Anomalous Binding of ^{57}Fe Atoms in Metallic Chromium

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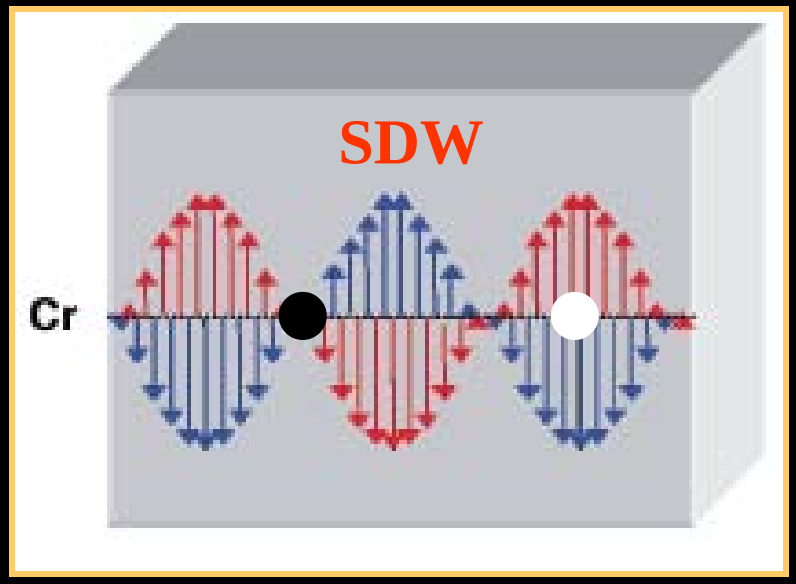
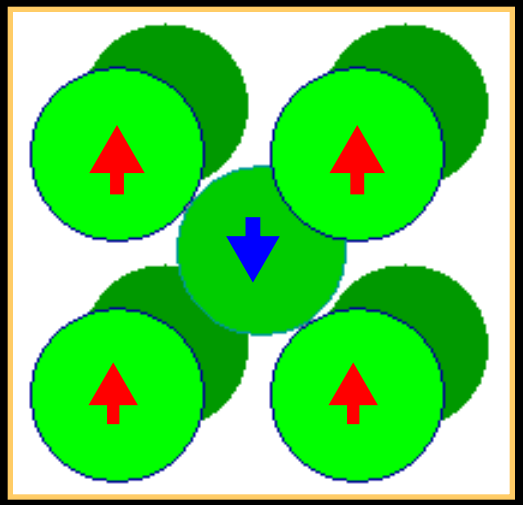


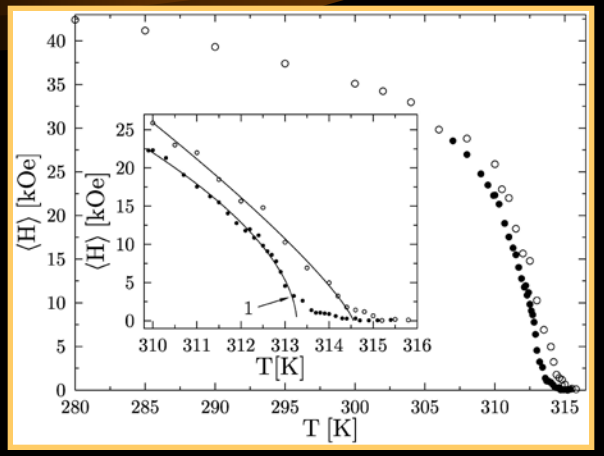
INTRODUCTION

Antiferromagnetism of chromium

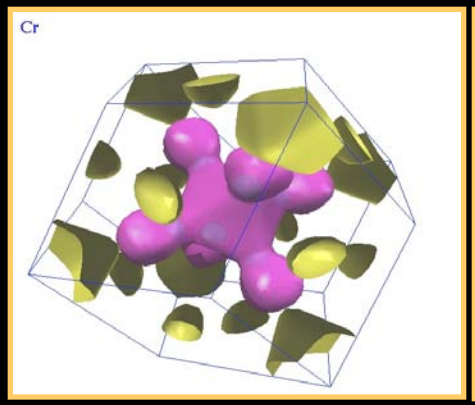
- **Néel temperature ~ 313 K**

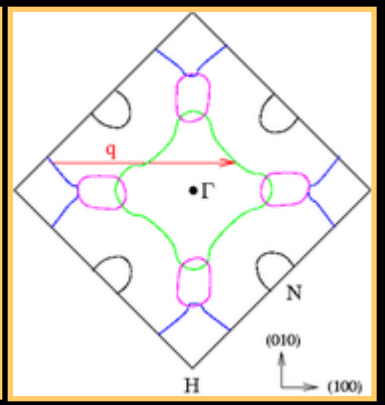


$$\mu = \mu_0 \sin(q \cdot r)$$



Dubiel & Cieslak, Europhys. Lett., (2001)

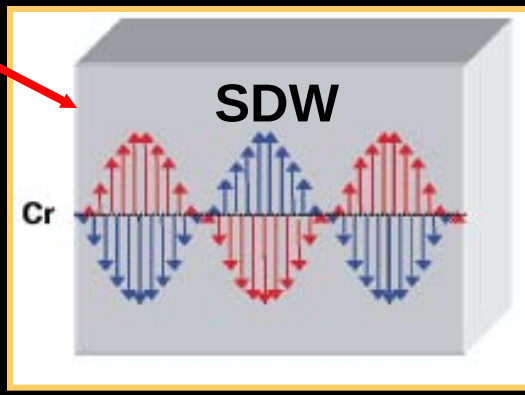




$$\Lambda = 2\pi/q$$

$$\Lambda \approx 78 \text{ Å (55 ML)}$$

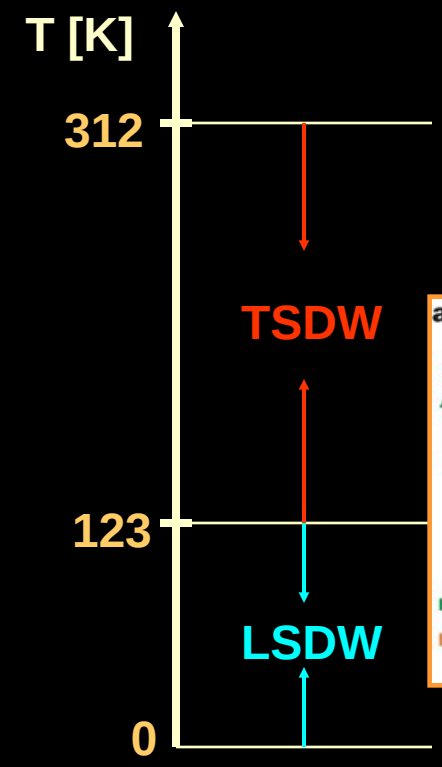
$$E_o = -0.5 \cdot n(E_F) \cdot |\Delta|^2$$



INTRODUCTION

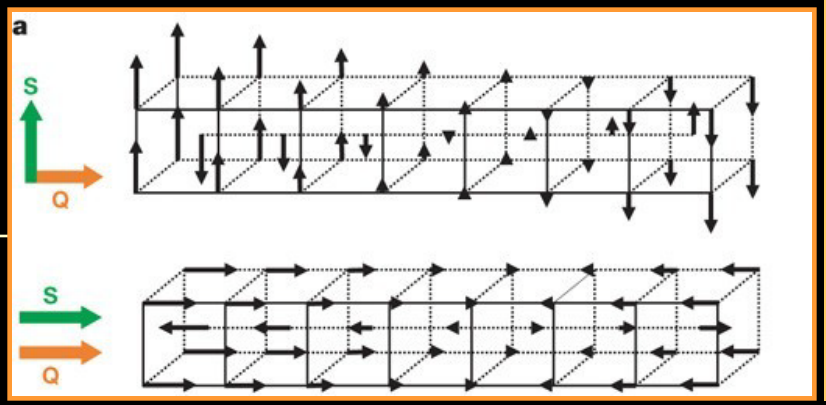
Antiferromagnetism of chromium

- Temperature phase diagram

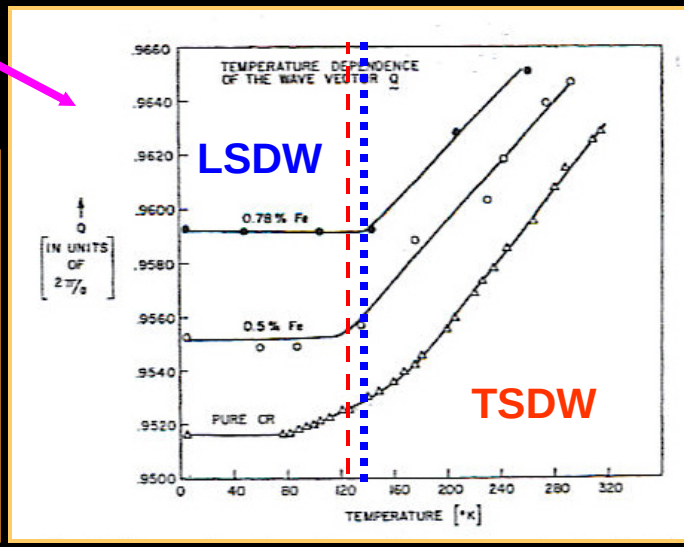


$$Q = \frac{2\pi}{a}(1 \pm \delta)$$

~0.037 ≤ δ ≤ ~0.050



A. Arrot et al., Phys. Rev., 153 (1967) 624



INTRODUCTION

SDWs – effect of impurities

- Theory – nonmagnetic
  - Weak ($< \Delta = 3.5 \cdot k \cdot T_N \approx 0.1$ eV) because, to the first order, the SDW has a uniform charge (G. Grüner, Sol. Stat. Phys., 10 (1983) 183)
  - Weak but inducing a distorsion of the charge-density near the impurity site (P. F. Tua & J. Ruvalds, PRB, 32 (1985) 4660)
  - Weak and only affect the LSDW (Ch. Seidel, Phys. Stat. Sol. (b), 148 (1988) 327)
  - Strong ($\sim\Delta$) and can lead to a static deformation of the SDW and destruction of a long-range order (I. Tütö & A. Zawadowski, PRL, 60 (1988) 1442)

INTRODUCTION

SDWs – effect of impurities

- Theory – magnetic

- According to all theoretical calculations magnetic impurities have a stronger effect on the SDW than nonmagnetic ones. The orientation of their spins is affected by the local magnetic field produced by the SDW.

- Magnetic impurities can pin both TSDW and LSDW (Ch. Seidel, Phys. Stat. Sol. (b), 149 (1988) 327)

INTRODUCTION

SDWs – effect of impurities

- Experiment – nonmagnetic

  - Au: no effect for 0.2 – 1.0 at% (T_N and T_{SF} unchanged)

  - Sn: ideal probe nucleus for MS; all features of SDWs measured with ^{119}Sn (T_N, T_{SF}, sign and amplitude of 3rd-order harmonics) as in pure Cr.

  - V: very strong effect; acts as electron acceptor and quenches SDWs (T_N decreases at the rate of ~ 80 K/at % i.e. $\leq$ 4 at% V drives T_N to 0 K).

$$E_o = -0.5 \cdot n(E_F) \cdot |\Delta|^2$$

INTRODUCTION

SDWs – effect of impurities

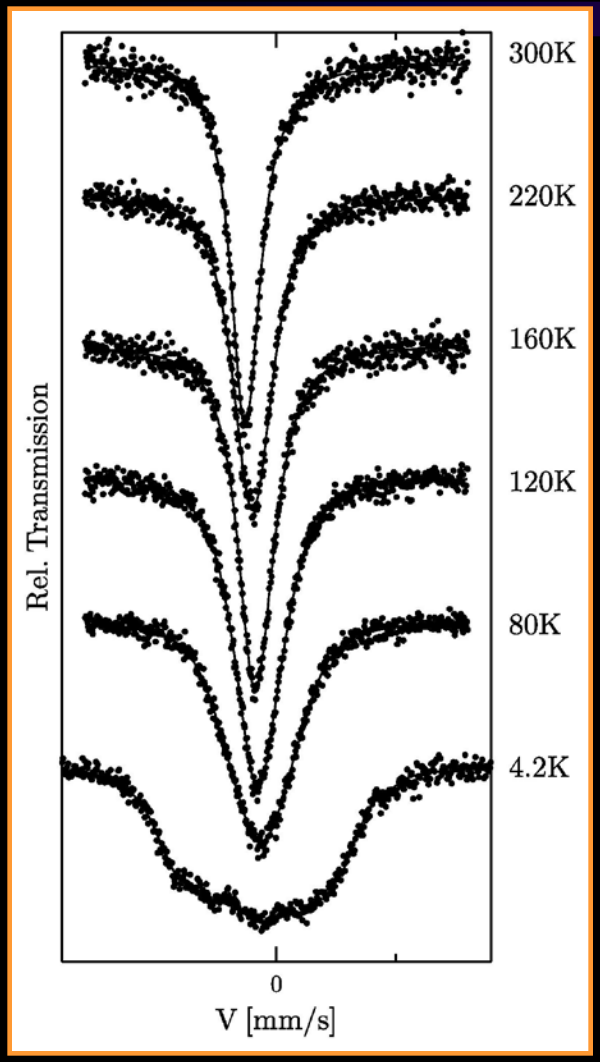
- **Experiment – magnetic**

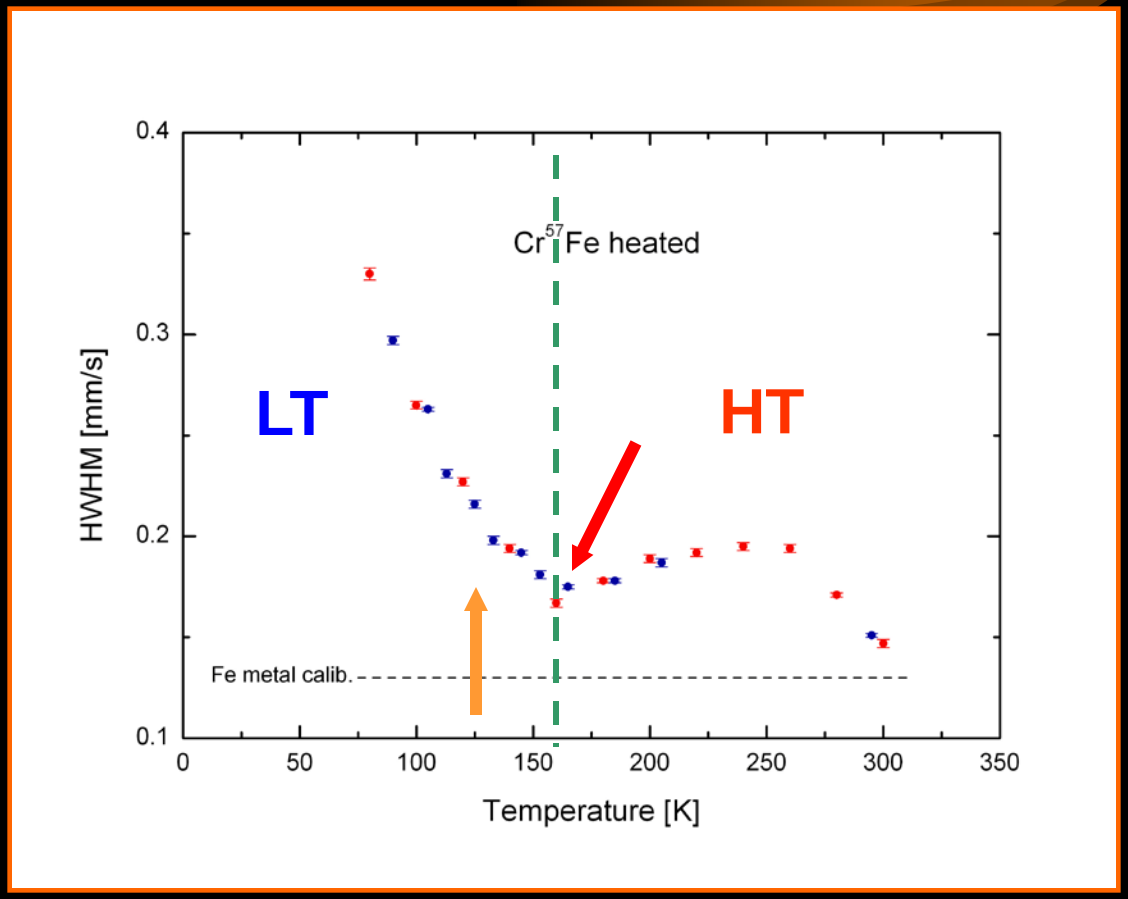
  - **Mn: very strong effect – acts like electron donor and supports SDWs (amplitude and T_N increase) but changes ISDWs into CSDWs ($\Lambda = n \cdot a$) at $x \approx 0.3$ at%. For $x \geq 1$ at% $\Lambda = \infty$ (normal AF).**
  - **Fe: very strange effect; decreases T_N (~20 K/at%) and T_{SF} and decreases the amplitude of SDWs, drives SDWs from ISDWs to CSDWs at $x \approx 2.3$ at%. ^{57}Fe ME spectrum is single-line at RT and slightly broadened at 4 K ($B_{hf} \approx 3.5$ T) despite strong (~1.5 μ_B) magnetic moment at Fe atom.**

RESULTS

Mössbauer spectra

Cr<0.1%^{57}Fe



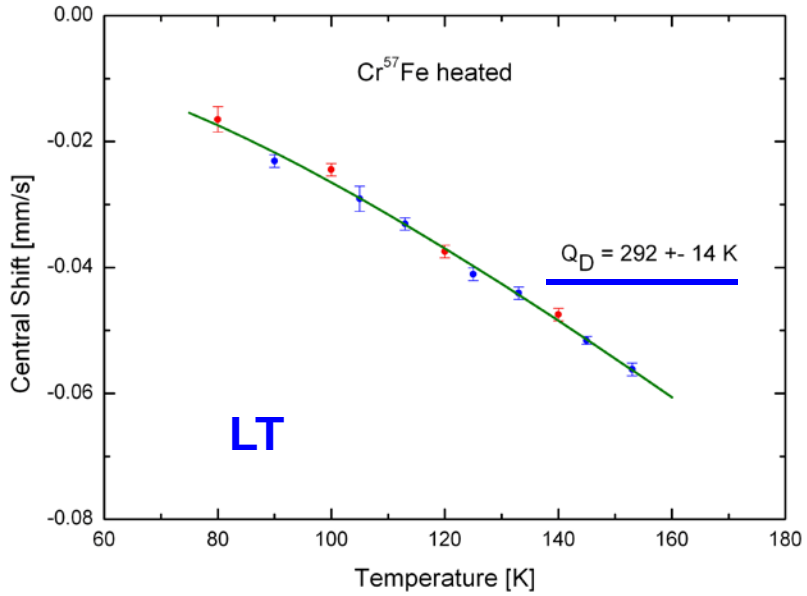


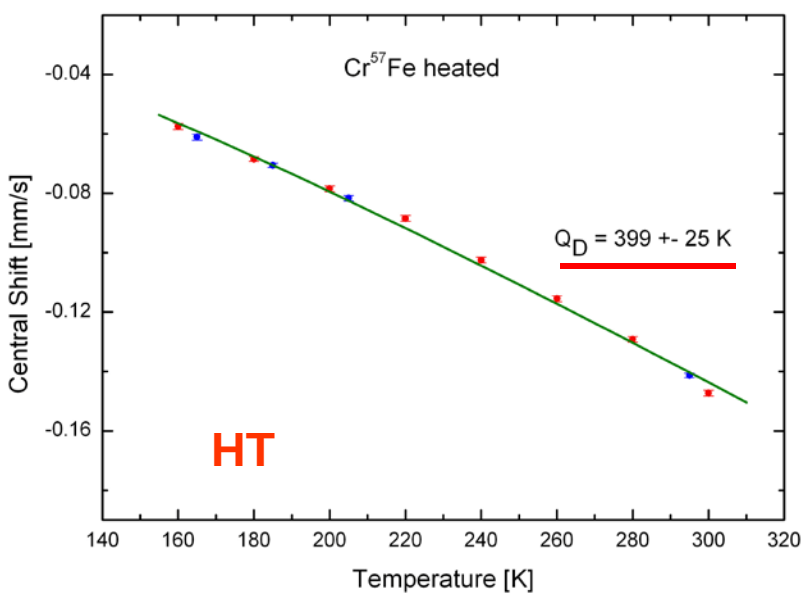
Kondo: Katano & Mobi, J. Phys. Soc. Jpn., 49 (1980) 1812

RESULTS

Debye temperature

$$< CS > (T) = IS(0) + \cancel{IS(T)} + SOD(T)$$





$\Delta\theta_D = \theta_D(HT) - \theta_D(LT) \approx 100$ K

RESULTS

Force constant - models

$$\kappa = \frac{m k_B^2 \Theta_D^2}{4\hbar^2}$$

Gupta & Lal, Phys. Stat. Sol. (b), 51 (1972) 233

$$\kappa'/\kappa = \left(\Theta_{eff}/\Theta_D\right)^2 \left(m'/m\right)$$

Visscher, PR, 129 (1962) 2059 (Steyert & Taylor, PR, 134(1964) A716)

RESULTS

Force constants - results

Visscher's model

- ^{57}Fe in Cr

LT: $\kappa_{57Fe}/\kappa_{Cr}$ = 0.235 (23) for 80 K ≤ T ≤ 155 K

HT: $\kappa_{57Fe}/\kappa_{Cr}$ = 0.440 (55) for 155 K ≤ T ≤ 300 K

→ Binding of ^{57}Fe atoms in HT Cr is ~2 times stronger

- ^{57}Fe in Fe

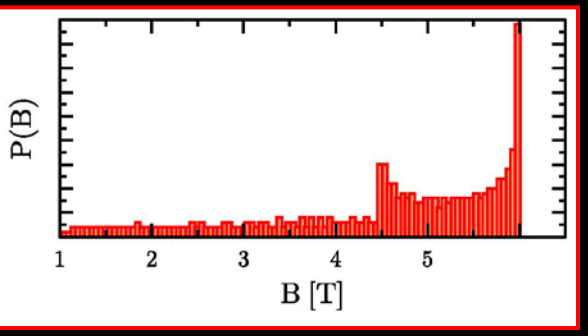
$\kappa_{57Fe}/\kappa_{Fe}$ = 0.865

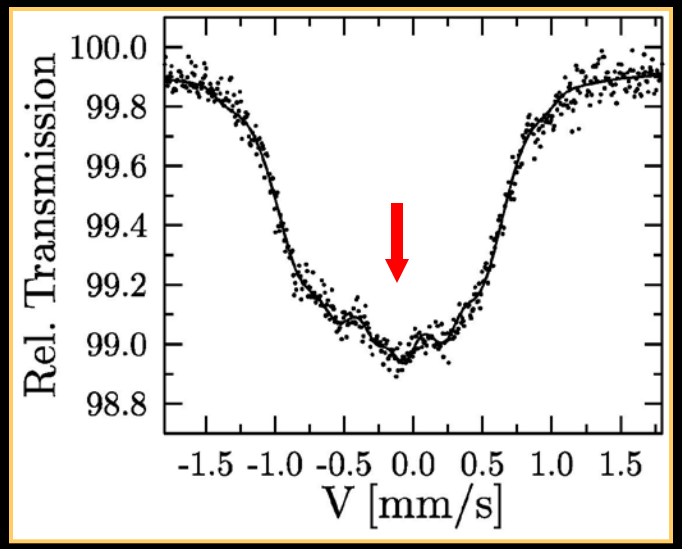
→ Binding of ^{57}Fe atoms in Fe is ~2 times stronger than in HT Cr and ~ 4 times stronger than in LT Cr

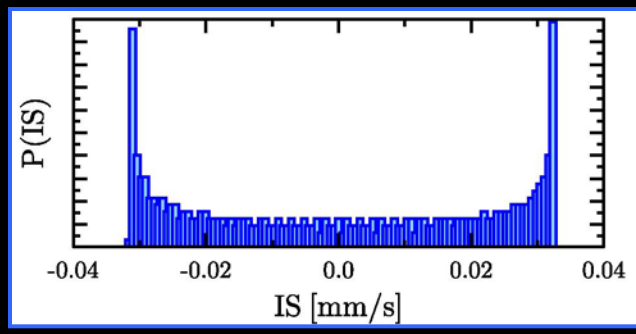
RESULTS

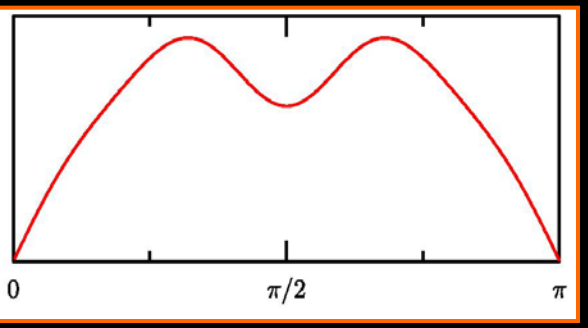
4.2 K spectrum

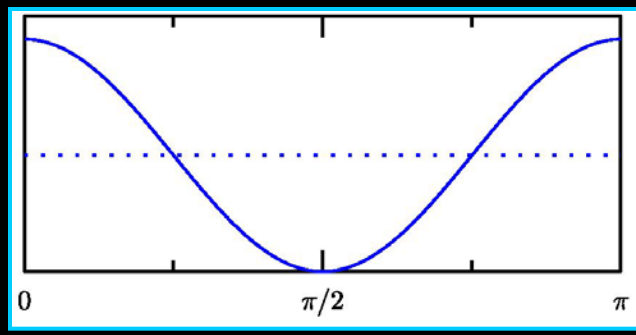
$B = 51.6 \sin\alpha + 11.1 \sin3\alpha - 3.7\sin5\alpha + 2.1\sin7\alpha$ + $IS = 0.03 \sin2\alpha$









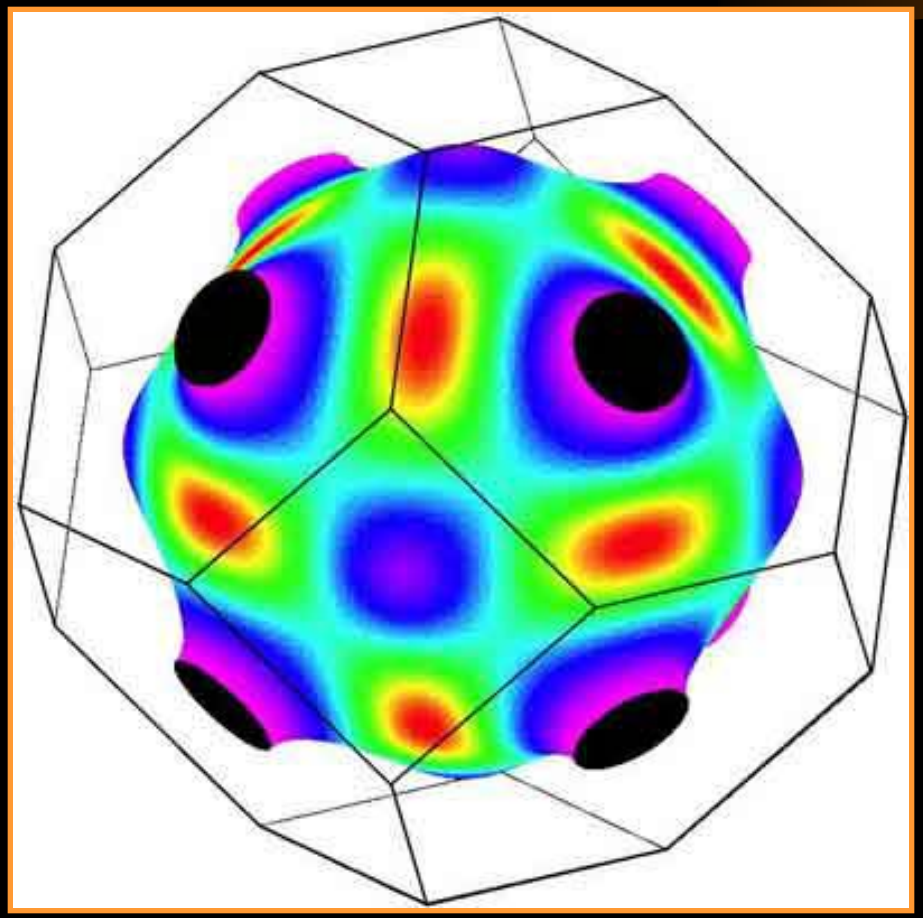


Distortion of the SDWs by ^{57}Fe atoms and GB

CONCLUSIONS

- ^{57}Fe atoms are very weakly coupleded to Cr matrix
- Strength of the coupling is anomalously temperature dependent; in HT ‘phase’ it is by a factor ~2 stronger than in LT ‘phase’
- ^{57}Fe atoms disturb (pin) SDWs – they affect both their amplitude and shape

Thank you for your attention



Temperature Dependence of Θ_D

- **metallic Fe (MS)**

$\Theta_D = 430 \pm 15$ K for T = 80 – 300 K

$\Theta_D = 400 \pm 30$ K for T = 300 – 700 K

$\Theta_D = 310 \pm 15$ K for 700 - 1050 K

$\Theta_D = 300$ K for T= 1050 – 1200 K

Costa, Cieslak & Dubiel, 2008

Preston et al., Phys. Rev., 128 (1962) 2207