THE ANISOTROPY AND SIGN CHANGE OF MAGNETORESISTANCE IN THE LAYERED QUASI ONE-DIMENSIONAL SEMICONDUCTOR TiS_3

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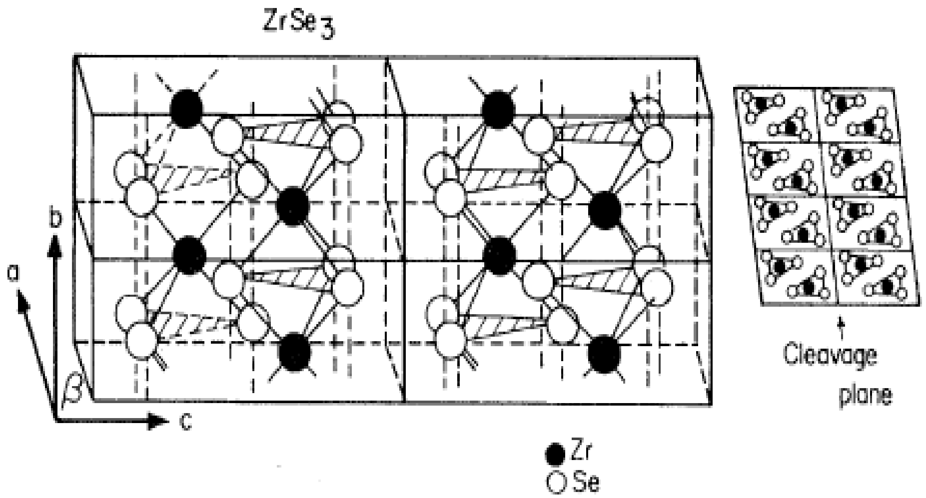
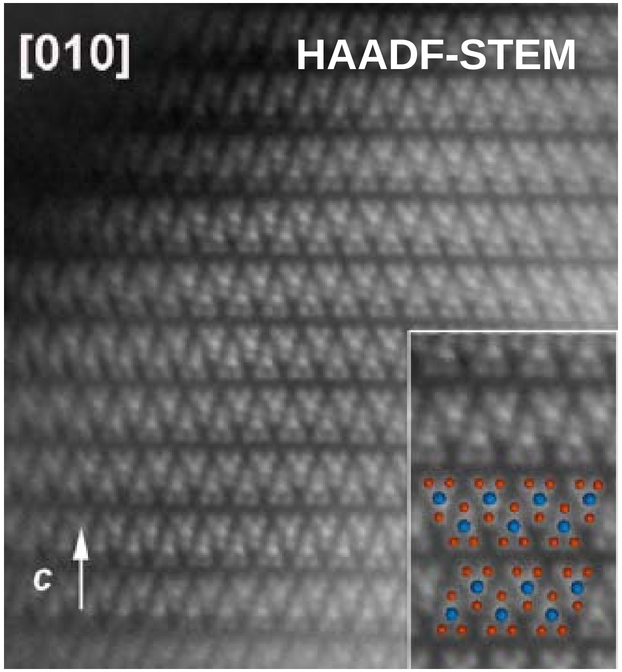
Crystal structure of TiS_3

Transition metal trichalcogenides of Group IV metals. MX_3, where M =Ti, Zr, Hf; and X=S, Se, Te, are layered quasi one-dimensional compounds. MX_3 are diamagnetic semiconductors. **$ZrTe_3$** and **TiS_3** show metallic properties. $ZrTe_3$ undergoes a phase transition at 63 K due to CDW formation.



TiS_3



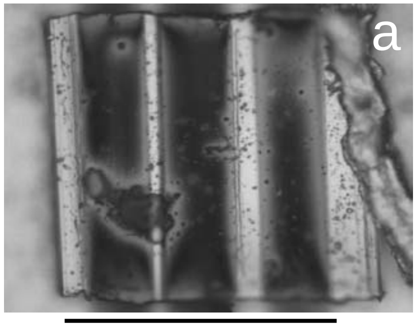
*F.S. Khumalo and H.P. Hughes, Phys.Rev.B, **22** 2078 (1980)*

*E. Guilmeau et.al., Chem. Mater., **26** 5585 (2014)*

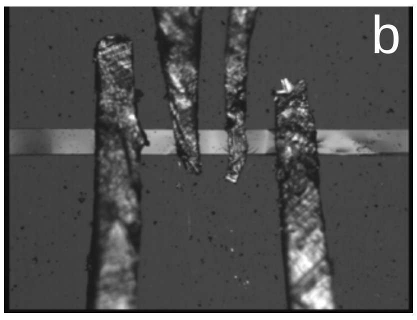
Unit cell parameters: ***a*=0.50 nm, *b*=0.34 nm, *c*=0.88 nm. *β*=98,4°**

Structural type – monoclinic. Space group – P21/m

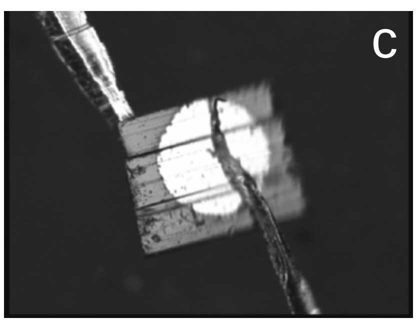
Samples



100µm

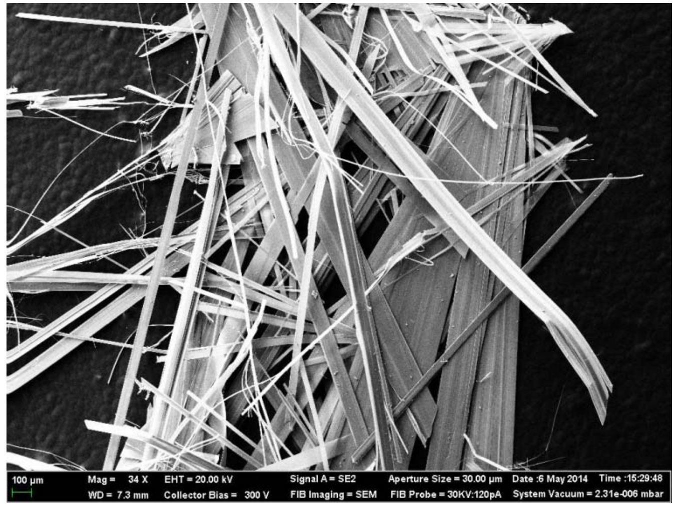


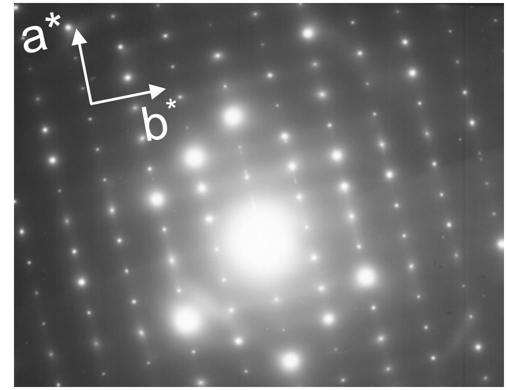
100µm



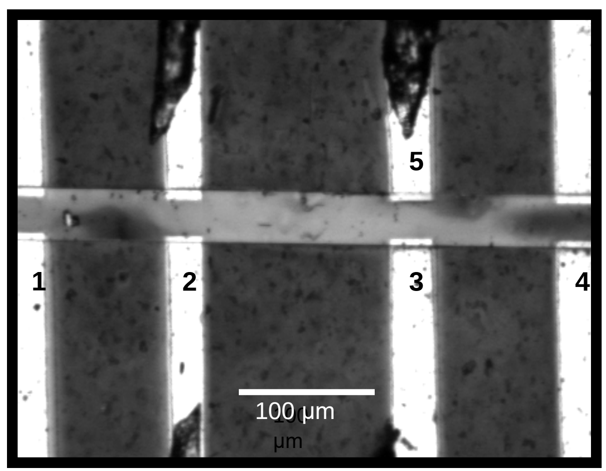
100µm

The TiS_3 whiskers with electrical contacts. The current flows along *a*- axis (a), *b*- axis (b), *c*- axis (c)

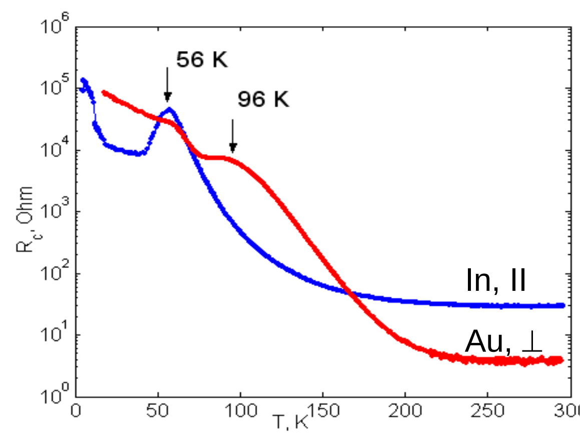




The diffraction patterns of the TiS_3 whisker at 285 K
HVEM JEM-1000

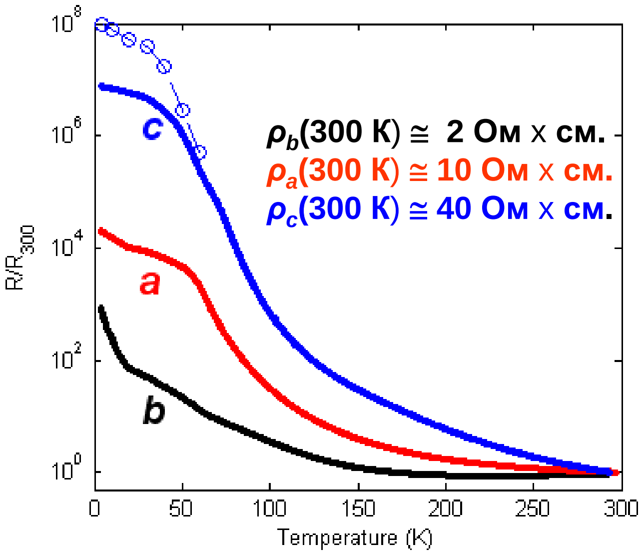


TiS_3 whisker (the gray stripe in the middle) with 8 Au contacts prepared for R_{xy} and R_{xx} measurements.

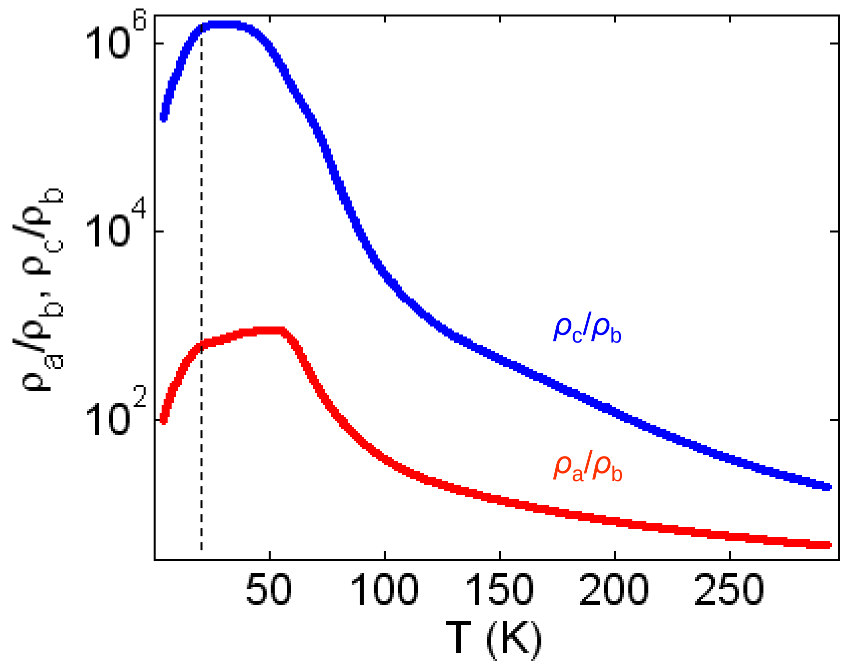


The temperature dependencies of the contact resistance to TiS_3 whiskers. Contact resistance at 300 K was ~ 10^{-6} Ohm x cm^2.

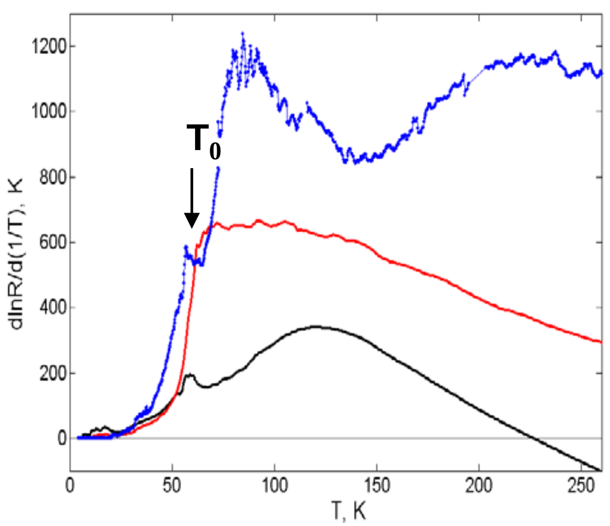
The anisotropy of conductivity of TiS_3 whiskers.



The temperature dependences of the resistance of TiS_3, measured along the ***a***, ***b***, and ***c*** axes



Temperature dependencies of the ratio ρ_a/ρ_b and ρ_c/ρ_b.
$\rho_a/\rho_b \sim 5$; $\rho_c/\rho_b \sim 20$ at 300 K.
$\rho_c{:}\rho_a{:}\rho_b \sim 10^6{:}10^3{:}1$ at T=50 K.



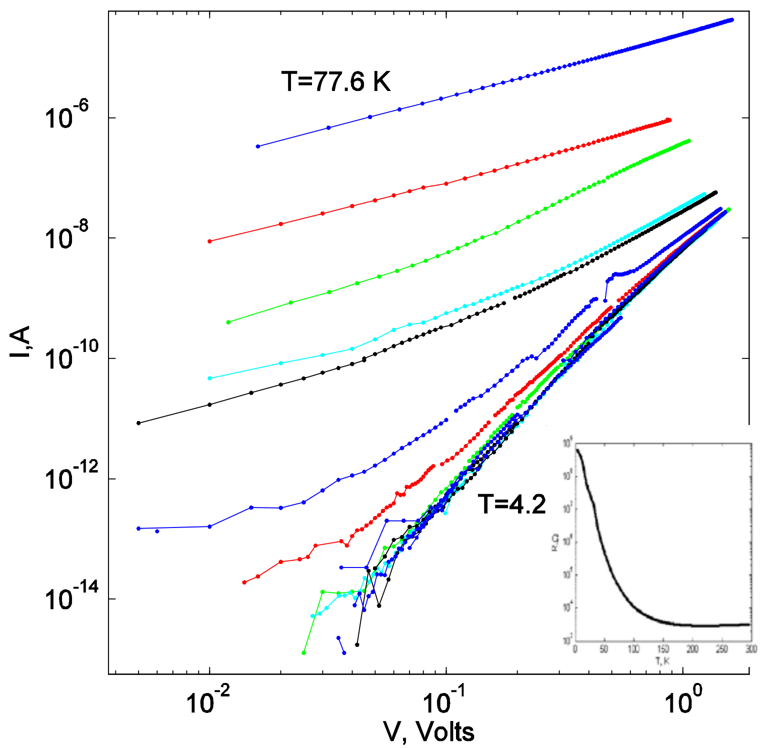
The temperature dependences of the logarithmic derivatives dln$R$/d(1/T) along the ***a***, ***b***, and ***c*** axes.

I.G. Gorlova S.G. Zybtsev and V.Ya. Pokrovskii, JETP Lett. ***100*** *256 (2014) .*

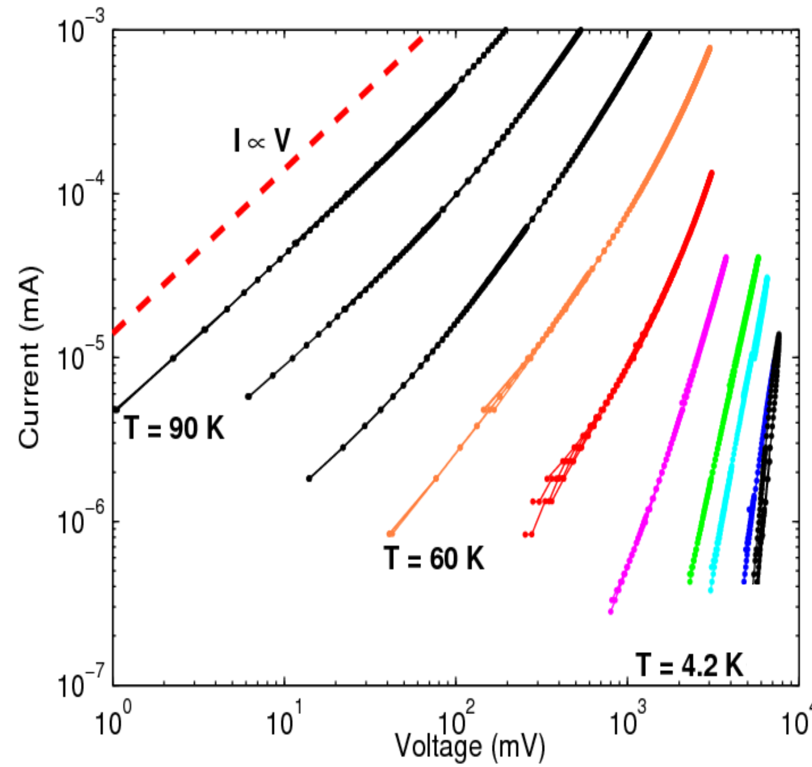
Power-law behavior of conductivity in TiS_3 whiskers.

$I \propto V^{\alpha(T)}$

In the *ab* plane



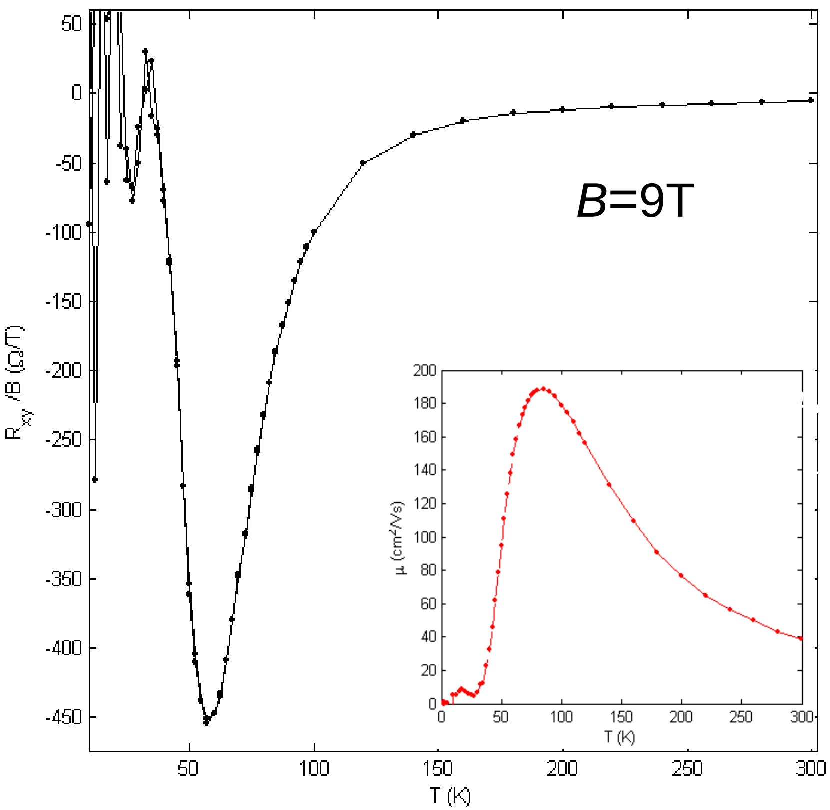
Out-of-plane



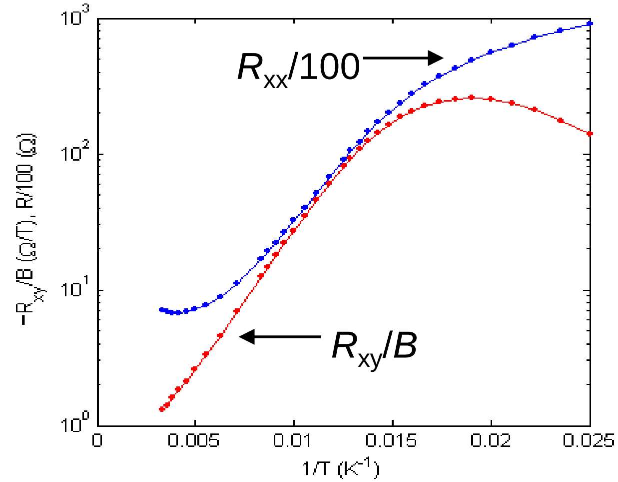
log *I*-log *V* curves measured along ***b*-axis**
at *T* =4.2, 5.2, 5.6, 6.4, 7.7, 12.8, 24.7, 26.6, 41.5, 58.9, 77.6 K. Inset: *R(T)* of the whiskers.
ρ_b(300 K) = 0.2 Ohm x cm.

log *I*-log *V* curves measured along ***c*-axis**
at *T* =4.2, 10, 20, 30, 40, 50, 60, 70, 80, 90 K

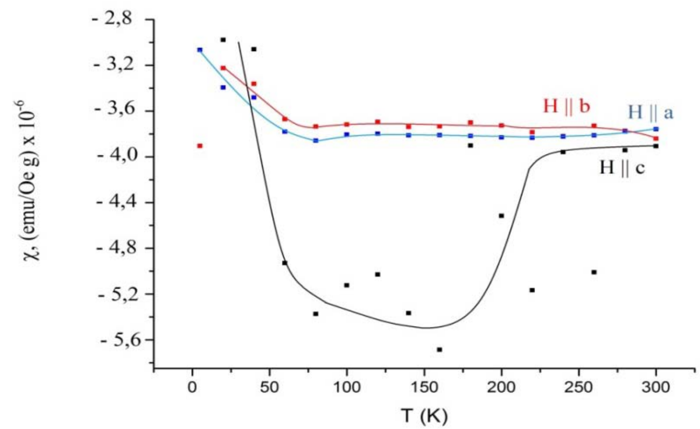
Hall effect and magnetic susceptibility for TiS_3



The temperature dependence of the Hall resistance for TiS_3 . Inset: temperature dependence of the Hall mobility. Electron density: n_{300}, ~10^{18} cm^{-3}, n_{50} ~10^{15} cm^{-3}. Electron density per elementary conducting layer at 300 K is ~10^{11}cm^{-2}, at 50 K - ~ 5×10^{8} cm^{-2}



The temperature dependencies of the Hall resistance R_{xy} (B=9 T) and b-axis resistance R_{xx} for the same whisker. The activation energy: for R_{xx}= 415 K, for R_{xy} = 469 K

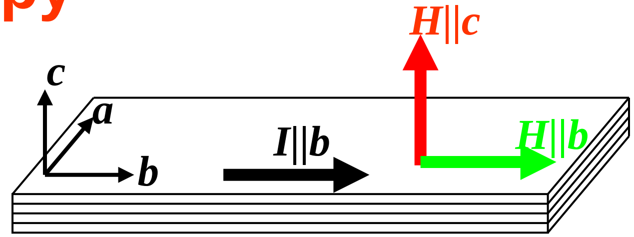


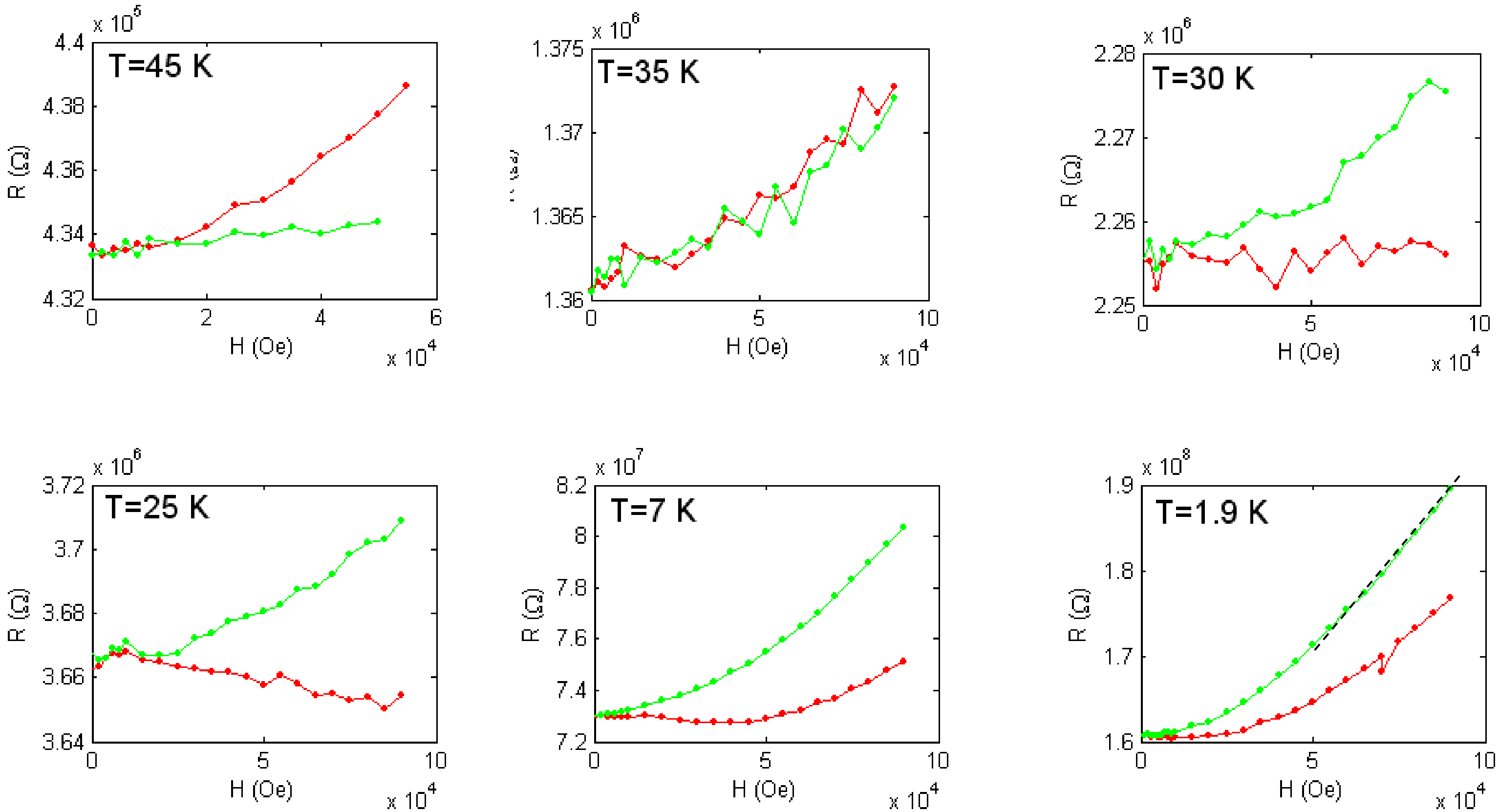
The temperature dependences of the magnetic susceptibility of TiS_3 along the ***a***, ***b***, and ***c*** axes.

*I.G. Gorlova et al., Physica B **460** 11-15 (2015).*

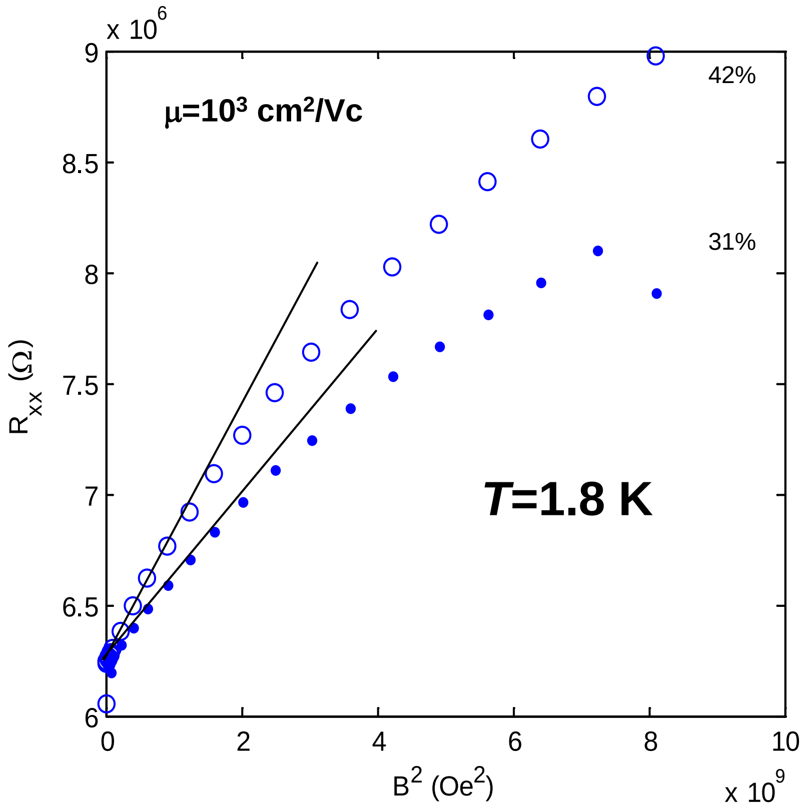
Magnetic field dependencies of *b*-axis resistance R_{xx}. *bc*-plane anisotropy

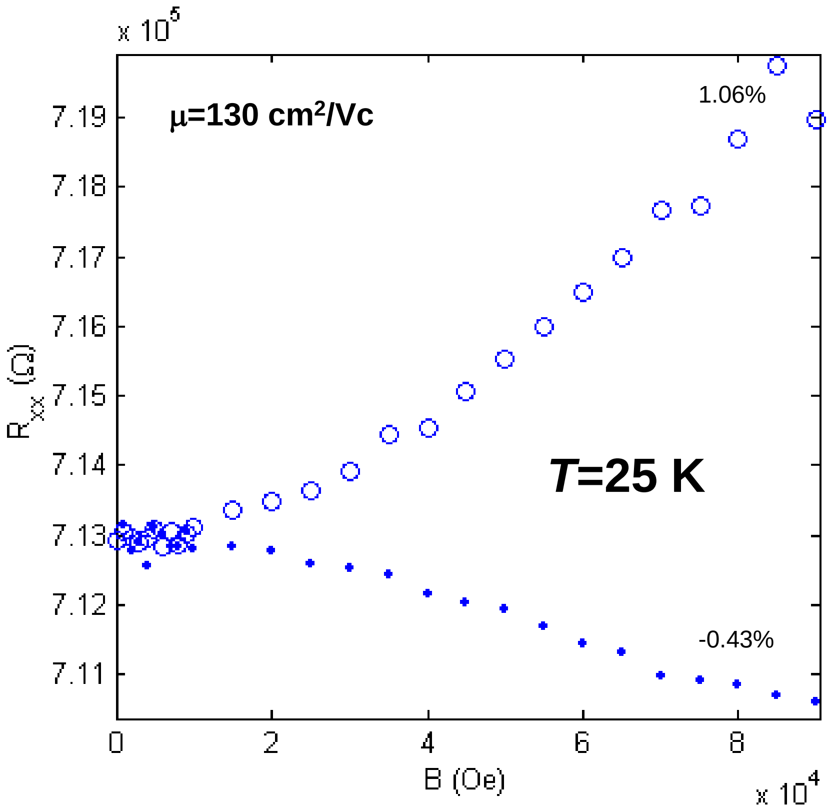
PPMS-9 *I*||*b*, ● - *H*||*b*, ● - *H*||*c*





Magnetic field dependencies of *b*-axis resistance R_{xx}

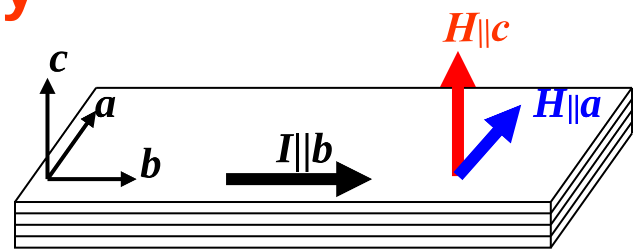


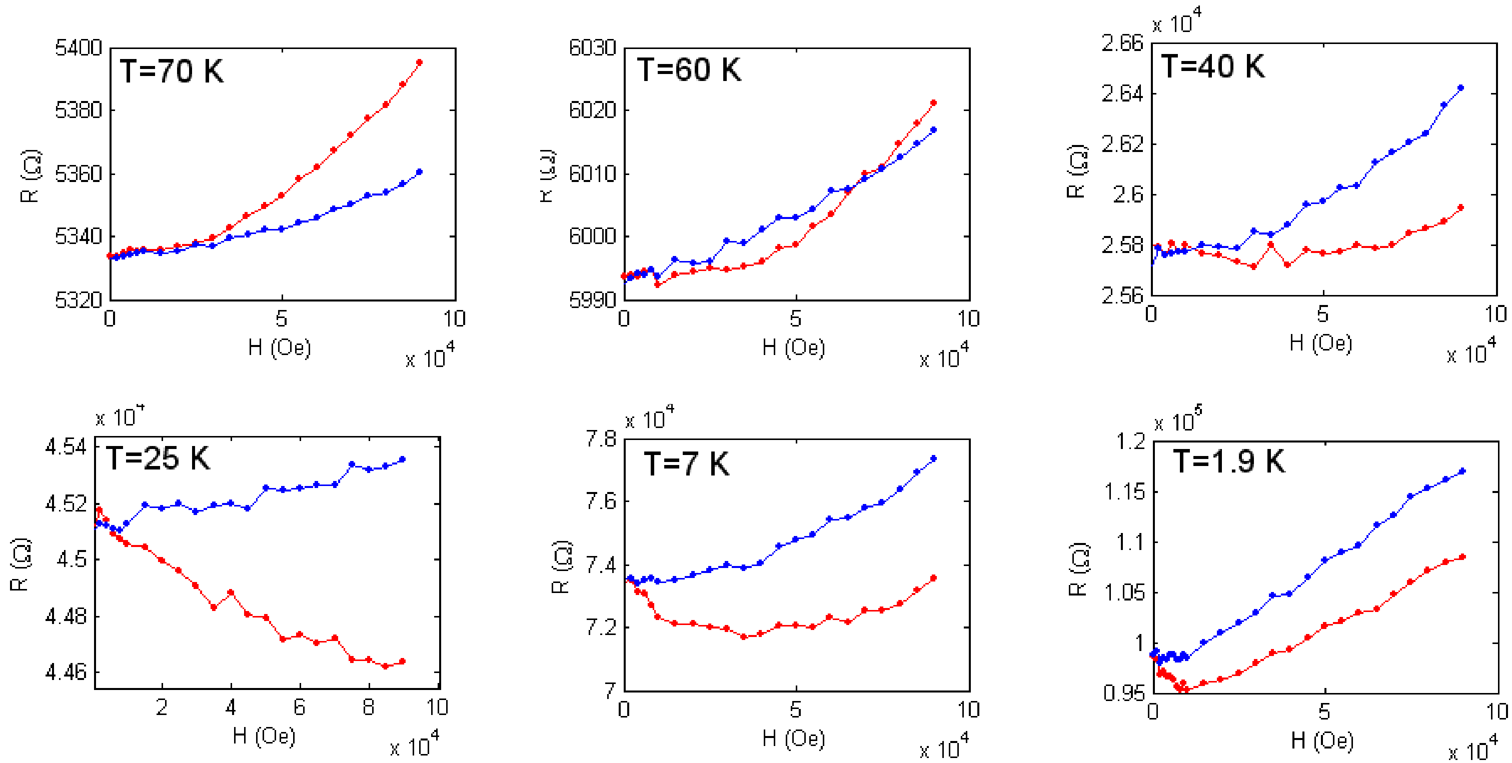


out-of plane fields, ***B***||*c* (●), in-plane fields, ***B***||***I***||*b* (○).

Magnetic field dependencies of *b*-axis resistance R_{xx}.
ac-plane anisotropy

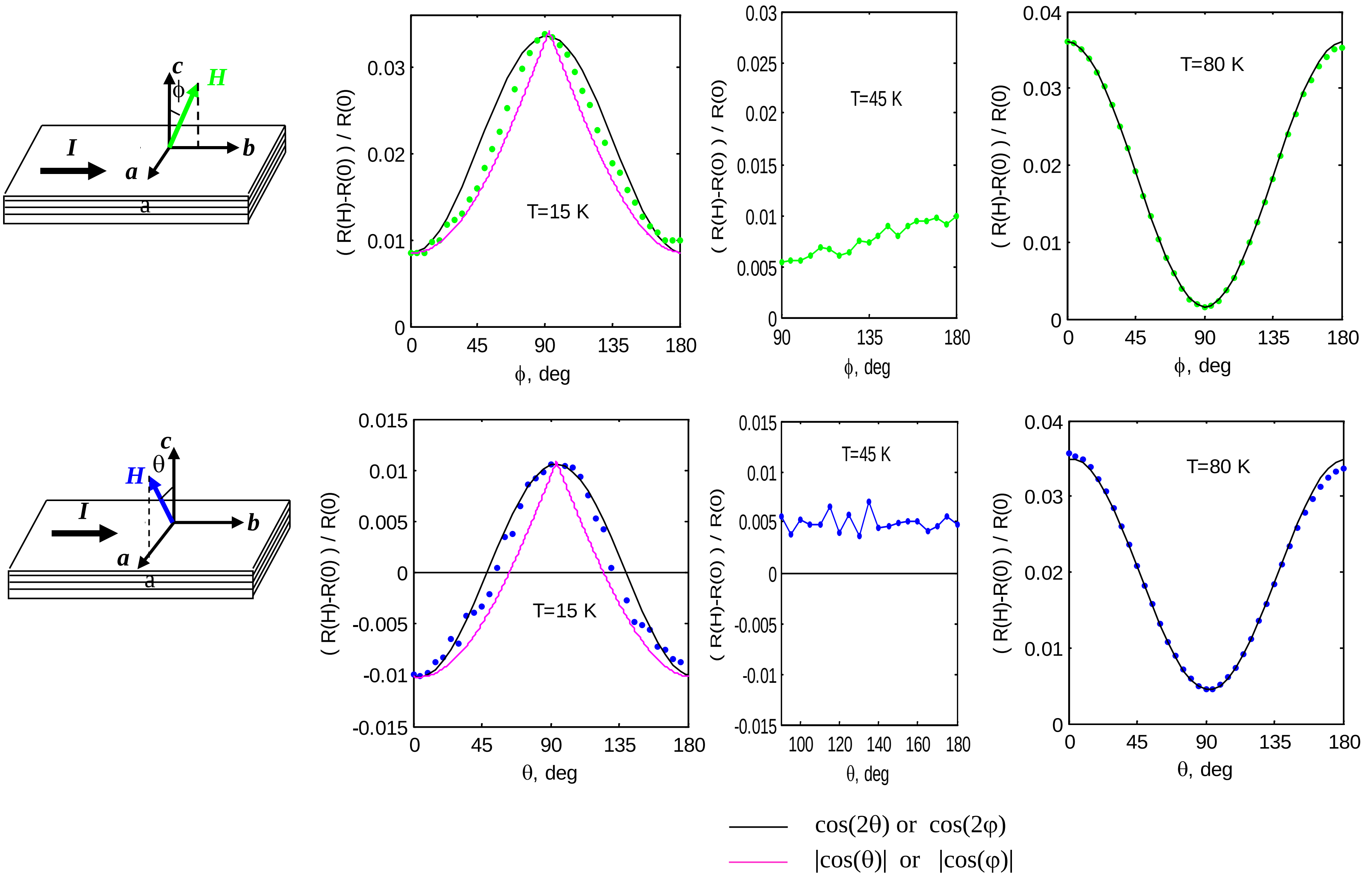
$H \perp I$, $I \| b$, •- $H \| a$, •- $H \| c$



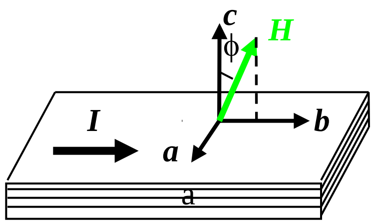


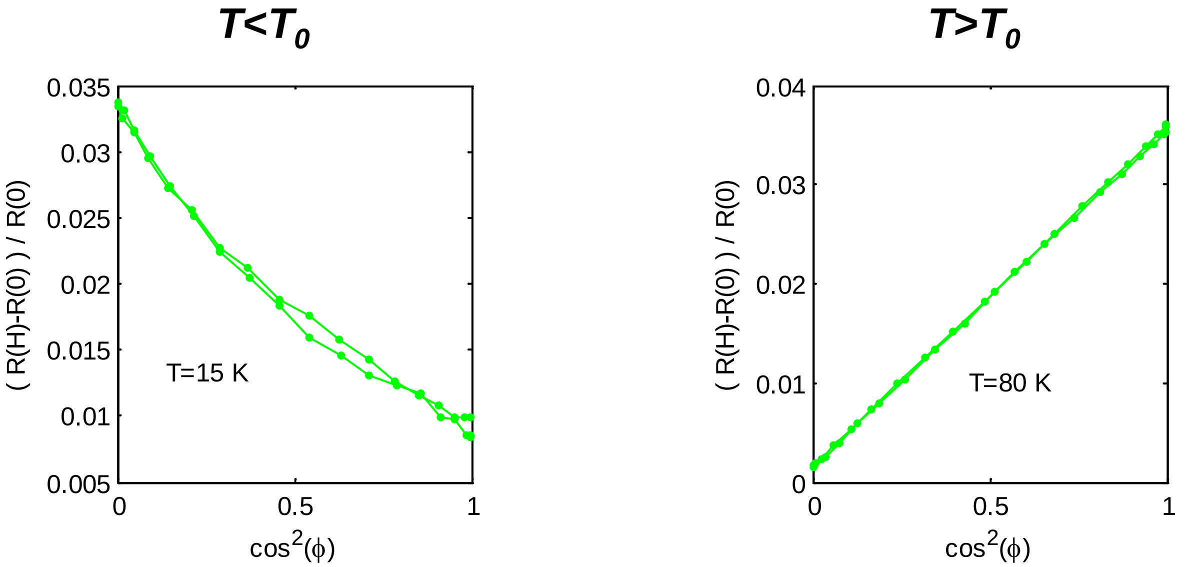
Angle dependences of magnetoresistance of TiS_3

$H = 4 \times 10^4$ Oe, $I \| b$ — $T<T_0$ — $T \approx T_0$ — $T>T_0$



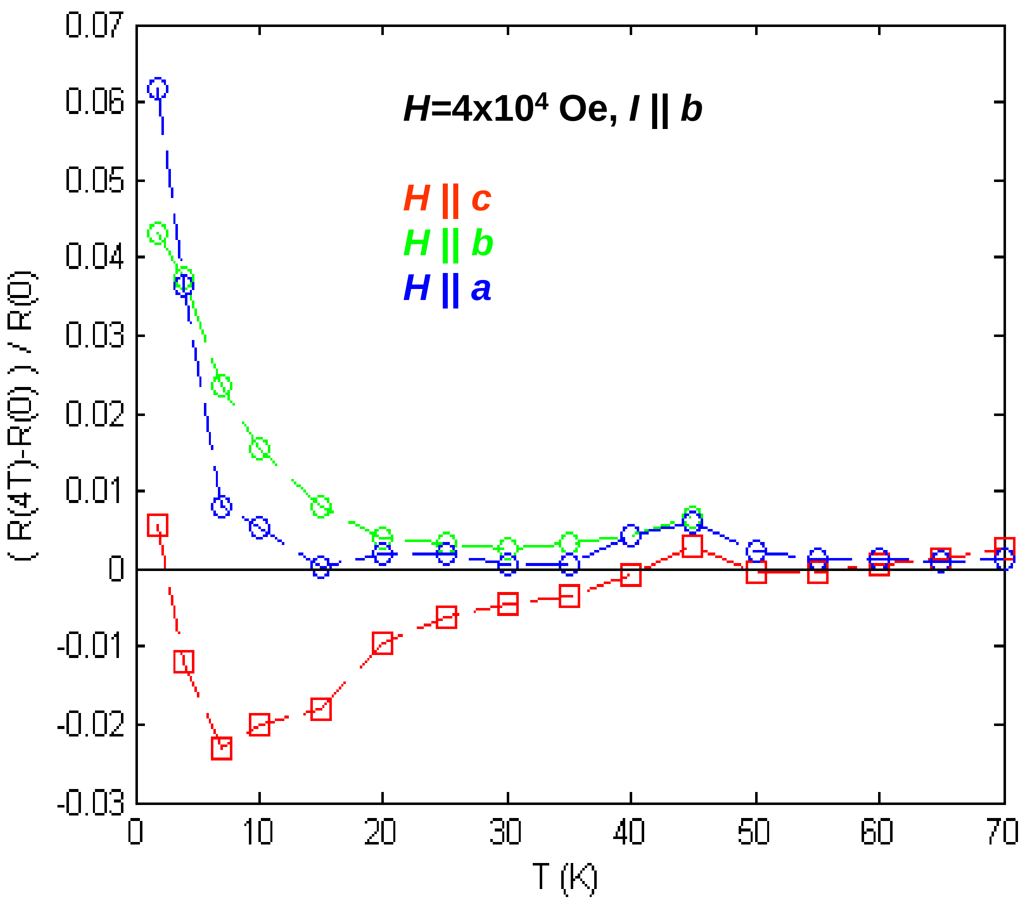
Angle dependences of magnetoresistance of TiS_3

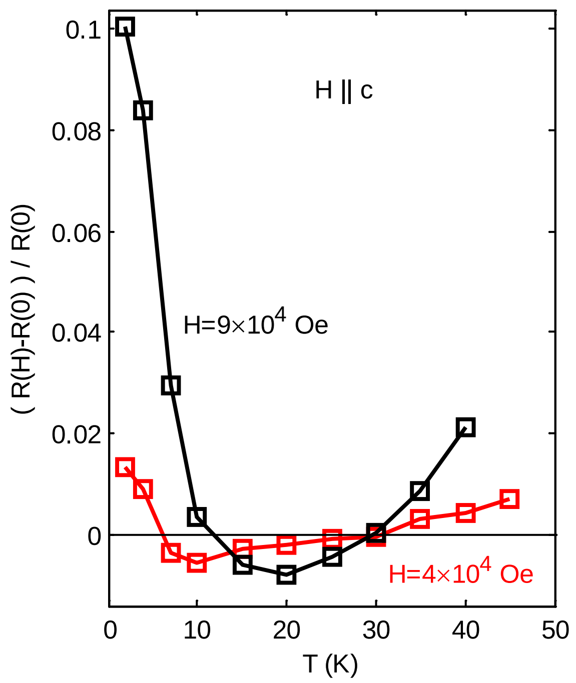




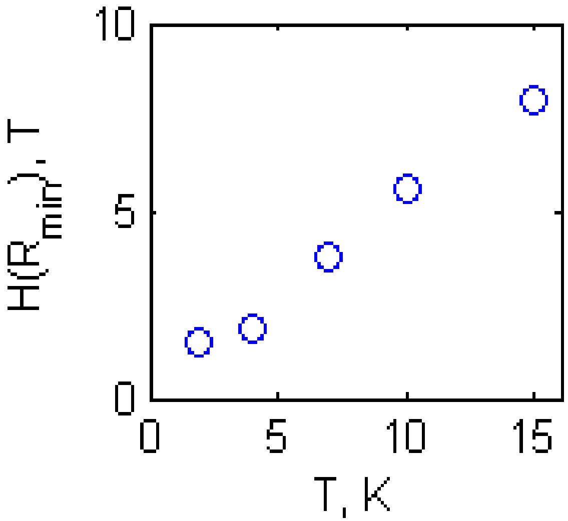
H = 4x10^4 Oe, I||b

The temperature dependences of the magnetoresistance of TiS_3, for the magnetic fields *B* directed along the three crystallographic axes.

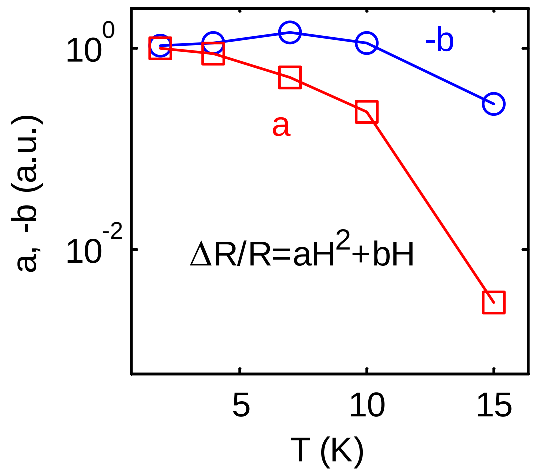


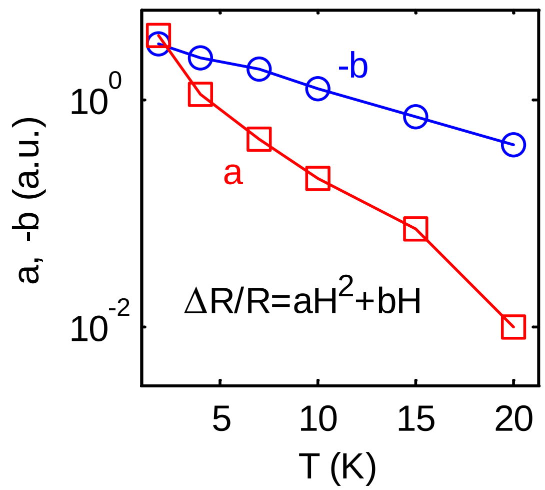


The transverse magnetoresistance (*H*||*c*) as a sum of linear negative and quadratic positive contributions $\Delta R/R = aH^2 + bH$.



At *H* corresponding to the minimum of *R*:
$\hbar\omega_c \approx kT$
($\hbar\omega_c \equiv eH/m_e$)





$\Delta R/R = \mu^2 H^2$

$a=10^0 \sim \mu=400\ cm^2/Vs$
$a=10^{-2} \sim \mu=40\ cm^2/Vs$

Possible mechanisms of magnetoresistance in TiS_3

Negative MR in transverse (out-of plane) fields, *B*||*c*

is observed in layered conductors with charge or antiferromagnetic ordering and is explained by localization induced by defects of different kind. E.g.:

$(DMtTSF)_2X$, X= BF_4, ClO_4, ReO_4. AF ordering**.** 2D weak localization induced by disorder in the anion lattice.
*J. P. Ulmet et al., Phys. Rev. B **38** 7782 (1988).*

α-$(BEDT\text{-}TTF)_2I_3$. Ferroelectric CO phase transition. 2D weak localization induced by disorder in I layers.
T. Ivek et al., PRB 96 (2017) 075141

***o*-TaS_3** CDW. Delocalization of quantum interference of CDW loop formed in domain structure.
*Katsuhiko Inagaki et al., Phys. Rev. B **93**, 075423 (2016)*

Positive MR in parallel (in-plane) fields, *B*||*I*||*b*, *B*||a

is observed in 2D interacting low-density carrier ($n\sim10^{11}$ cm^{-2}) electron systems, 2D EG. **Si-MOS structures**.

Explanations:
Zeeman spin-splitting. *V. T. Dolgopolov and A. V. Gold, JETP Lett. **71**, 27 (2000).*

Both the spin and Coulomb interaction effects *V. M. Pudalov et al., JETP Lett. **65**, 932 (1997)*

The two parallel dissipation channels : scattering of the electrons by impurities in 2D Fermi liquid and Coulomb scattering of electrons by the collective localized states (spin droplets). *L. A. Morgun et al., Phys.Rev.B **93**, 235145 (2016)*

Intermediate phase between the Fermi-liquid and the Wigner crystal phases. *B. Spivak, Phys.Rev.B **67**, 125205 (2003)*

CONCLUSIONS

The magnetoresistance of whiskers of q-1D layered semiconductor TiS_3 was studied for current flowing along the metal chains (*I* ||*b*) and for the magnetic field *B* directed along the three crystallographic axes: (*B*||*a*), (*B*||*b*), (*B*||*c*), 0<*B*<9 T.

Angular dependences of magnetoresistance reveal quasi 2D nature of the electronic system for *T*< 100 K.

Anomalous behavior of *R*(*H*) below $T_0 \approx 50$ K is observed. A negative transverse (*B*||*c*) and positive longitudinal (*B*||*b*||*I*) magnetoresistance has been found.

The results indicate charge- or magnetic-ordering phase transition in 2D layers.