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MAGNETIC SUSCEPTIBILITIES OF SEVERAL RARE EARTH SELENIDES AND TELLURIDES

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SUMMARY

The magnetic susceptibilities of monoselenides of Gd, Nd, Ce, Yb, and Sm and monotellurides of Yb, Ce, and Sm and $GdTe_2$ have been measured at temperatures from 2 to 300 K in applied magnetic fields up to 3.4 T. With the exception of $GdTe_2$ all were found to have negative paramagnetic Curie temperatures indicative of antiferromagnetic ordering. Spontaneous magnetization was observed in CeSe at and below 4 K. The effective magnetic moment per atom agrees in most cases with that calculated for the tripositive rare earth ion.

INTRODUCTION

Magnetic and electrical measurements have been made on numerous rare earth compounds in recent years. The rare earth chalcogenides are of interest partly because they include both ferromagnetic and antiferromagnetic insulators (1). VanHouten (1) and Argyle (2) have measured the magnetization of Eu chalcogenides, Busch et. al. (3, 4, 5) have measured the magnetization of rare earth phosphides and arsenides, and Reid et. al. (11) have measured electrical conductivity in rare earth selenides and tellurides. Iandelli (6), Adamyan and Loginov (8, 9), and Holtzberg et. al. (7) have also performed magnetic measurements on the rare earth chalcogenides and the pertinent results of these investigations are summarized in table I. A comprehensive review of the subject has been made by Gibson and Harvey (10). The present work includes measurements on several compounds not previously reported, extends the measurements of Iandelli (6) to 2 K, and corroborates the work of Adamyan and Loginov (8, 9).

EXPERIMENTAL

A Foner vibrating sample magnetometer (14) has been employed to determine the magnetic moments of the following rare earth chalcogenides: GdSe, NdSe, SmSe, CeSe, YbSe, YbTe, CeTe, SmTe, and $GdTe_2$. All are cubic (NaCl) except $GdTe_2$ which is tetragonal. All samples were in powder form. The moments were measured isothermally with the samples maintained at temperatures between 2 and 300 K. The applied magnetic field was varied from 0 to 3.4 T.

RESULTS AND DISCUSSION

The data are presented as isotherms of σ vs H_I and $1/\chi$ vs T for all samples, and additionally as isofields of σ vs T for GdSe, SmSe, NdSe, and $GdTe_2$. For purposes of clarity only selected isotherms are shown. The transition temperatures and effective magnetic moments per atom are tabulated in table I. NdSe, GdSe, and SmSe are antiferromagnetic with well defined Neèl temperatures. The evidence is conflicting for CeSe, which has a spontaneous moment but also some characteristics, e. g., a negative paramagnetic Curie temperature, of a classical antiferromagnet.

NdSe was found to be antiferromagnetic. The magnetization curves, Fig. 1, show a slight curvature at 2 and 4 K indicating some field dependence of the susceptibility or antiferromagnetic saturation. The $1/\chi$ vs T and σ vs T plots, Figs. 2 and 3, show the Neèl temperature to be 11 K and yield the value of $\mu^E_{eff} = 3.58$. Extrapolating the $1/\chi$ vs T curve using only the data below 100 K yields a T_Θ which is in better agreement with that of Adamyan and Loginov (8); however, it is felt that extrapolation of the high temperature data is more meaningful since in this region the sample is presumably free of any spontaneous ordering.

GdSe displayed no evidence of field dependent susceptibility or spontaneous magnetization. The effective moment per atom agrees well with theory and the results of other investigators. The Neèl temperature was found to be 68 K. The additional peak in σ vs T, Fig. 6, at 15 K and the shape of $1/\chi$ vs T, Fig. 5, indicate the possibility of rather complex magnetic ordering and perhaps the presence of an impurity phase.

The SmSe exhibits no spontaneous moment but some curvature in the magnetization is evident at low temperatures, Fig. 7. The μ^E_{eff}, which agrees well with that of Iandelli (6), is considerably greater than that predicted by theory $\mu^T_{eff} = 0.86$. Sm has an excited state very near the ground state, but a calculation by VanVleck and Frank (13) taking this into account yields only $\mu^T_{eff} = 1.55$. No explanation for this discrepancy is offered here, nor in the work of Iandelli (6). The Neèl temperature of 65 K and the shape of $1/\chi$ vs T, Fig. 8, below 100 K suggest the possibility of some additional magnetic ordering at low temperatures.

The only compound studied which displayed a spontaneous magnetization was CeSe. This is in agreement with Adamyan and Loginov (9); however, in this investigation a spontaneous moment was not observed at 8 K or above, Fig. 10. The shape of $1/\chi$ vs T, Fig. 11, and negative T_Θ are characteristic of antiferromagnetic ordering. However, a peak in σ vs T which would define a Neèl temperature was not observed. A fan type antiferromagnetic structure has this type behavior and seems to be a likely possibility.

The data for YbSe and YbTe are quite similar. A slight field dependence of χ is evident at low temperatures, Figs. 12, 14. Although a Neèl temperature could not be determined in either case, the shape of $1/\chi$ vs T, Figs. 13, 15, and the negative T_Θ are indicative of antiferromagnetic ordering, probably well below 4 K. The discrepancy between μ^E_{eff} and μ^T_{eff} is probably due to the tendency of Yb to use the 5d electron to fill the 4f shell.

CeTe displayed a slight field dependence of χ below 4 K, Fig. 16, but no spontaneous moment. Again the shape of $1/\chi$ vs T, Fig. 17, and the negative T_Θ indicate the possibility of antiferromagnetic ordering below 4 K. The effective moment per atom agrees well with theoretical prediction and with the results of Adamyan and Loginov (9). Our extrapolation to T_Θ was made using the high temperature data (50 to 300 K) while Adamyan and Loginov extrapolated from 77 K. Extrapolating our data below 100 K yields $T_\Theta = -5$ K.

The $1/\chi$ vs T curve, Fig. 19, for $GdTe_2$ has the shape and positive intercept, T_Θ, which are characteristic of ferromagnetic ordering. However there is no evidence of a spontaneous moment and the magnetization curves, Fig. 18, do not show the field dependent susceptibility of a ferromagnet. There is also no indication of a Neèl temperature, Fig. 20. The magnetization curves are linear, and have a change in slope at a temperature-independent field, Fig. 18. No explanation for this behavior is offered here, except to suggest the possibility of anisotropy effects.

SmTe does not exhibit a spontaneous moment or a peak in σ vs T which would define a Neèl temperature. However, the shape of $1/\chi$ vs T, Fig. 22, and the large negative T_Θ are characteristic of antiferromagnetic ordering. As in the case of SmSe, μ^E_{eff} is in agreement with the results of Iandelli (6) and both are greatly in excess of the theoretical prediction.

The magnetic behavior of these compounds is apparently quite complex and not readily resolved through susceptibility measurements, especially on powder samples which tend to mask anisotropy effects. Susceptibility measurements on single crystals would be useful perhaps. However, neutron diffraction work on single crystals would be the best way to determine their magnetic structure.

SYMBOLS

H_A applied magnetic field, tesla

H_I internal magnetic field, tesla

T temperature, K

T_N Neèl temperature, K

T_θ paramagnetic Curie temperature, K

μ_{eff}^{E} effective magnetic moment, Bohr magnetons per atom, experimental

μ_{eff}^{T} effective magnetic moment, Bohr magnetons per atom, theoretical

σ magnetic moment cgs units per gram

χ susceptibility

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TABLE I

Compound	μ^E_{eff}	μ^T_{eff}	T_θ	T_N	Source
GdSe	7.99	8	-95	68	This investigation
	8.20	8	-28.5	--------	(6)
NdSe	3.58	3.64	-28	11	This investigation
	3.40	3.64	-9	14	(8)
SmSe	4.00	0.86	-175	52.5	This investigation
	4.53	0.86	-273.5	--------	(6)
CeSe	2.28	2.57	-30	9.	This investigation
	2.58	2.57	-32.5	12	(9)
YbSe	1.61	4.56	-16.3	Not observed	This investigation
YbTe	2.38	4.56	-11.3	Not observed	This investigation
CeTe	2.36	2.57	-50	Not observed	This investigation
	2.49	2.57	-7.5	10	(9)
SmTe	4.27	0.86	-390	Not observed	This investigation
	4.33	0.86	-248	--------	(6)
$GdTe_2$	6.02	8	+33	--------	This investigation

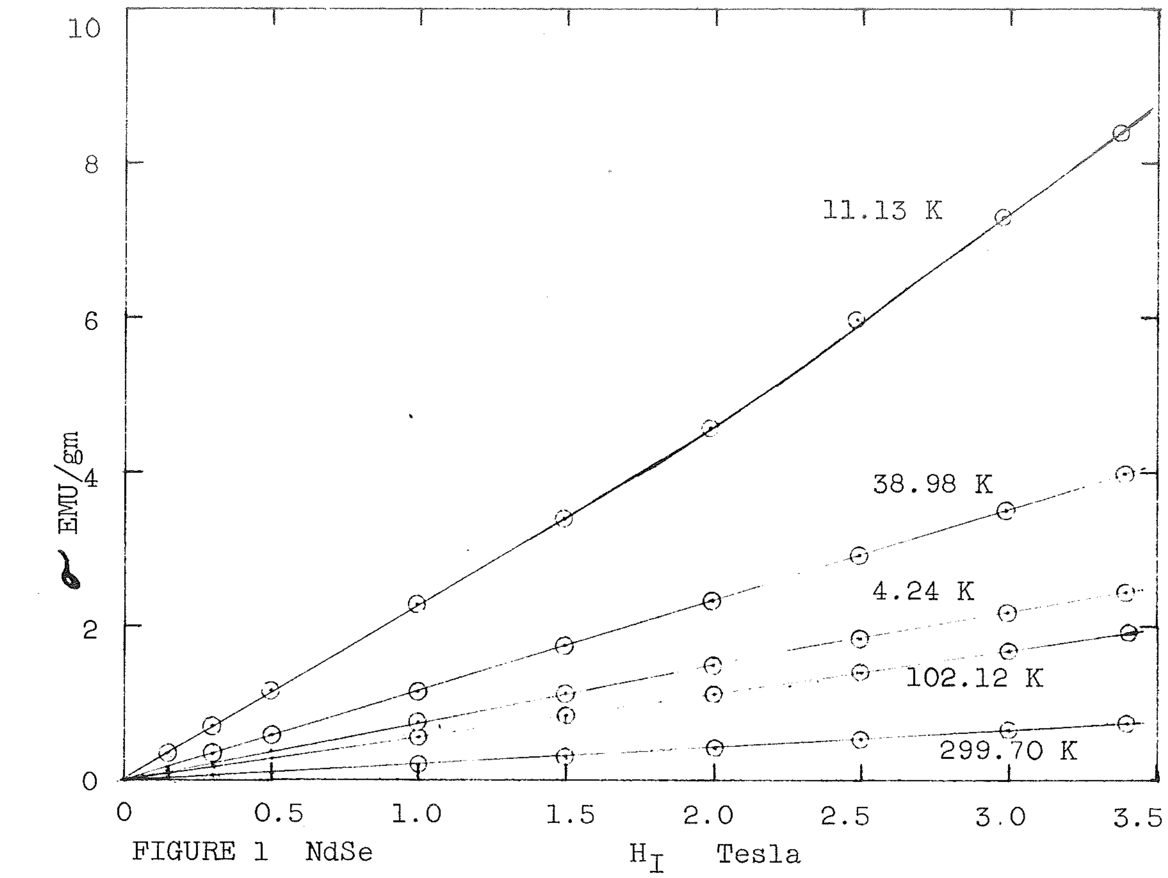


FIGURE 1 NdSe

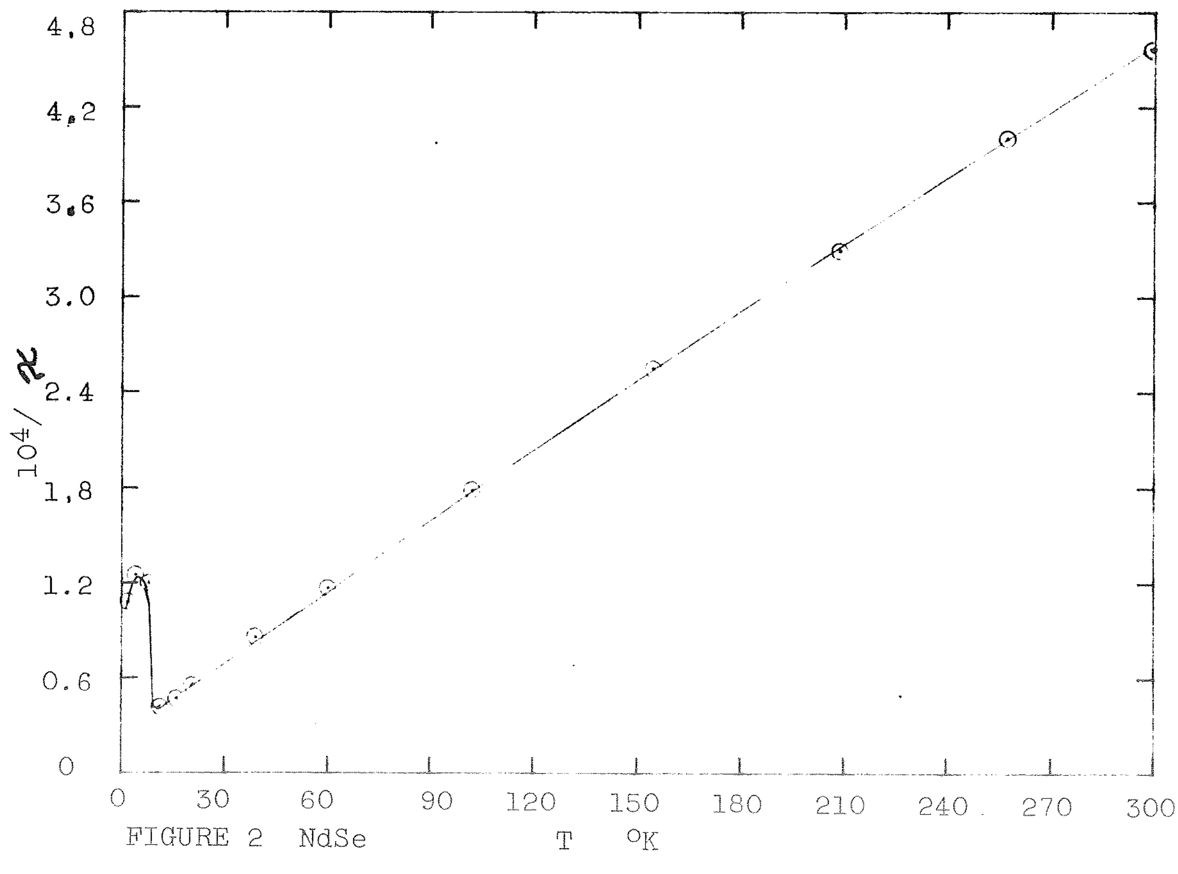
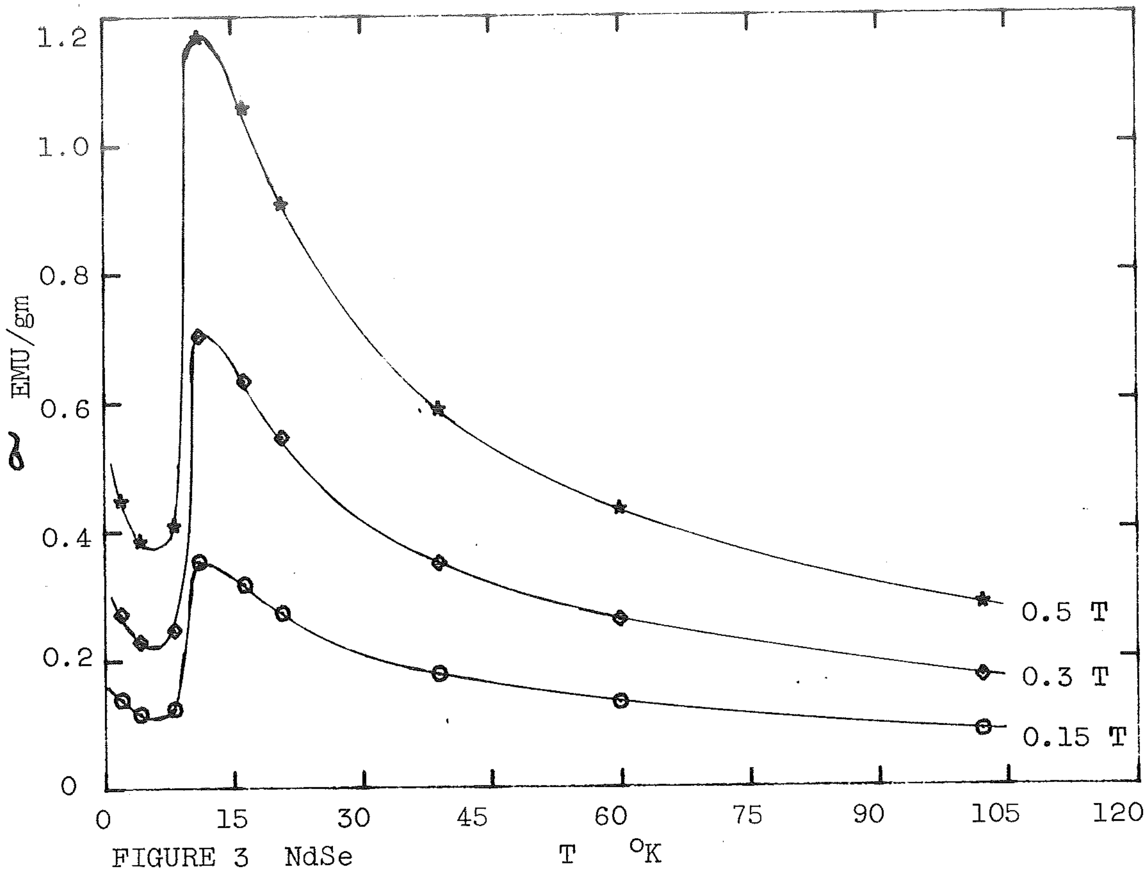


FIGURE 2 NdSe



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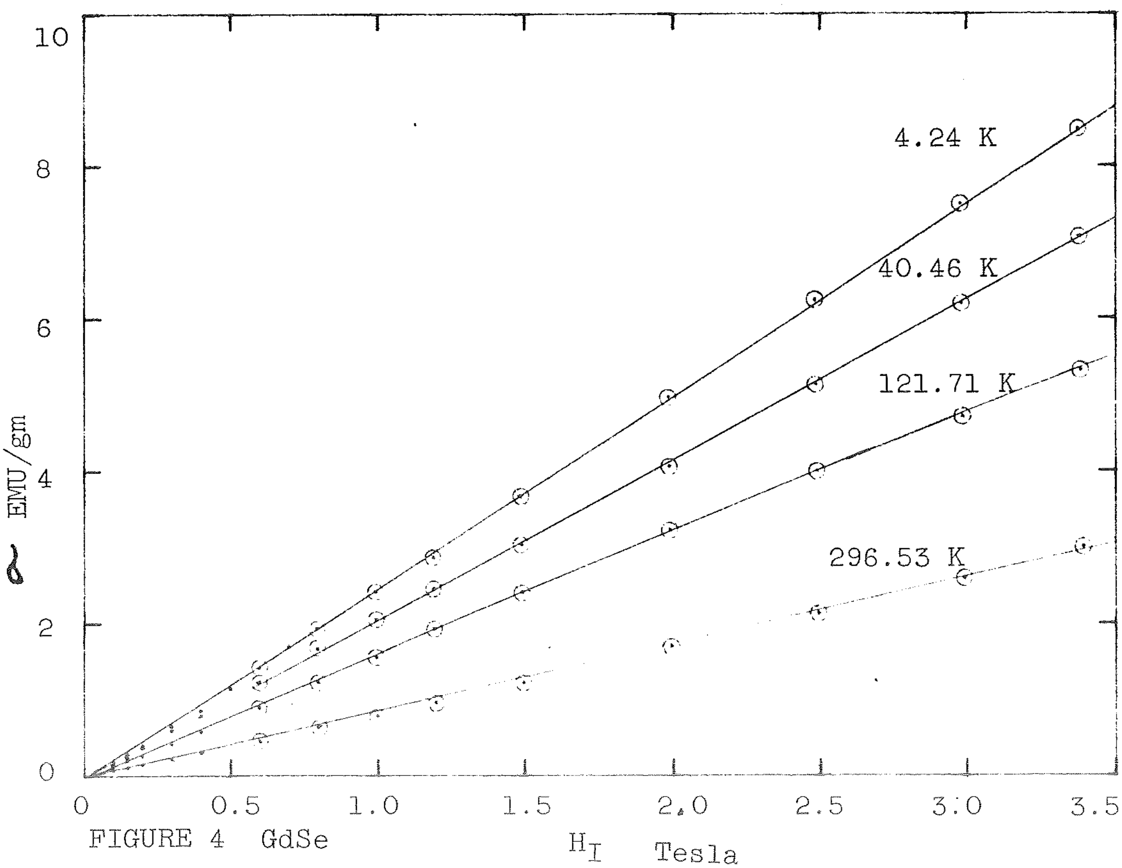

FIGURE 4 GdSe

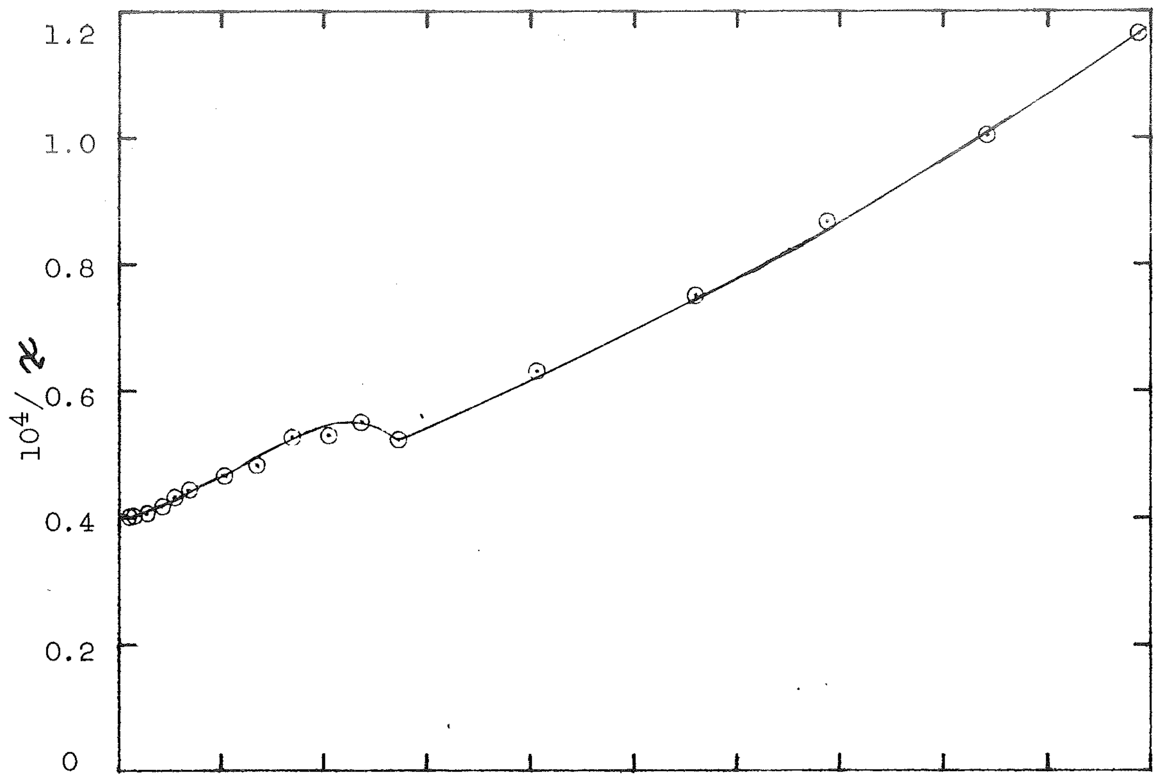

FIGURE 5 GdSe T °K

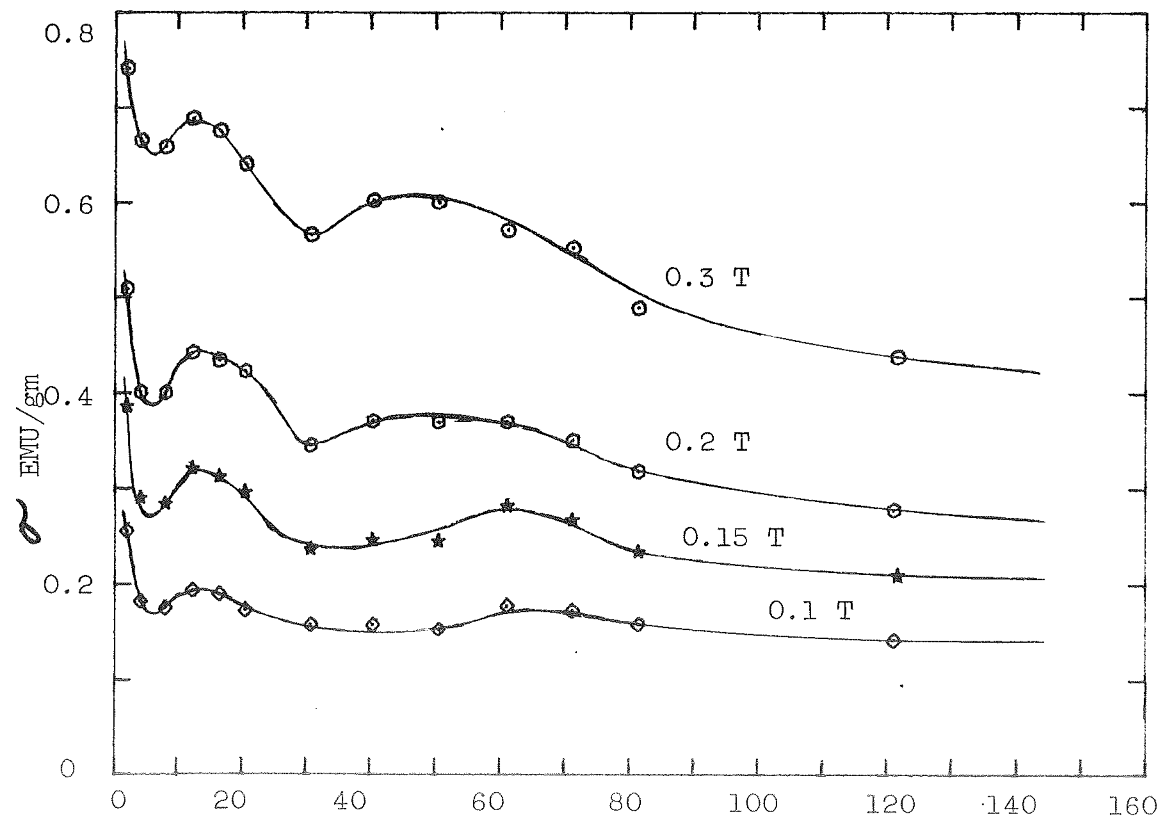

FIGURE 6 GdSe T °K

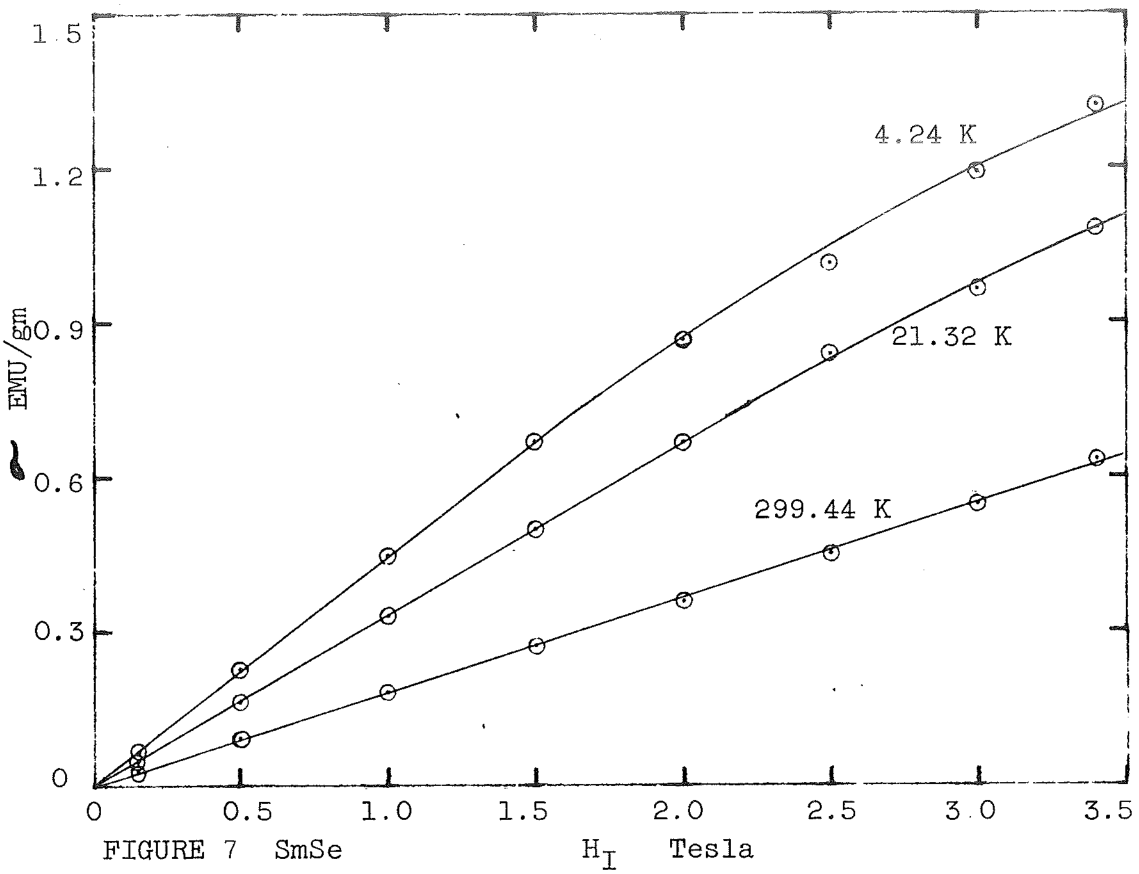

FIGURE 7 SmSe

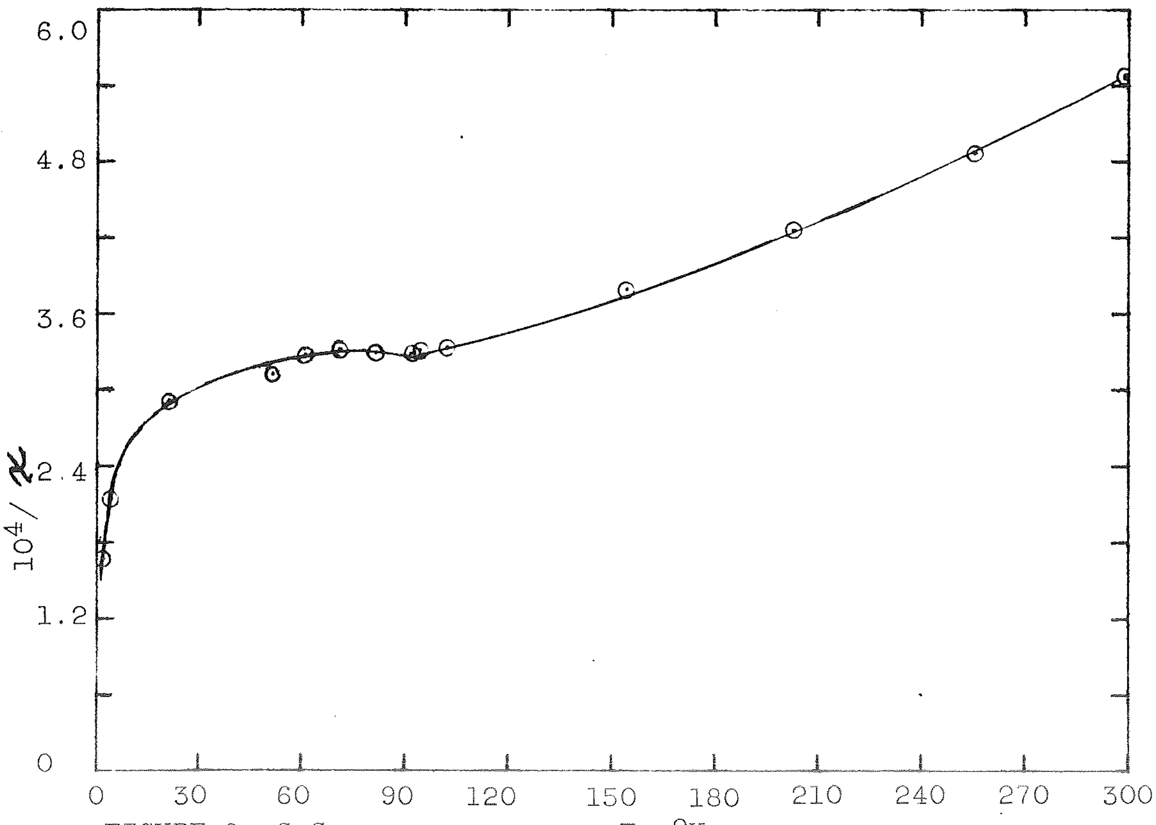

FIGURE 8 SmSe

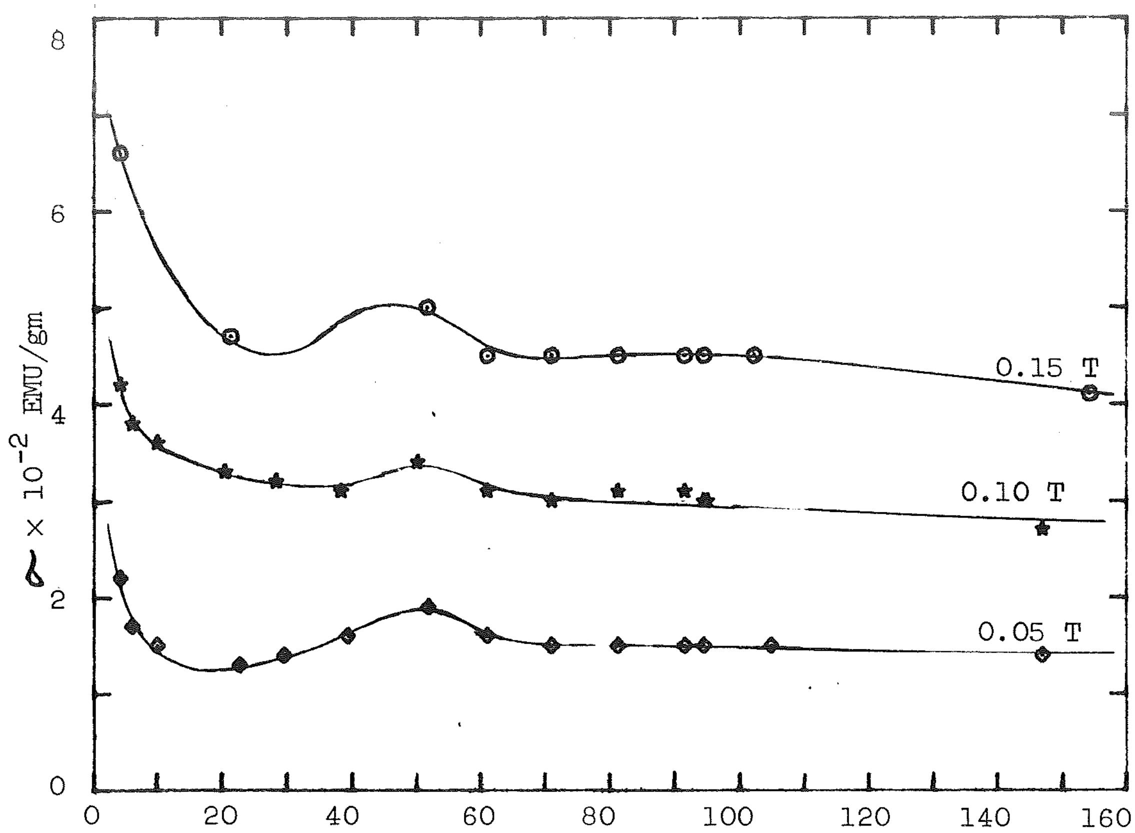

FIGURE 9 SmSe T °K

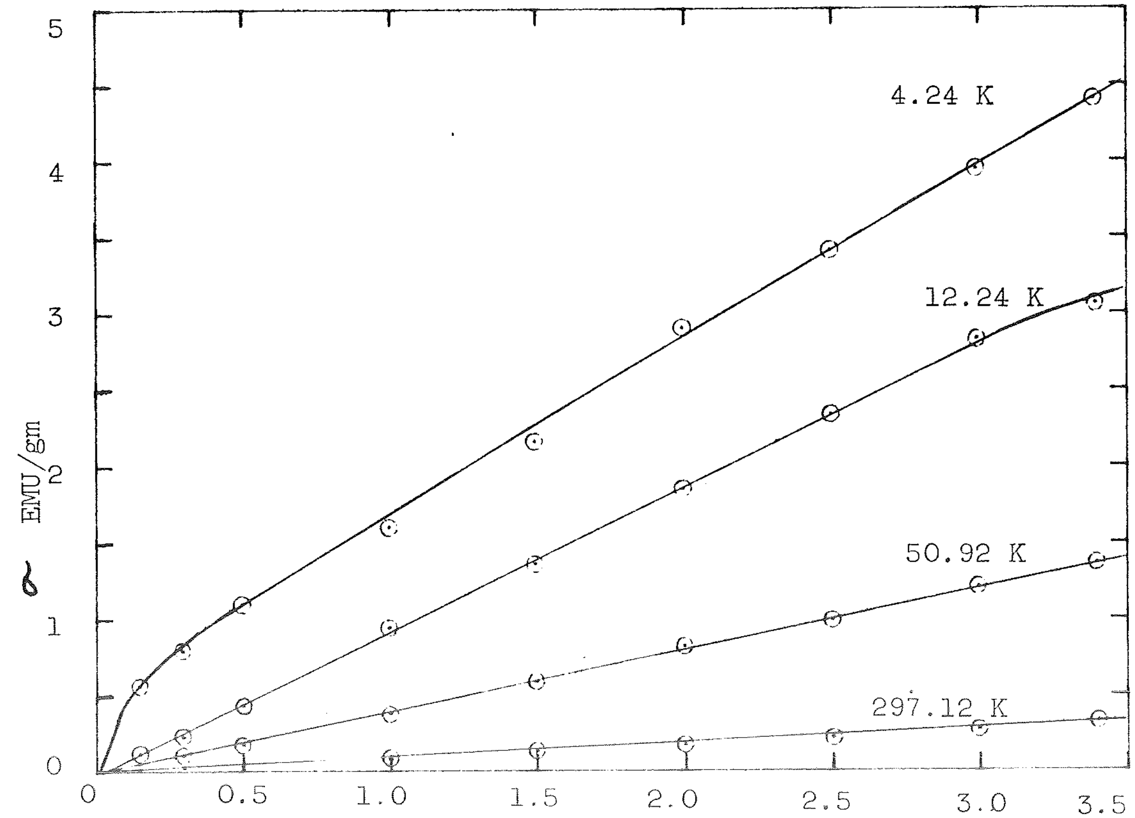

FIGURE 10 CeSe H_I Tesla

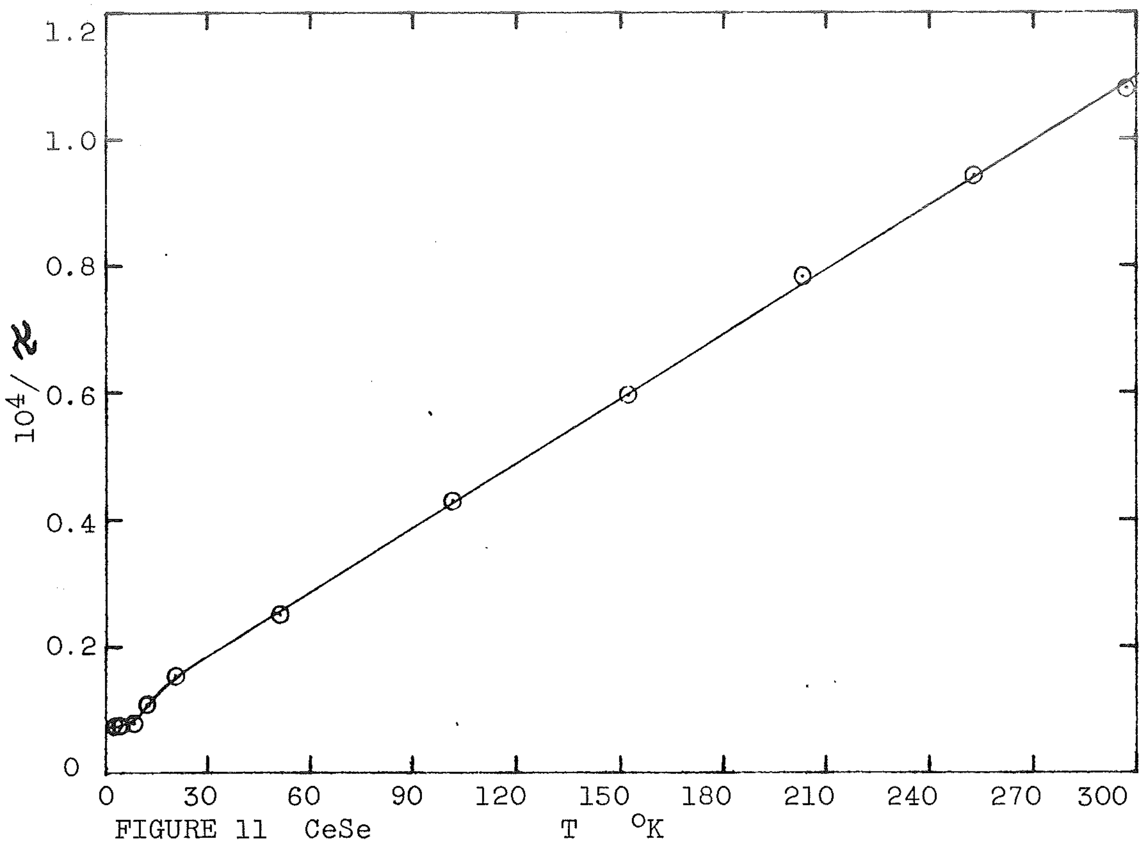

FIGURE 11 CeSe

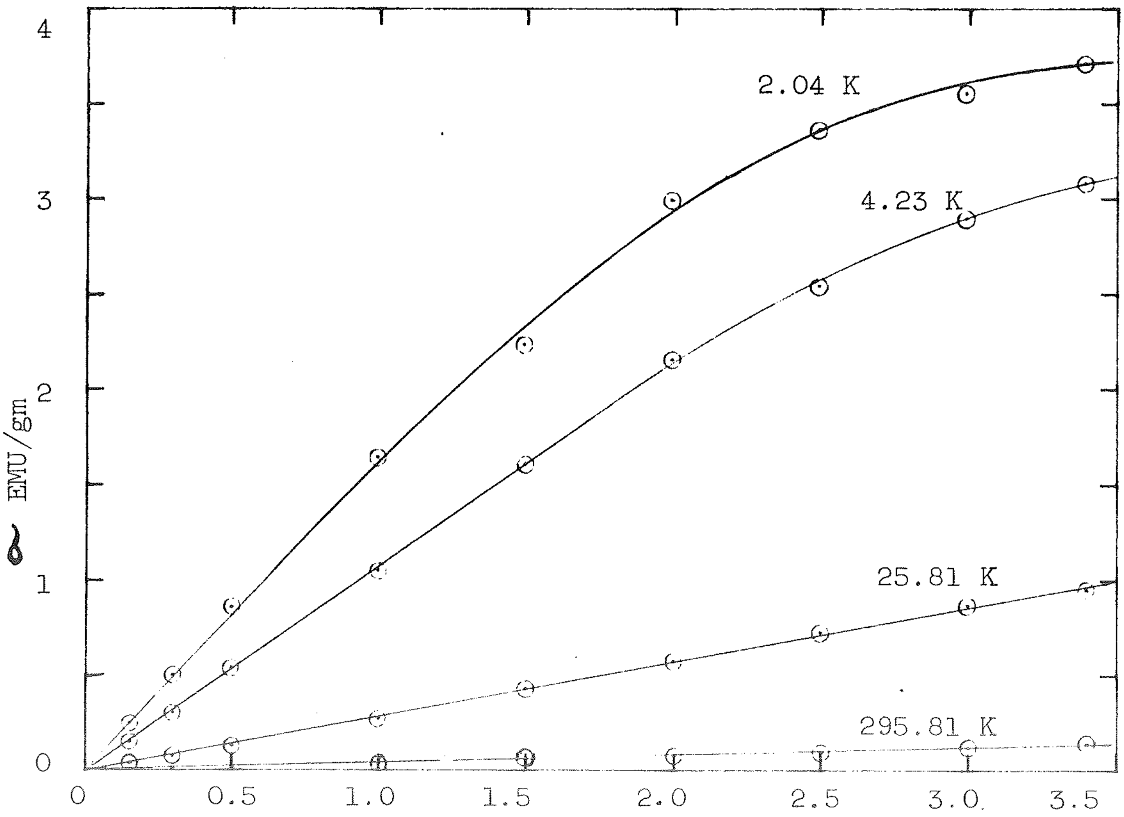

FIGURE 12 YbSe

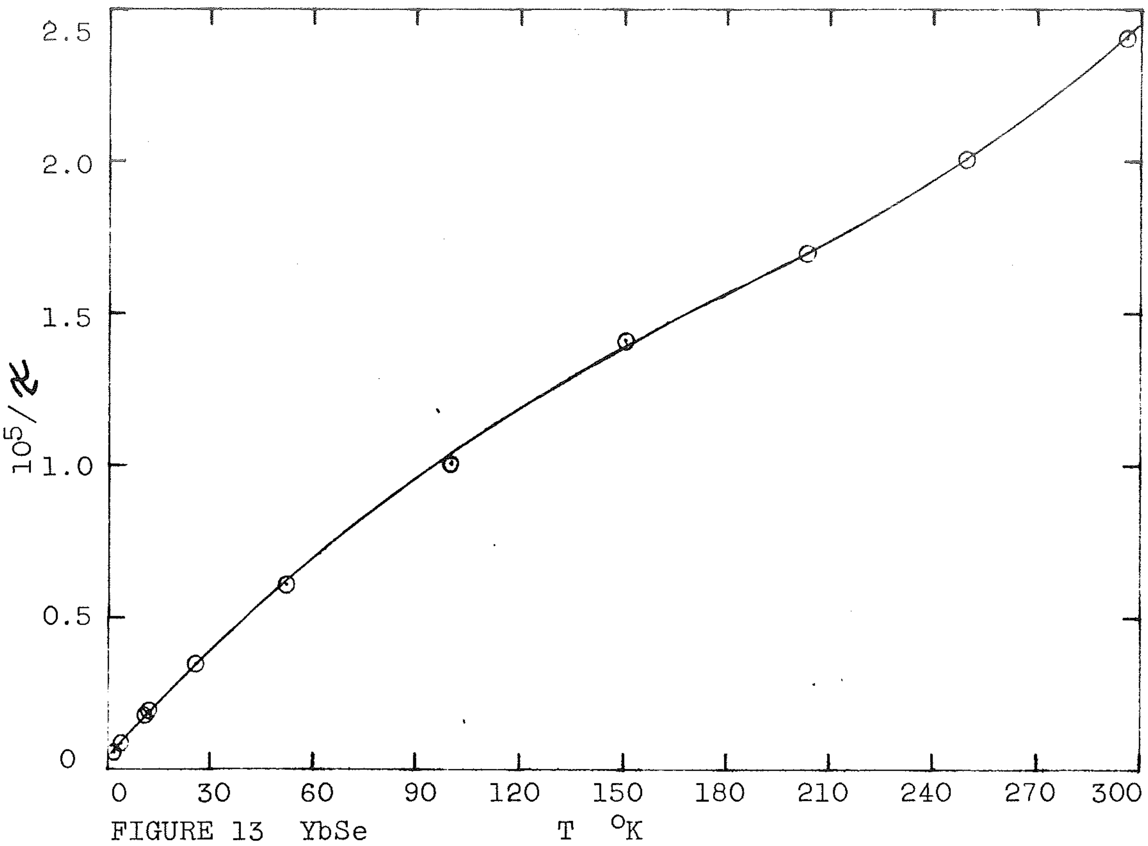

FIGURE 13 YbSe

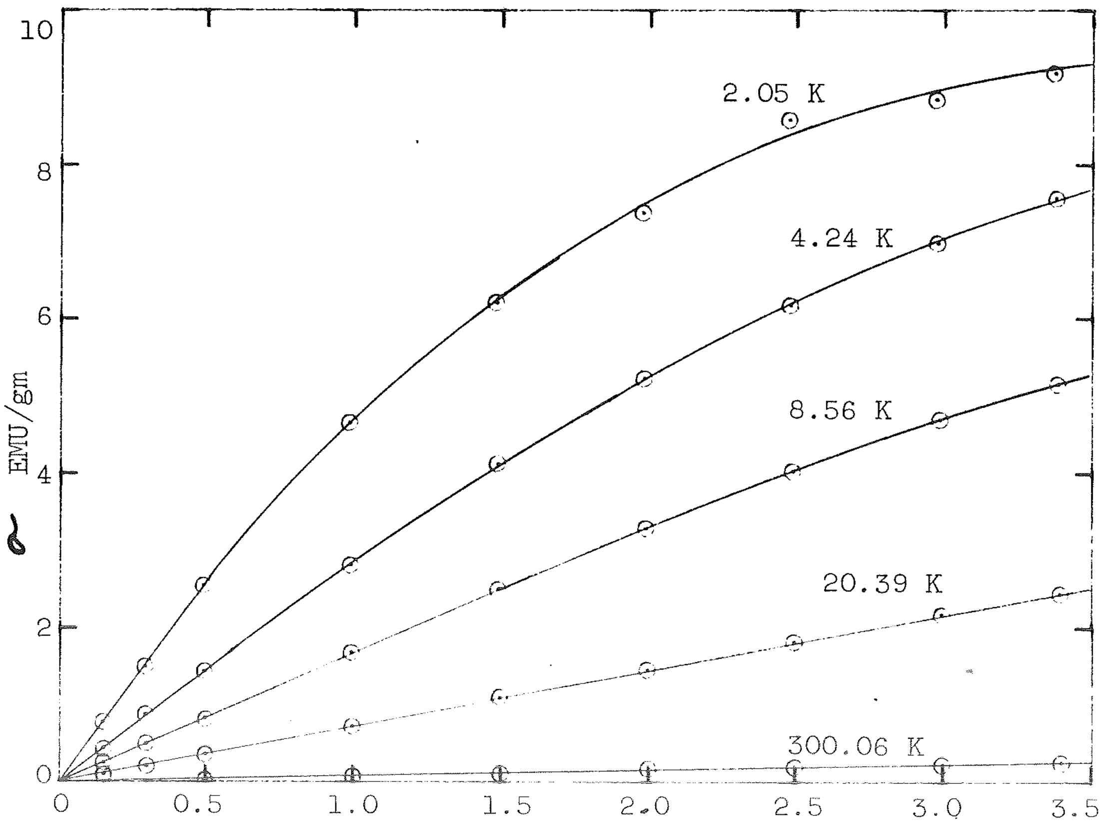

FIGURE 14 YbTe

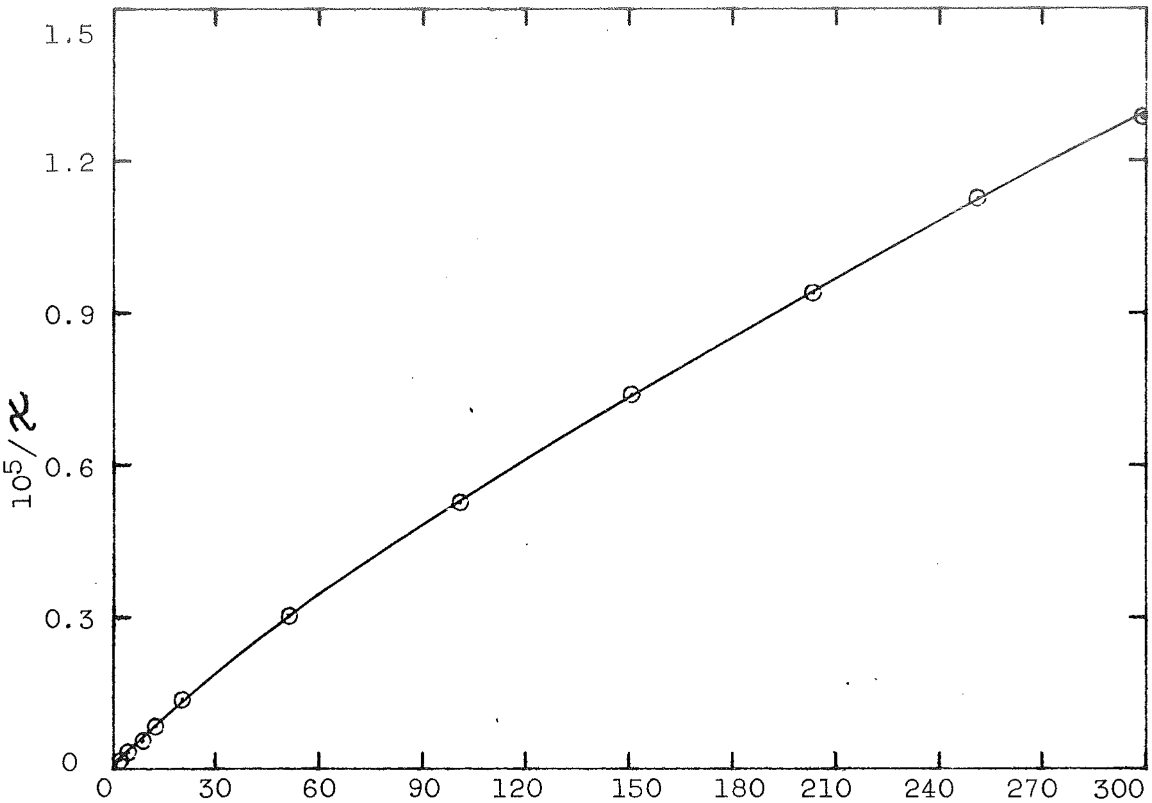

FIGURE 15 YbTe T °K

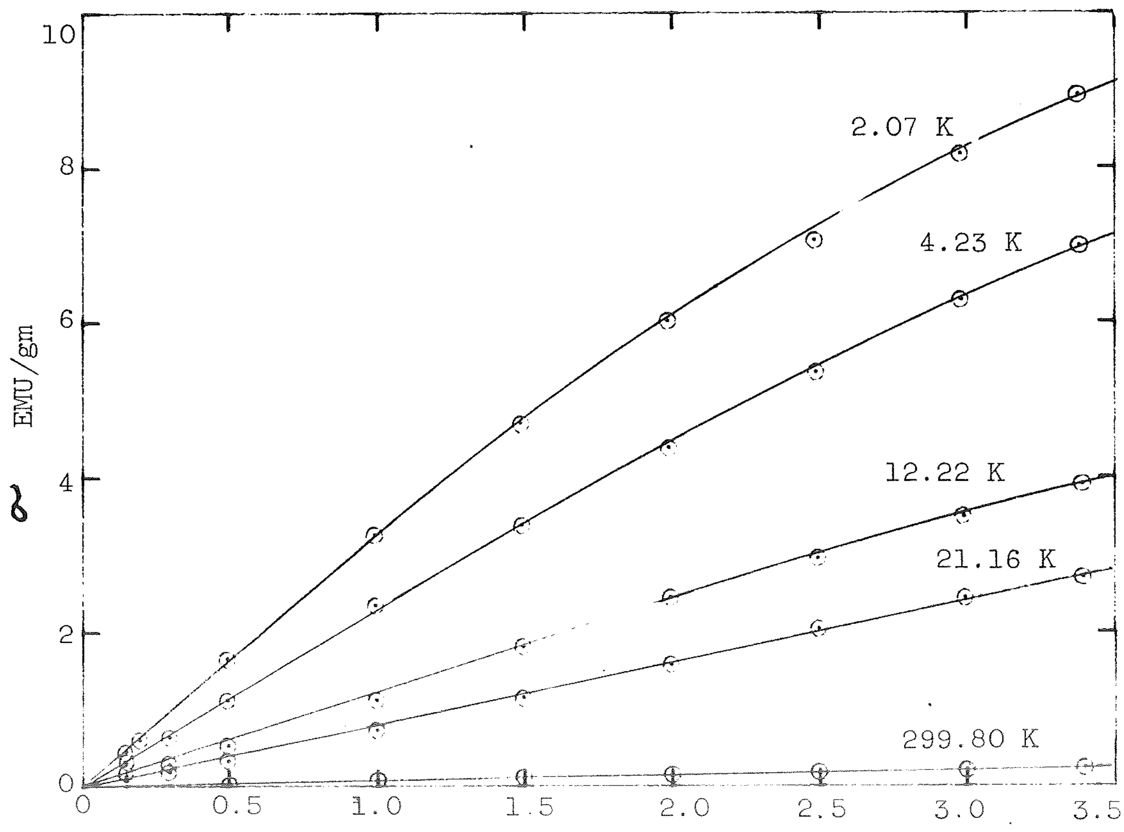

FIGURE 16 CeTe H_I Tesla

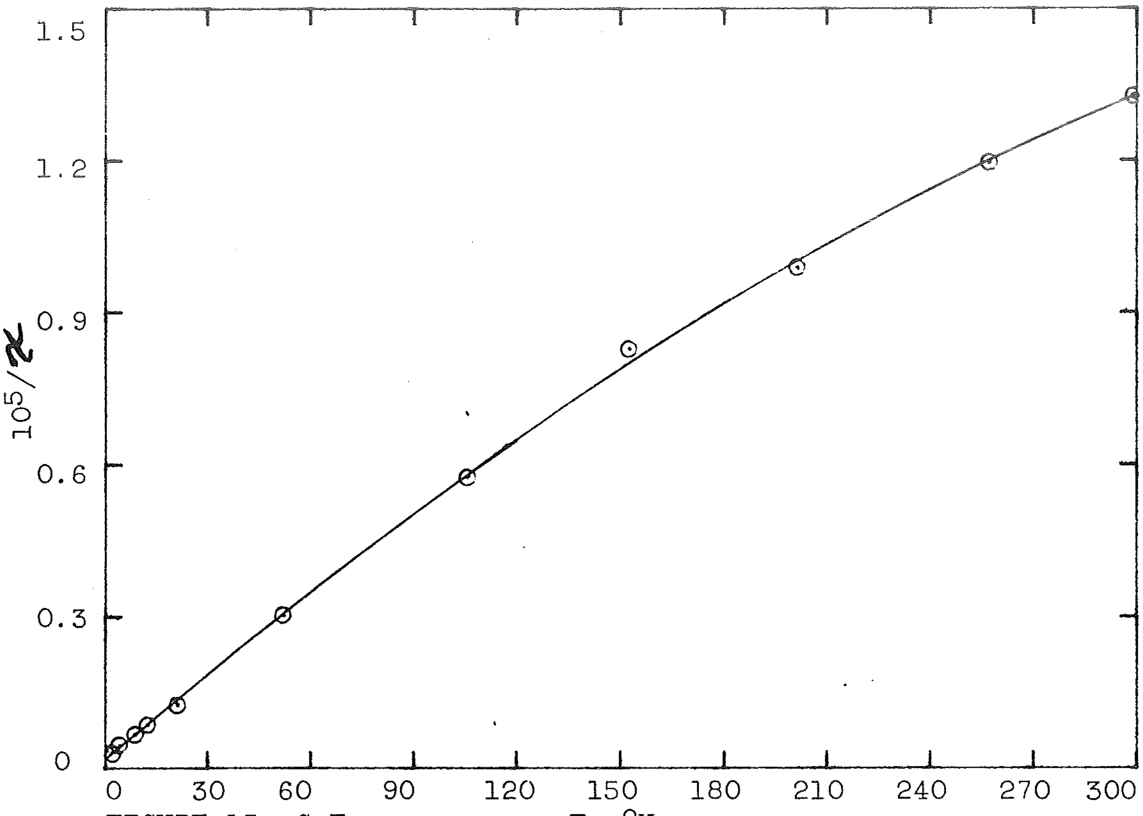

FIGURE 17 CeTe

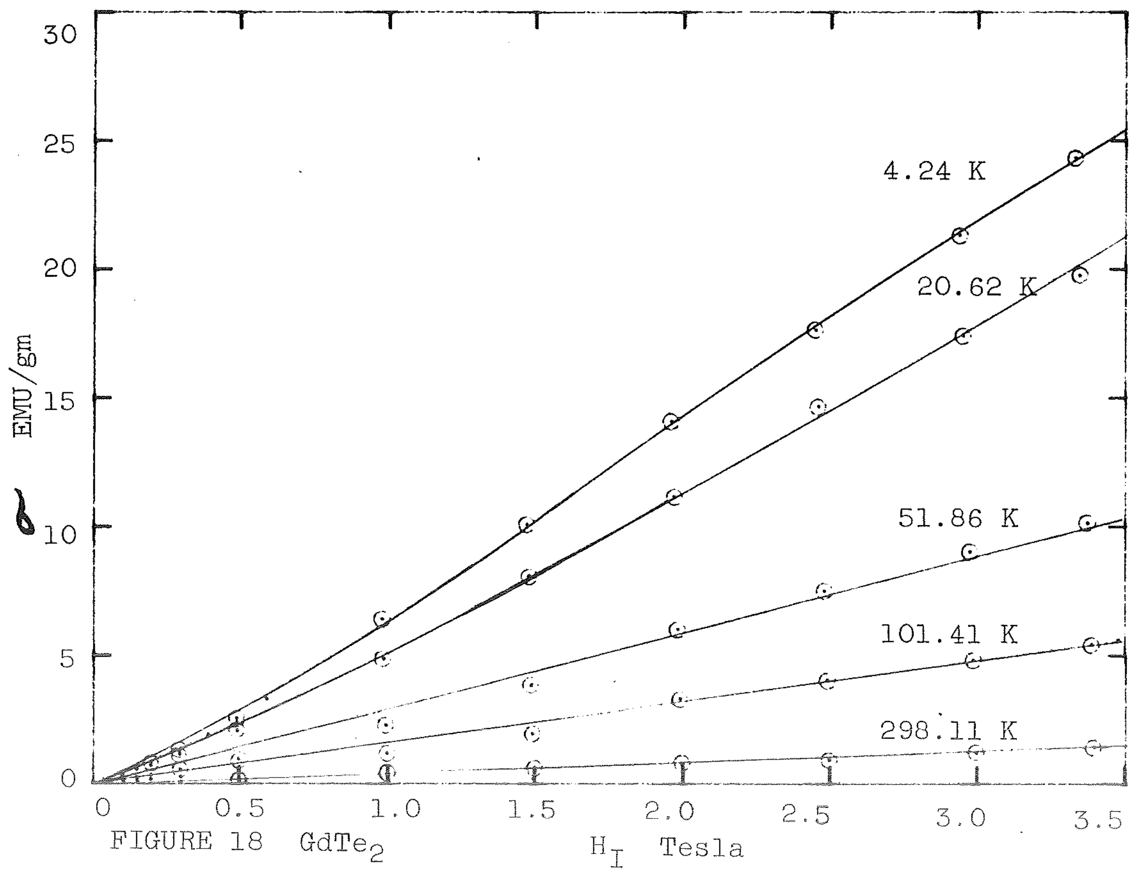

FIGURE 18 $GdTe_2$

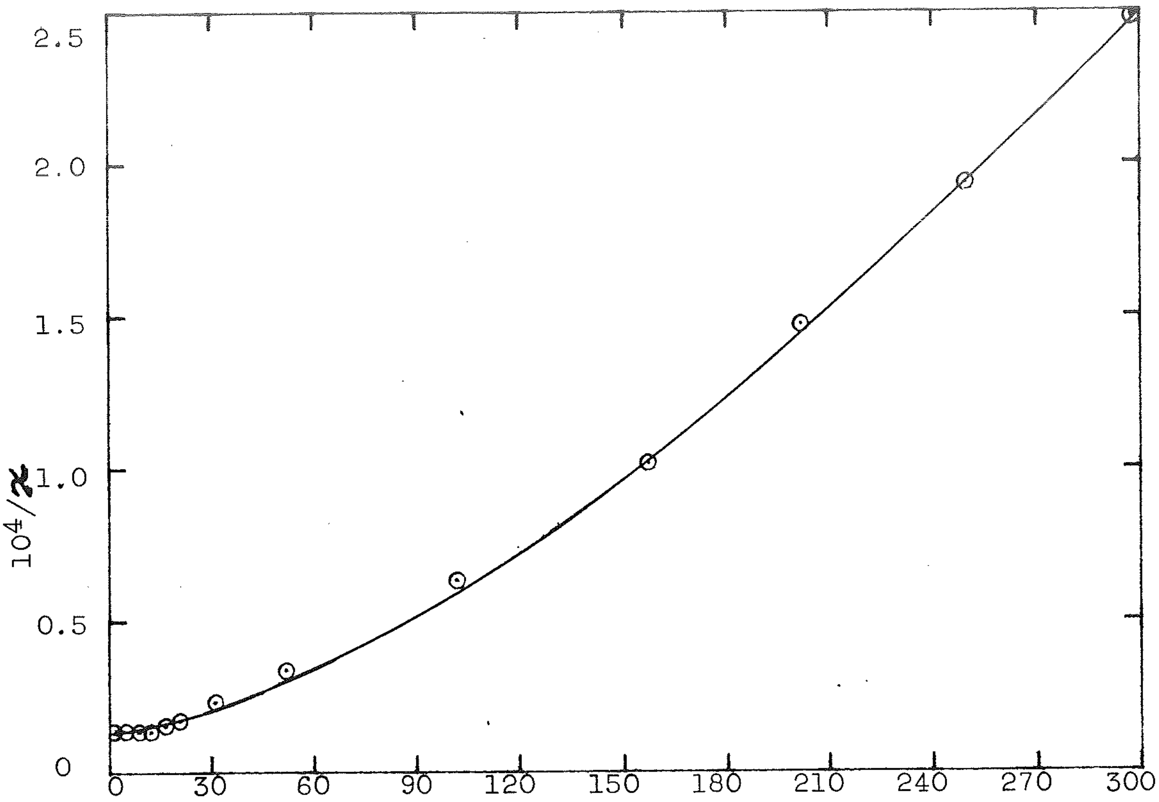

FIGURE 19 $GdTe_2$ T °K

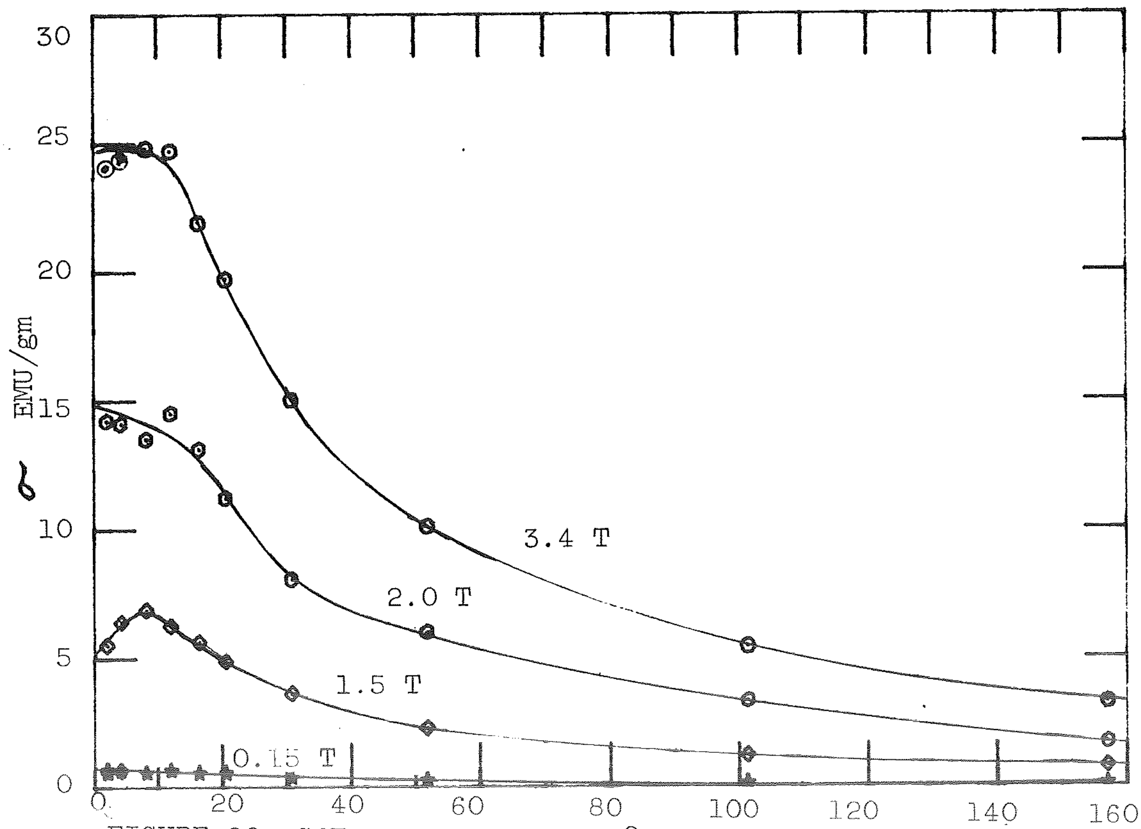

FIGURE 20 $GdTe_2$ T °K

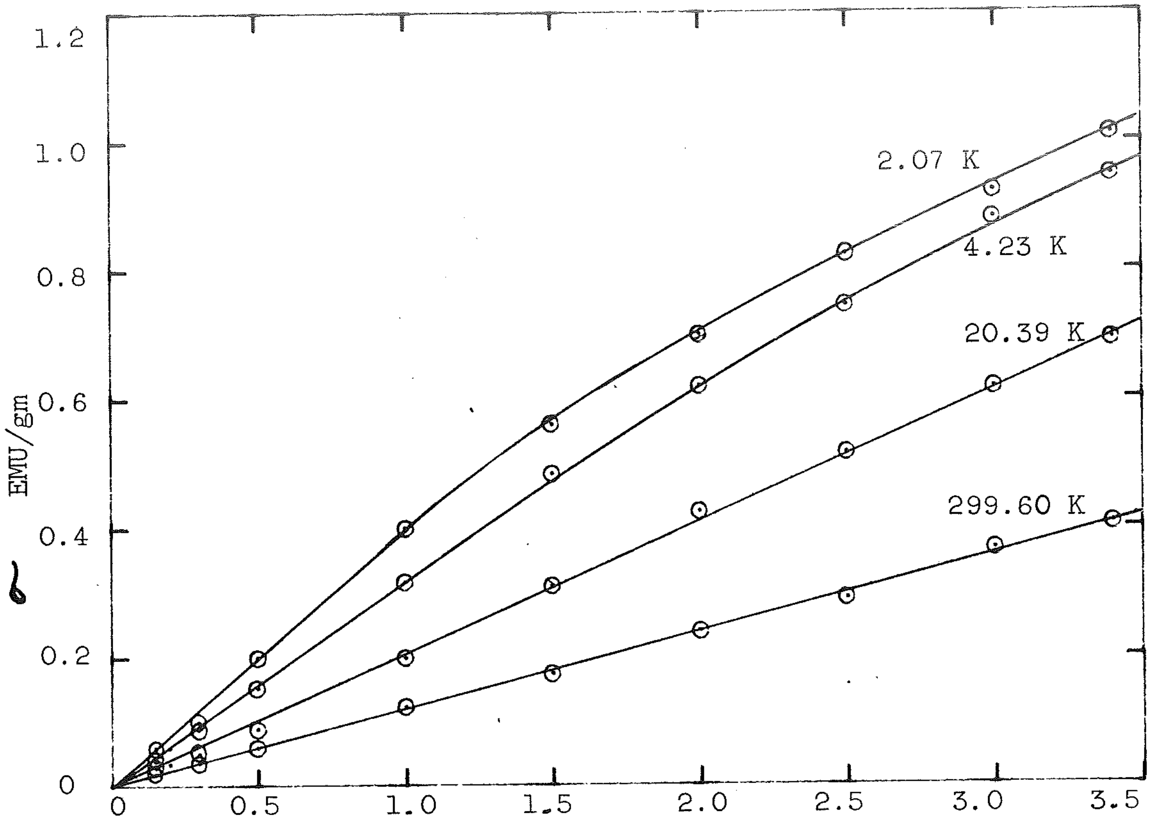

FIGURE 21 SmTe H_I Tesla

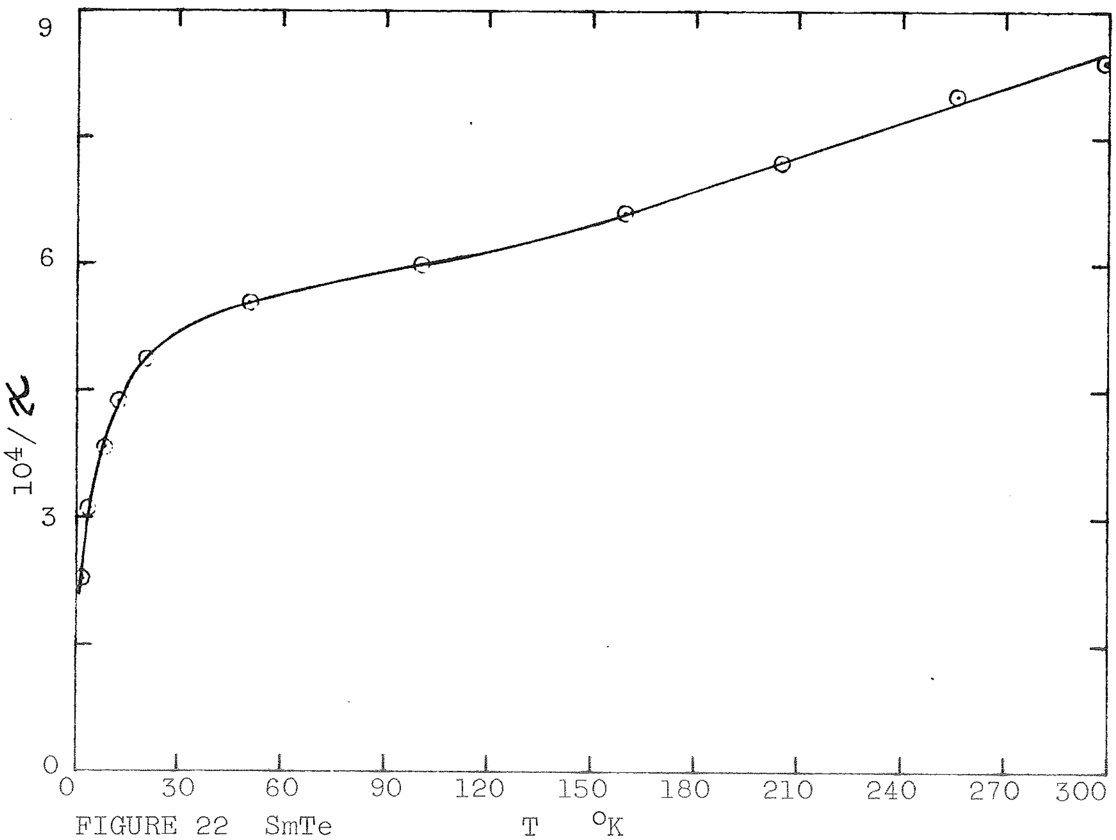

FIGURE 22 SmTe T °K