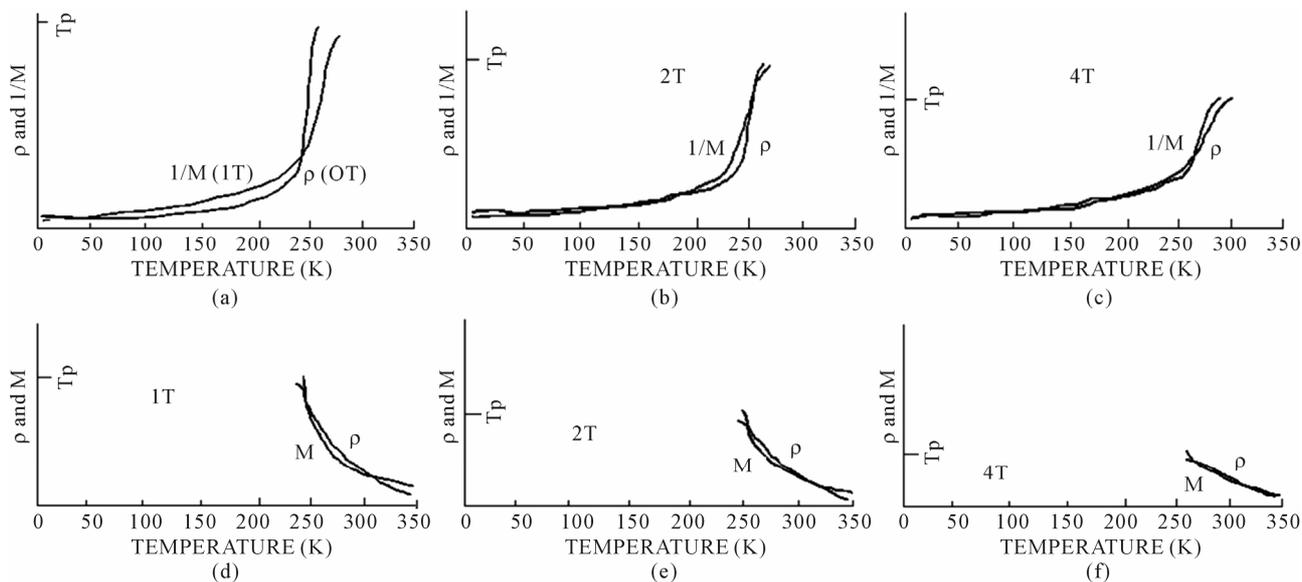


Figure 2. (a) Showing $1/M$ ($M =$ magnetization) versus temperature (T) curve and resistivity (ρ or rho) versus (T) curve together. ρ - T curve is at zero magnetic field, but $1/M$ - T curve is at 1 Tesla. Magnetic field is essential for the measurement of M and hence one of the lowest magnetic fields (in the measurement of M) has been chosen for comparing the two curves; (b) $1/M$ - T and ρ - T curves together, both at magnetic field of 2 Tesla; (c) $1/M$ - T and ρ - T curves together at magnetic field of 4 T (Tesla); (d)-(f) showing (M - T) and (ρ - T) curves beyond T_p (peak temperature = 250°) at 1, 2 and 4 teslas respectively. All these figures have been derived from Figure 1.

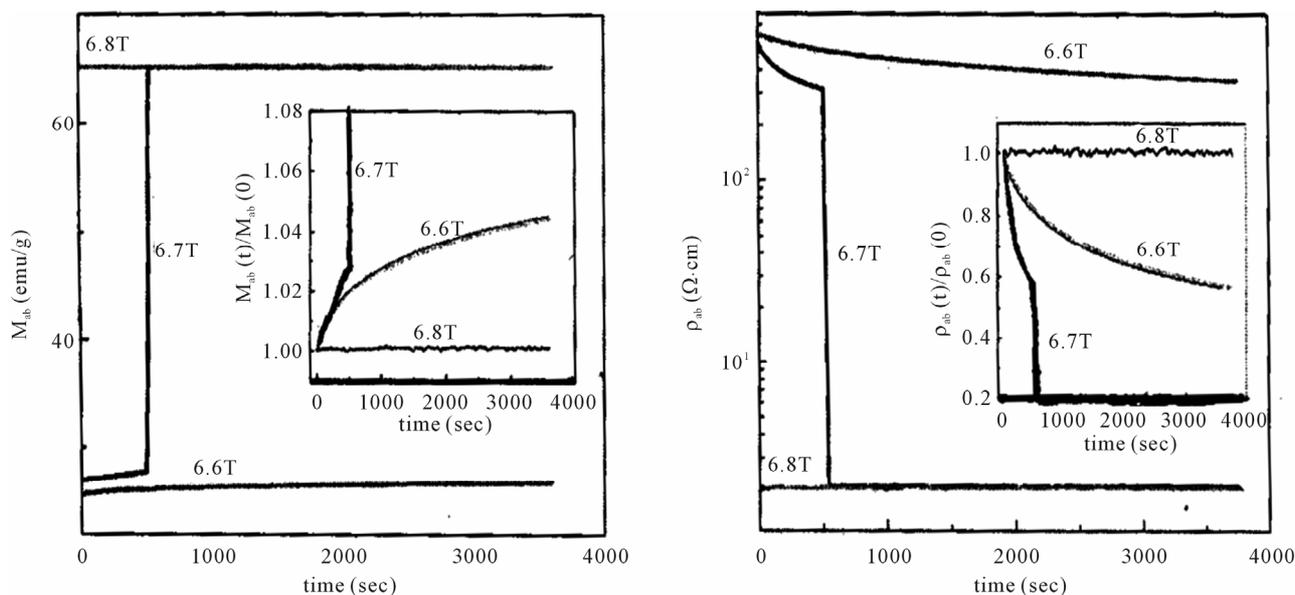


Figure 3. Step-like magnetization and resistivity jumps at magnetic fields of 6.6, 6.7 and 6.8 Tesla in bilayered $[(\text{La}_{0.5}\text{Nd}_{0.5})_{1.2}\text{Sr}_{1.8}\text{Mn}_2\text{O}_7]$ single crystal in its ab plane at 2 K [Daquan Liao, Young Sun, Renfu Yang, Qing'an Li and Zhaohua Cheng, *Physical Review B* 74, (2006) 174434-174439].

there is a main section and an inset. In the main section of the left part, magnetization of $[(La_{0.5}Nd_{0.5})_{1.2}Sr_{1.8}Mn_2O_7]$ at 6.6, 6.7, 6.8 Tesla (T) at 2 K has been shown. In the main section of the right part, resistivity of the same sample at the same values of magnetic fields and temperatures have been shown. Even a cursory view of these figures will unmistakably reveal inverse proportionality between magnetization and resistivity. In the inset of the left part of the figure, increase of magnetization with time after the imposition of 6.6 T of magnetic field has been shown. In the inset of the right part of the figure, the decrease of resistivity with time after the imposition of 6.6 T of magnetic field has been shown. In **Figure 4** is shown a plot of $M_{ab}(t)/M_{ab}(0)$ versus $1/[\rho_{ab}(t)/\rho_{ab}(0)]$. Very strong inverse proportionality between time dependence of growth of M and ρ is clearly seen.

3. Chemical Constitution and Arrangement of Mn^{3+} and Mn^{4+} Ions in One-Dimensional Manganites with Different Hole Concentrations

Chemical constitution of 1-D manganite and arrangement of Mn^{3+} and Mn^{4+} ions in them for different hole concentrations (x) have been given in **Table 1**.

Chemical constitution of 1-D chains and arrangement of Mn^{3+} and Mn^{4+} ions in them has been chosen in such a manner that the magnetic and electrical characteristics of the 1-D chains vary in the same proportion as in the 3-D manganite shown in the phase diagram [16] of LCMO (**Figure 5**). It is hoped that the information obtained from 1-D manganite may help in understanding the constitution, structure and other properties of 3-D manganites. It has been found that in manganite samples, there are ordered grains separated by spans of disordered materials. In 1-D manganites also, there is expected to be chains of certain lengths with ordered arrangement of atoms/ions separated by smaller lengths of disordered material.

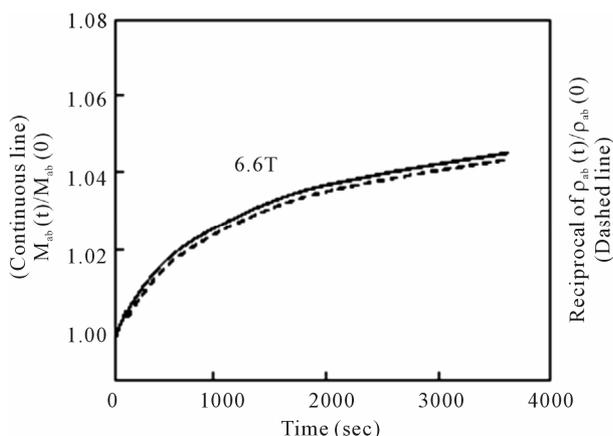


Figure 4. Showing coincidence of $M_{ab}(t)/M_{ab}(0)$ and reciprocal of $\rho_{ab}(t)/\rho_{ab}(0)$. This figure is based on **Figure 3**.

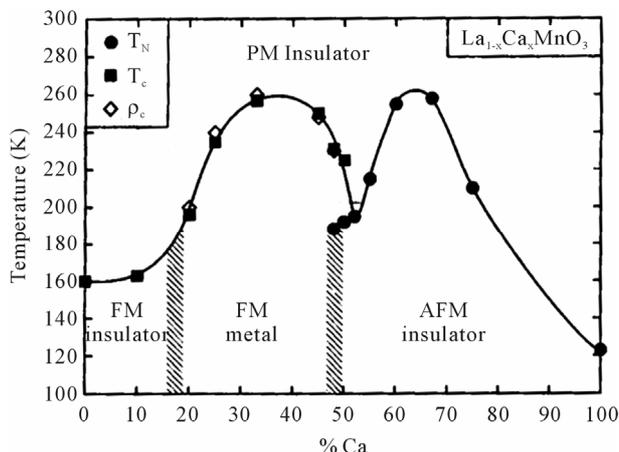


Figure 5. Phase diagram of $La_{1-x}Ca_xMnO_3$ [P. Schiffer, A. P. Ramirez, W. Bao and S.-W. Cheong, *Physical Review Letters*, 75 (1995) 3336-3339].

Hence in proposing structure of any specimen for any x , the constitution and arrangement of atoms/ions only in the ordered chains will be given. The role of intervening disordered chains will be discussed later. In 1-D manganite, the ordered chain will be a linear chain of Mn^{3+} and Mn^{4+} ions. It is because of the fact that magnetic and electrical properties of manganites are mainly decided by the relative abundance of Mn^{3+} and Mn^{4+} ions and the sequence in the arrangement of these two ions. Other atoms/ions play subservient roles. As regards the number of Mn^{3+} and Mn^{4+} ions corresponding to a particular Mn-valency, their numbers are adjusted in such a manner that the particular Mn-valency is obtained. For the purpose of calculation, Mn^{3+} ($t_{2g}^3 e_g^1$) has valency = 3 and Mn^{4+} (t_{2g}^3) has valency = 4. In the manganite ($Re_{1-x}M_x Mn O_3$), the number of Mn^{3+} is proportional to $(1 - x)$ and of Mn^{4+} proportional to (x) . In the presentation of linear chains in **Table 1** and elsewhere also, for simplicity, Mn^{3+} will be represented as “3” and Mn^{4+} as “4”. Linear chains of 3 and 4 ions representing different Mn-valencies (3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0) have been shown in **Table 1**.

The principle in deciding the sequence of the ions 3 and 4 for Mn-valencies from 3.1 to 3.4 is the condition of minimum Madelung potential. For valencies 3.6 to 3.9, charge ordering is the guiding principle, according to which in the chain, first all 3 ions are placed and then all 4 ions. For Mn-valencies = 3.0 and 4.0, there is no choice. For valency = 3.0, all ions are 3 and for valency = 4.0, all ions are 4. Mn-valency = 3.5 occupies a special position in all manganites. It has been found to have CE-configuration which means coexistence of ferromagnetism and charge ordering. In **Table 1**, the same rule has been applied for the Mn-valency = 3.5.

In **Table 1**, ions suffixed by “u” are in the direction of the applied magnetic field and those suffixed by “d”

Another important thing to be noted is that the interaction between adjacent ions is of super-exchange type as was established by Anderson [20] in the early days of manganites. Thus the interaction between the nearest Mn-ions in **Table 1**, has been decided by the rules of SE interaction. Only nearest neighbour exchange interaction has been considered. SE interaction is expressed in terms of Goodenough-Kanamori [21-23] semi-empirical rules. We will point out only those rules which have been used here. They are: 1) The SE interaction is antiferromagnetic (spin directions reversed in the interacting ions *i.e.*, from u to d or from d to u) between two magnetic ions with half filled orbital which couple through a non-magnetic ion (as O^{2-}), which means that interaction between Mn^{3+} and Mn^{3+} or between 3 and 3 will be of AF type. 2) Coupling between a half-filled orbital and a vacant orbital is ferromagnetic *i.e.*, interaction between Mn^{3+} and Mn^{4+} or between Mn^{4+} and Mn^{3+} (or between 3 and 4 or between 4 and 3) will be ferromagnetic. The ferromagnetic interaction means that the spin directions of both the interacting ions will be the same (both being “u” or both being “d”). 3) SE interaction between two empty orbitals provided each cation carries a net spin and empty orbitals share the anion p-orbitals will be antiferromagnetic, which means that the interaction between Mn^{4+} and Mn^{4+} or between 4 and 4 will be antiferromagnetic.

4. Double Exchange Mechanism in Linear Chains

We will show how electric current flows through a 1-D manganite by DE mechanism. According to DE, an electron jumps from Mn^{3+} to O^{2-} and at the same time an electron jumps from O^{2-} to Mn^{4+} thus completing transfer of an electron from Mn^{3+} to Mn^{4+} . In **Table 2**, we will show the flow of electric current in LCMO with $x = 0.3$, whose composition has been given in **Table 1**. In the first row of **Table 2**, composition of the manganite consisting of total of 20 Mn^{3+} (3) and Mn^{4+} (4) ions with different u and d direction of spins has been given. The second row represents the arrangement and directions of spins of ions (u or d) after DE has taken place in all the possible pairs in the first row. As a matter of fact, any row represents the arrangement and directions of spins of ions after DE has taken place in all the possible pairs in the previous row. **Table 2** extends upto 13 rows because in the 13th row there are no pairs of 3u-4u ions left to allow any further DE jump. As seen in **Table 2**, in going from one row to the next row after executing DE jumps in 3u-4u pairs, a new pair of 3u-4u is generated displaced one place to the left side of the table. But this process is disturbed on reaching near the left or the lower boundary of the table as can be verified by 3u-4u pairs in the row 1 and columns 3, 4; row 1 and columns 9, 10 and row 1 and columns 15, 16. Their march have been shown

Table 2. Electrical conduction in the linear chain corresponding to the Mn-valency = 3.3. All nearest neighbour spins in a row are connected by super-exchange interaction. Double exchange electron jump takes place only between ions 3 and 4 both being in the same direction “u”. The spin state of ions in a row is decided with respect to any 3u-4u pair in the row by the rules of super-exchange interaction. Symbols u, d, ch have the same meanings as in Table 1. All double exchange electron jumps are between 3u and 4u ions and are denoted here as uu type. C = column number and R = row number.

R \ C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	u, d, ch, type		
1	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	16, 4, 6, --		
2	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	16, 4, 6, uu	
3	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	16, 4, 6, uu		
4	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	3d	16, 4, 5, uu	
5	4d	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	3d	3u	3d	14, 6, 4, uu
6	4u	4d	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	3d	3u	3d	3u	14, 6, 4, uu
7	4d	4u	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	3d	3u	3d	3u	3d	14, 5, 4, uu
8	4u	4d	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	14, 6, 3, uu								
9	4d	4u	4d	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	12, 8, 2, uu								
10	4u	4d	4u	4d	3d	3u	4u	3u	4u	3u	3d	3u	12, 8, 2, uu										
11	4d	4u	4d	4u	3u	4u	3u	4u	3u	3d	3u	3d	12, 8, 2, uu										
12	4u	4d	4u	4d	4u	3u	4u	3u	3d	3u	12, 8, 1, uu												
13	4d	4u	4d	4u	4d	4u	3u	3d	3u	3d	10, 10, 0, --												

by slanting lines in the table (by solid lines till 3u-4u pairs are maintained and by dotted lines, when they are disturbed). But changes observed in the 3u-4u pair is not something inherent. It is solely due to the limitation on the length of the chain. Had it been infinite or of very big length, such changes would not have occurred or would have been inconsequential. What is important in the table is that in the last row all the Mn^{3+} (or 3) ions (with one electron in the e_g level) have collected on the right hand side of the table and all the Mn^{4+} (4) ions have collected on the left hand side, which means that electron current has flown in the right hand side of the table. In this table, it needs to be specially mentioned that DE electron jump is always between 3u to 4u ion and directions of spins of other ions in each row is adjusted according to the rules of SE interaction with respect to any 3u-4u ion pair in that row.

There can be other ways in which the u- and d-directions of the spins can be adjusted. One method is that the direction of the spin of the first ion on the left side of each row is assigned u direction and the directions of all the other ions in that row is adjusted with respect to this ion according to the rules of SE interaction. Following this rule, **Table 3** has been prepared for the same Mn-valency = 3.3. In this table also, electrons (ion 3) have collected on the right hand side and ions 4 have collected on the left hand side showing that electron current has flown to the right hand side. Limitations on the length of

the chain has similar effects here also. But what seems to be not acceptable is that from one row to the next, spin directions of ions mostly change from u to d. This can be checked by proceeding along the slanting lines starting from row 1 and columns 8, 9 or from row 1 and columns 17, 18. On applying the unidirectional magnetic field, as is done in the experiments, this kind of change of spin directions does not seem to be reasonable. Hence **Table 2** represents the correct way in which the electric current flows in a 1-D manganite.

There is another point to be considered in discussing the flow of current through a chain. In 3-D manganites, there are supposed to be FM metallic islands separated by insulating regions. In these manganites, current through metallic islands flows through intrinsic conduction and through insulating regions by spin polarized tunnelling [24] or by opening temperature and magnetic field dependent new channels [25]. In 1-D manganites also, chains can not be of infinite lengths and there should be ordered chain lengths intervened by smaller chain lengths which have no order and can be insulating or less conducting. So in 1-D manganites also there should be intrinsic flow through the ordered portion of the chain and extrinsic flow through the disordered chains governed by the same mechanisms given in [24,25].

The important question that remains to be answered is how the study of 1-D manganite will help in understanding the properties and characteristics of 3-D manganites?

Table 3. Electrical conduction in the linear chain corresponding to the Mn-valency = 3.3. The spin states of ions in a row are decided in a different way from that of Table 2. Here the spin states (u or d) of ions in a row is decided by the state of the ion occurring in the first column of each row (always taking it to be in u-state) by the rules of superexchange interaction. Symbols have the same meanings as in Tables 1 and 2. Type uu denotes DE jump between 3u and 4u; dd represents DE jump between 3d and 4d. C = column number, R = row.

R \ C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	u, d, ch, type
1	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	16, 4, 6, --
2	3u	3d	4d	3d	4d	3d	3u	3d	4d	3d	4d	3d	3u	3d	4d	3d	4d	3d	3u	3d	8, 12, 6, dd
3	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	16, 4, 6, uu
4	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	16, 4, 5, uu
5	4u	4d	3d	3u	3d	4d	3d	4d	3d	3u	3d	4d	3d	4d	3d	3u	3d	3u	3d	3u	6, 14, 4, dd
6	4u	4d	3d	3u	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	3d	3u	14, 6, 4, uu
7	4u	4d	3d	4d	3d	4d	3d	3u	3d	4d	3d	4d	3d	3u	3d	3u	3d	3u	3d	3u	6, 14, 4, dd
8	4u	4d	4u	3u	4u	3u	3d	3u	4u	3u	4u	3u	3d	3u	3d	3u	3d	3u	3d	3u	14, 6, 3, uu
9	4u	4d	4u	4d	3d	3u	3d	4d	3d	4d	3d	3u	8, 12, 2, dd								
10	4u	4d	4u	4d	3d	3u	4u	3u	4u	3u	3d	3u	12, 8, 2, uu								
11	4u	4d	4u	4d	3d	4d	3d	4d	3d	3u	8, 12, 2, dd										
12	4u	4d	4u	4d	4u	3u	4u	3u	3d	3u	12, 8, 1, uu										
13	4u	4d	4u	4d	4u	4d	3d	3u	10, 10, 0, --												

In polycrystalline manganites, the ordered chains separated by disordered chains may be expected to be distributed uniformly in space and the properties of 3-D manganites may be described by the bundle of chains in the direction it is investigated. In polycrystalline materials, the properties may be isotropic, but in crystals, there may be directionalities. There may be need to consider additional lateral interaction in 3-D manganites. One thing has to be pointed out here that according to the model of Luttinger [26], in one-dimensional system, spin and charge are separated. But in the present case, one dimensional manganite is simply a thread of three dimensional manganite chosen here for discussion to drive home the points more clearly.

Summary. Three important features of manganites have been investigated here: 1) correlation between electrical resistivity and magnetization in the same temperature range at different hole concentrations (x-values); 2) arrangement of Mn^{3+} and Mn^{4+} ions for different x-values; and 3) the way the electric current flows through manganites by means of double exchange mechanism. The first feature has been investigated in three dimensional manganites and the last two in one-dimensional case for the sake of clear understanding of problems and then they have been generalized. The first problem suggests that before T_c , magnetization and resistivity are inversely proportional and beyond T_c , they are directly proportional. The second problem gives us idea about the electrical and magnetic characteristics of the material and the third problem suggests how u (parallel to the magnetic field) and d (antiparallel to the magnetic field) spins connected by superexchange are affected when double exchange of electrons from Mn^{3+} and Mn^{4+} ions takes place any where in the linear chain. This study may be extended for understanding the behaviours of other manganites of large and small bandwidths if magnetization and resistivity as a function of temperature at various magnetic fields and phase diagram of other manganites are available.

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