Magnetic Behavior of Light Rare – Earth Titanates

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Abstract: Magnetic susceptibility were measured as a function of temperature in a range of 300-1000K for light rare earth Titanates. Magnetic susceptibility for these compounds follows the Curie- Weiss law at high temperature. The studied materials have ionic bonding and magnetic ions contribute towards magnetic susceptibility.

Keyword:

Introduction: The material $RTiO_3$ (where R= La, Ce, Pr, Nd, Sm and Eu) have attracted attention due to surprising variety of physical properties exhibited within an isostructural and chemically similar series of compound [1]. Low temperature magnetic susceptibility studies of these compounds have been reported [2-5]. At low temperature ant ferromagnetic ordering has been observed in La, Ce and Pr Titanates, whereas in Nd no ordering has been observed. Heavy rare- earth Titanates show ferri or ferromagnetic ordering [6-8].

No study of high temperature magnetic susceptibility has been reported in the literature so far. This prompted me to investigate high temperature bulk magnetic behavior of these compounds.

Experimental Procedure: All the studied Titanates have been prepared by solid state reaction technique and characterized by x-ray diffraction (XRD) pattern using CuK line with wavelength(λ) equals to 1.540nm. the starting materials for preparation of $LaTiO_3$, $CeTiO_3$, $PrTiO_3$, $NdTiO_3$, $SmTiO_3$ and $EuTiO_3$ have their common oxide namely La_2O_3 ,CeO_2 ,Pr_6O_{11} , Nd_2O_3 , Sm_2O_3 , and Eu_2O (all produced from Flueka AG, Switzerland with stated purity of 99.9%) and TiO_2 produced from bonds, India with stated purity of 99.9%. The stoichiomtric amounts of respective oxides and TiO_2 were taken to mix thoroughly. After mixing, these materials were pressed and fired at 1200K for 50 hours with one intermediate grinding. The XRD analysis shows that this procedure results in single phase compound and no part of the starting materials remains unreacted. Magnetic susceptibility measurement was done on powdered samples using Faraday's method [9].

Results and discussion: The magnetic susceptibility measurement of all light rare-earth Titanates have been done both in heating and cooling cycles in the temperature range of 300-1000K. No hysteresis was observed and χ_m were found to be same in heating and cooling cycles. The results are given in figure (1-6) for $LaTiO_3$, $CeTiO_3$, $PrTiO_3$, $NdTiO_3$, $SmTiO_3$ and $EuTiO_3$ respectively. In these figures magnetic susceptibility (χ_m) and its inverse (χ_m^{-1}) has been plotted as a function of absolute temperature.

It is seen that these figures that (χ_m) vs T plots are linear and can be expressed by the relation

$$\chi_m = C / T-\theta \qquad [1]$$

where C is the curie constant and θ is the asymptotic curie temperature. The evaluated value of C and θ are given

EVALUATED VALUES OF CURIE CONSTANT (C) AND ASYMPTOTIC CURIE TEMPERATURE (θ) OF STUDIED COMPOUNDS

Compound with R =	La	Ce	Pr	Nd	Sm	Eu
C (m^3K/mole)	2.25×10^{-6}	3.04×10^{-6}	5.91×10^{-6}	6.18×10^{-6}	1.84×10^{-6}	5.18×10^{-6}
Θ (K)	-438	-160	-285	-514	-40	-382

Among the studies material lanthanum compound is magnetically simple and contain only one magnetic ion $R^{3}+$ and $Ti^{3}+$. Thus at room temperature much higher than ordering temperature, the molar magnetic susceptibility of all these compounds can be approximated by the relaation

$$(\chi_m) = N\mu^2_\beta\mu_0 / 3k\,[\,P_1^2 / T-\theta_1 + P_2^2 / T-\theta_2] \qquad [2]$$

Where N is Avogadro number, P_1 and P_2 are the magnetron number of the two magnetic ions and θ_1 and θ_2 are the paramagnetic curie temperatures each of which taken into account the effect of various interactions. Equation [2] can be written as

$$(\chi_m) = N\mu^2_\beta\mu_0 / 3k\,(T-\theta_1)\,[P_1^2 + P_2^2\,(T-\theta_1) /(\,T-\theta_2)] \qquad [3]$$

At much high temperature when $T \Rightarrow \infty$, $(T-\theta_1) / (T-\theta_2)$ will tend to unity and above equation will reduce to

$$(\chi_m) = N\mu^2_\beta\mu_0 / 3k\,(T-\theta_1)\,[P_1^2 + P_2^2] \qquad [4]$$

Or $$\chi_m^{-1} = 3k\,(T-\theta_1) / N\mu^2_\beta\mu_0\,[P_1^2 + P_2^2] \qquad [5]$$

Taking into consideration that there are 2N magnetic ions in these compounds one can define an average effective magneton number (P) given by the expression

$$P^2 = P_1^2 + P_2^2 / 2 \qquad [6]$$

With this introduction equation (5) reduce to

$$(\chi_m^{-1}) = 3k\,(T-\theta_1) / 2N\mu^2_\beta\mu_0\,P^2 \qquad [7]$$

The experimental χ_m^{-1} vs T plot straight line and can be expressed by the relation

$$\chi_m^{-1} = T-\theta / C_M \qquad [8]$$

comparing equation [7] and [8], we get

$\theta_1 = \theta$, $C_M = 2N\mu^2_\beta\mu_o P^2/3k$

this yields

$$P = [3k\, C_M / 2N\mu^2_\beta\mu_o]^{1/2} \qquad [9]$$

Thus experimental value of P can be evaluated from the value of C_M.

In order to get theoretical value of P one has to know P_1 and P_2 . for this one has to recognize the magnetic ions in $RTiO_3$. if we take titanate as ionic compound, than the ions in their structure will be R^{3+}, Ti^{3+} and O^{2-}. O^{2-} is diamagnetic ion and contribute very little towards magnetic susceptibility. Thus the magnetic ions in these compounds will be R^{3+} and Ti^{3+}. Theoretical value of effective magneton number for these ions are known. Hence one can evaluate the theoretical value of P. thus we can move a comparison of theoretical and experimental values of average magneton number P. this has been done in table (2)

EXPERIMENTAL AND THEORETICAL VALUES OF AVERAGE MAGNETON NUMBER PER MAGNETIC ION (P) FOR $RTiO_3$

Compound	magnetic ion		values of P	
			Experimental value	theoretical value
$LaTiO_3$	-	Ti^{3+}	1.69	1.73
$CeTiO_3$	Ce^{3+}	Ti^{3+}	1.97	2.18
$PrTiO_3$	Pr^{3+}	Ti^{3+}	2.74	2.81
$NdTiO_3$	Nd^{3+}	Ti^{3+}	2.80	2.84
$SmTiO_3$	Sm^{3+}	Ti^{3+}	1.53	1.64
$EuTiO_3$	Eu^{3+}	Ti^{3+}	2.58	2.70

It is seen from this table that there is a fair agreement between theoretical and experimental values of P, if magnetic ions are taken as given in table 2. The slight difference can be assigned due to diamagnetic contribution. In all cases experimental P is observed to be less, theoretically evaluated P. this may be due to slight covalent nature of the binding.

Conclusions: On the basis of high temperature magnetic susceptibility and its analysis, following conclusions can be drawn.

1) All the studied compounds exhibit typical Curie-Weiss law behavior was at higher temperature will negative value paramagnetic Curie temperature.

2) The studied materials have ionic bonding and magnetic ions contribute towards magnetic susceptibility as per their effective magneton number.

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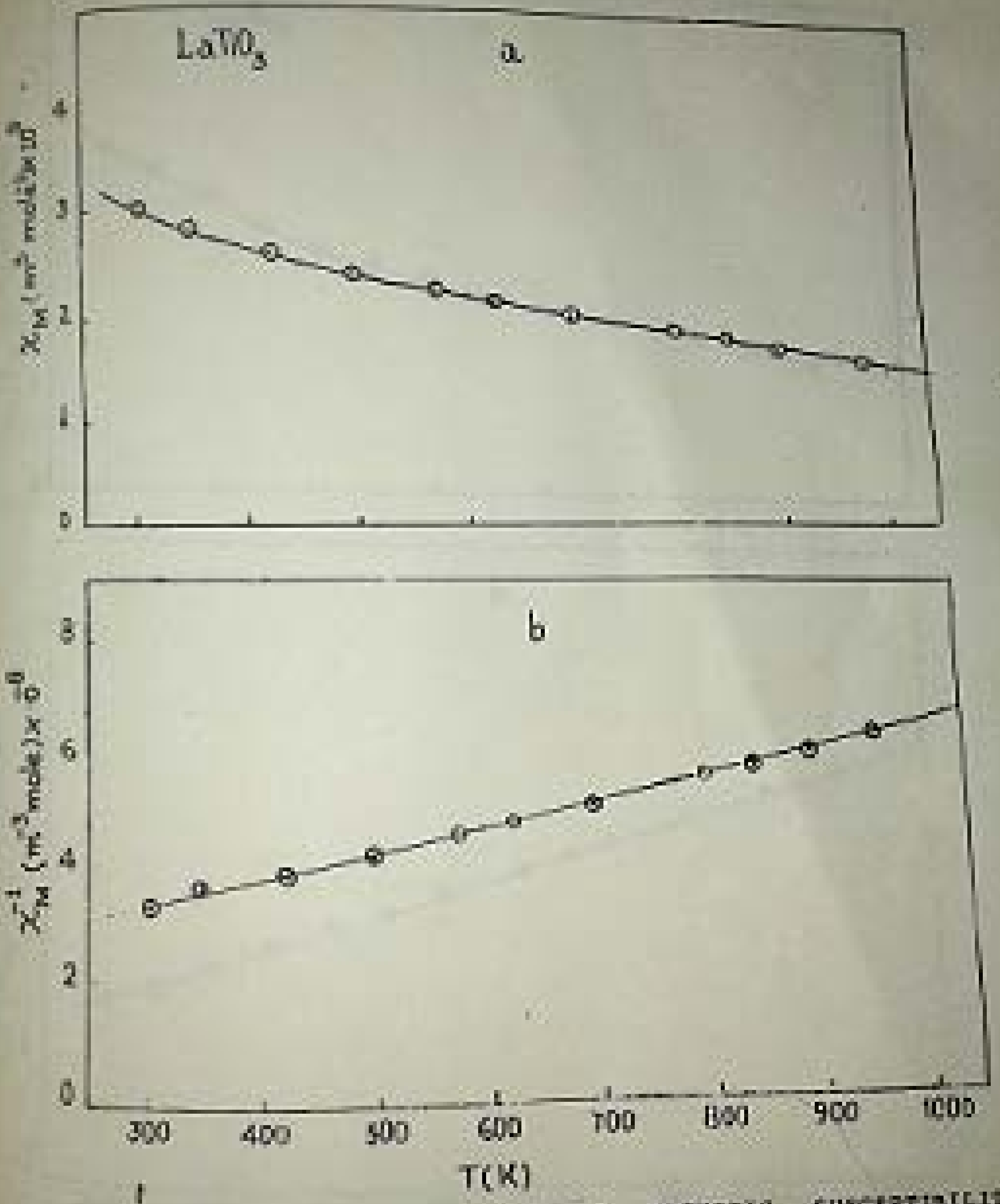


FIG. ~~4.1~~ 1 (a) VARIATION OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M) WITH ABSOLUTE TEMPERATURE FOR LANTHANUM TITANATE

(b) VARIATION OF INVERSE OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M^{-1}) WITH ABSOLUTE TEMPERATURE FOR LANTHANUM TITANATE

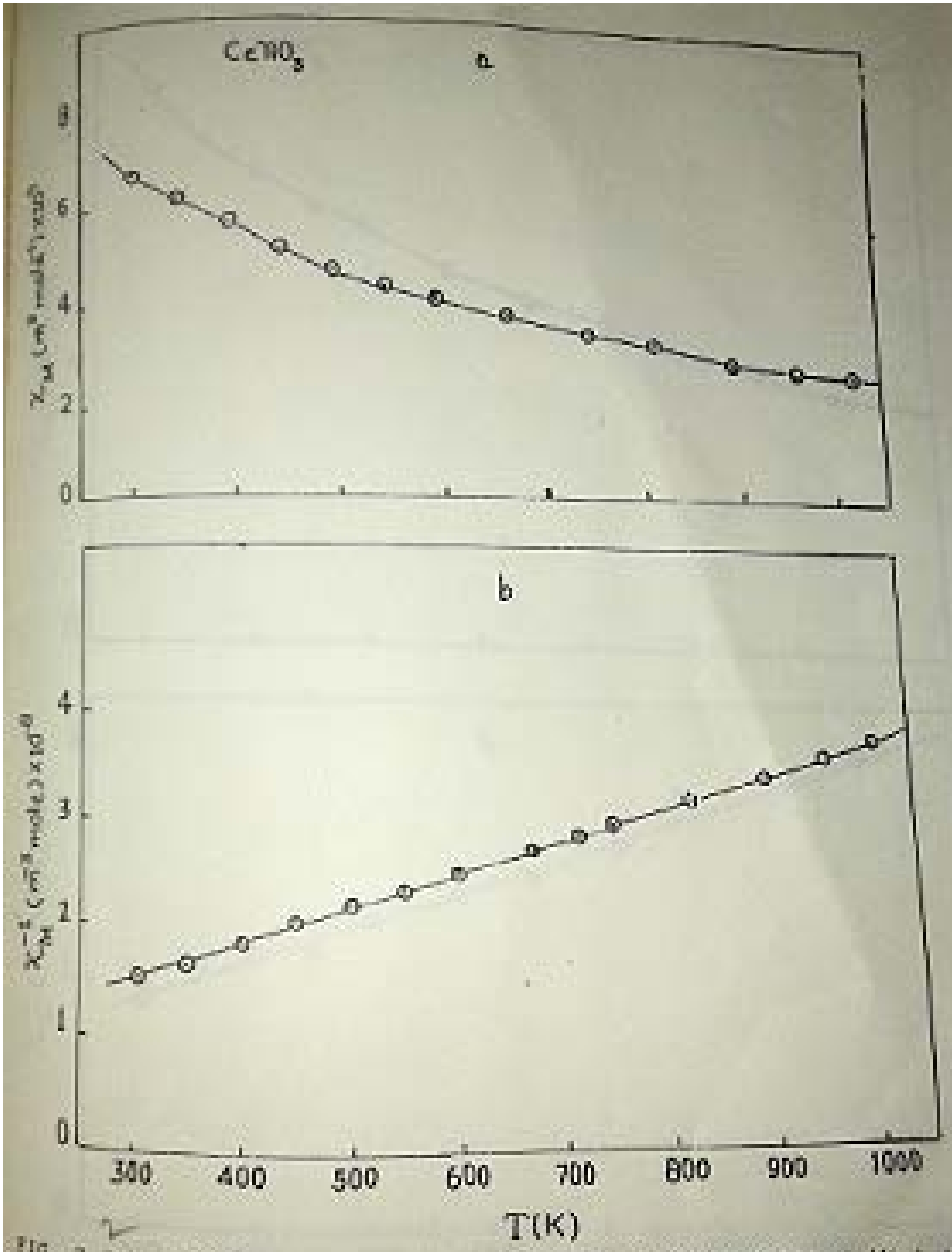
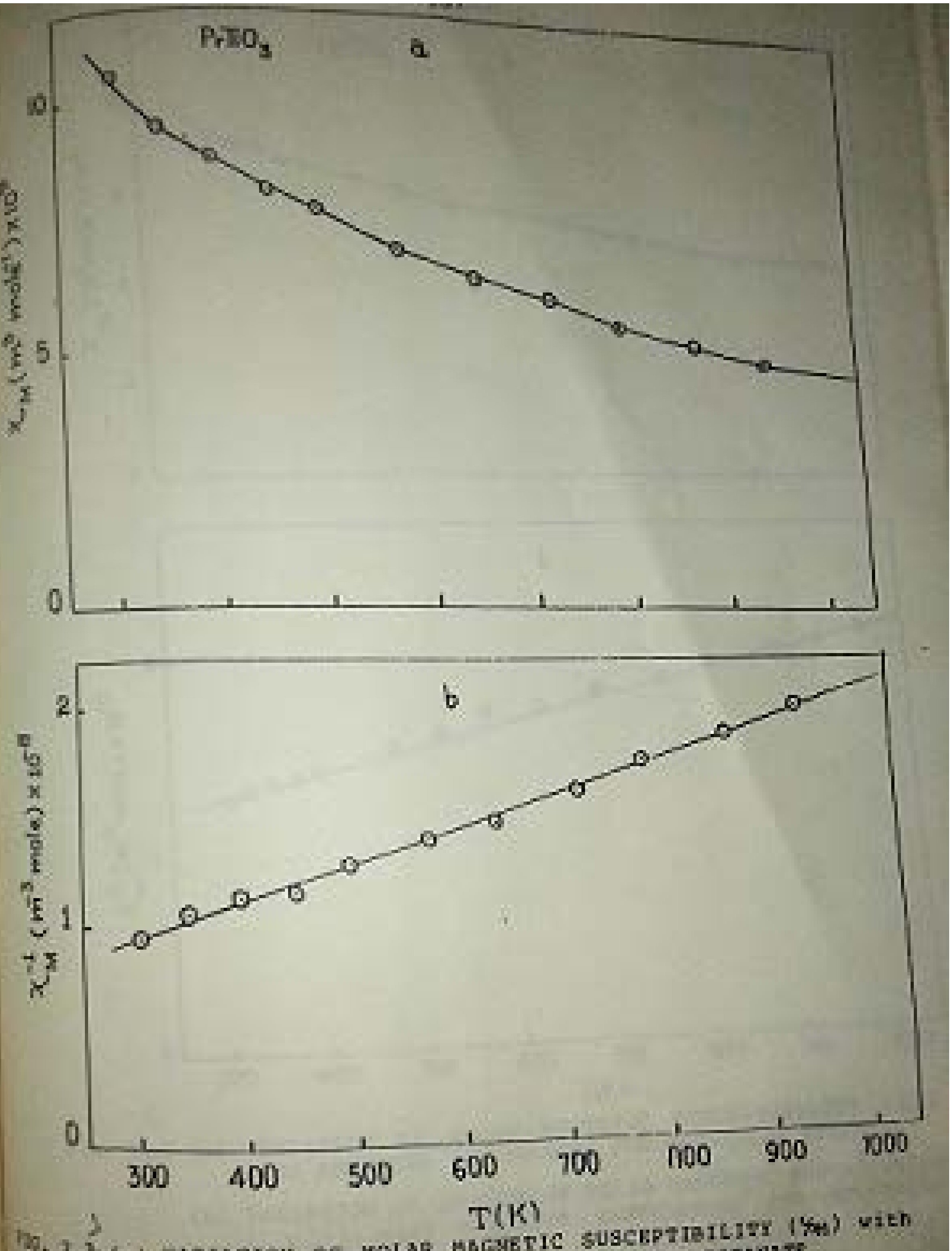


FIG. ~~1.2~~ 2 (a) VARIATION OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M) WITH ABSOLUTE TEMPERATURE FOR CERIUM TITANATE

(b) VARIATION OF INVERSE OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M^{-1}) WITH ABSOLUTE TEMPERATURE FOR CERIUM TITANATE



IG. [illegible] (a) VARIATION OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M) with ABSOLUTE TEMPERATURE FOR PRASEODYMIUM TITANATE

(b) VARIATION OF INVERSE OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M^{-1}) WITH ABSOLUTE TEMPERATURE FOR PRASEODYMIUM TITANATE

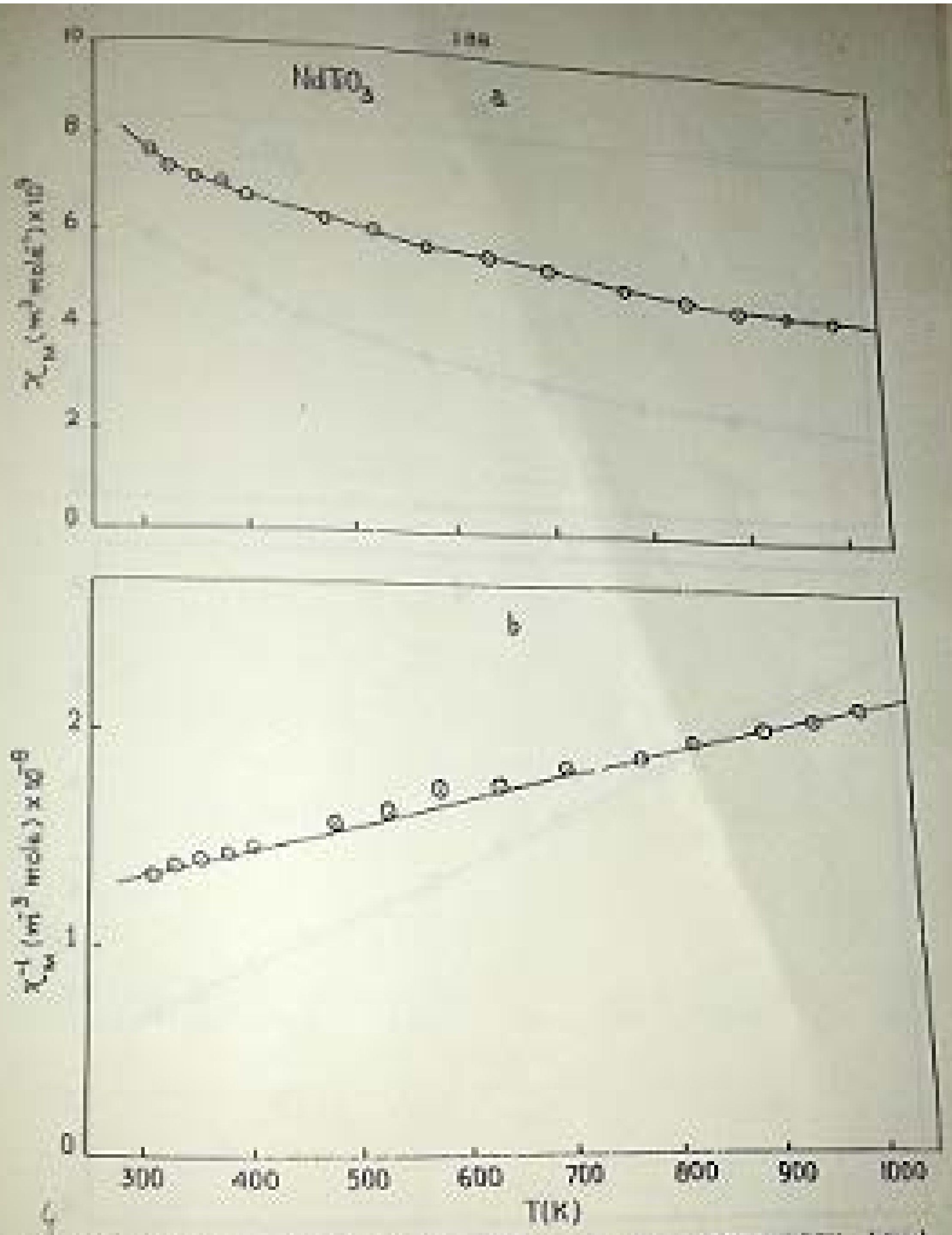


FIG. 2.4 (a) VARIATION OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M) WITH ABSOLUTE TEMPERATURE FOR NEODYMIUM TITANATE

(b) VARIATION OF INVERSE OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M^{-1}) WITH ABSOLUTE TEMPERATURE FOR NEODYMIUM TITANATE

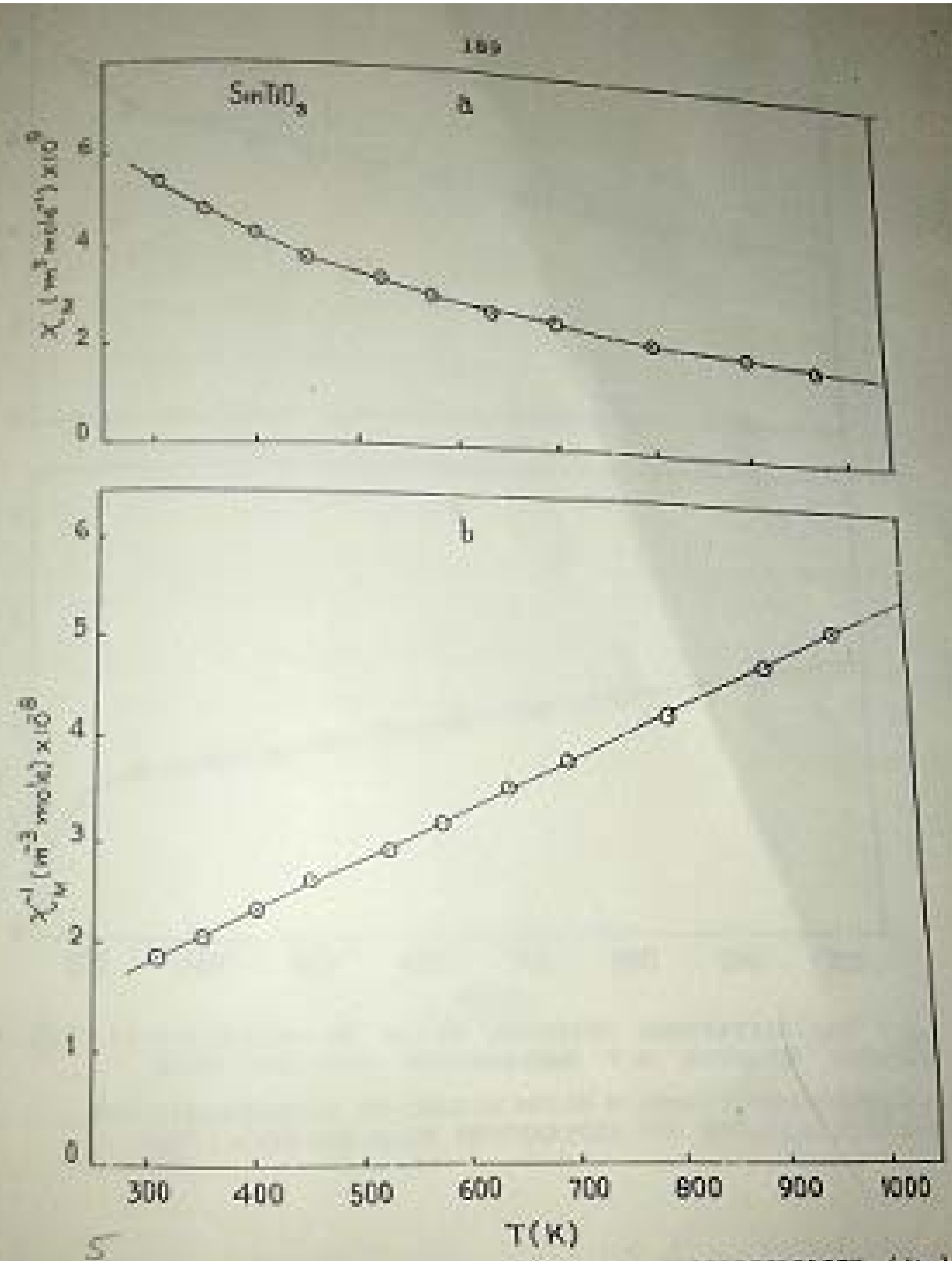


FIG. ~~7.5~~ 5 (a) VARIATION OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M) WITH ABSOLUTE TEMPERATURE FOR SAMARIUM TITANATE

(b) VARIATION OF INVERSE OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M^{-1}) WITH ABSOLUTE TEMPERATURE FOR SAMARIUM TITANATE

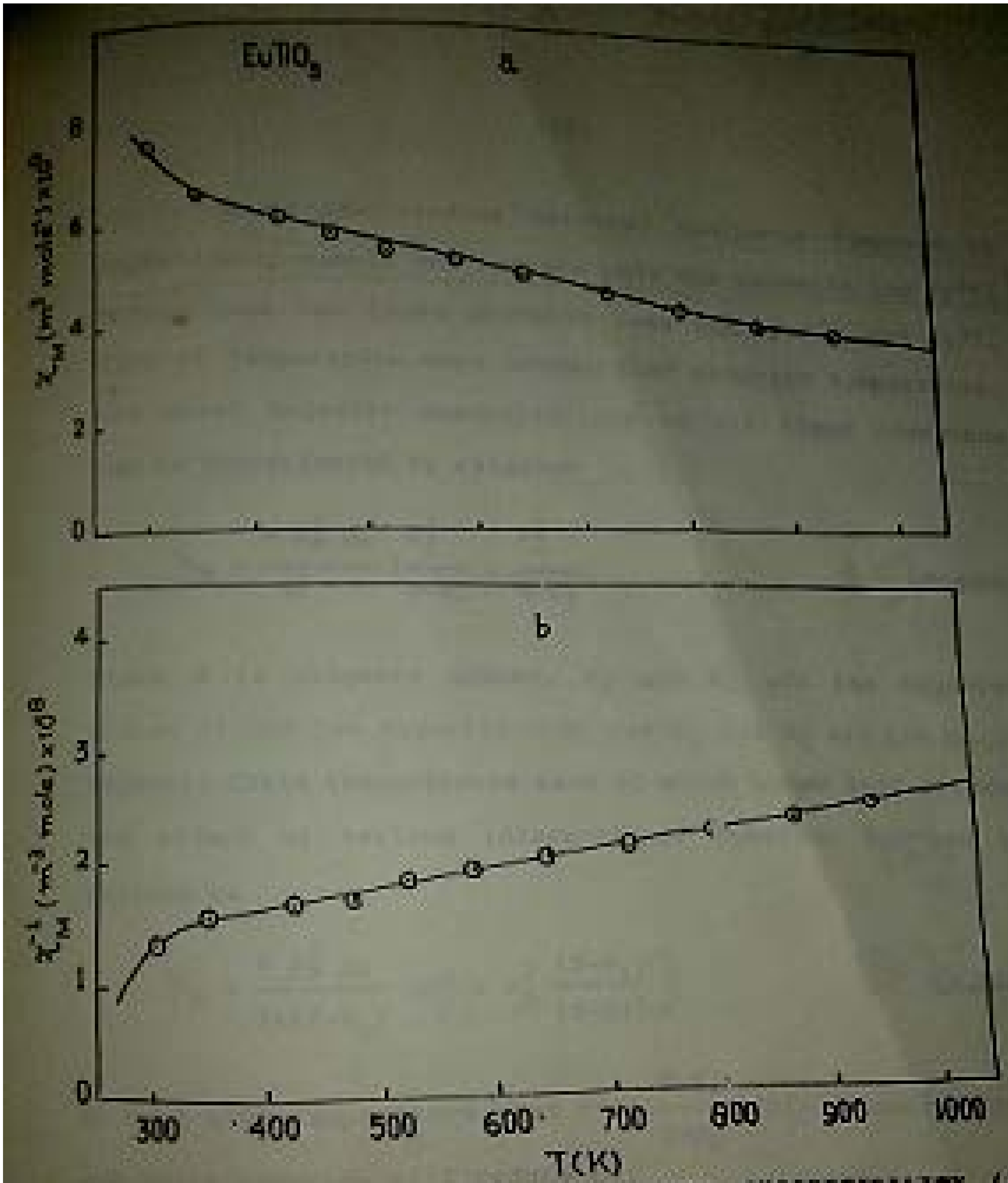


FIG. [illegible]6 (a) VARIATION OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M) WITH ABSOLUTE TEMPERATURE FOR EUROPIUM TITANATE

(b) VARIATION OF INVERSE OF MOLAR MAGNETIC SUSCEPTIBILITY (χ_M^{-1}) WITH ABSOLUTE TEMPERATURE FOR EUROPIUM TITANATE