Faculty of Physics and Applied Computer Science,
AGH University of Science and Technology
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Własności magnetyczne związków międzymetalicznych pod wysokim ciśnieniem

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Introduction

I. Experiment under high pressure

II. Magnetostructural phase transitions in $Co_xNi_{1-x}MnGe$ under pressure

III. Magnetic properties of $MnFeP_{1-x}As_x$ series
–pressure, magnetic field, electronic structure

IV. Magnetoelastic phase transitions, pressure effect electronic structure

a) $MnRhP_{1-x}As_x$
b) $MnRh_{1-x}Co_xAs$
c) $(Mn_{1-x}Co_x)_2P$
d) $MnRu_{1-x}Rh_xAs$

Conclusions

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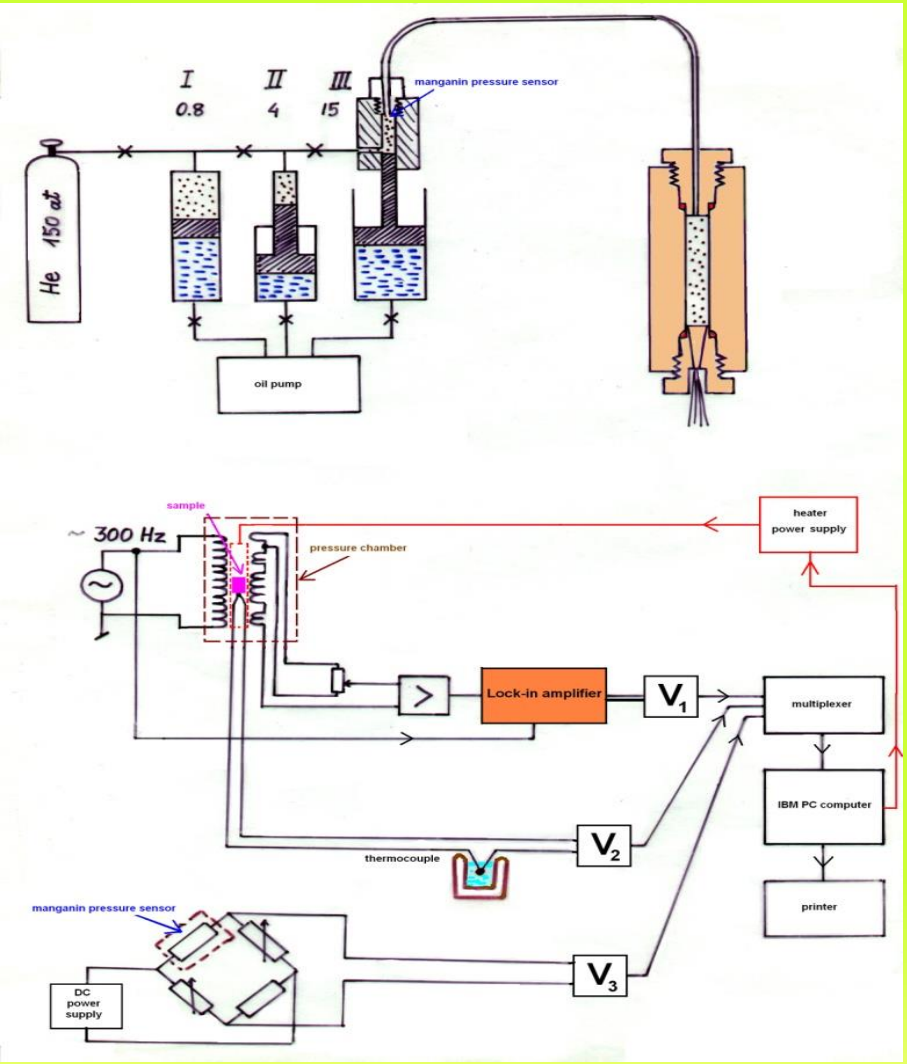
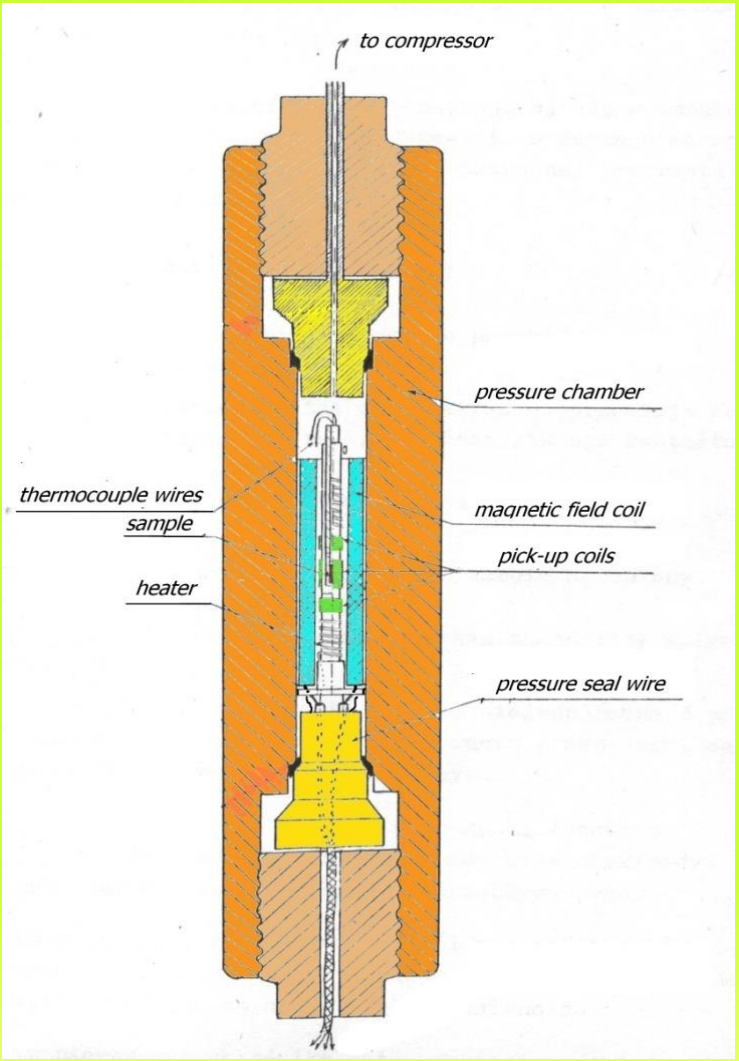
EXPERIMENTAL METHODS

* **X-ray diffraction**
  (Philips' diffractometer, ICh UJ, Cracow, Poland)
* **Neutron diffraction**
  (Institute Laue Langevin, Grenoble, France
  D1B spectrometer, $\lambda=2.4*10^{-10}$ m)
* **Magnetization measurements**
  (up to 10T, Insitute Néel, CNRS, Grenoble, France
  up to 23T, LNCI, CNRS, Grenoble, France
  up to 50T, Osaka University, Japan)
* **A.C. susceptibility measurements under pressure**
  (up to 2 GPa, CUT, Cracow, Poland
  up to 8 GPa, Osaka University, Okayama University, Japan)
* **Magnetization measurements under pressure**
  (up to 1.5 GPa and 17 T CUT, Cracow, Poland
* **Synchrotron diffraction under high pressure**
  (up to 60 GPa, Photon Factory, Tsukuba, Japan)
  Spring 8, Kobe, Japan)

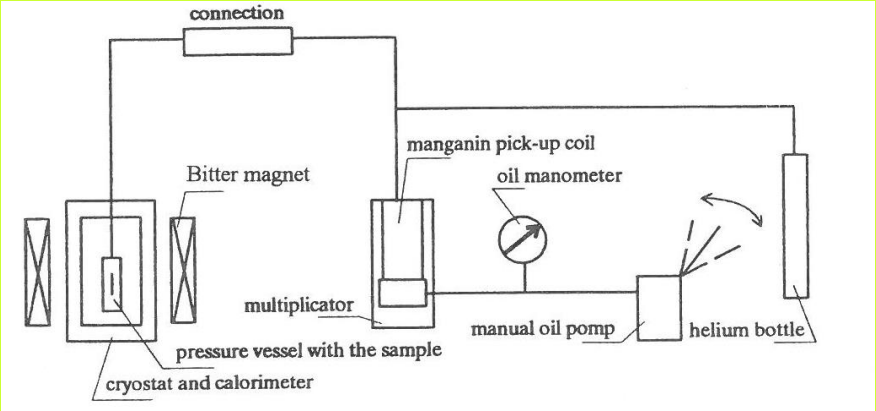
a.c. susceptibility and magnetization measurements under pressure up to 2 GPa, temp.range 4.2 – 400 K, Cracow, Poland

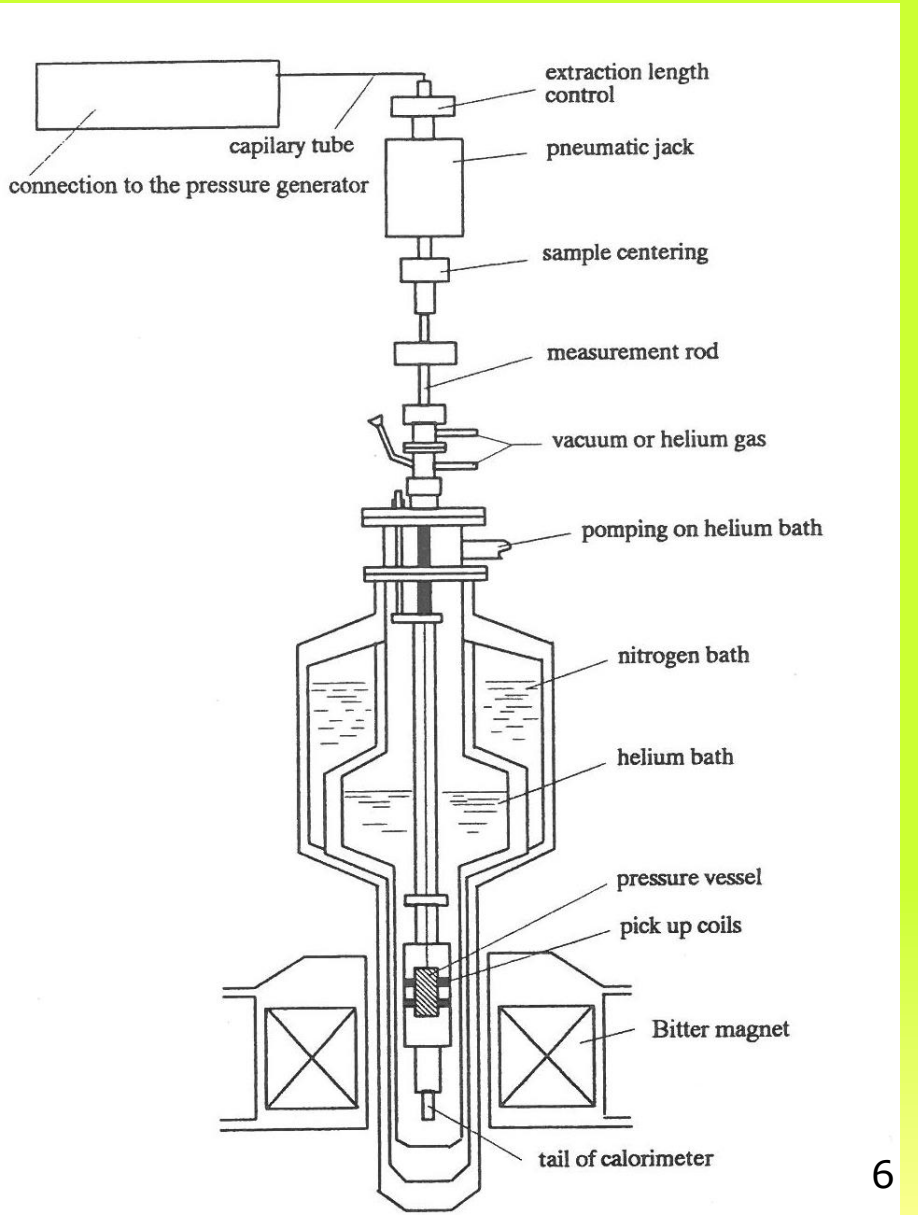




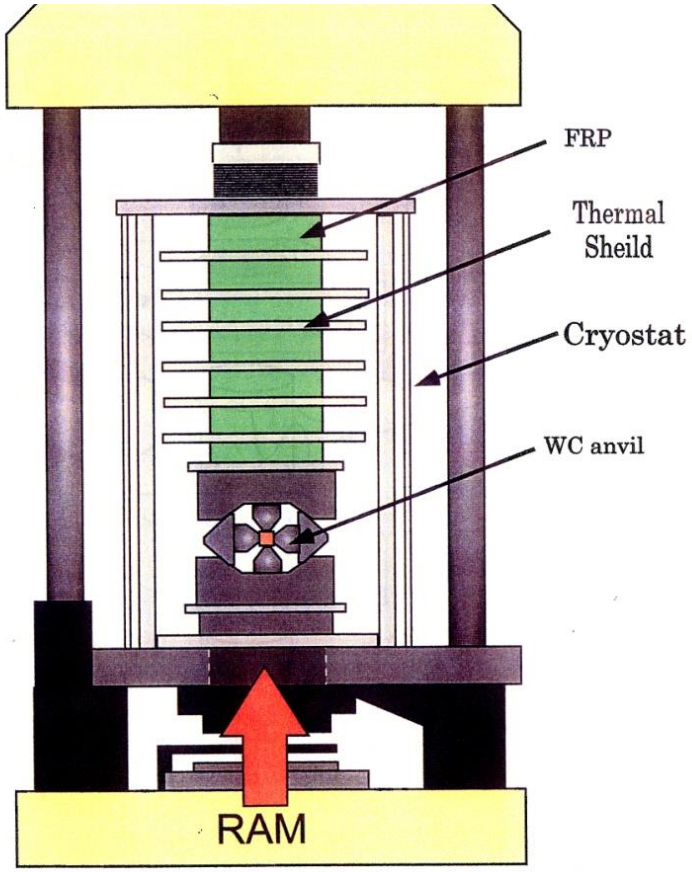
B. Średniawa, R. Zach, R. Duraj, M.Guillot Acta Phys. Pol. A vol. 97, 917 (2000)

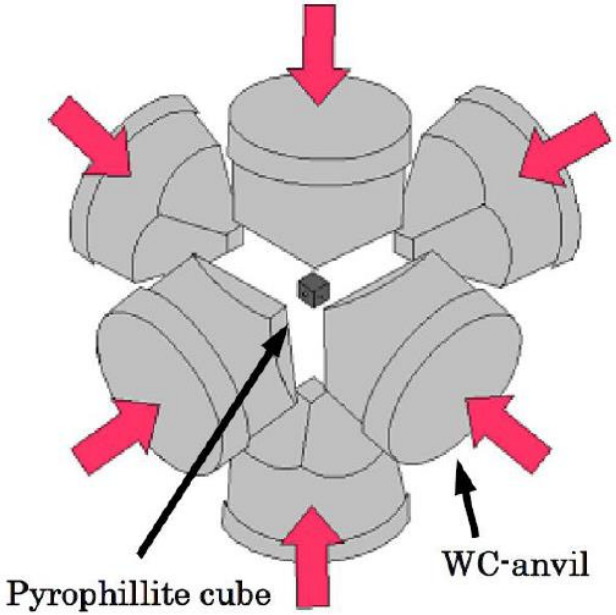
Magnetization measurements under pressure up to 2 GPa and up to 23 T, d.c. magnetic field, temp: 4.2 – 400 K, LMCI, Grenoble





a.c. susceptibility measurements under pressure up to 8 GPa, Osaka University, Okayama University, Japan

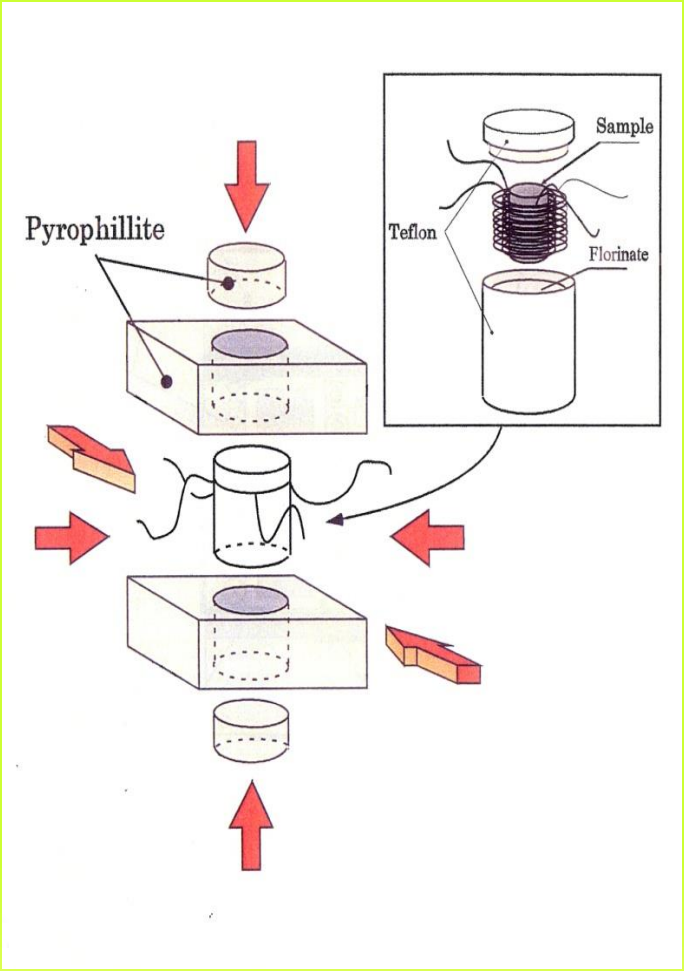


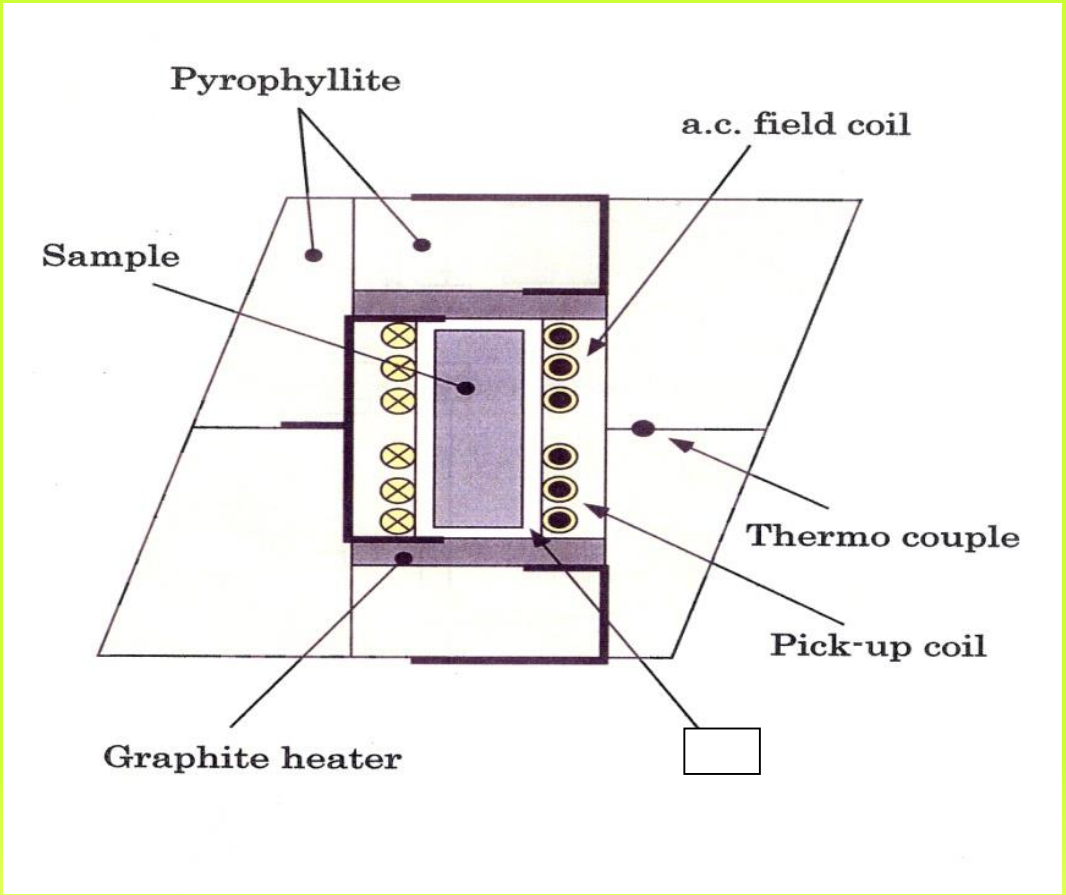


An illustration of the six tungsten-carbide anvils compressing a pyrophillite cube at the center of the anvils.

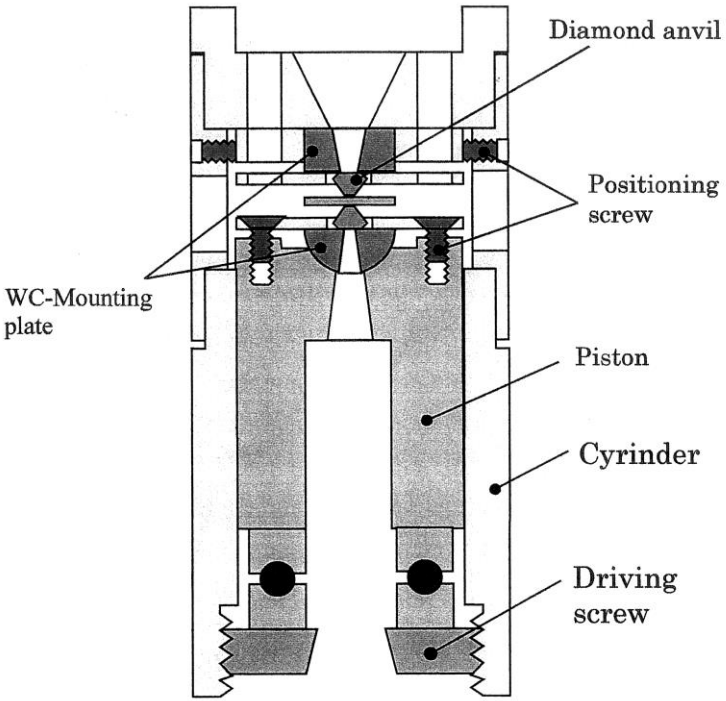
The set of the anvils is operated by a 250-ton press.

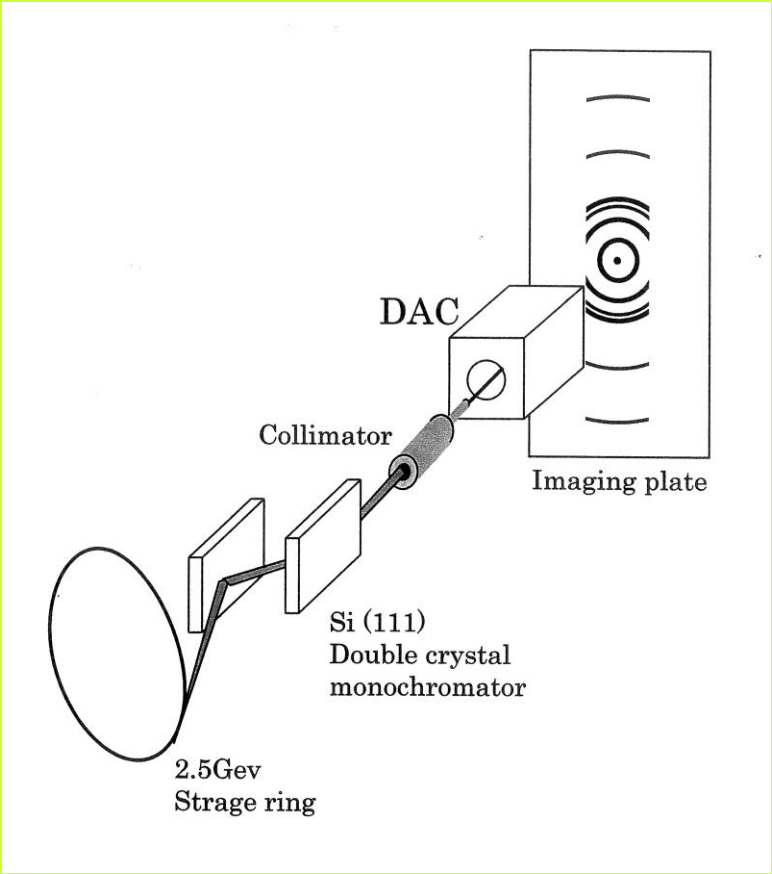
a.c. susceptibility measurements under pressure up to 8 GPa, Osaka University, Okayama University, Japan





Diffraction of synchrotron radiation under extreme pressure up to 60 GPa, Photon Factory, Tsukuba, Japan





λ=0.6199 A

Powder samples were filled together with a 4:1 methanol-etanol mixture in a hole of 0.1 mm in the gasket made of steinless steel

I. *Experiment under high pressure*

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III. *Magnetic properties of $MnFeP_{1-x}As_x$ series –pressure, magnetic field, electronic structure*

IV. *Magnetoelastic phase transitions, pressure effect, electronic structure*

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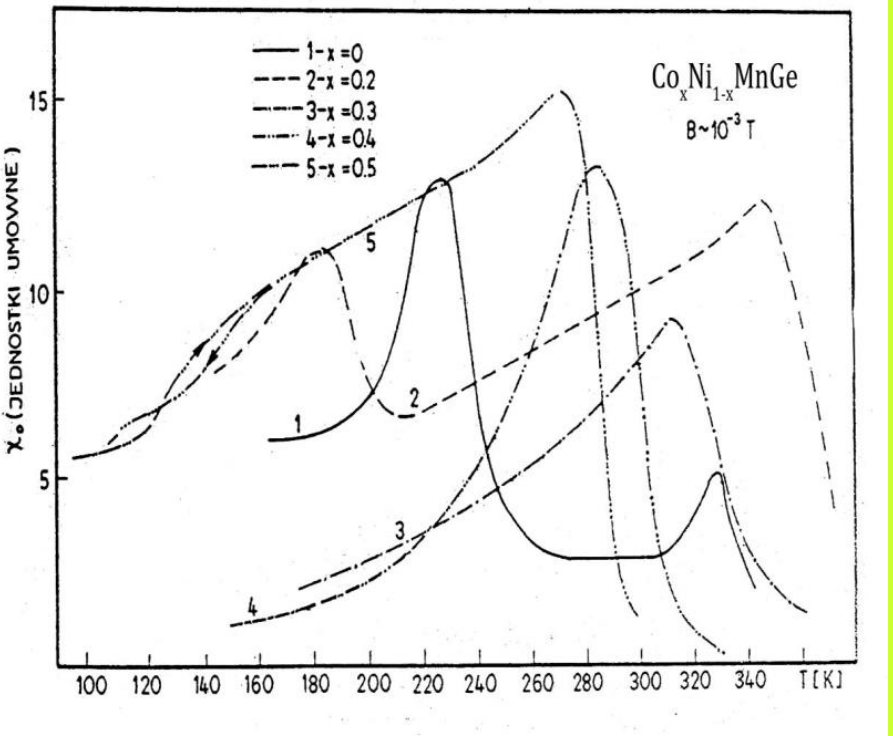
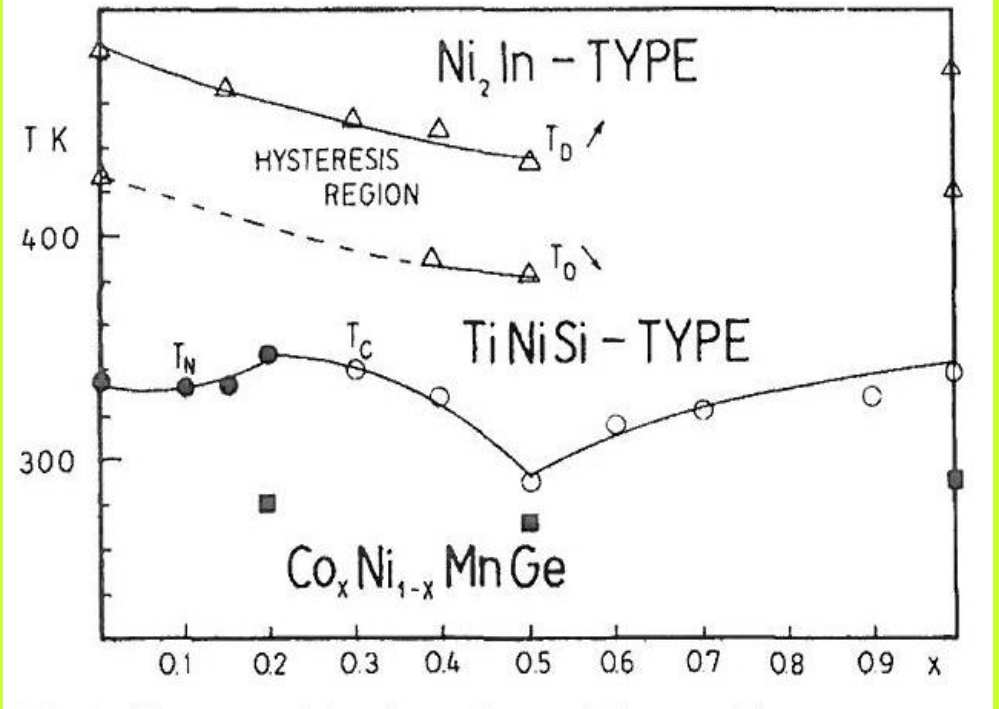
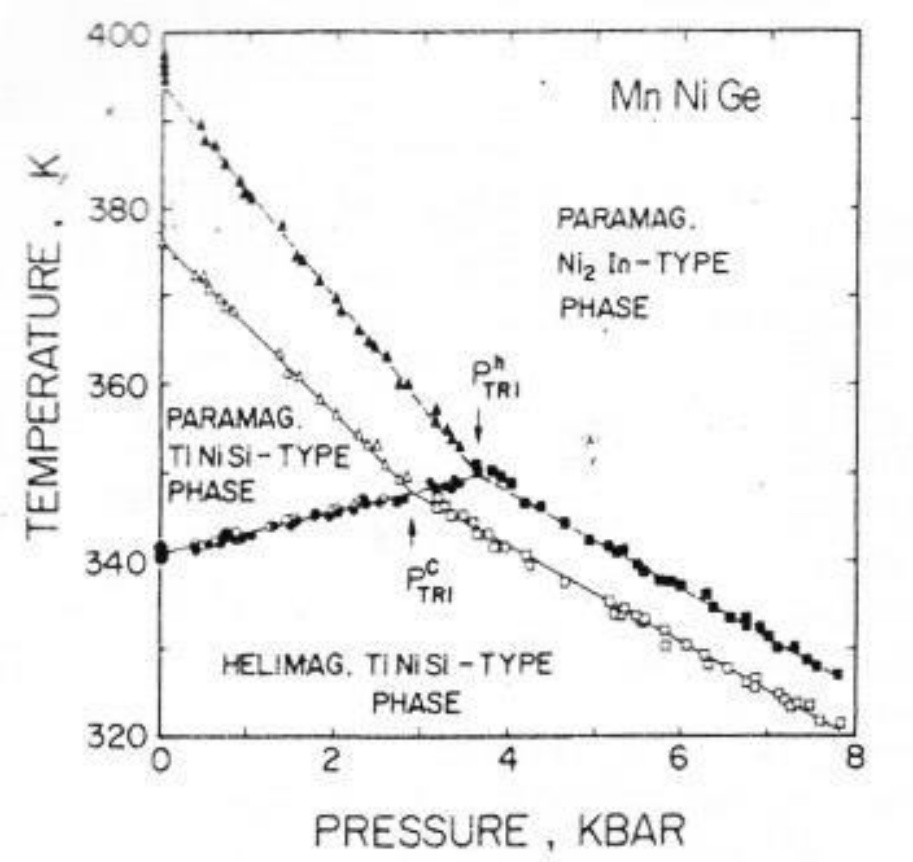
Pressure induced magnetostructural phase transitions in $Co_xNi_{1-x}MnGe$

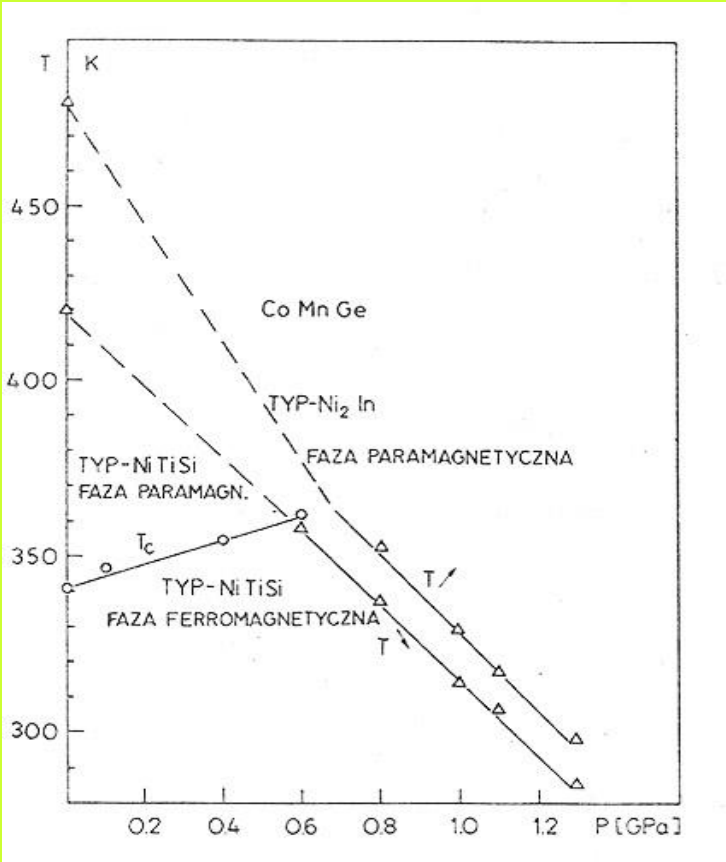




NiMnGe and CoMnGe shows the evidence of the structural and magnetic transitions. The structural transition appears the discontinuous distortion type from the high temperature hexaginal Ni_2In-type crystal structure to the distorted orthorhombic TiNiSi-type phase.

Pressure induced magnetostructural phase transitions in $Co_xNi_{1-x}MnGe$

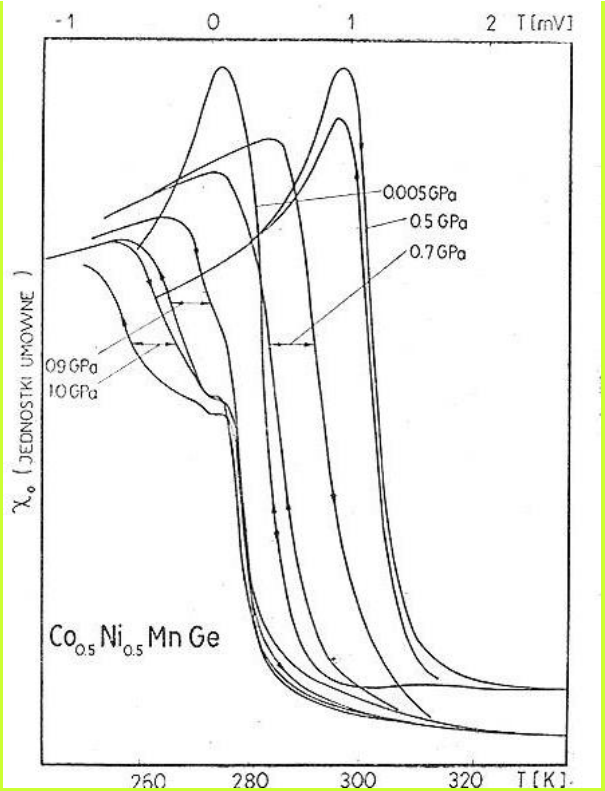


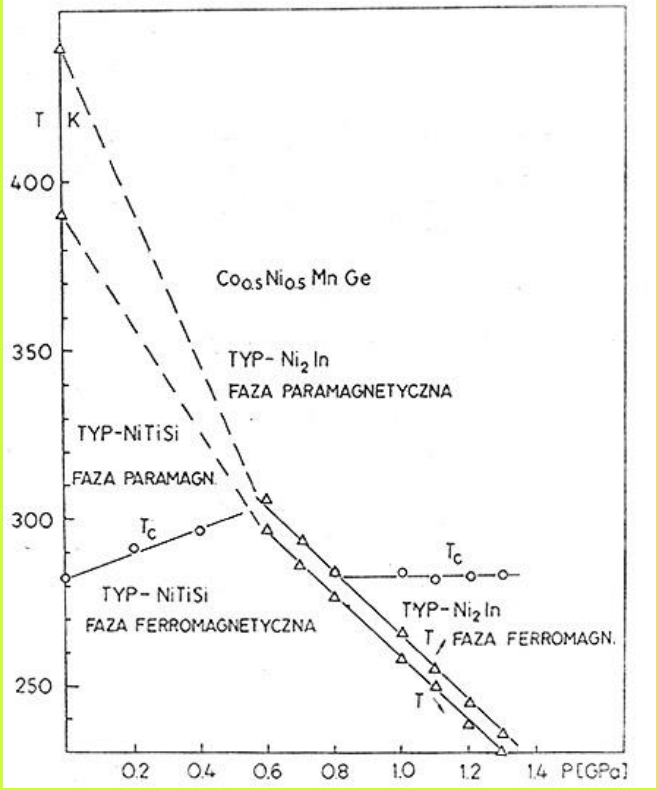


In both compounds the critical points on *(P,T)* phase diagrams were found

S.Anzai, K.Ozawa Phys. Rev. B 18, 2173 (1978) concers NiMnGe
S.Nizioł, A.Zięba, R.Zach, M.Baj, L.Dmowski J.Mag. Mag. Mat. 38, 205 (1983) concerns $Co_xNi_{1-x}MnGe$
R.Zach, R.Duraj, A. Szytuła Phys. Stat. Sol. A84 (1984) 229

Pressure induced magnetostructural phase transitions in $Co_xNi_{1-x}MnGe$





The interaction of magnetic (T_C) and first-order distortion-type structural T_D transitions in $Co_xNi_{1-x}MnGe$ system was investigated using the ac susceptibility method under hydrostatic pressure. For all compositions T_C increases and T_D decreases versus pressure

$$G(T,P,\zeta,\eta)=a(T-\theta_D)\zeta^2+e\zeta^4+k\zeta^6+b(T-\theta_C)\eta^2+f\eta^4+g\zeta^2\eta^2$$

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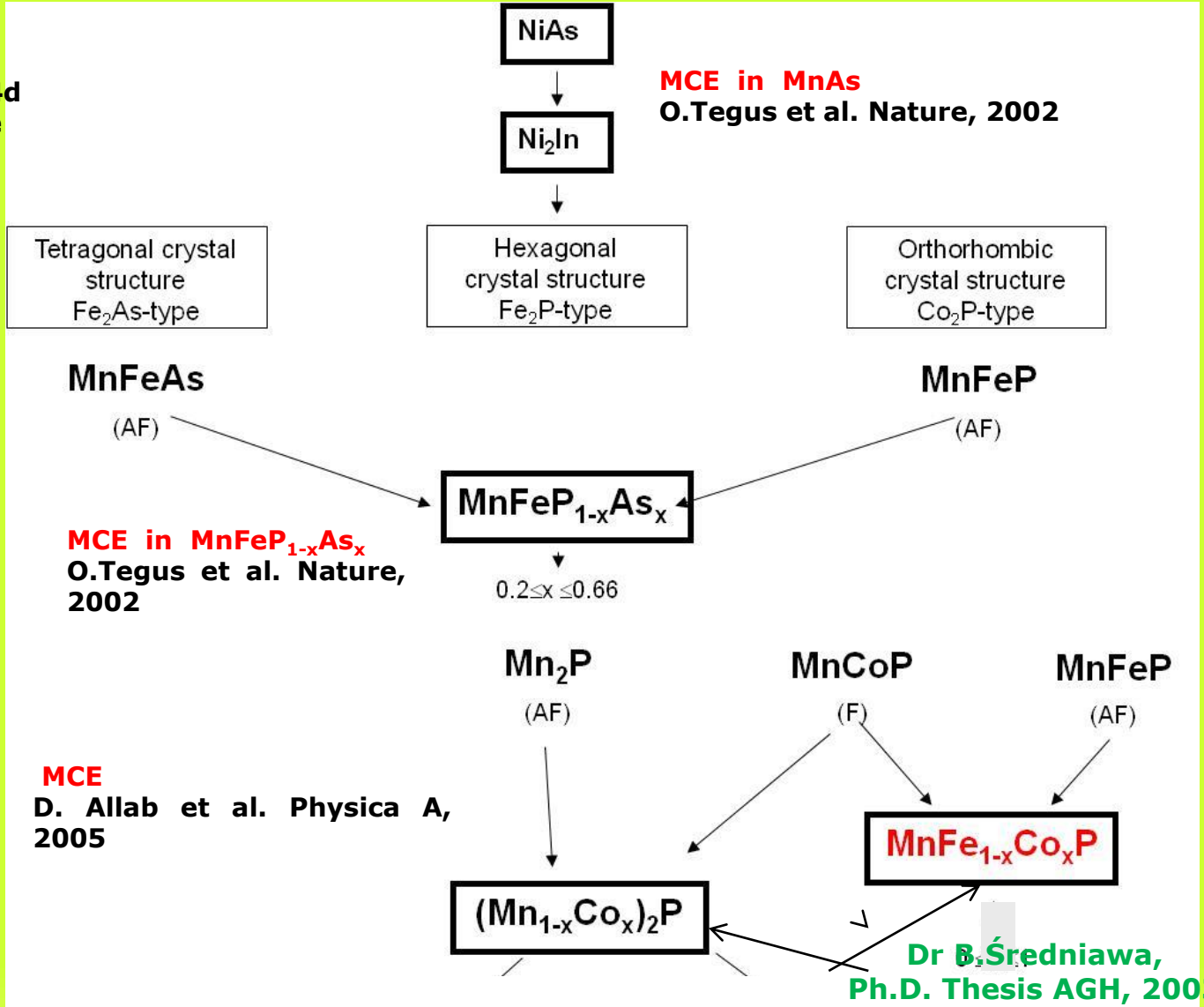
MM'X - type
M -- metal 3d
M'-- metal 3d,4d
X-- As,P,Si,Ge



MCE in MnAs
O.Tegus et al. Nature, 2002

MCE in $MnFeP_{1-x}As_x$
O.Tegus et al. Nature, 2002

MCE
D. Allab et al. Physica A, 2005

Dr B.Średniawa, Ph.D. Thesis AGH, 2003

$MnRu_{1-x}Rh_xAs$ (0 ≤x≤1)

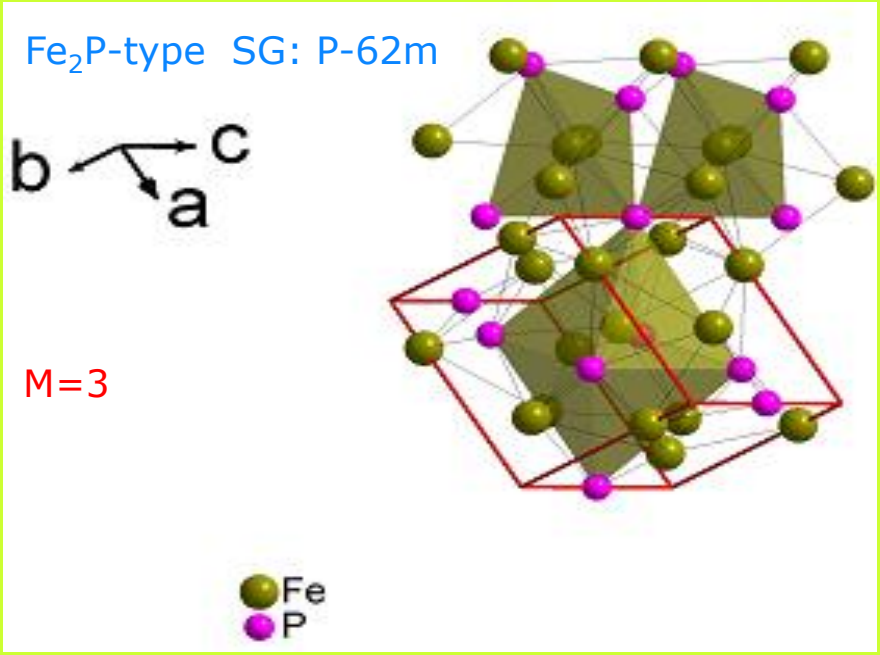
MCE
R. Zach et al. Sol. St. Phenomena 2013

$MnRh_{1-x}Co_xAs$

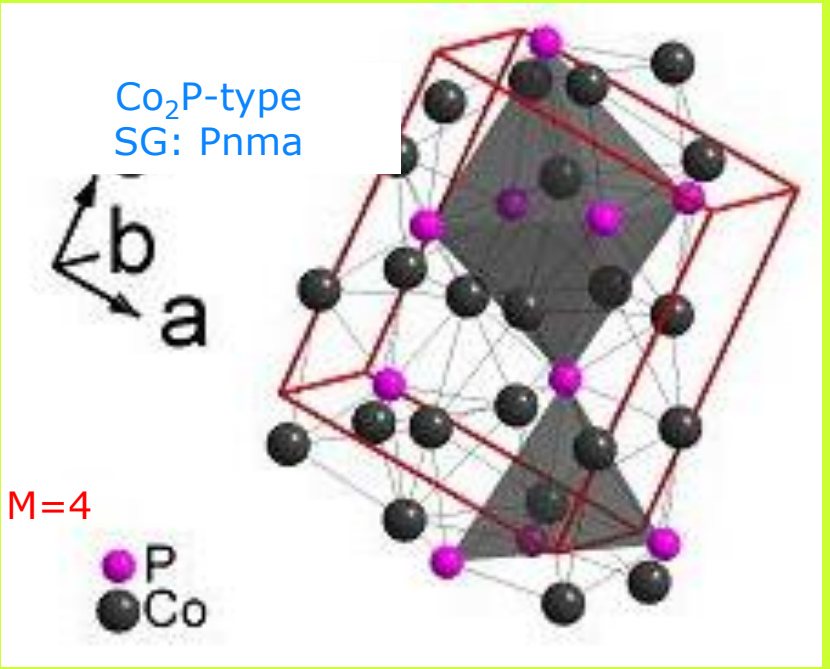
0≤x≤0.8

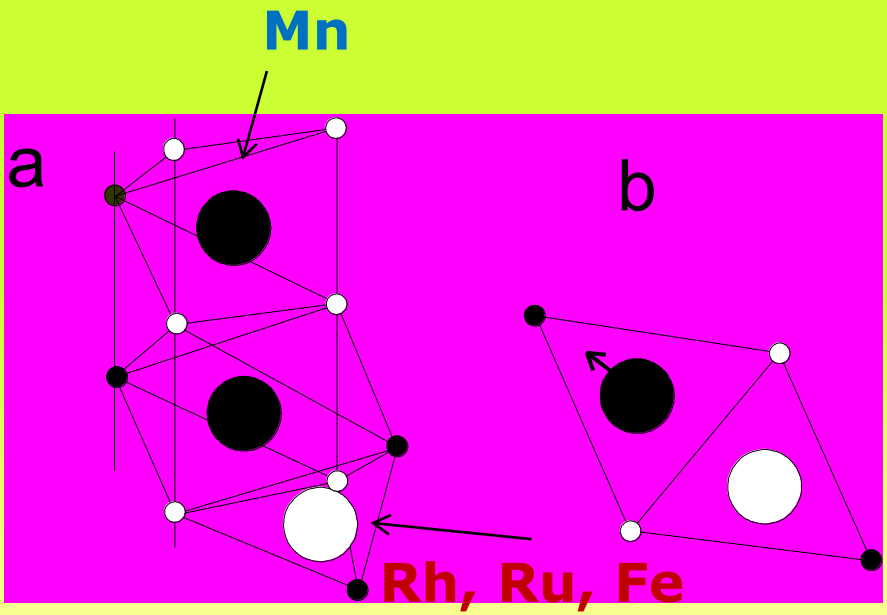
0.9≤x≤1

Fe_2P-type SG: P-62m

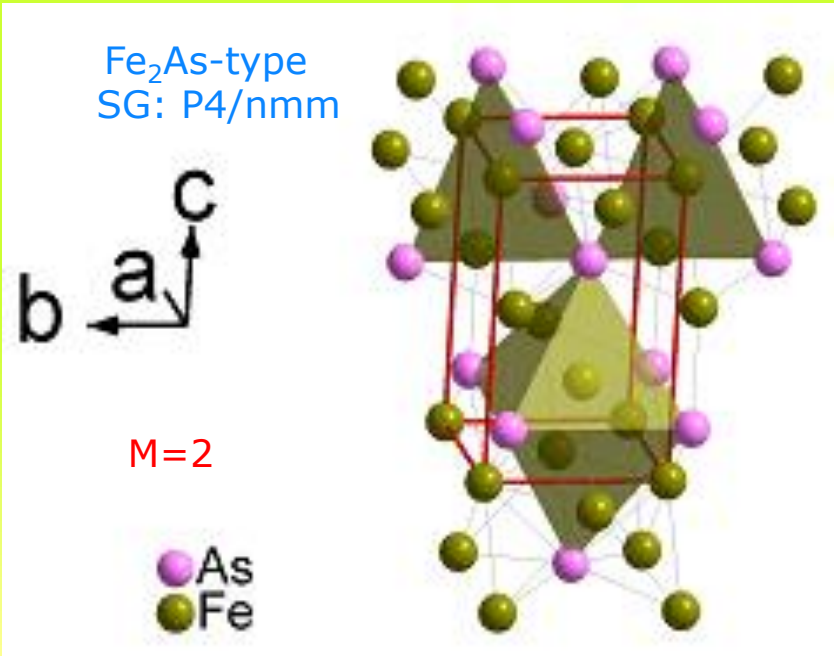


Co_2P-type
SG: Pnma

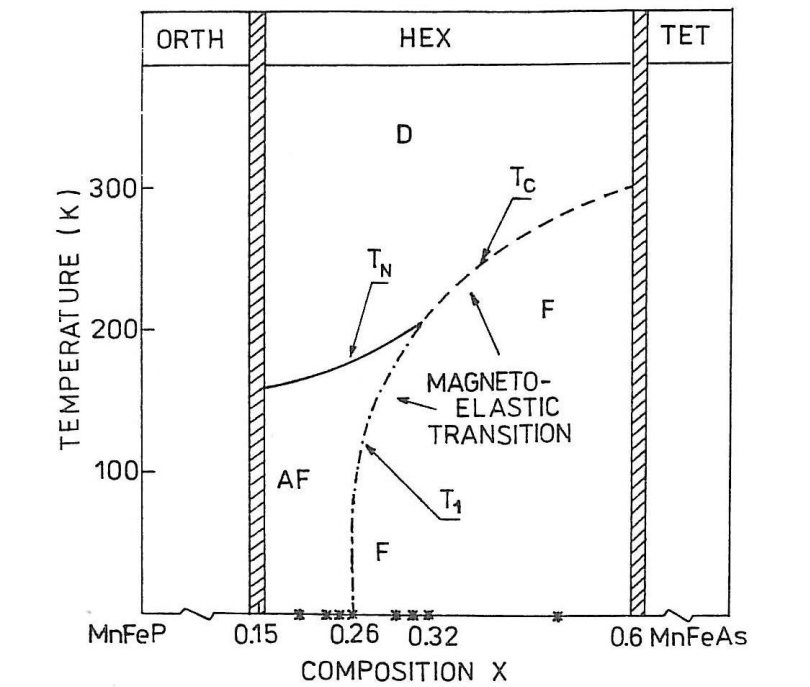


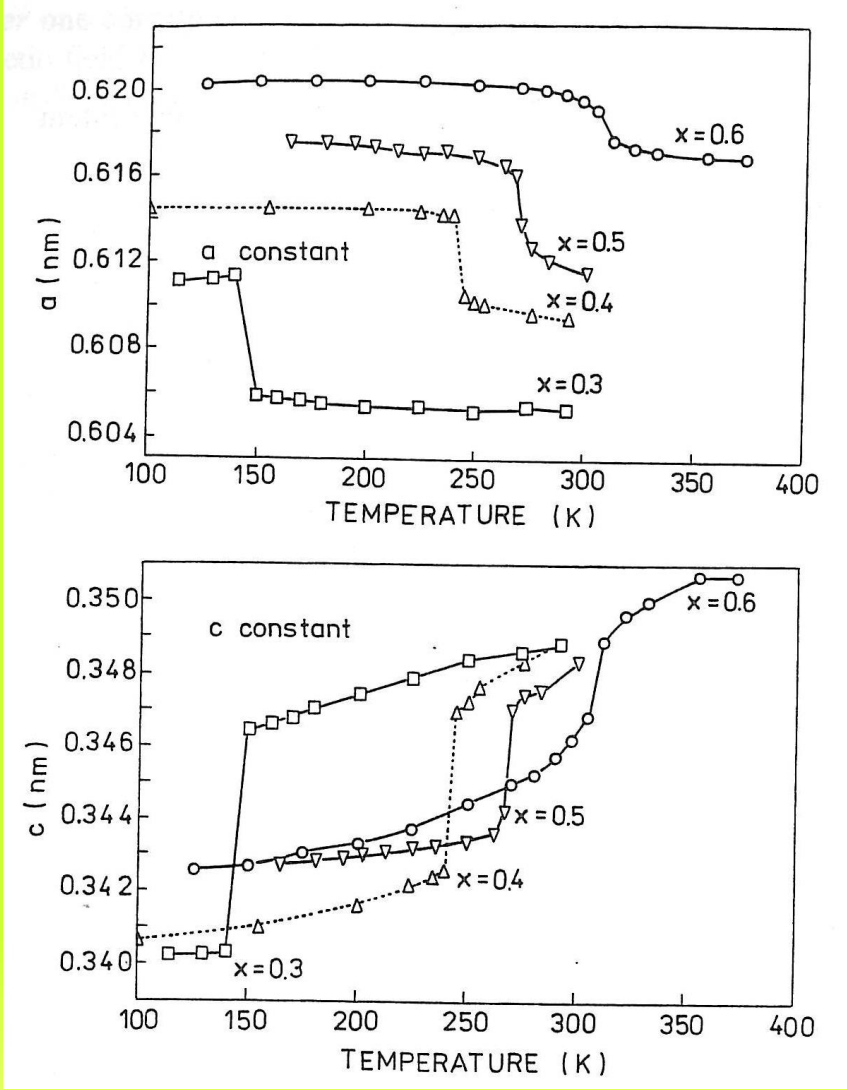


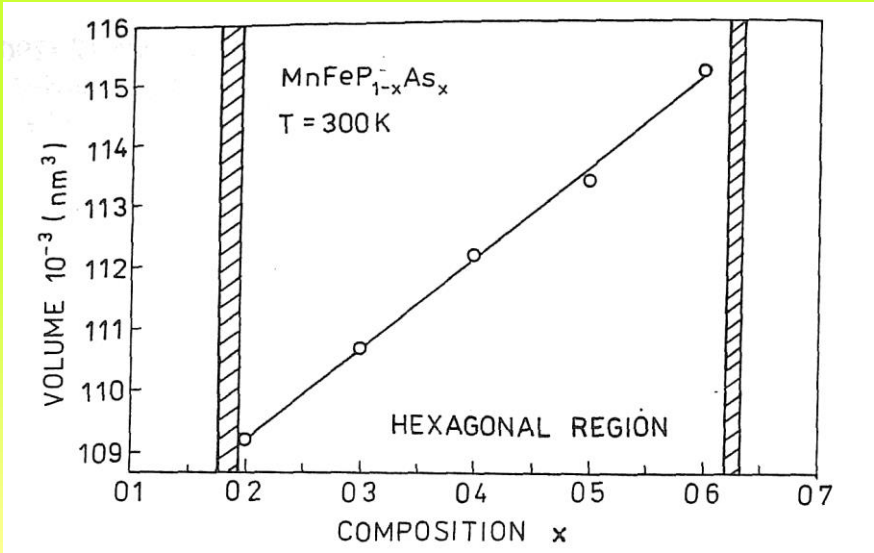
Fe_2As-type
SG: P4/nmm



Magnetic properties of $MnFeP_{1-x}A_x$ series

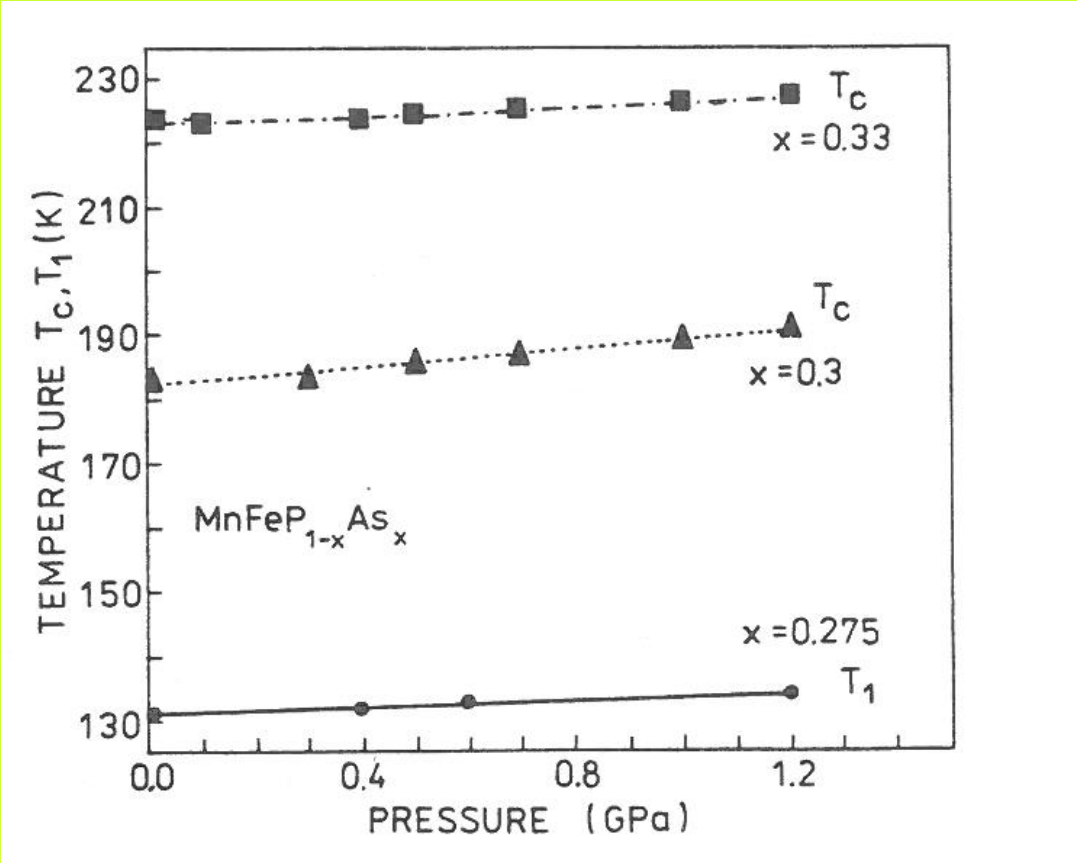






A. Krumugel-Nylund Thesis, (Paris 1974)
R.Zach, Hab. Thesis, WFiIS, AGH University, (1997)

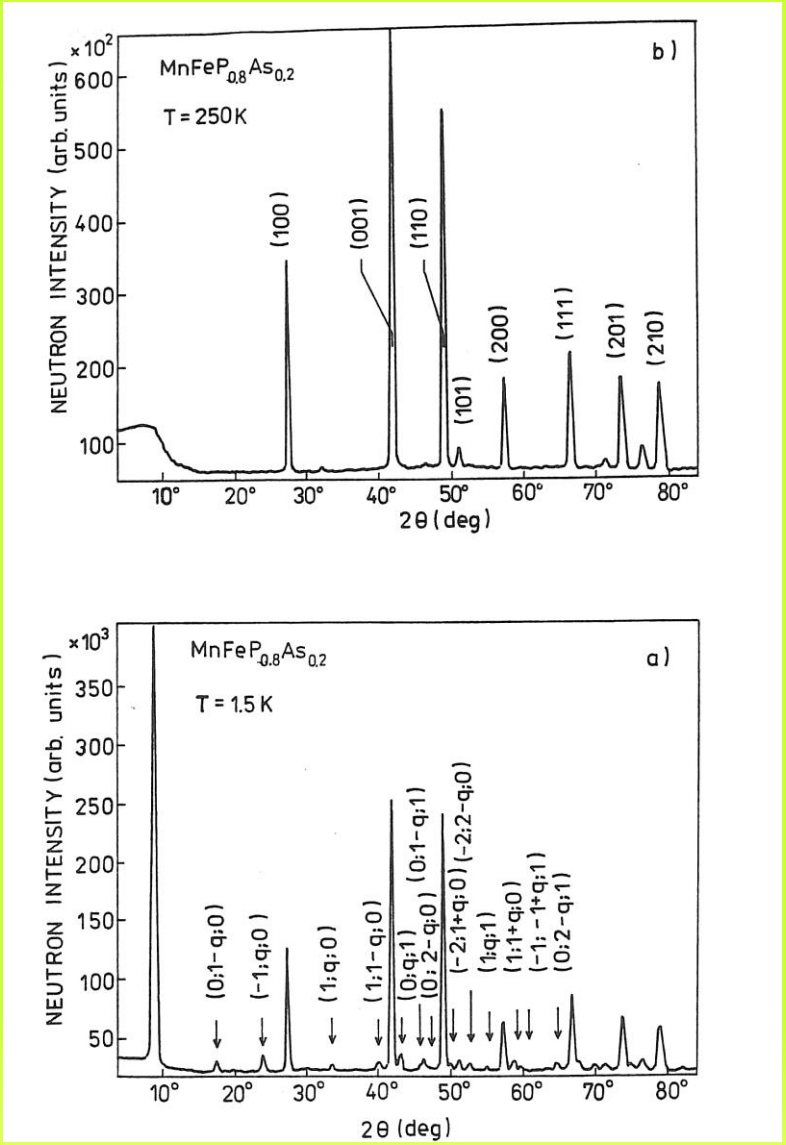
(P,T) magnetic phase diagram for $MnFeP_{1-x}As_x$

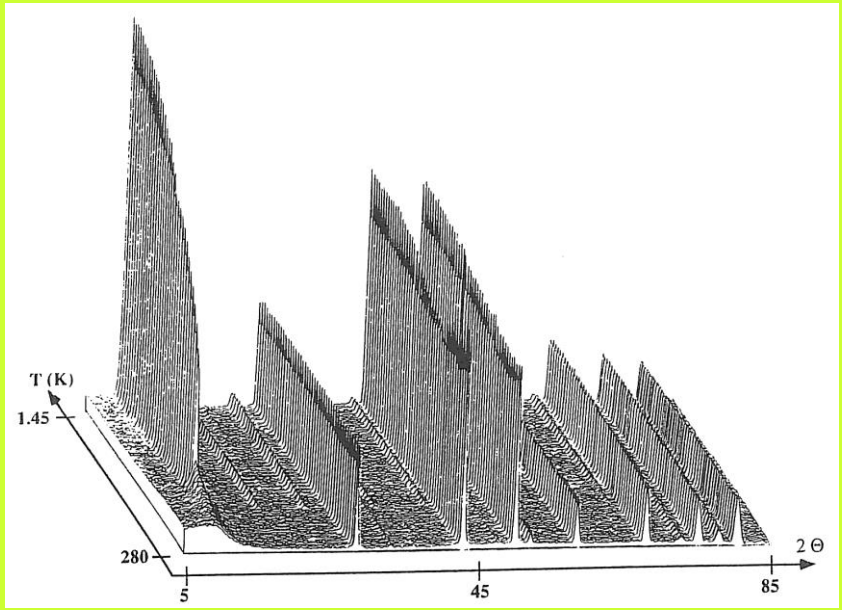


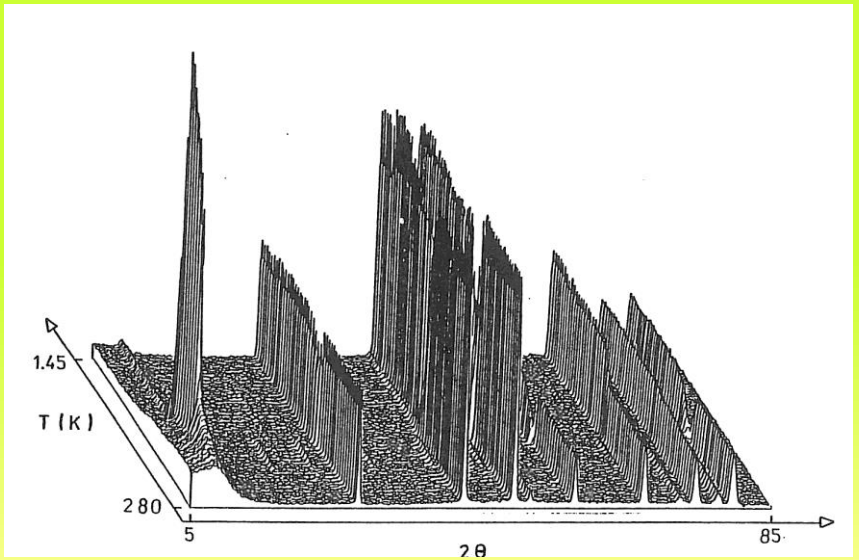
No the unit cell volume change at the transitions at T_C and T_1

Magnetic properties of $MnFeP_{1-x}A_x$ series

X=0.2





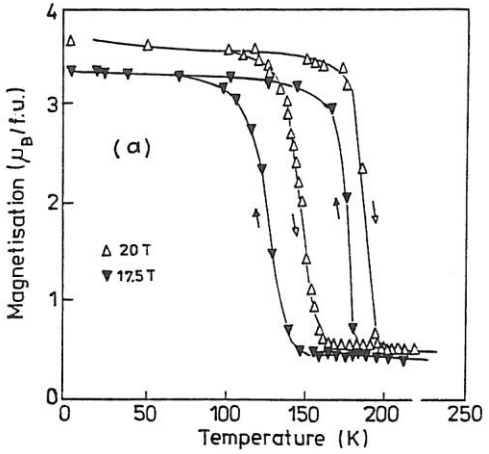


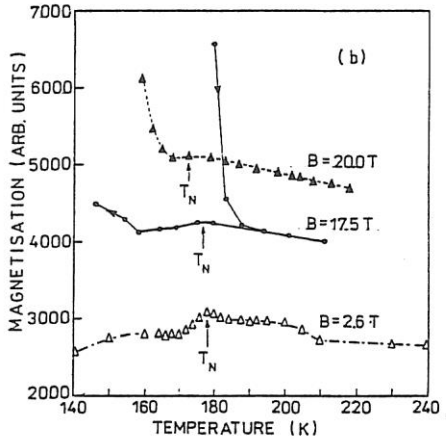
X=0.2

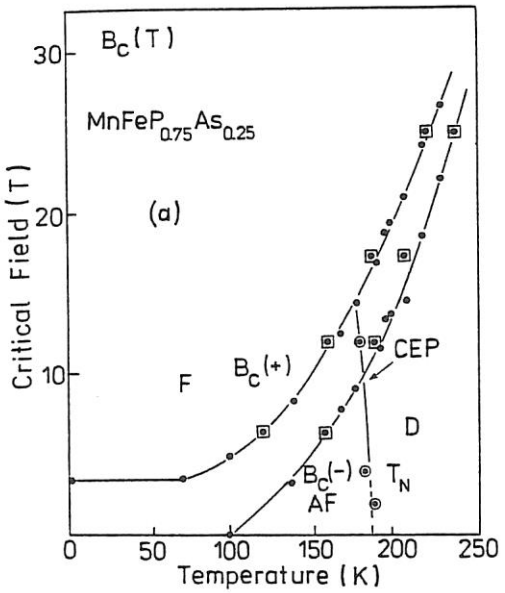
X=0.275

R.Zach, Hab. Thesis, WFiIS, AGH University, (1997)

Magnetic properties of $MnFeP_{1-x}A_x$ series







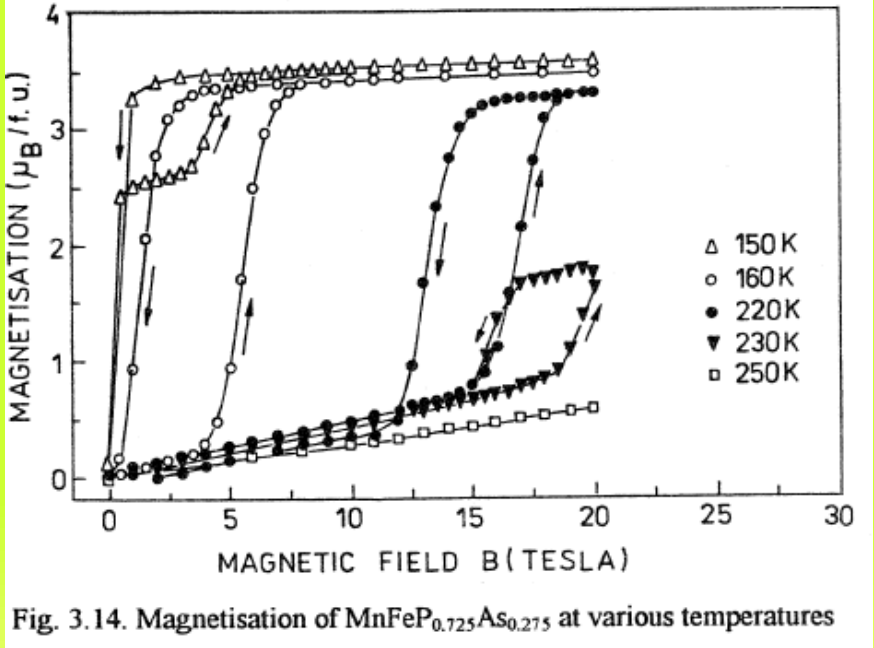
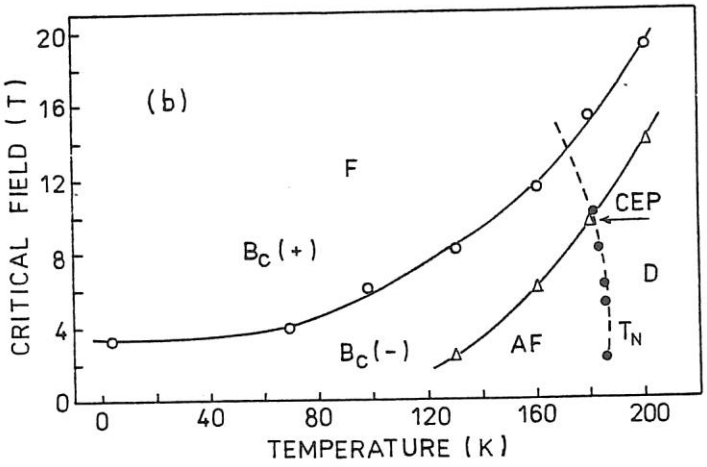


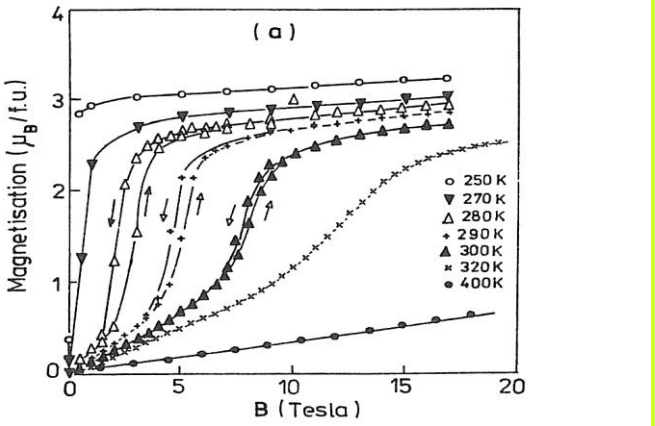
Fig. 3.14. Magnetisation of $MnFeP_{0.725}As_{0.275}$ at various temperatures

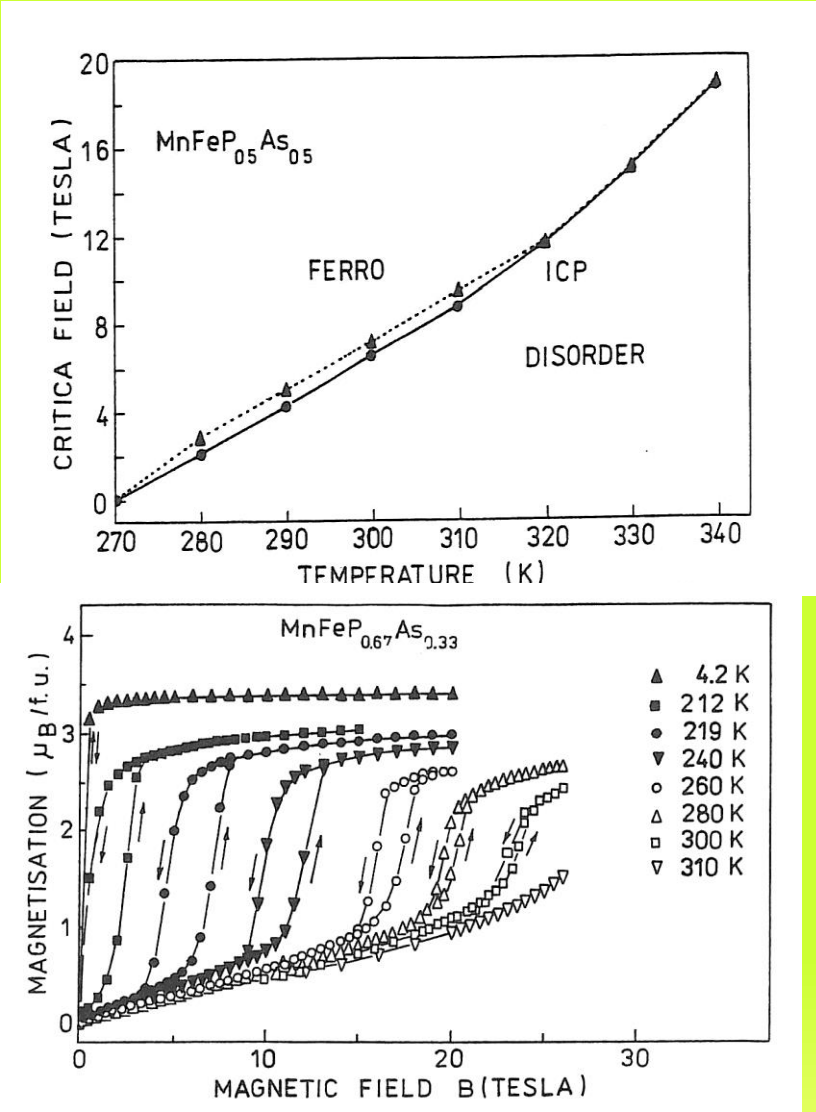


Critical end point – the critical point where the line of the second order phase transition terminates in the line of the discontinuous phase boundary. The discontinuous phase boundaries are tagent one to each other at the CEP

R.Zach, M.Guillot, R.Fruchart J. Magn. Magn. Mat. 89 221 (1990)

Magnetic properties of $MnFeP_{1-x}A_x$ series





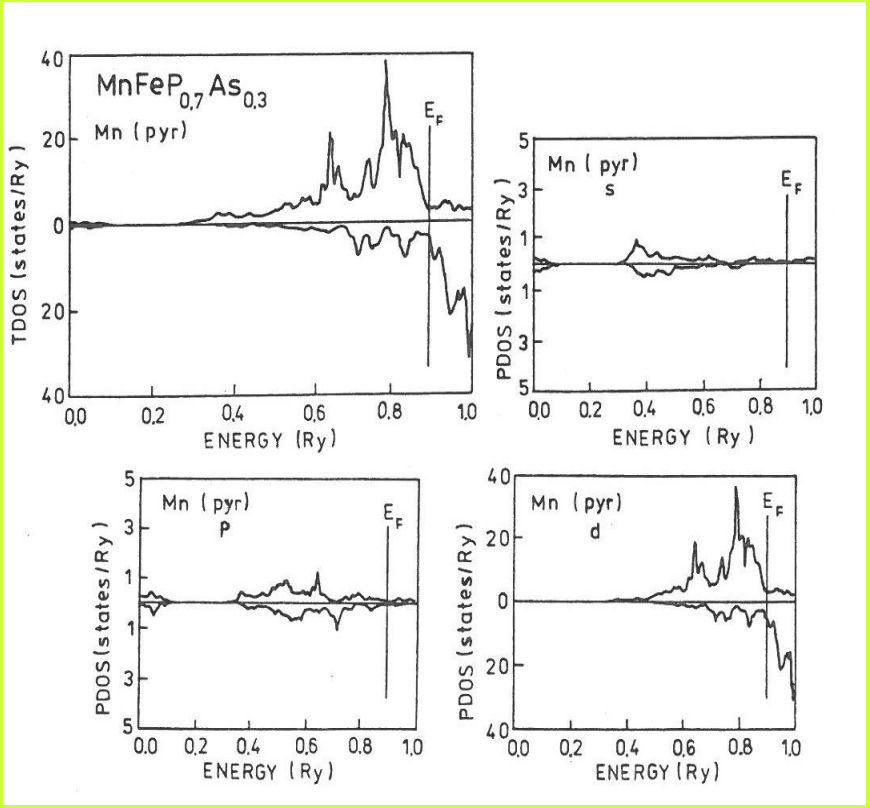
Isolated Critical Point –

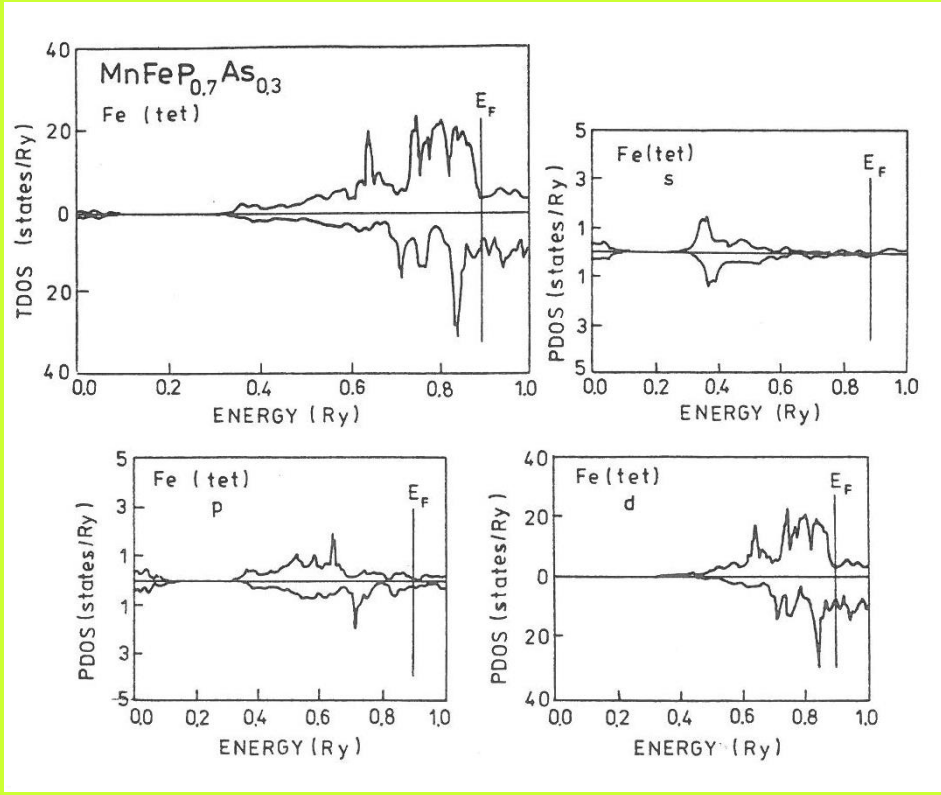
Tshe critical point where the first order phase transition between the state and the ordered one terminates. The critical line separates two different phaseshaving the same symmetry.

R.Zach, M.Guillot, J.Toboła J.Appl. Phys. Vol. 83 (1998) 7237

KKR-CPA electronic band structure calculations – $MnFeP_{1-x}As_x$

x=0.3





MnFe(As,P)
Measured and calculated magnetic moments
KKR-CPA

	Magnetic moment [μ_B]		Hyperfine field [T]	
	Measured	*Calculated*	*Measured*	*Calculated*
$MnFeP_{0.7}As_{0.3}$				
Mn	2.55 (0.2)	3.02	--------	18,6
Fe	1.25 (0.2)	1.25	19.1	15,3
$MnFeP_{0.5}As_{0.5}$				
Mn	2.02 (0.3)	3.01	--------	18,2
Fe	1.48 (0.3)	1.20	18.1	15,6
MnRhAs				
Mn	3.5 ÷ 3.6	3.42		
Rh	0 ÷ 0.2	0.0		
MnRhP				
Mn	3.13 (0.1)	2.99		
Rh	0.02 (0.1)	0		
$MnRhP_{0.8}As_{0.2}$				
Mn	3.14(0.1)	3.2		
Rh	--------	0		

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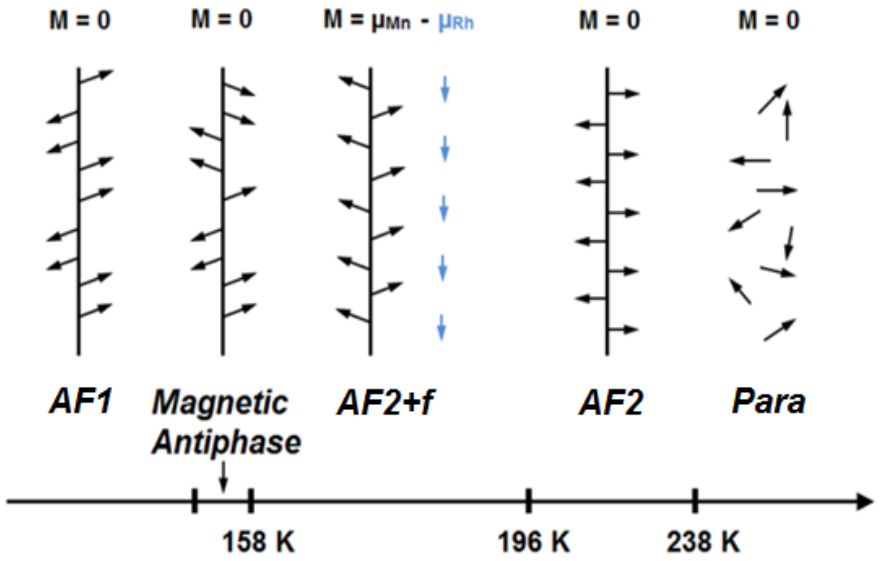
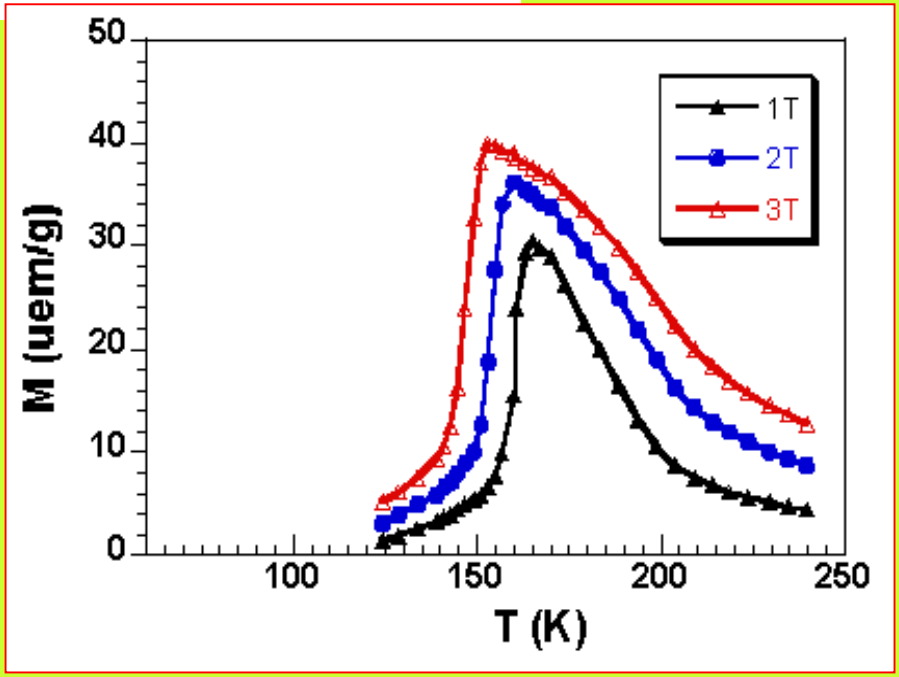
Magnetic structures of MnRhAs





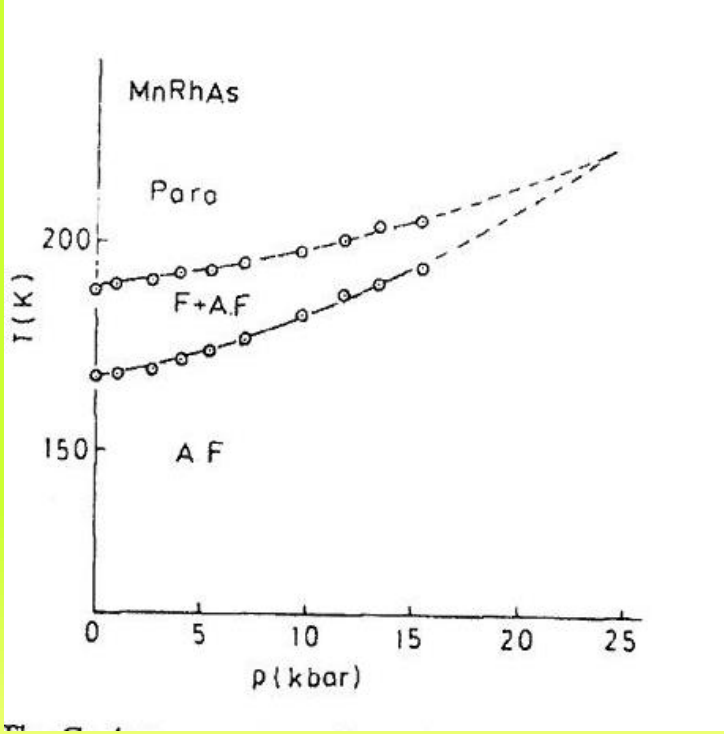
Crystal structure: hexagonal Fe_2P-type,
T_t = 158 K and T_C=196 K magnetoelastic phase transitions
T_N = 238 K Néel temperature
***AF1* – non-collinear antiferromagnetic phase,**
Magnetic Antiphase boundaries (ab) ranging between the *AF1* and *AF2+f* configuration,
***AF2 + f* – complex antiferromagnetic + ferromagnetic ordering,**
***AF2* – collinear antiferromagnetic phase,**
Para - paramagnetic state

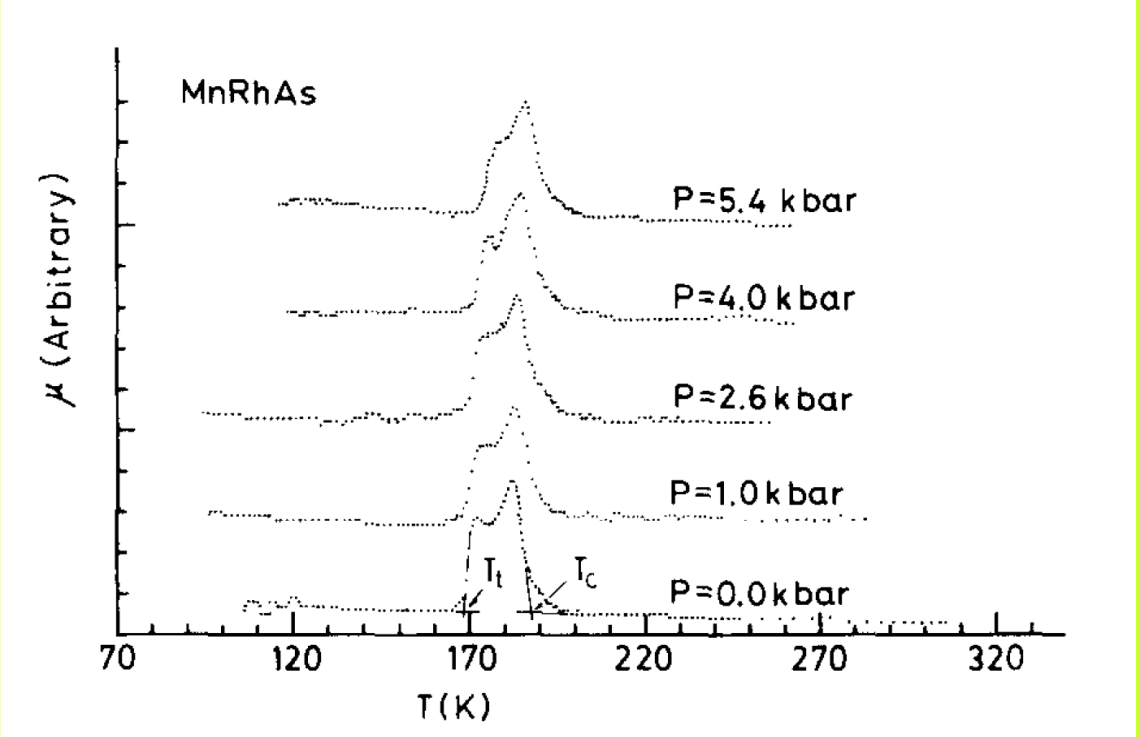
B. Chenevier, PhD Thesis UJF Grenoble, France (1990).
B. Chenevier, M. Bacmann, D. Fruchart, J.P. Sénateur, R . Fruchart, Phys. Stat. Sol. (a) 90(1) (1985) 331.
M. Balli, D. Fruchart, R. Zach, J. Appl. Phys. 115 (2014) 2039091.

MnRhAs under pressure up to 1.5 GPa

Magnetisation vs. T recorded at constant pressure

(P,T) magnetic phase diagram

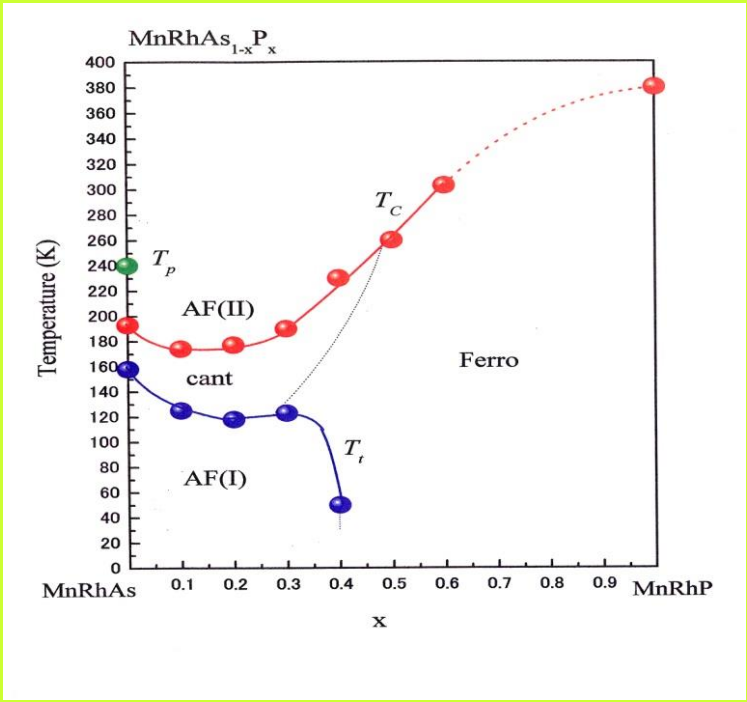


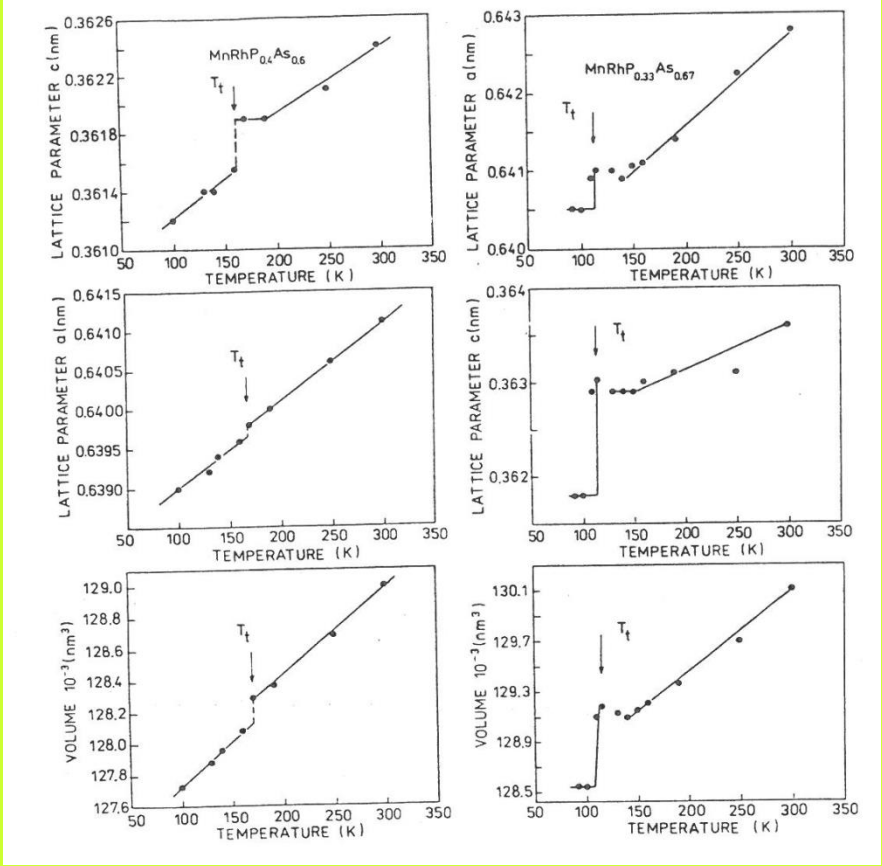


It is found that T_c and T_t increases vs. applied pressure and the pressure dependence of T_C and T_t is nonlinear. Kanomata et al. suggested critical point at P=2.45 GPa and T=224 K

T. Kanomata et al. J.Mag. Mag. Mat. 68, 286 (1987)

Magnetic and crystal structure properties of $MnRhP_{1-x}As_x$



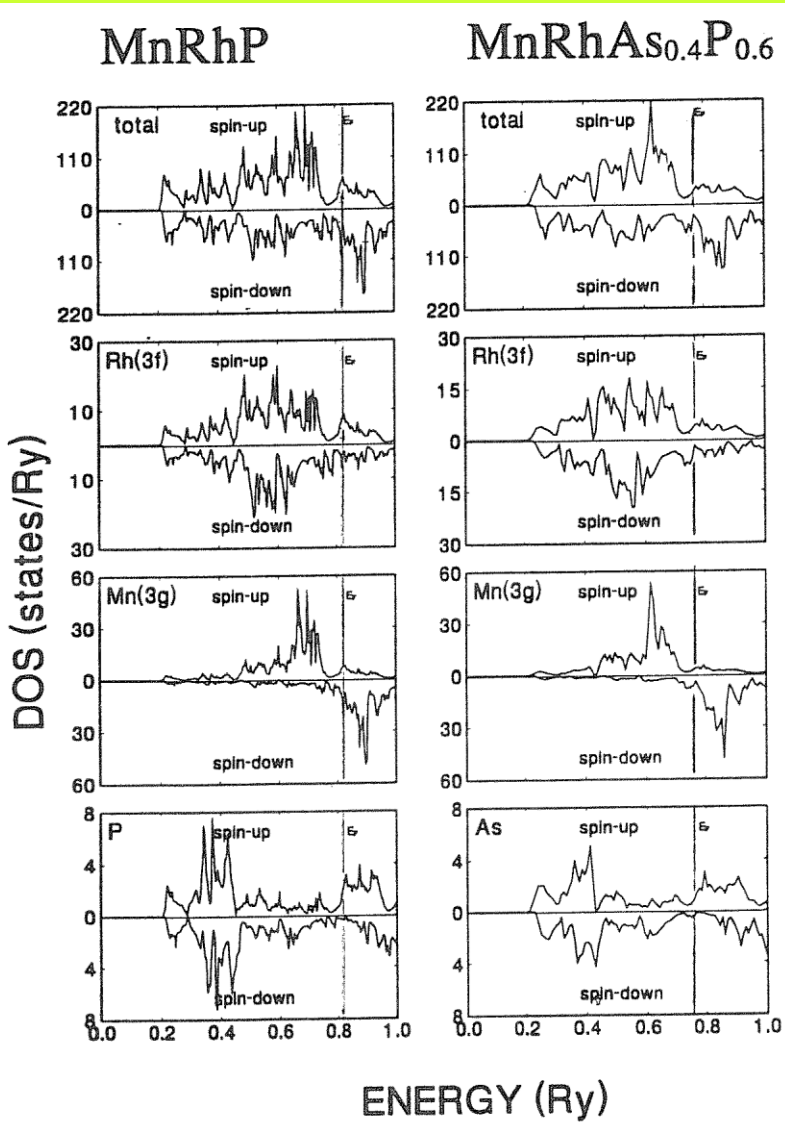


A. Roger, Thesis, Paris 1970
B. N. Fuji Thesis Osaka 2002

Crystal structure: hexagonal Fe_2P-type
Volume of elementary cell linearly decreases with the <u>increase</u> of the phosphorus content
Transitions at T_t: magnetoelastic phase transition
The abrupt volume change is found for two studied contents.

R.Zach, Hab. Thesis, WFiIS, AGH University, (1997)

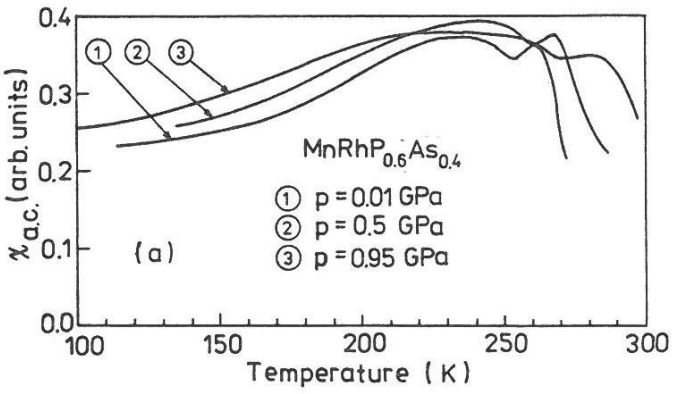
Electronic band structure calculations KKR (KKR_CPA) MnRhP and $MnRhAs_{0.4}P_{0.6}$

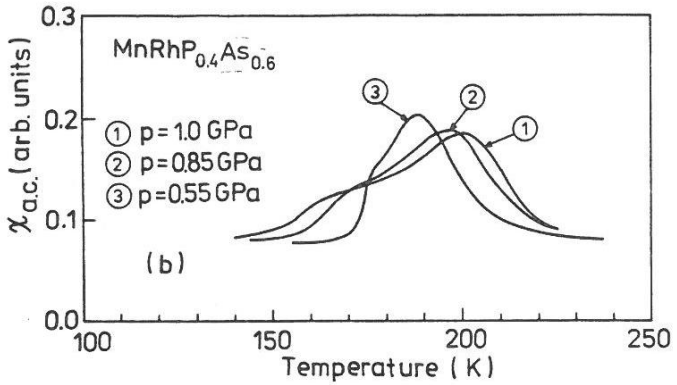


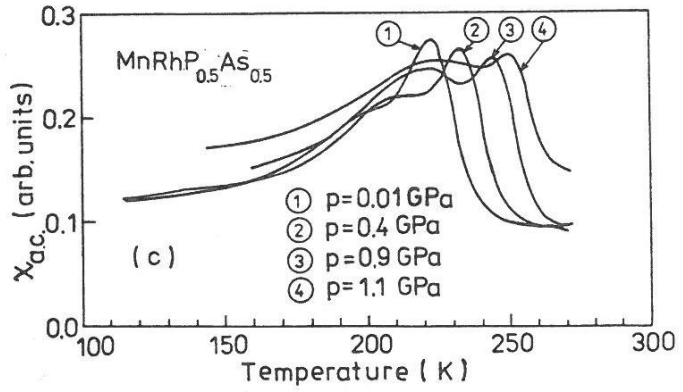
MnFe(As,P)

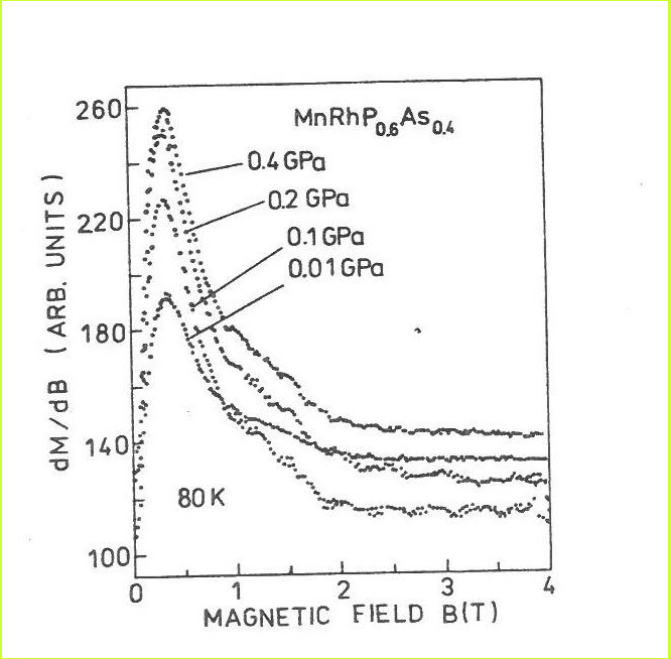
	Magnetic moment [μ_B]		Hyperfine field [T]	
	Measured	*Calculated*	*Measured*	*Calculated*
		$MnFeP_{0.7}As_{0.3}$		
Mn	2.55 (0.2)	3.02	--------	18,6
Fe	1.25 (0.2)	1.25	19.1	15,3
		$MnFeP_{0.5}As_{0.5}$		
Mn	2.02 (0.3)	3.01	--------	18,2
Fe	1.48 (0.3)	1.20	18.1	15,6
		MnRhAs		
Mn	3.5 ÷ 3.6	3.42		
Rh	0 ÷ 0.2	0.0		
		MnRhP		
Mn	3.13 (0.1)	2.99		
Rh	0.02 (0.1)	0		
		$MnRhP_{0.8}As_{0.2}$		
Mn	3.14(0.1)	3.2		
Rh	--------	0		

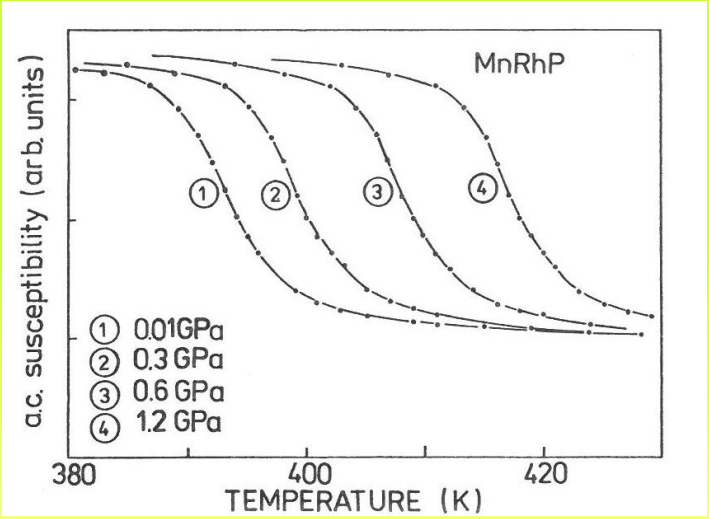
$MnRhP_{1-x}As_x$ under pressure up to 1.5 GPa





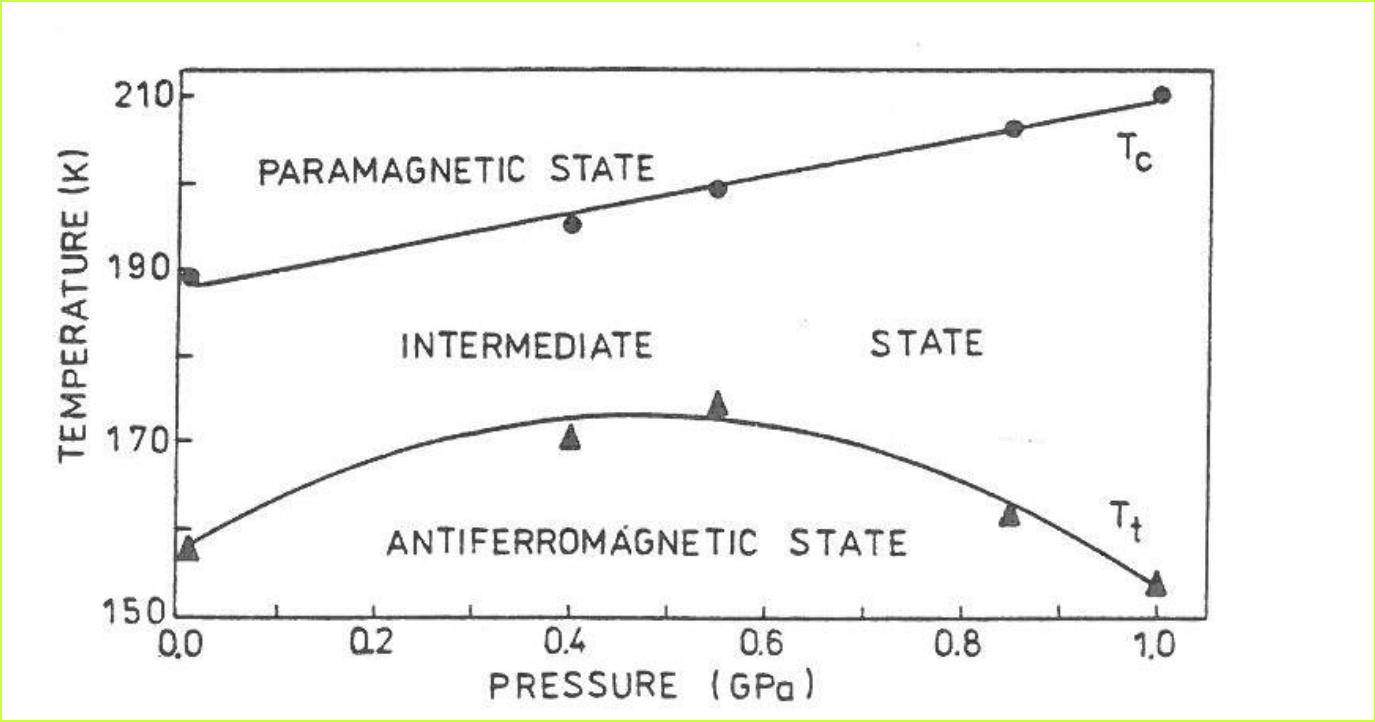






$MnRhAs_{1-x}P_x$ under pressure up to 1.5 GPa

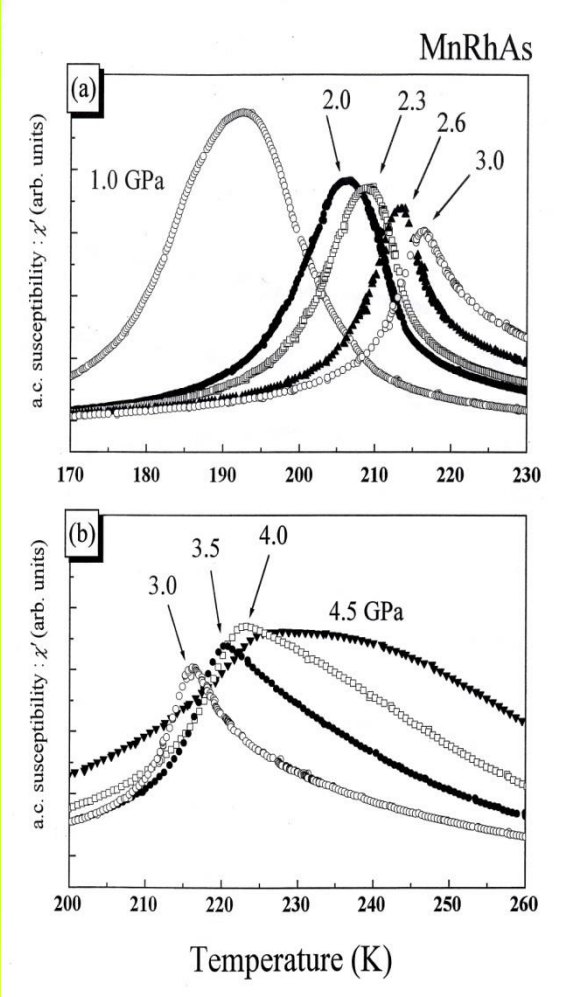
$MnRhP_{0.4}As_{0.6}$

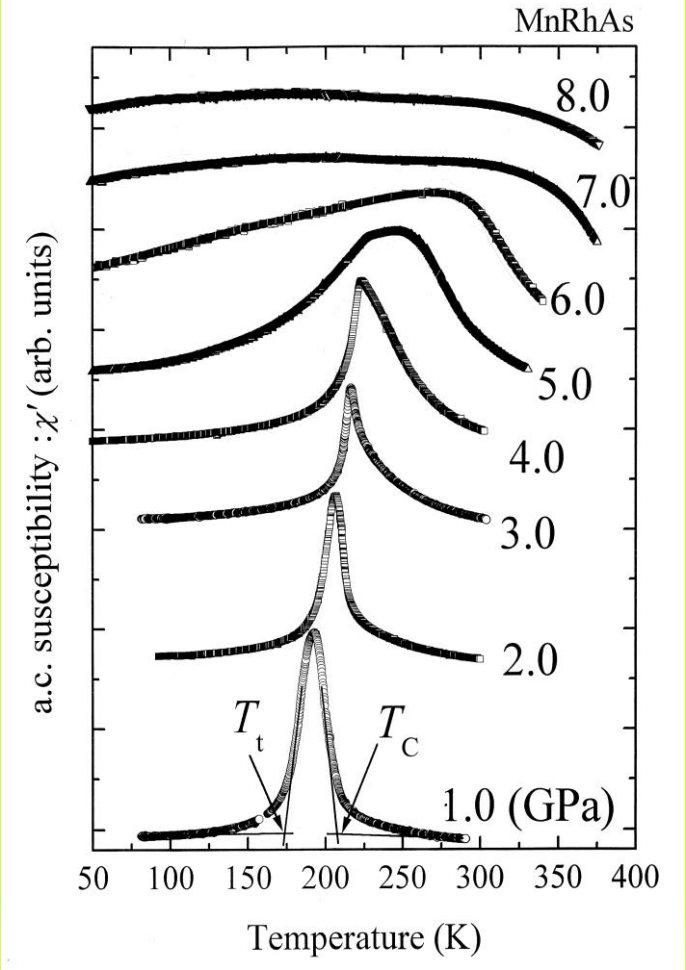


* The (P,T) magnetic phase diagrams were determined.
* The Curie temperature increases vs. pressure for all specimens.
* The pressure variation of the T_t critical temperature depends on composition.
* In the case of $MnRhP_{0.4}As_{0.6}$ the T_t variation versus external pressure P and versus chemical substitution x presents the same nonlinear character. The ferromagnetic state is stabilised under higher pressure.

R.Zach Hab. Thesis, WFiIS, AGH University, 1997

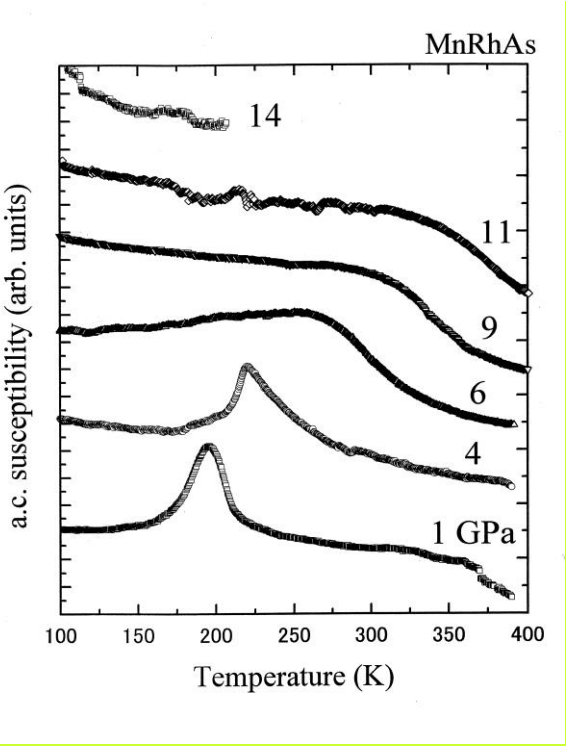
MnRhAs under pressure
a.c. suscpetibility measurements up to 8 GPa

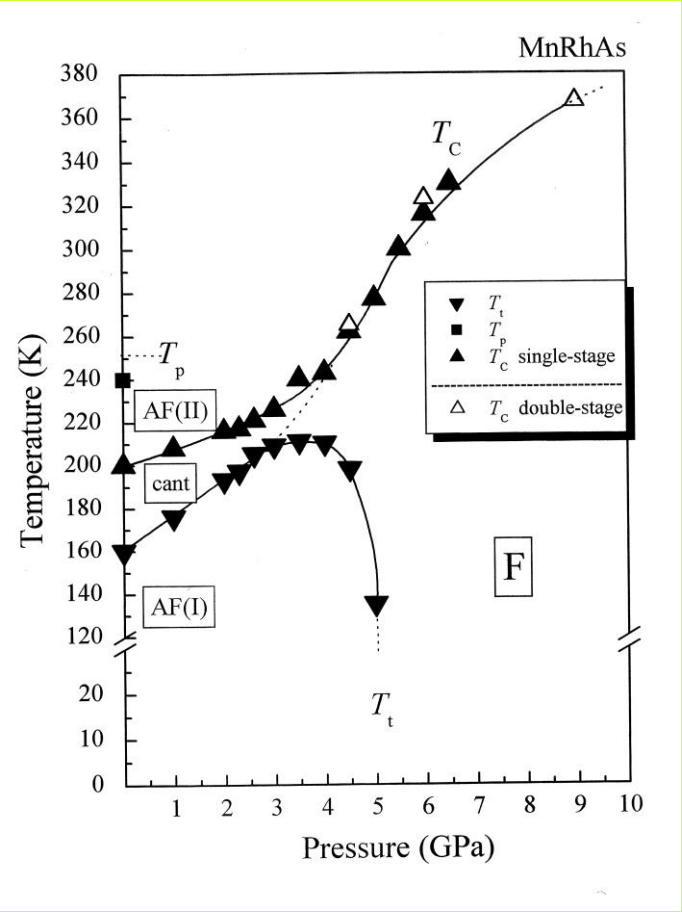


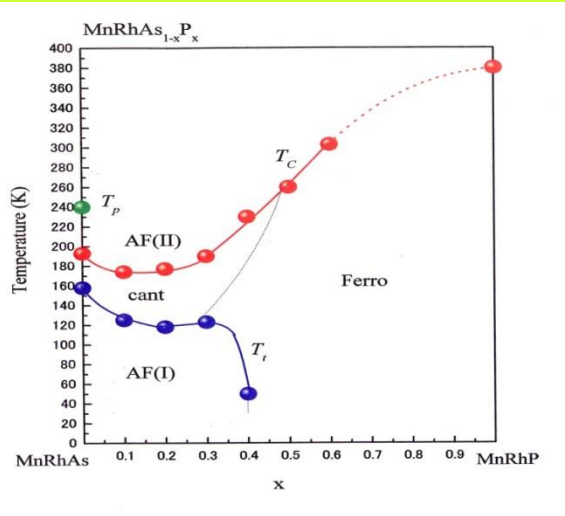


N.Fujii, R.Zach, M.Ishizuka, S.Endo, F.Ono, T. Kanomata
J.Magn.Magn.Mat. 224, (2001) 12

(P,T) magnetic phase diagram of MnRhAs



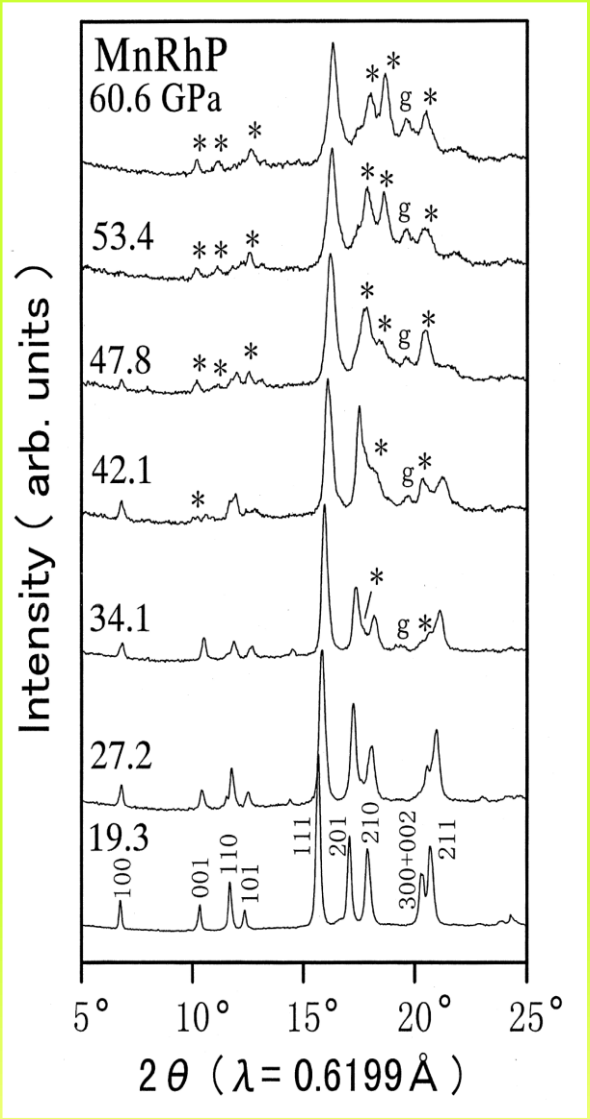


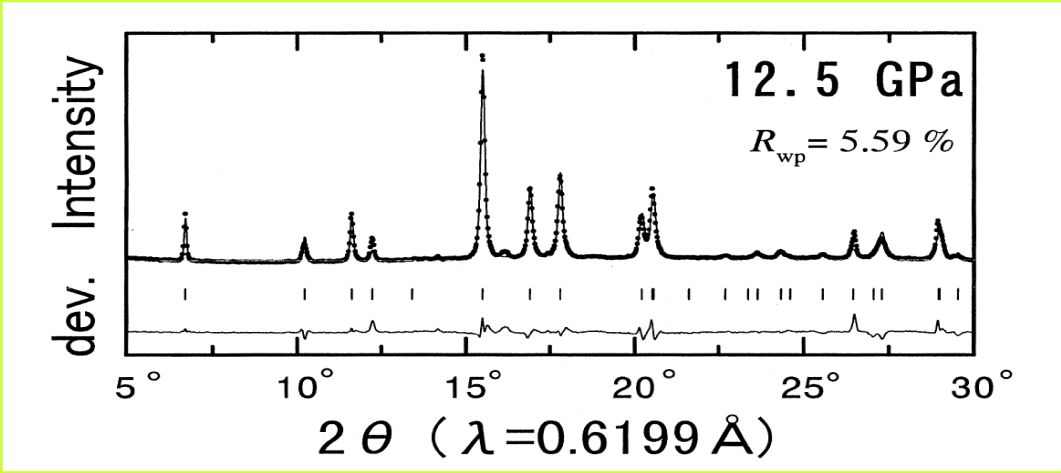


Pressure induced ferromagnetic state above 5 GPa in MnRhAs

N.Fujii, R.Zach, M.Ishizuka, S.Endo, F.Ono, T. Kanomata
J.Magn.Magn.Mat. 224, (2001) 12

Pressure induced structural transition in MnRhP



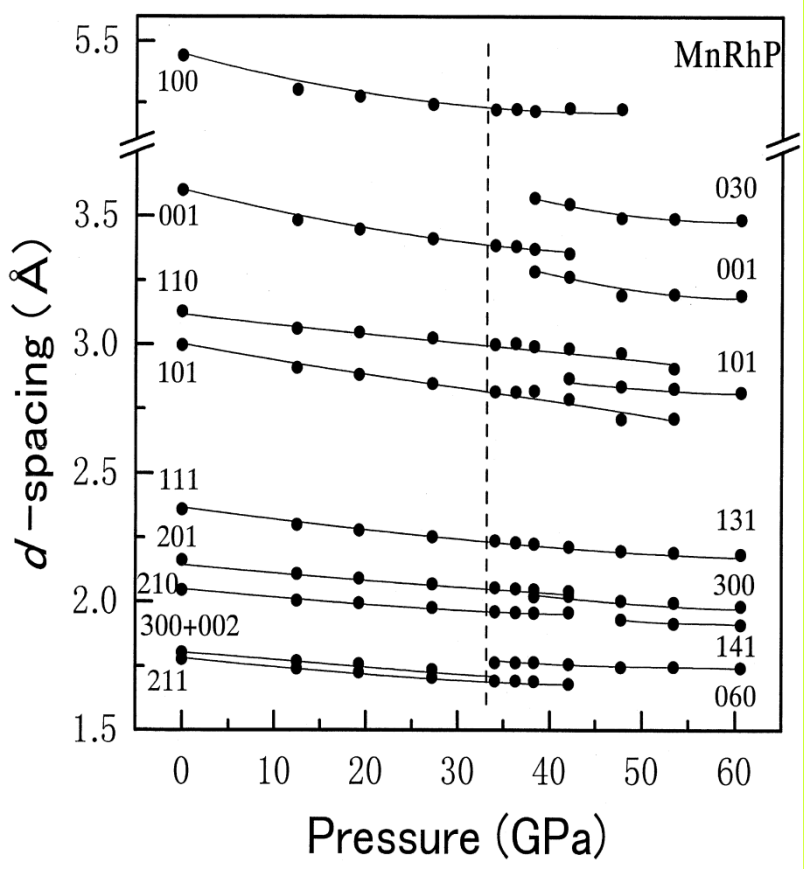


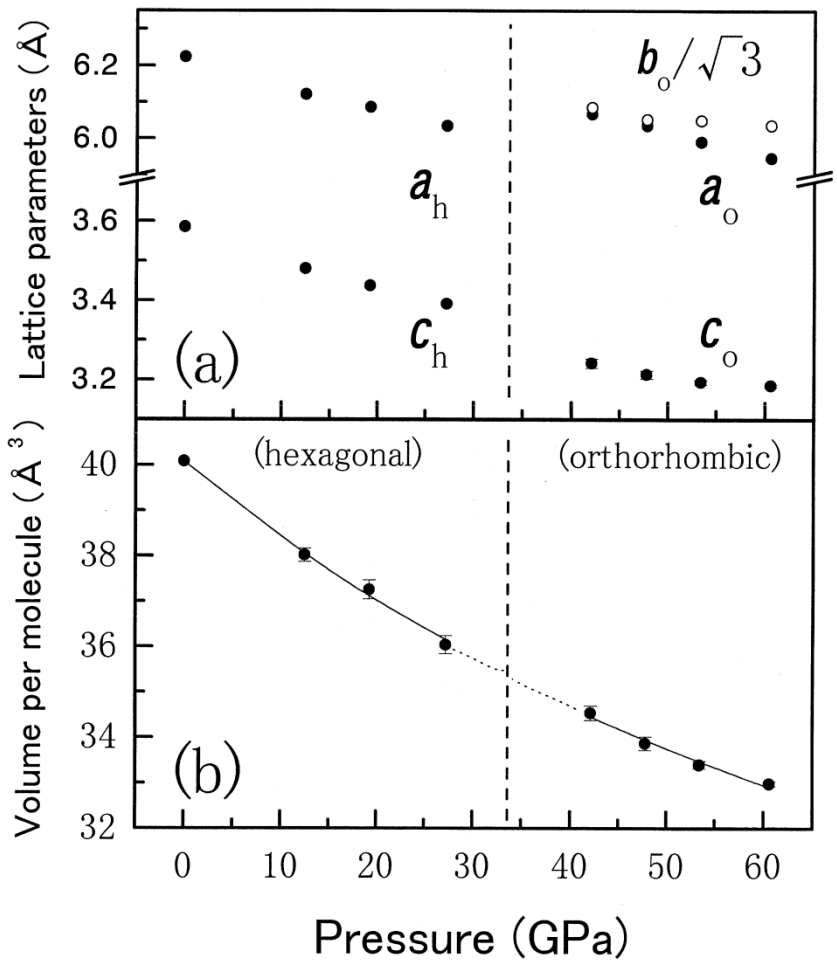
Results of Rietveld analysis for low pressure phase of MnRhP. Observed pattern is indicated by dots

A transition from the hexagonal Fe_2P-type structure to an orthorhombic one was observed in MnRhP at a pressure of approximately 34 GPa

T.Eto, M.Yamagishi, M.Ishizuka, S.Endo, T.Asida, T.Kanomata, T.Kikegawa, R.Zach
J.All. Comp 307 (2000) 96

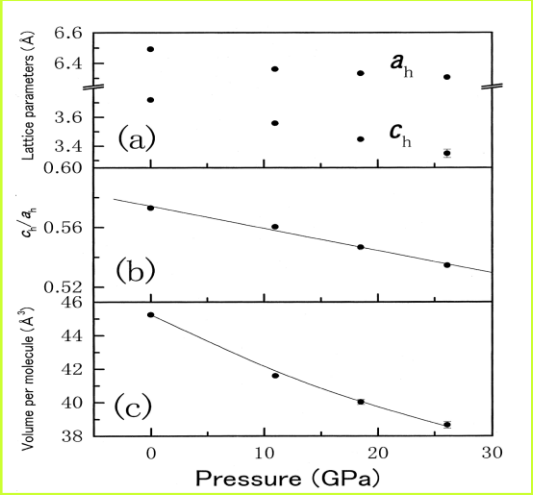
Pressure induced structural transition in MnRhP



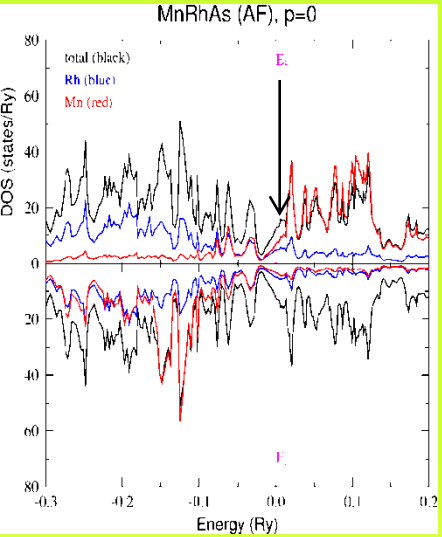


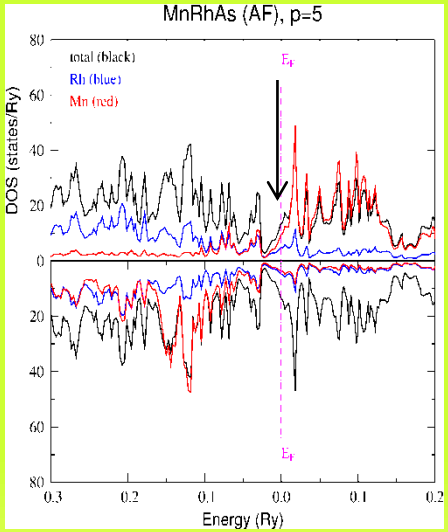
T.Eto, M.Yamagishi, M.Ishizuka, S.Endo, T.Asida, T.Kanomata, T.Kikegawa R.Zach JALCOM 307, p.96 (2000)

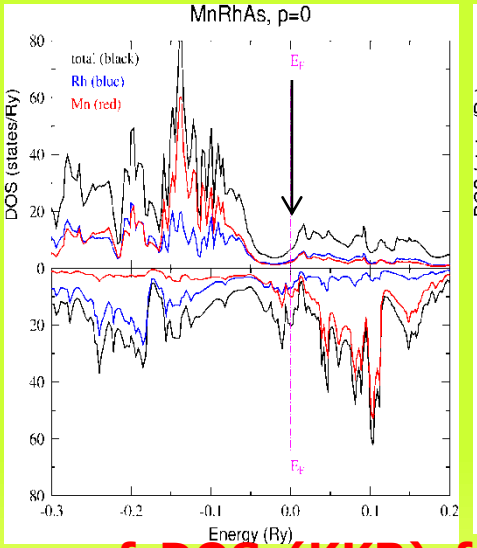
Electronic band structure calculations for MnRhAs „under pressure” KKR

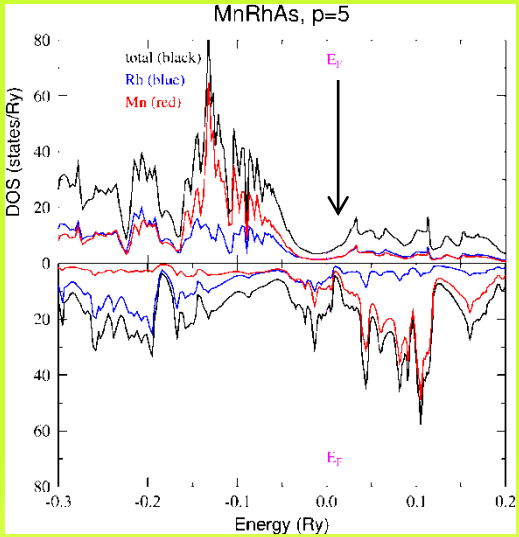


P [GPa]	DOS at E_F in *Ferro state* [states/Ry]	DOS at E_F in *AF* state [states/Ry]
0	27.0	24.8
3	23.5	26.5
5	20.7	27.1





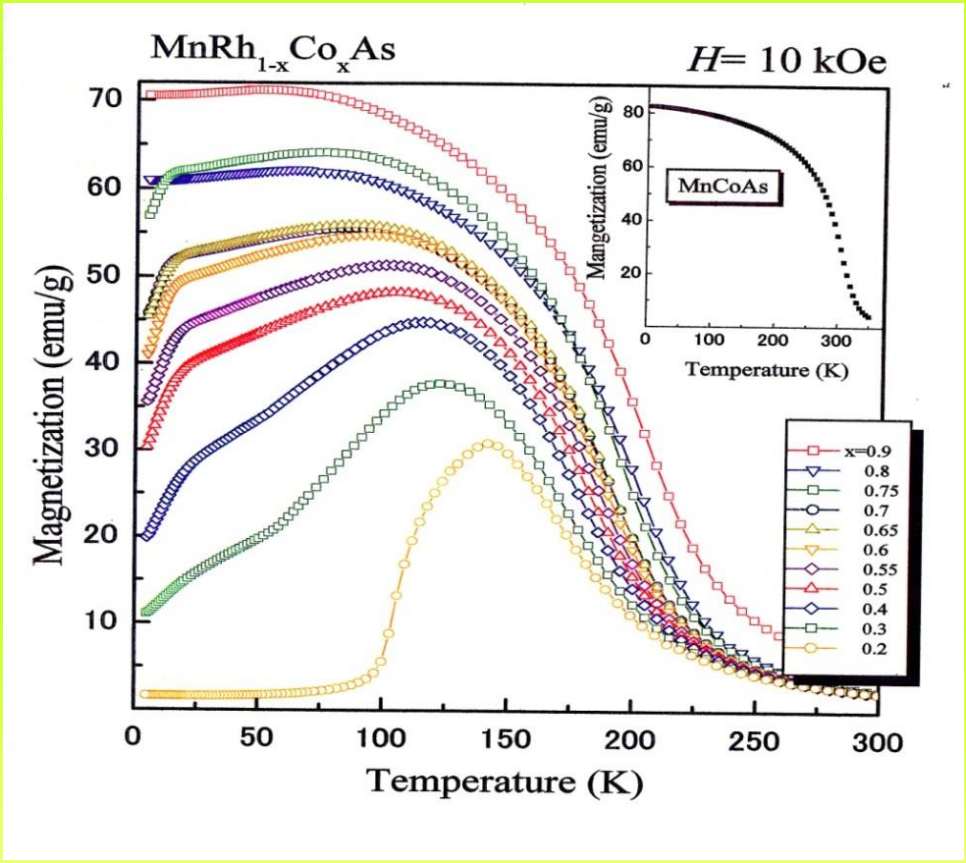


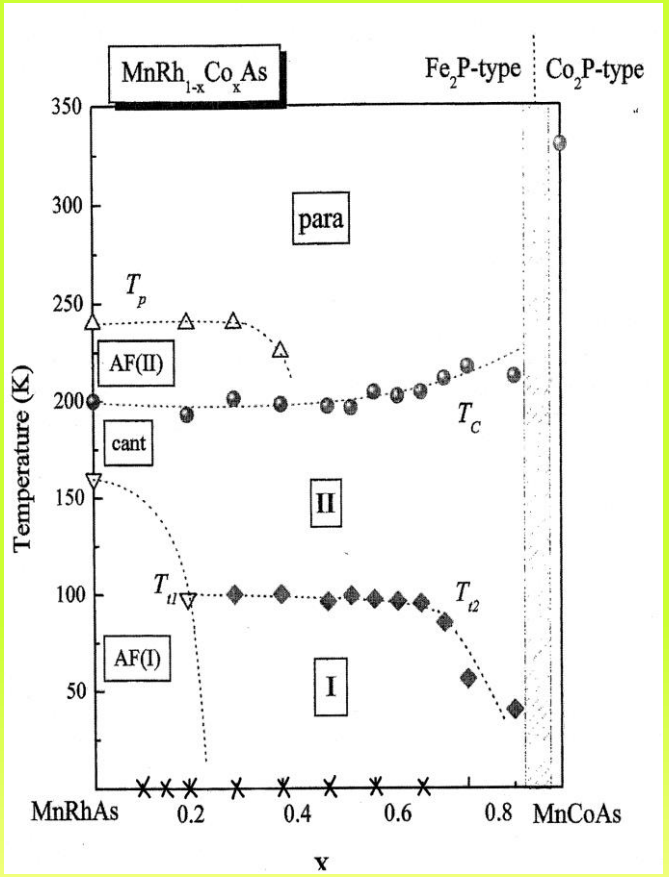


In the case of MnRhAs the calcultions of DOS (KKR) for 0, 3, 5 GPa were performed. It was conluded, that in the atmospheric pressure the *AF* state was more favorized, however under pressures 3 GPa and 5 GPa the *F* state was found as the most stable (it remains in good agreement with experiments)

Magnetoelastic phase transitions in $MnRh_{1-x}Co_xAs$

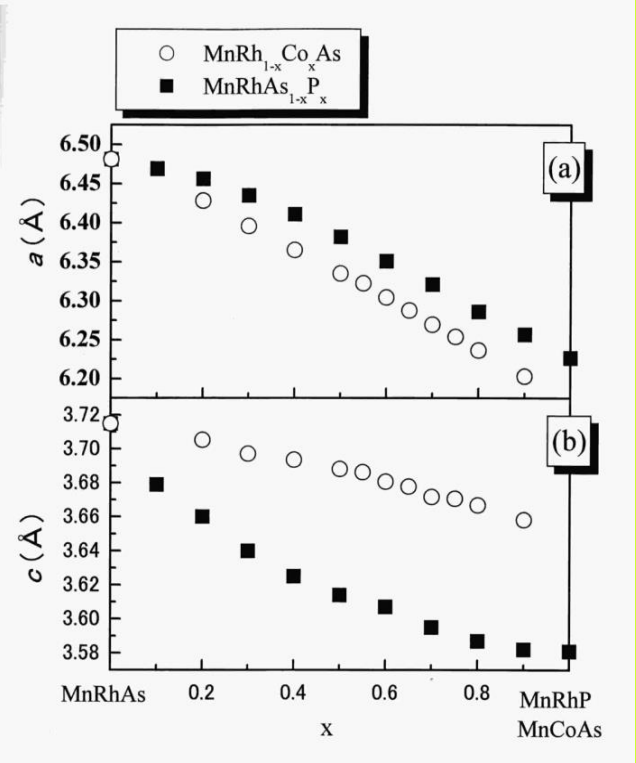
The $MnRh_{1-x}Co_xAs$ isoelectronic system of solid solutions has a complex *(x,T)* magnetic phase diagram caused by the substitution in the metal sublattice. The crystal structure of the $MnRh_{1-x}Co_xAs$ system is a hexagonal one of the Fe_2P-type except for the samples with the composition in the close vicinity of MnCoAs, which exhibits orthorhombic crystal structure of the Co_2P-type.

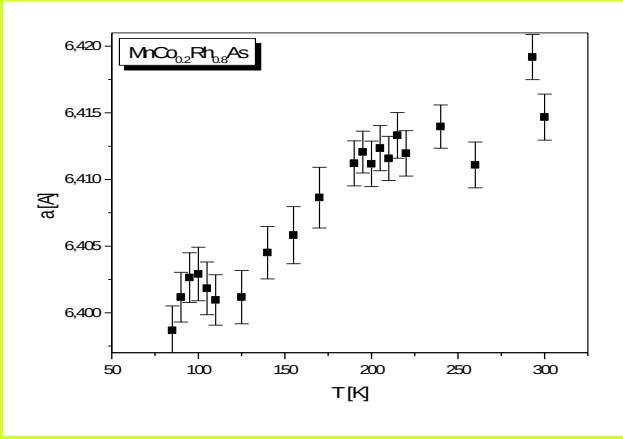


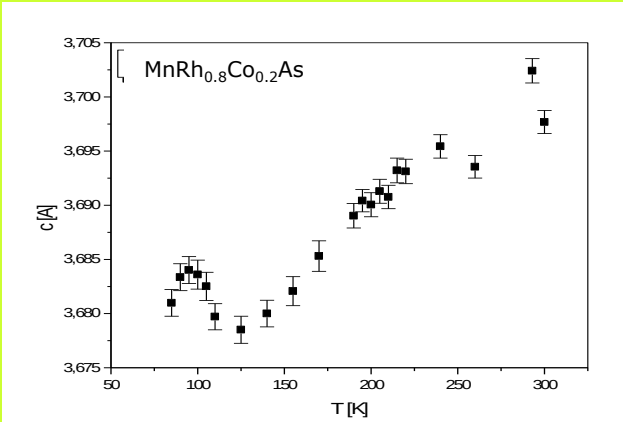


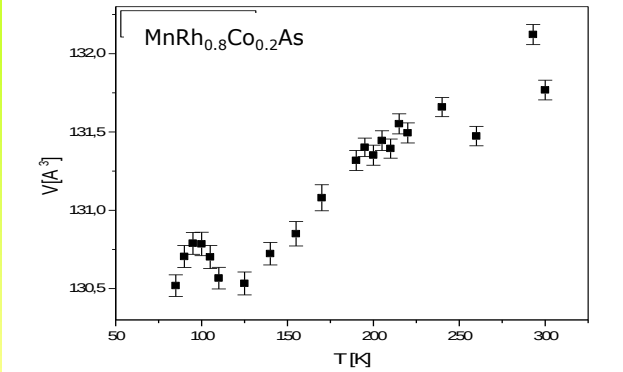
N. Fujii,_R.Zach, T.Kanomata, H.Nishihara, F.Ono, M.Ishizuka, S.Endo J.Alloys Comp. 345 (2002) 59

X ray diffraction studies $MnRh_{1-x}Co_xAs$









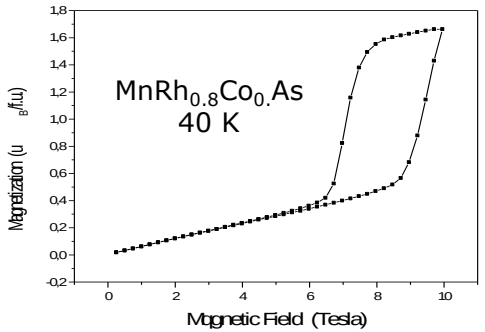
* it was found that with the increase of cobalt content x the elementary cell volume linearly decreases,

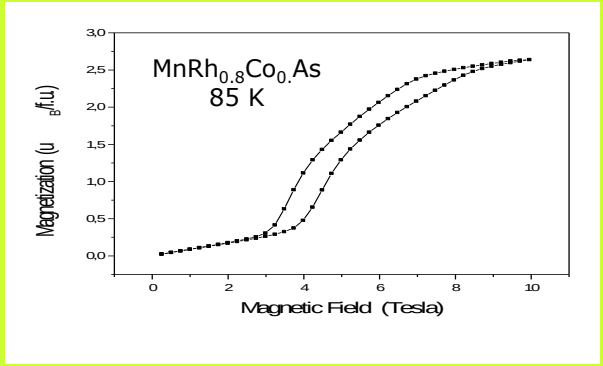
** the jump in both lattice parameters and in the unit cell volume associated with the phase transition was found,

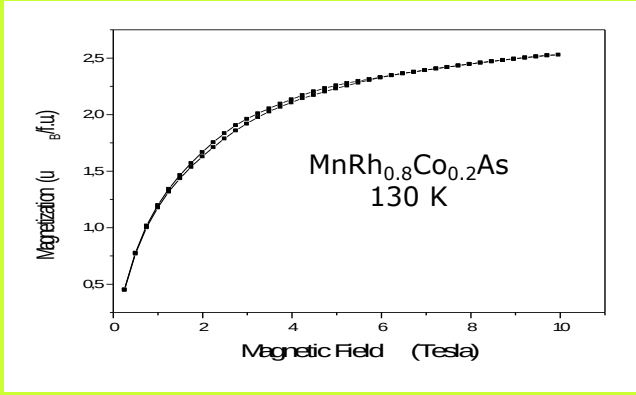
*** interatomic distances mainly Mn-Mn and Mn-Rh change at the phase transitions,

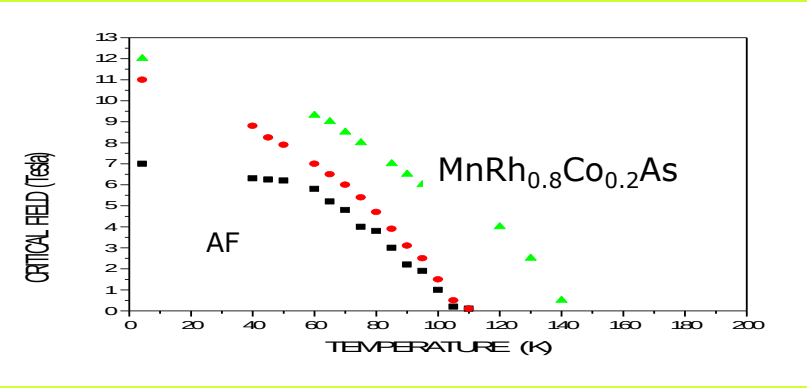
**** lattice and atomic parameters determined by means of X-ray diffraction were used in the KKR-CPA electronic structure calculations.

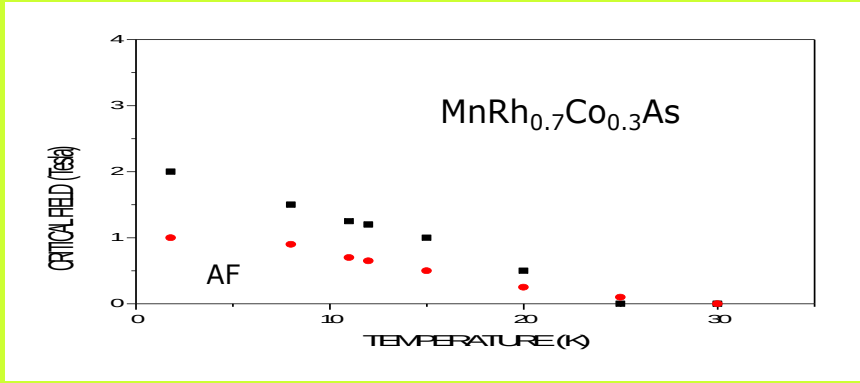
High d.c. field magnetization studies $MnRh_{1-x}Co_xAs$











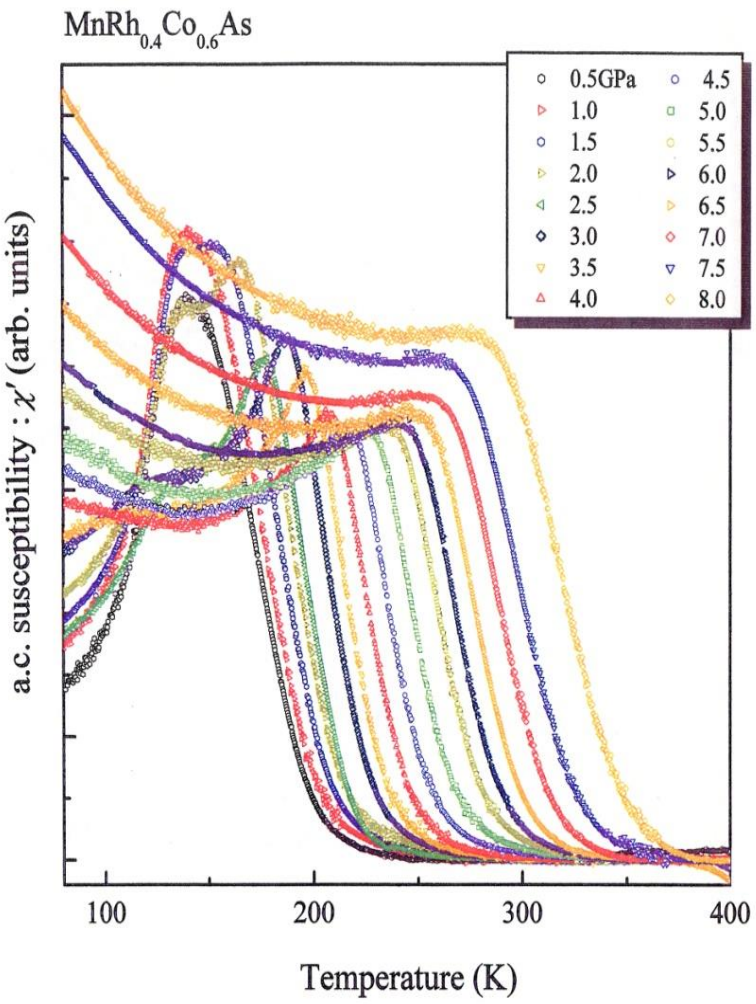
To summarize the experimental results the *(B,T)* magnetic phase diagrams were proposed. The following conclusions could be drawn:

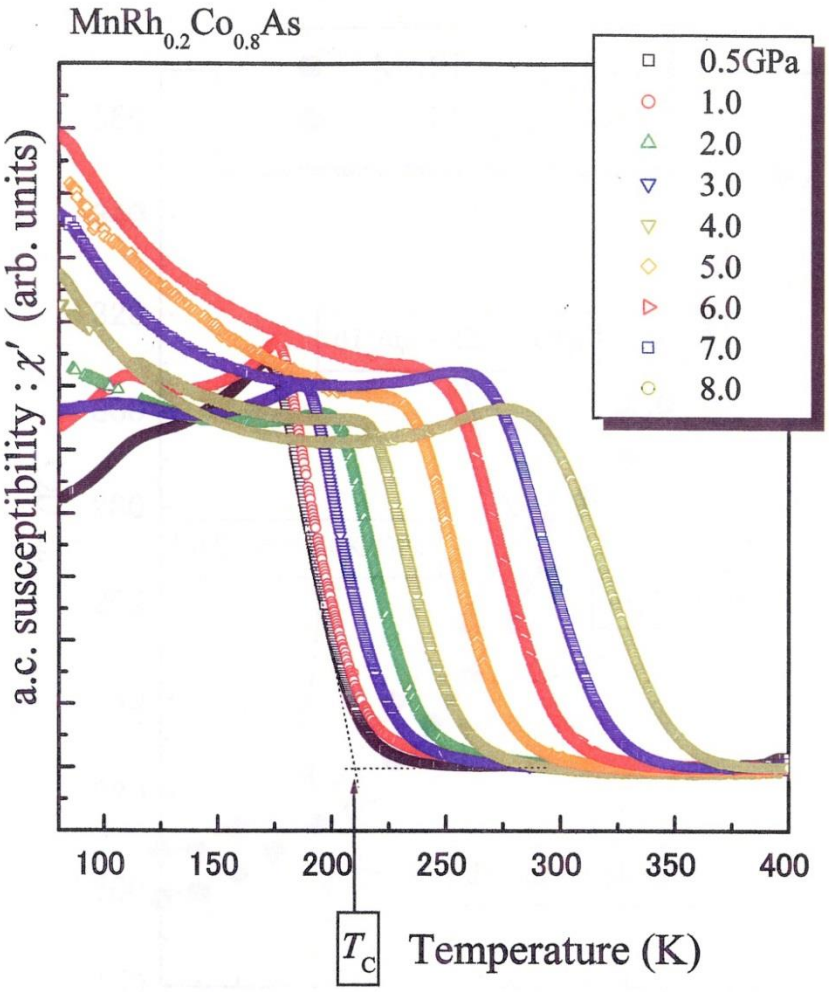
i) the field induced discontinuous phase transitions were discovered,

ii) the critical fields decrease with temperature for both studied compounds,

iii) the critical field values and the width of the hysteresis vanish to zero for both samples, however at markedly different temperatures.

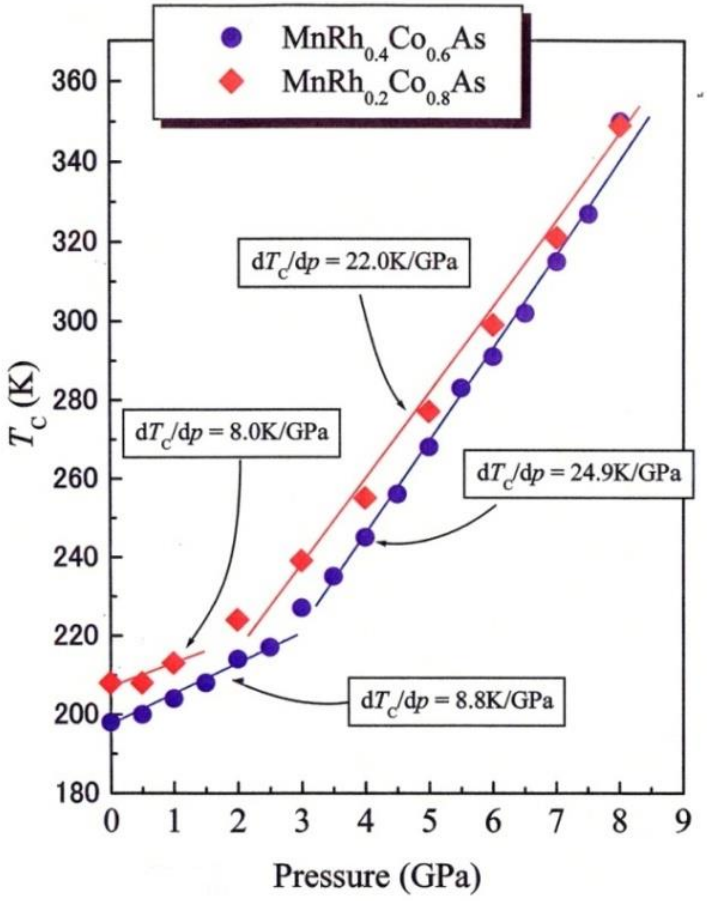
High pressure a.c. susceptibility studies of $MnRh_{1-x}Co_xAs$



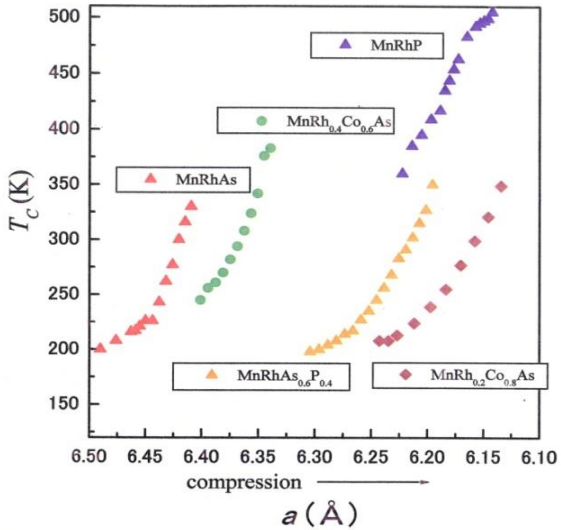


N. Fujii,_R.Zach, T.Kanomata, H.Nishihara, F.Ono, M.Ishizuka, S.Endo J.Alloys Comp. 345 (2002) 59

High pressure a.c. susceptibility studies of $MnRh_{1-x}Co_xAs$

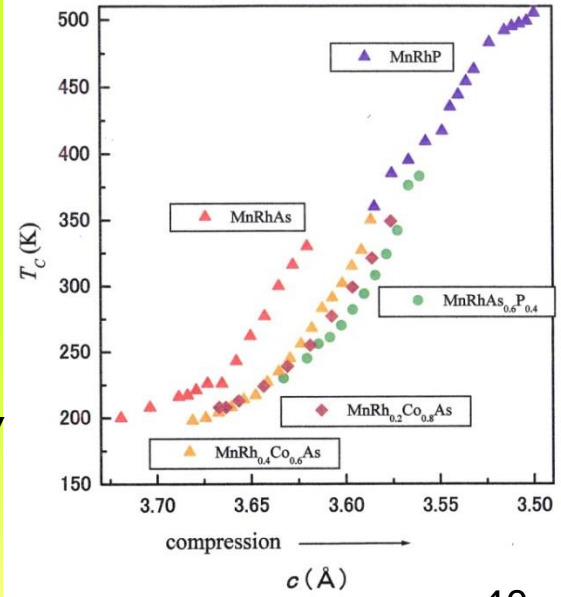


T_C is widely scattered, which suggests that T_C is not directly related to the *a*-value



T_C is plotted against the *c-value*

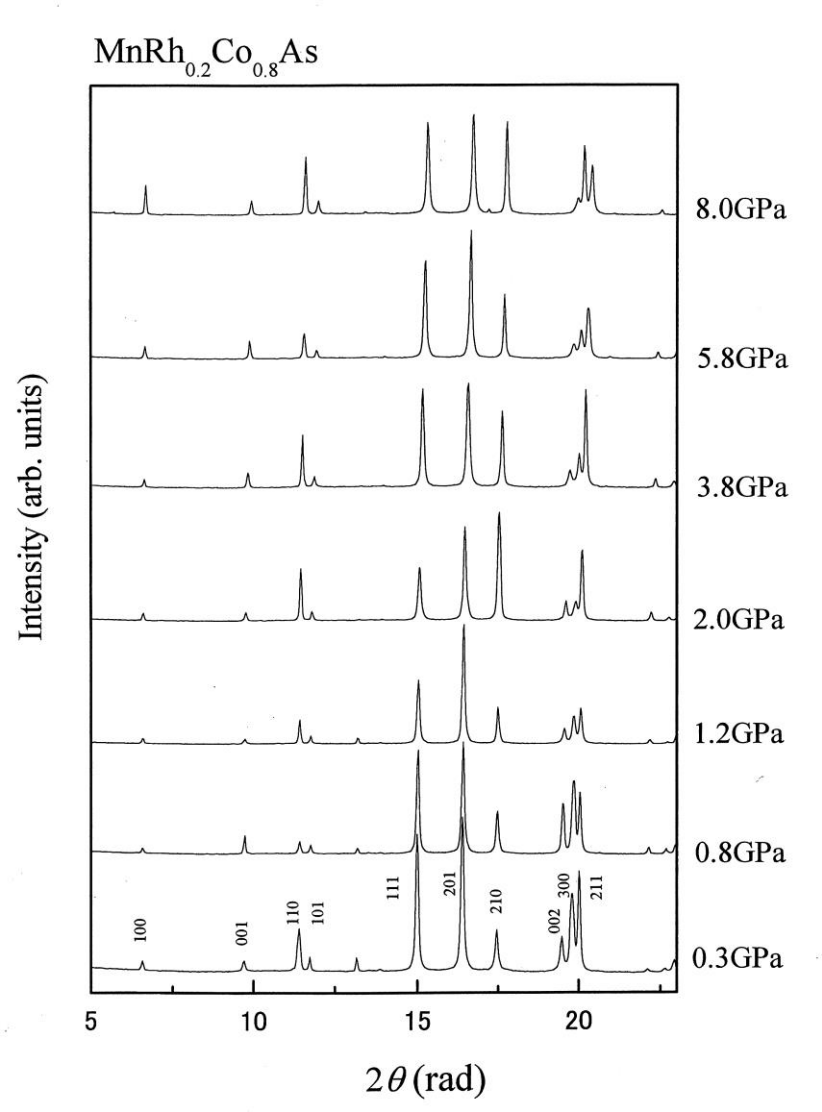
all the points concentrate on an almost single T_C line versus *c* curve.

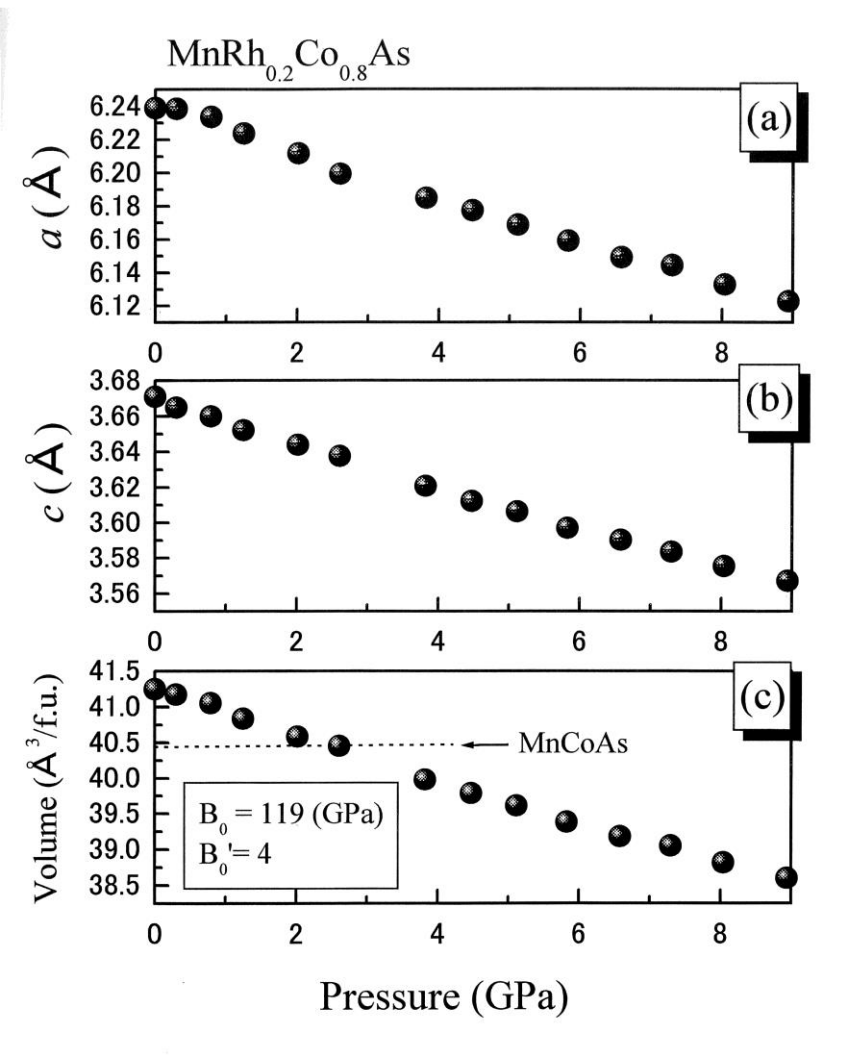


Thus, the pressure effect on T_C strongly depend on the *c*-value, but not on the a-value

T_C versus the lattice parameter *a* and *c* of Mn(Rh,Co)As.

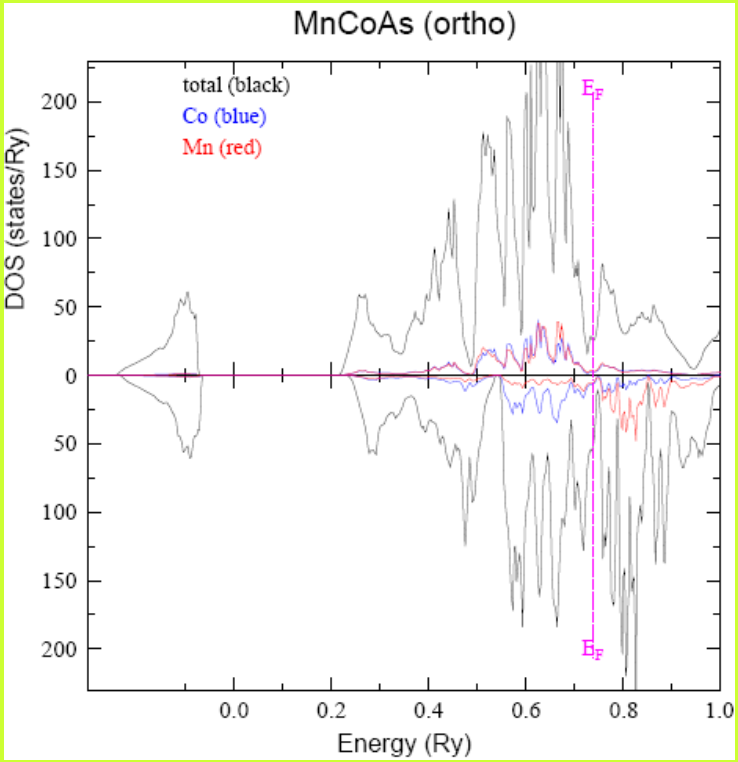
Crystal structure under pressure in $MnRh_{1-x}Co_xAs$

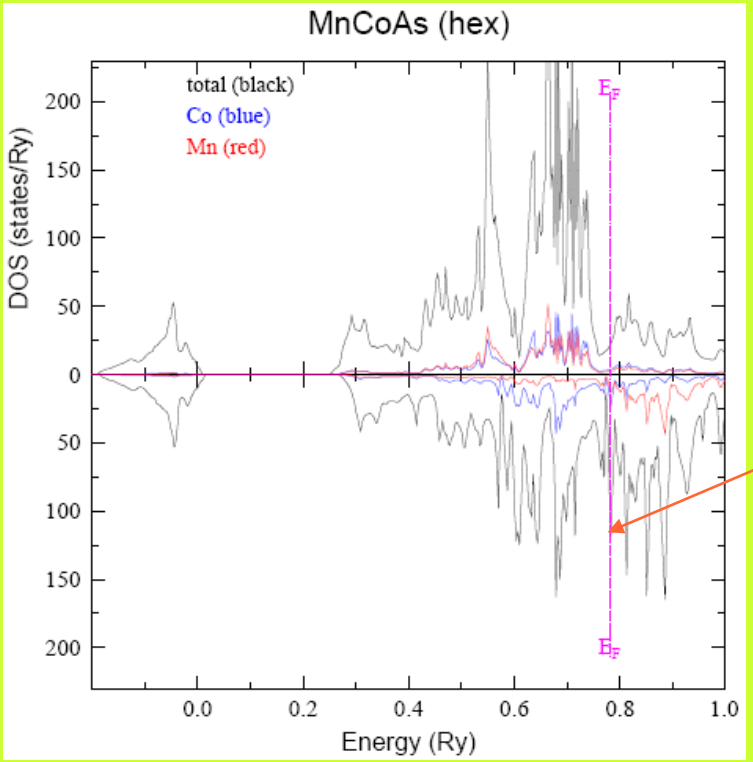




MnCoAs (ortho) and MnCoAs (hex)

$n(E_F)$
↑ 22.5
↓ 48.3



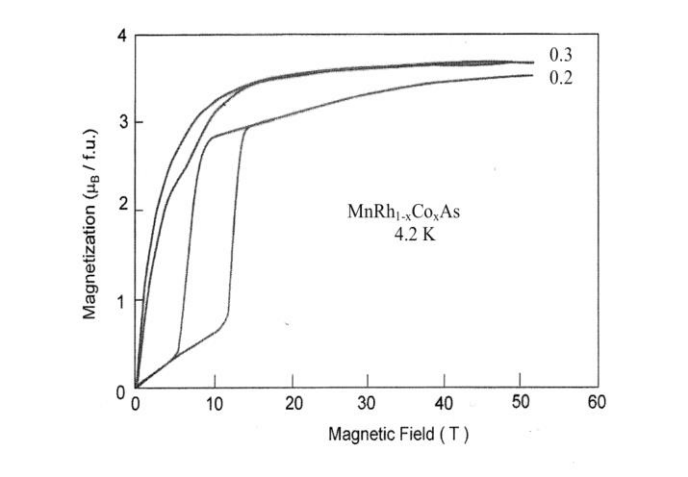


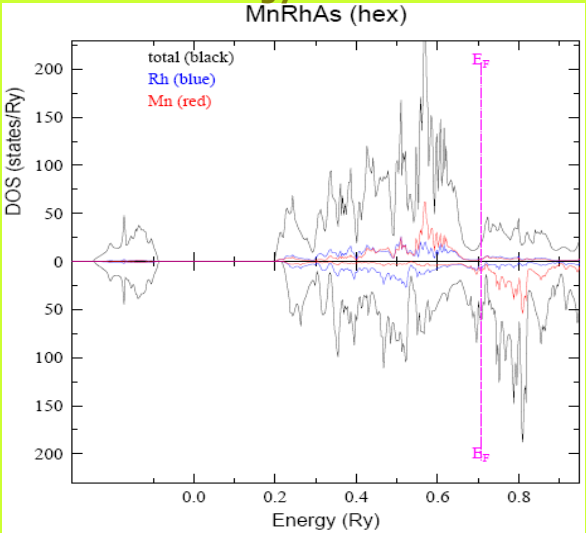
$n(E_F)$
↑ 16.1
↓ 76.3

In MnCoAs the electronic band structure calculations were carried not only in the case of the real orthorhombic crystal structure but also in the case of the hypothetical hexagonal one.

The crystal structure parameters by extrapolations of those a and c lattice parameters from the hexagonal domain of the $MnRh_{1-x}Co_xAs$ ($x<0.9$) system were used.

A very interesting property was established for the hexagonal crystal structure: the Fermi level for the spin down subbands in the maximum of DOS is placed. This fact may be the reason why no hexagonal crystal structure of MnCoAs is observed. Contrary, in the orthorhombic crystal structure for both spin directions the Fermi level close to deep DOS valley is located.



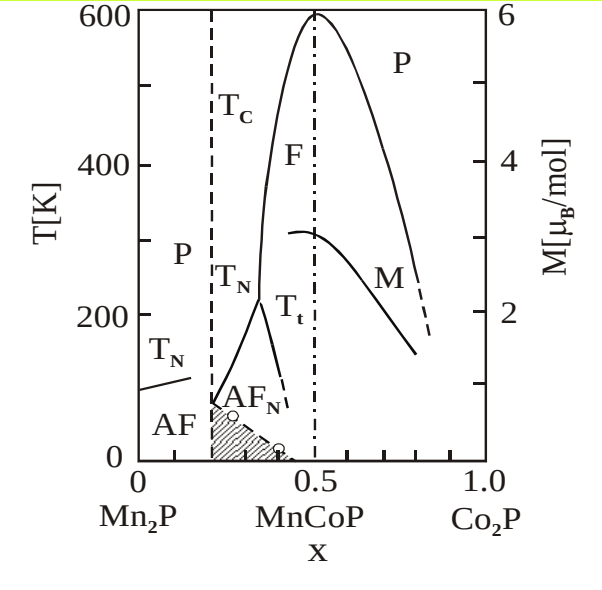


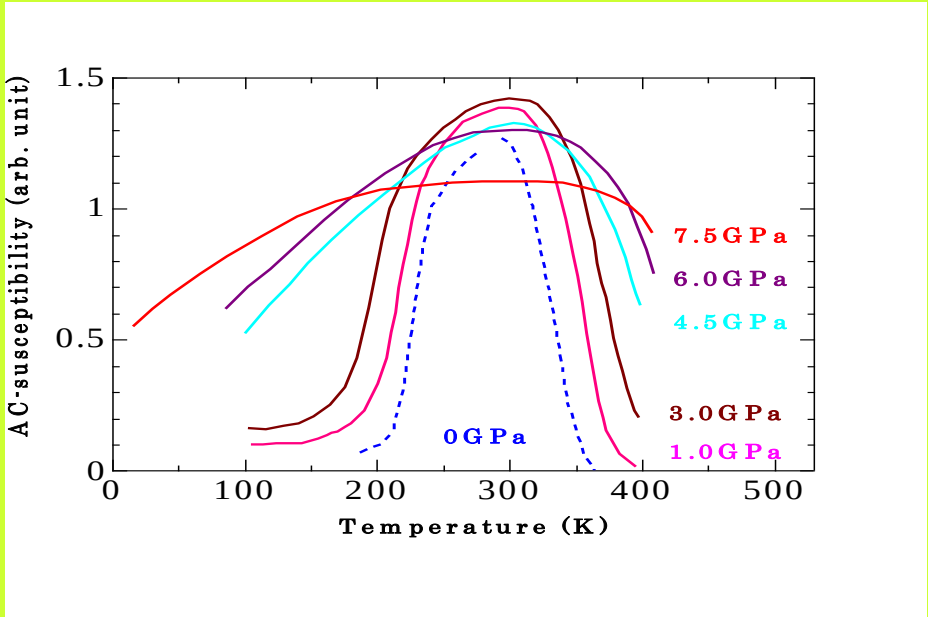
Magnetic moments calculated for $MnRh_{1-x}Co_xAs$

Compound	Tot [μ_B/f.u.]	Mn [μ_B]	Rh [μ_B]	Co [μ_B]	Tot [μ_B/f.u.] - exp
MnRhAs	**3.31**	3.45	0.02	—	**3.5**
$MnRh_{0.7}Co_{0.3}As$	**3.27**	3.17	0.03	0.26	**3.5**
MnCoAs (hex)	**3.21**	3.02	—	0.25	—
MnCoAs (ort)	**3.15**	3.14	—	0.13	**3.0**

The DOS plots obtained for Mn, Co and Rh atoms indicate strong *s, p and d* hybridization of the electron states observed for all the studied samples. It may be concluded that the covalent character of chemical bonds is also present. A fair agreement between calculated and experimental values of magnetic moments was established.

Pressure induced magnetic phase transitions in $(Mn_{1-x}Co_x)_2P$ with x=0.35





To summarize the ac susceptibility behavior under high pressure it may be concluded that:

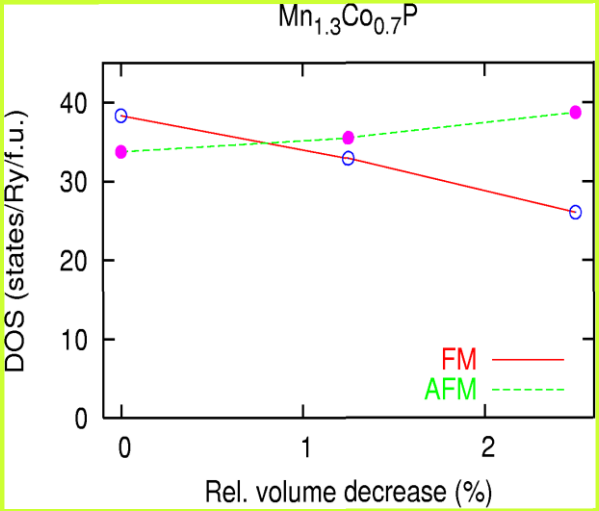
i) the Curie temperature increases with pressure;

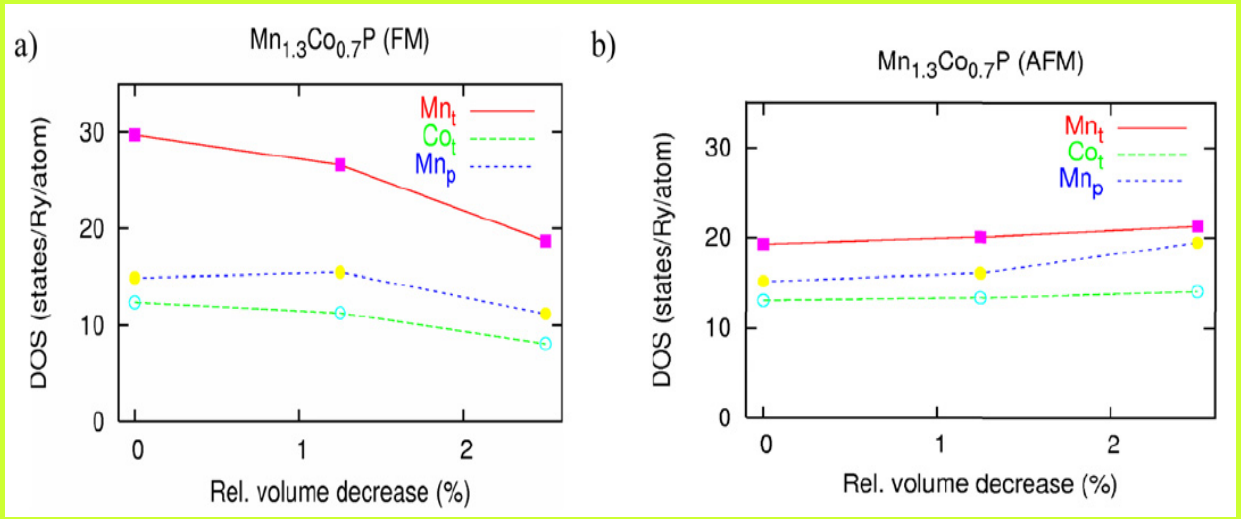
ii) the *AF_N-F* phase transition temperature *T_t* strongly decreases with pressure;

iii) the pressure induced ferromagnetic state was established at low temperatures (4.2.K – 80 K) and at 6 – 8 GPa pressure range.

R. Zach, Y. Fukami, F.Ono, J. Toboła and D.Fruchart *Pressure induced state in the orthorhombic $(Mn_{1-x}Co_x)2P$ system,* Journal of Physics Condensed Matter 20 195207 (2008)

Electronic band structure calculations for $(Mn_{0.65}Co_{0.35})_2P$ with x=0.35 under pressure (KKR-CPA)





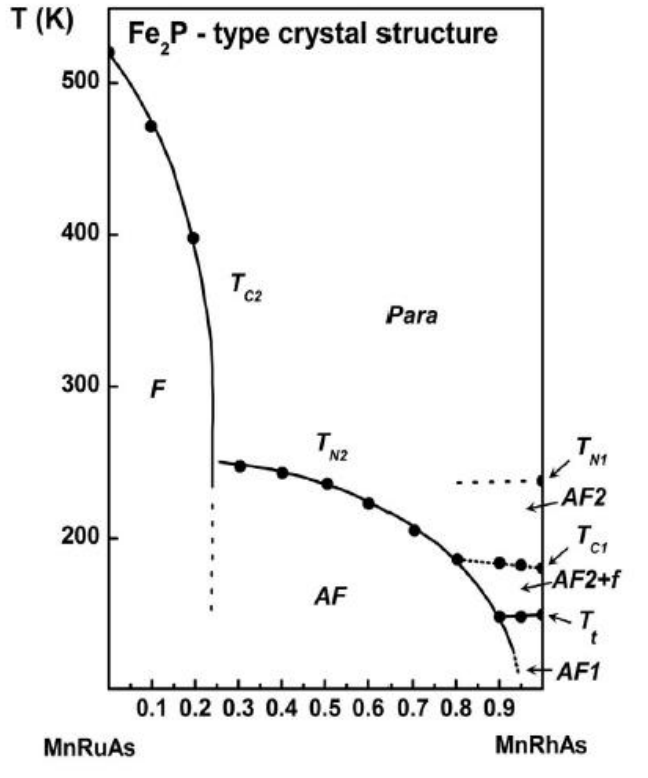
i) The DOS at the Fermi level decreases with pressure applied along any axis. The highest decrease of DOS was found in the case of c-axis applied pressure.

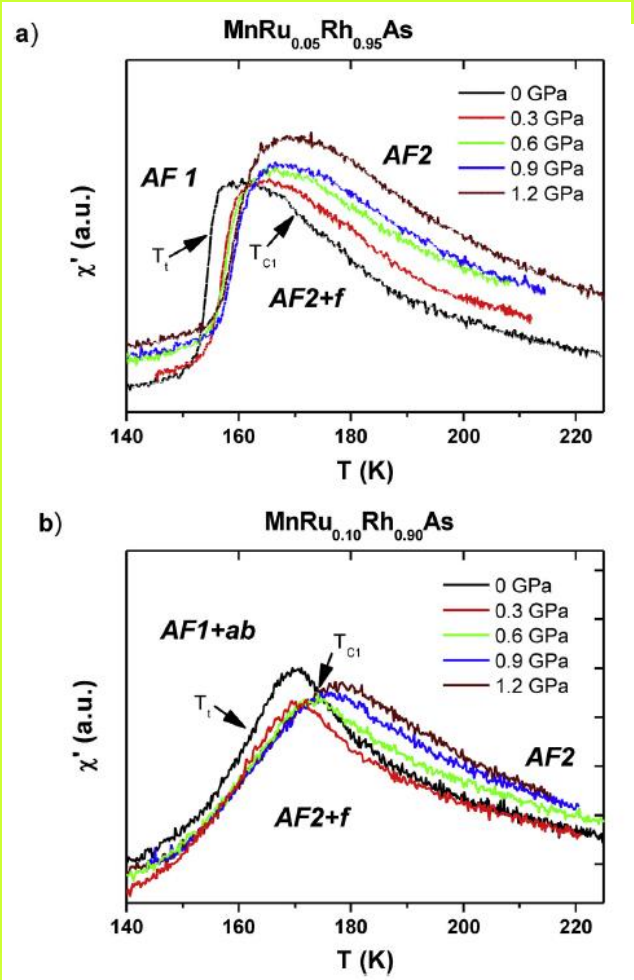
ii) The computed local magnetic moments in x=0.35 decrease versus pressure (particularly for large magnetic moment on the pyramidal Mn atoms) and are comparable in F and AF states

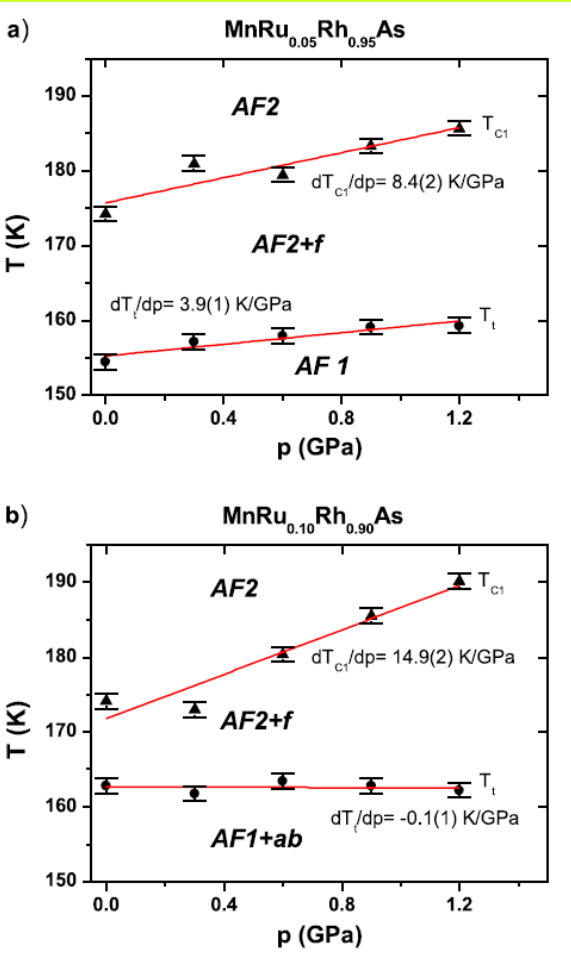
iii) The magnetic moments on Mn atoms on tetrahedral sites are sensitive to the volume decrease and practically disappear with c axes compression while they decreases only slightly on the Co atoms. This type of behavior may be responsible for pressure induced AF-F phase transition.

iv) For the c-axis compression in x=0.35 the total DOS at the Fermi level behaves in the opposite way i.e. it rapidly decreases in the Ferro state, whereas it slightly increases in the AF state.

Magnetic properties of $MnRh_{1-x}Ru_xAs$

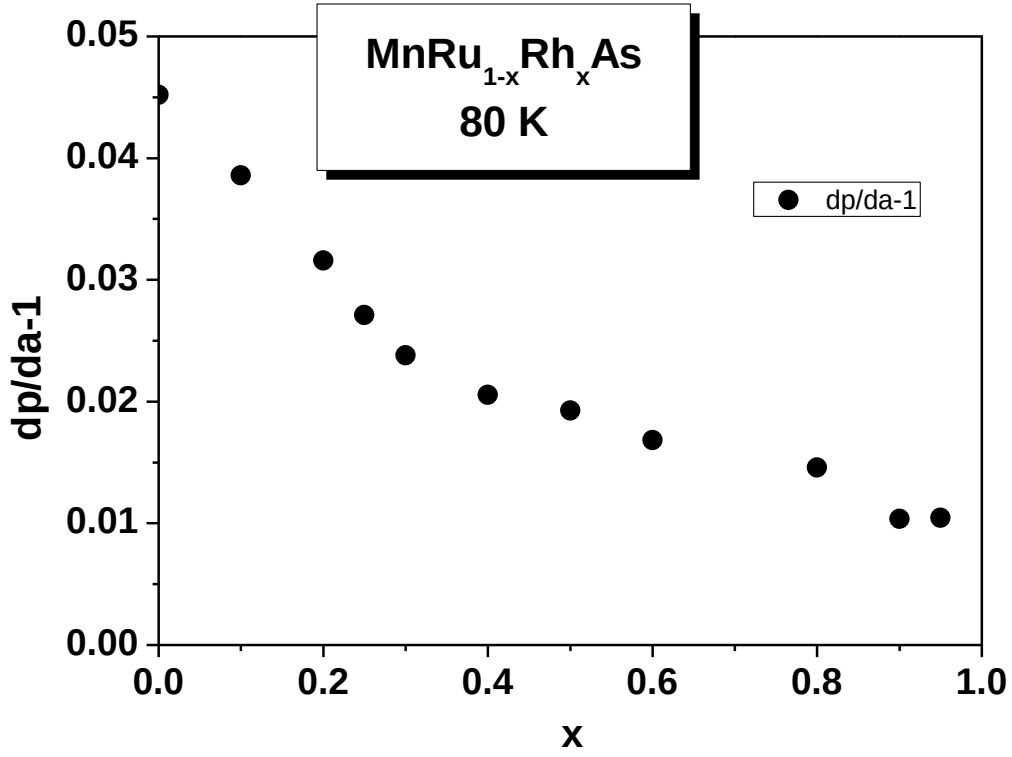


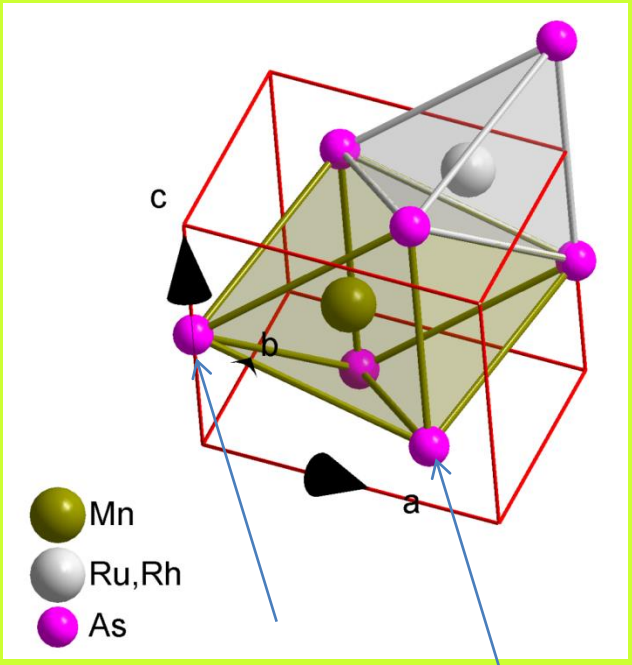




From pressure measurements we may conclude that the ferromagnetic orderings becomes more favorable under higher pressure. This tendency was also discussed on the basis of electronic structure KKR calculations suggesting ferromagnetic state in MnRhAs to be more favorable with unit cell contractions. Similarly substitution of Ru to Rh leads to a stability of the ferromagnetic state in agreement with (x,T) diagram.

D.Szymanski , R.Zach , W. Chajec, R Duraj , J.Tobola , M.Guillot , S.Haj-Khlifa, D. Fruchart J.Alloys Comp 776 (2019) 59-70





$$\delta = \frac{dp}{da} - 1 = \frac{d_{\mathbf{As(2c)-As(2}c\mathbf{)}}}{c} - 1$$

Distortion of the tetrahedral site δ (%)
MnRuAs 4.07 %
MnRhAs 0.73 %

Fe: $Ar3d^64s^2$ **Co:** $Ar3d^74s^2$
Ru: $Kr\mathbf{4}d^75s^1$ **Rh:** $Kr\mathbf{4}d^85s^1$

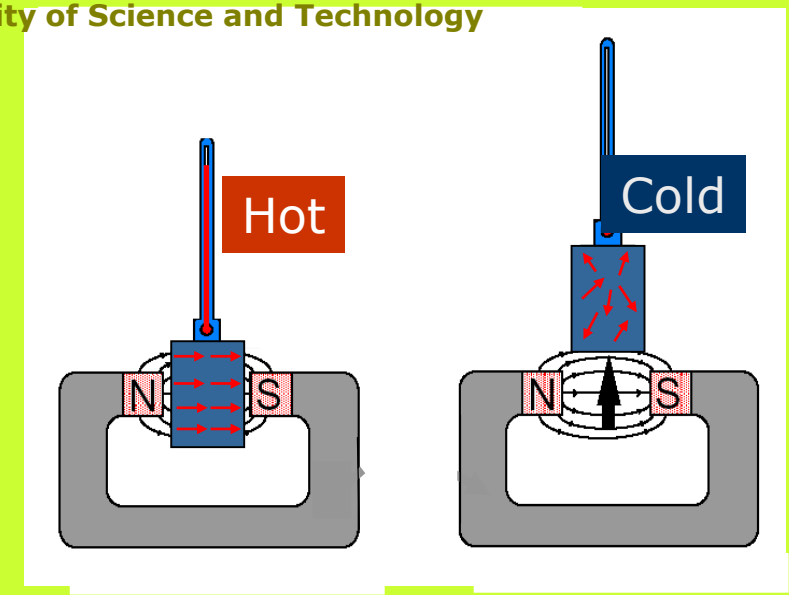
dp -- the edge of the rectangle defined by the two atoms in the As-2 position of the ab plane
da=c: -- short parameter of the hexagonal unit cell

MAGNETOCALORIC EFFECT

Intrinsic property of a material

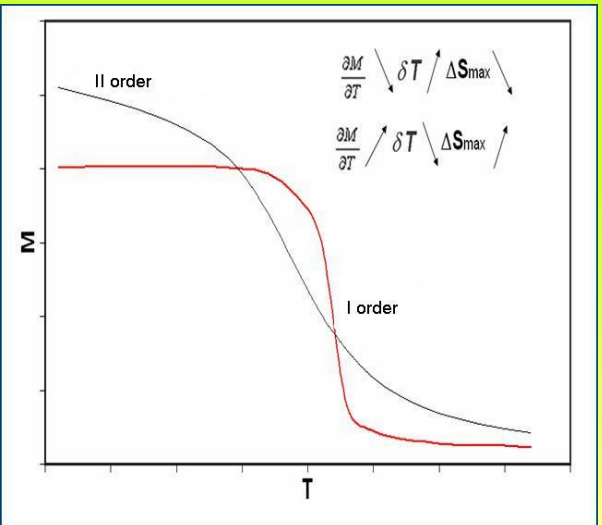
The concept of magnetic fridge is based on the **magneto-caloric effect**.

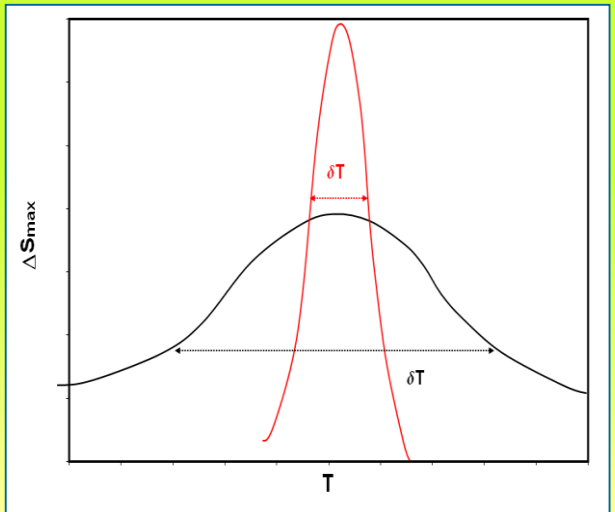
It involves a process in which reversible heating or cooling down of specific magnetic materials result from the application or suppression of an external magnetic field.



Adiabatic
Magnetisation / Demagnetisation

Ferromagnet, Ferrimagnet, Antiferromagnet, Inhomogeneous Ferromagnet, Amorphous, Superparamagnet….





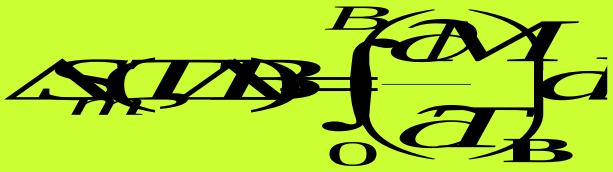
Conditions for giant MCE
What model to apply for ?

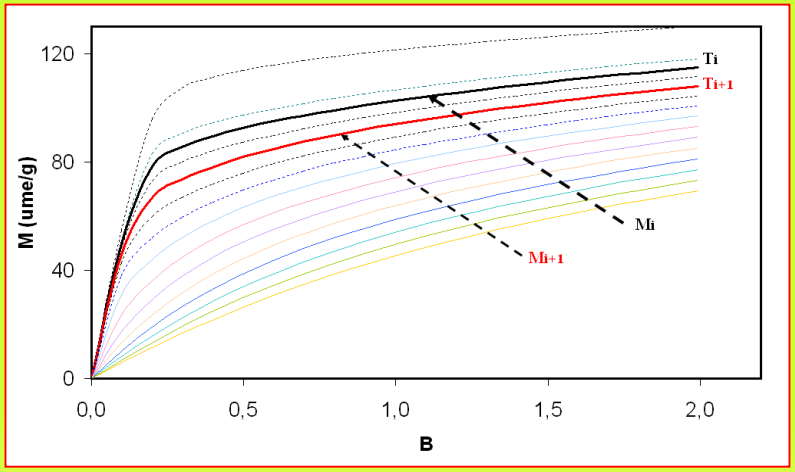
It depends on:
the nature of the transition,
the type of magnetic ordering,
the nature of the material….

MAGNETOCALORIC EFFECT

Integration from isothermal magnetization curves

Magnetization measurements





Analysis of the data

Magnetic measurements

M(T,B)

Correction of demagnetising field

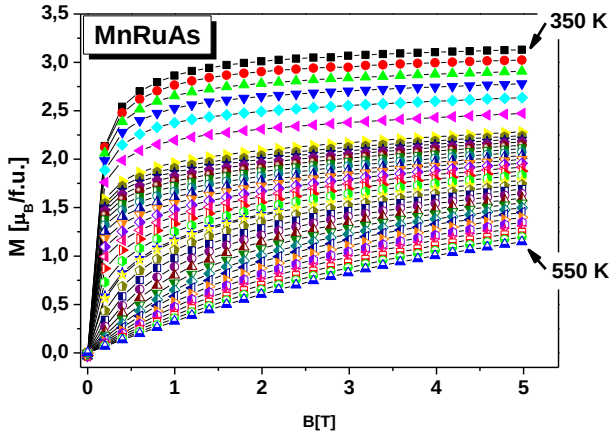
($-N_d M$)

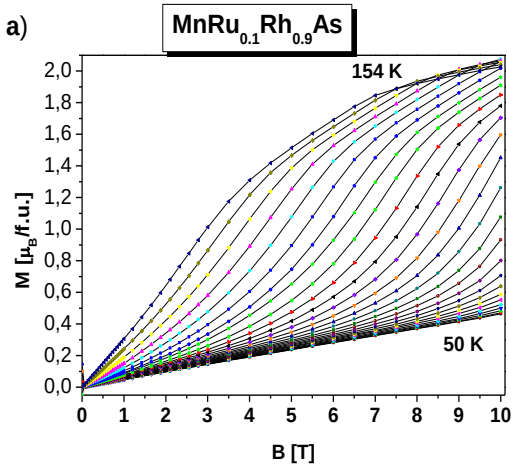
$$\Delta S_m = \sum_i \frac{1}{T_{i+1} - T_i}(M_{i+1} - M_i)\Delta B_i$$

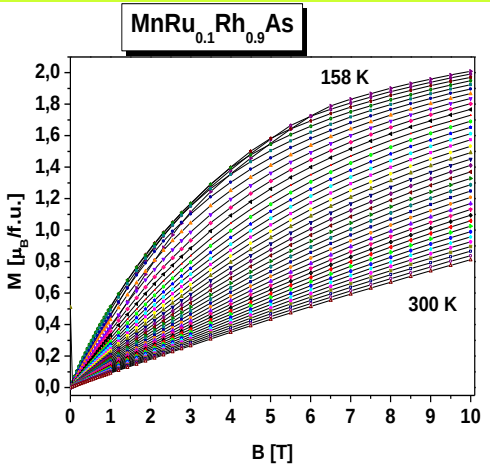
$$\Delta T_{ad}(T,B) = -\int_0^B \frac{T}{C(T,B')}\left(\frac{\partial M}{\partial T}\right)_B dB'$$

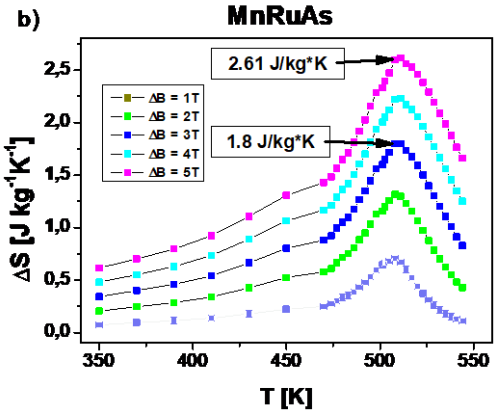
Directly measured or computed from specific heat measurements

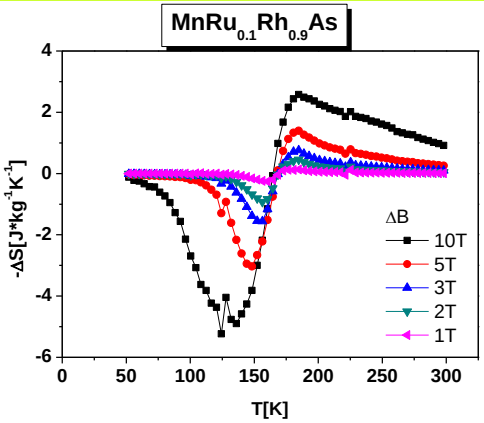
MAGNETIZATION AND MAGNETOCALORIC EFFECT

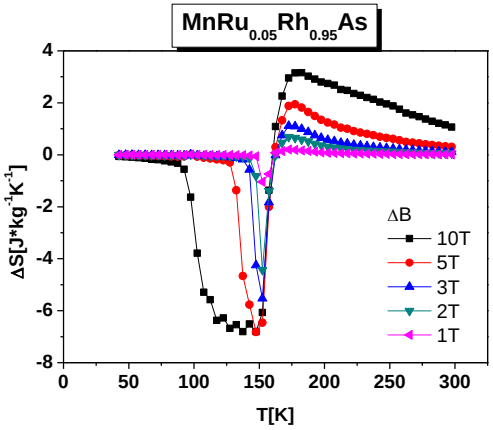












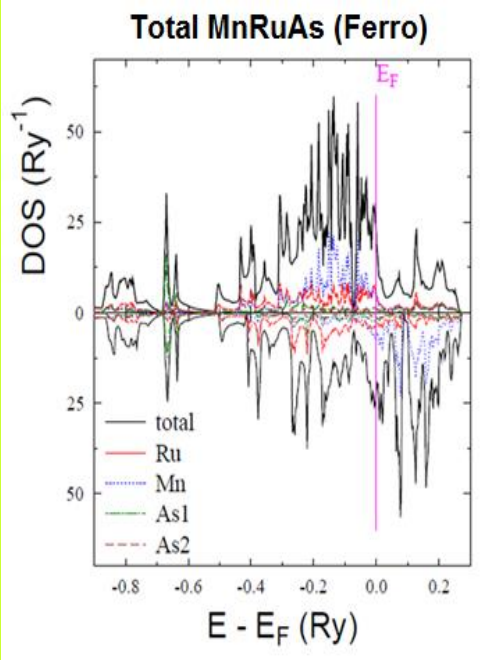
Conventional and Negative MCE

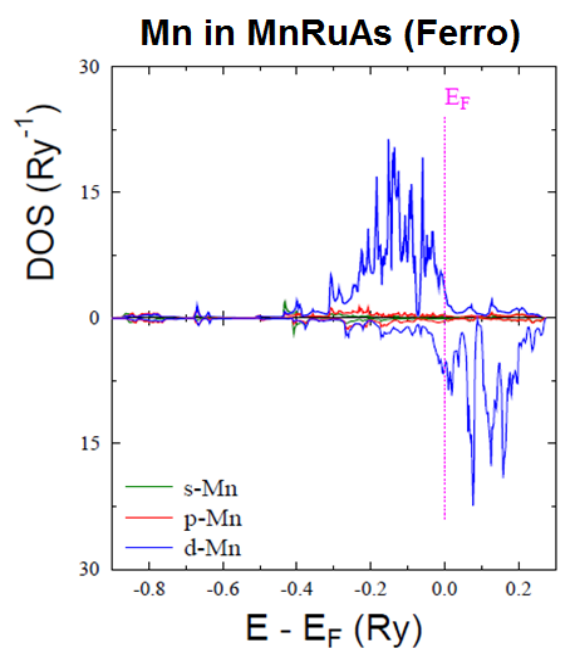
Mn_3GaC	15 [J/Kkg]	
CoMn(SiGe)	1 [J/Kkg]	
MnRhAs	4 [J/Kkg]	(single crystal)
$MnRh_{0.95}Ru_{0.05}As$	2 [J/Kkg]	

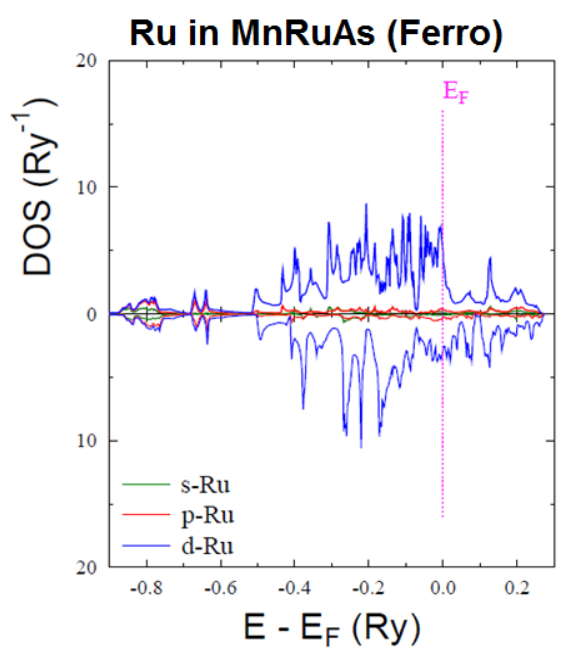
M. Balli, D. Fruchart , R. Zach, J. Appl. Phys. 115 (2014)

Electronic band structure calculations

The electronic band structure calculations have been performed for x = 0, 0.2, 0.5, 0.95 in *F* and *AF* states (KKR-CPA, full potential). Our experimental values of the cell parameters and the atomic positions (X-ray data, this work) were used for computations.



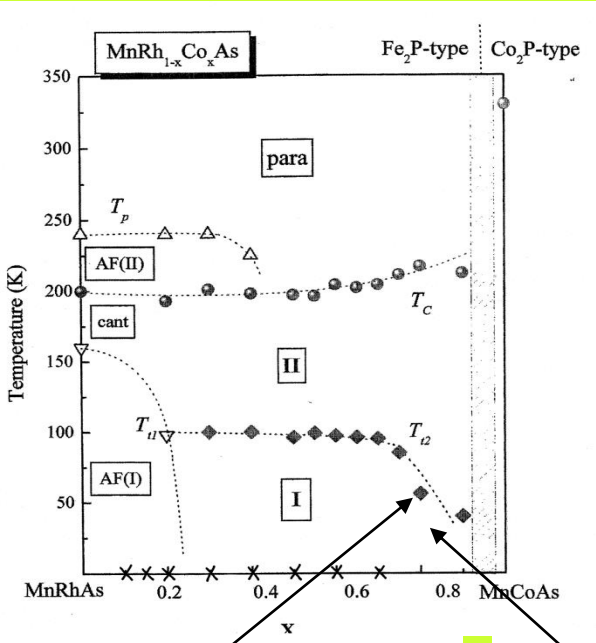


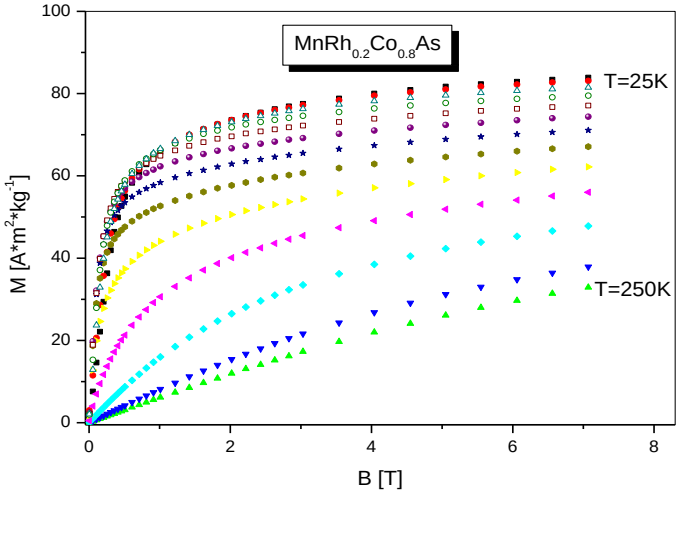


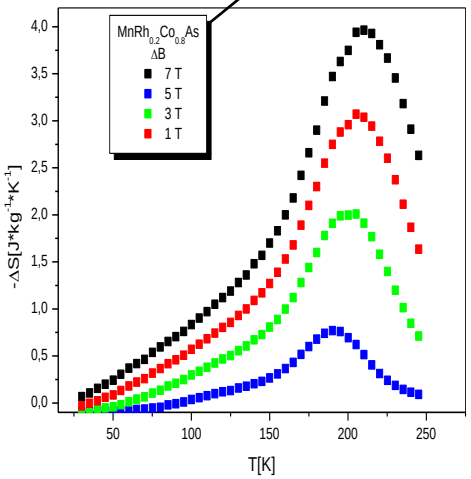
Density of states in for x = 0, 0.2, 0.5, 0.95, 1.0 exhibits a strong spin polarization arising mainly from a splitting of the Mn states in both (*F*) and (*AF*) states.

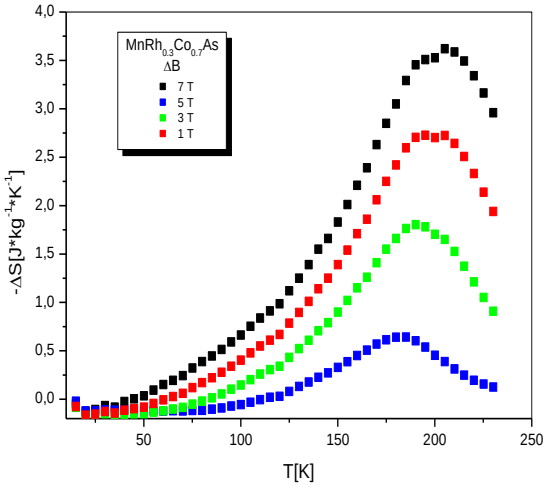
D.Szymanski , R.Zach , W. Chajec, R Duraj , J.Tobola , M.Guillot , S.Haj-Khlifa, D. Fruchart
J.Alloys Comp. 776 (2019) 59-70
Przewód doktorski mgra D.Szymańskiego, IFJ PAN, 2019

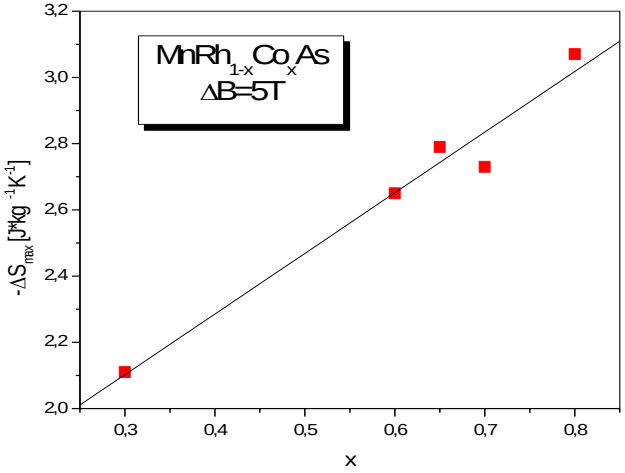
MCE w układzie $MnRh_{1-x}Co_xAs$











Zach, R.; Tobola, J.; Chajec,W.; Fruchart, D.; Ono, F. Magnetic properties of MM'X (M = Mn, M' = 3d or 4d metal, X = P, As, Si, Ge) compounds with hexagonal or orthorhombic crystal structure. Sol. State Phenomena 194 (2013) 98–103.

C O N C L U S I O N S

* Magnetostructural phase transitions induced by external pressure in $Co_xNi_{1-x}MnGe$,
* Critical behavior under magnetic field in $MnFeP_{1-x}As_x$ series
* New crystal structure in MnRhAs, MnRhP and MnRuP under extreme pressure,

* Pressure induced ferromagnetic state in MnRhAs and in $MnRh_{1-x}Co_xAs$ and $(Mn_{1-x}Co_x)_2P$,

* Magnetoelastic character of AF-F, AF-P and F-P phase transitions in studied series of compounds was established

* Magnetic entropy change ΔS_M was determined for several (Rh,Ru) contents. Conventional and negative MCE was reported.

* Electronic band structure calculations performed „under pressure" confirmed stability of the pressure induced ferromagnetic state in MnRhAs and $(Mn_{1-x}Co_x)_2P$

* Electronic band structure was calculated both in ferromagnetic and antiferromagnetic state. Good agreement between calculated and experimental values of magnetic moments was found.

1. Grant KBN nr 2 P 302 10307, główny wykonawca 1996-1997.
2. Projekt polsko-francuski: **Action Themmatique Programme,** (ATP S15) 1995.
3. Projekt polsko-francuski: **Action Integreé No 5242.**
4. Projekt polsko-francuski **TEMPRA Rhone Alpes 2001 - 2002,** Uniwersystet Joseph Fourier Grenoble.
5. Projekt polsko-francuski **ECO-NET /lata: 2004-2005/,** granat międzynarodowy, Nr 08133RA, kierownik projektu ze strony polskiej.
6. Program Ramowy Akademickie Centrum Technologii _ Małopolska, **AKCENT 2004-2006;** (UJ, AGH, PK) (Nr WKP_1/1.4.3/1/2004/22/22/73) finansowany przez Europejskie Fundusze Strukturalne oraz MNiI (KBN)
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8. Projekt polsko-francuski **POLONIUM 2006-2007**, kierownictwo projektu
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Dr B. Średniawa, Cracow, Poland
Dr M. Michalec, ICh UJ, Cracow, Poland

Thank you very much for your attention!!!!