Lecture 11

Strange Electrons in One Dimension ("Nano"-physics)

Marx: Quantitative differences become qualitative ones.

Fitzgerald: The rich are different from us.
Hemingway: Yes, they have more money.

Quotes in P.W. Anderson, "More is different"

What is (Weiss) Mean-Field Theory?

$$H = -J \sum_{\langle i,j \rangle = nn} \vec{S}_i \cdot \vec{S}_j$$

n.n. = nearest neighbor

$$\vec{S}_i = \underbrace{\langle \vec{S}_i \rangle}_{\text{Thermo-dynamic average}} + \delta \vec{S}_i \qquad \delta \vec{S}_i = \vec{S}_i - \langle \vec{S}_i \rangle$$

$$H = -J \sum_{\langle i,j \rangle = nn} \vec{S}_i \cdot \vec{S}_j \approx -J \sum_i \vec{S}_i \cdot \sum_{j = nn} \langle \vec{S}_j \rangle$$

$\langle \vec{S}_i \rangle$ = uniform for FM, alternating for AFM

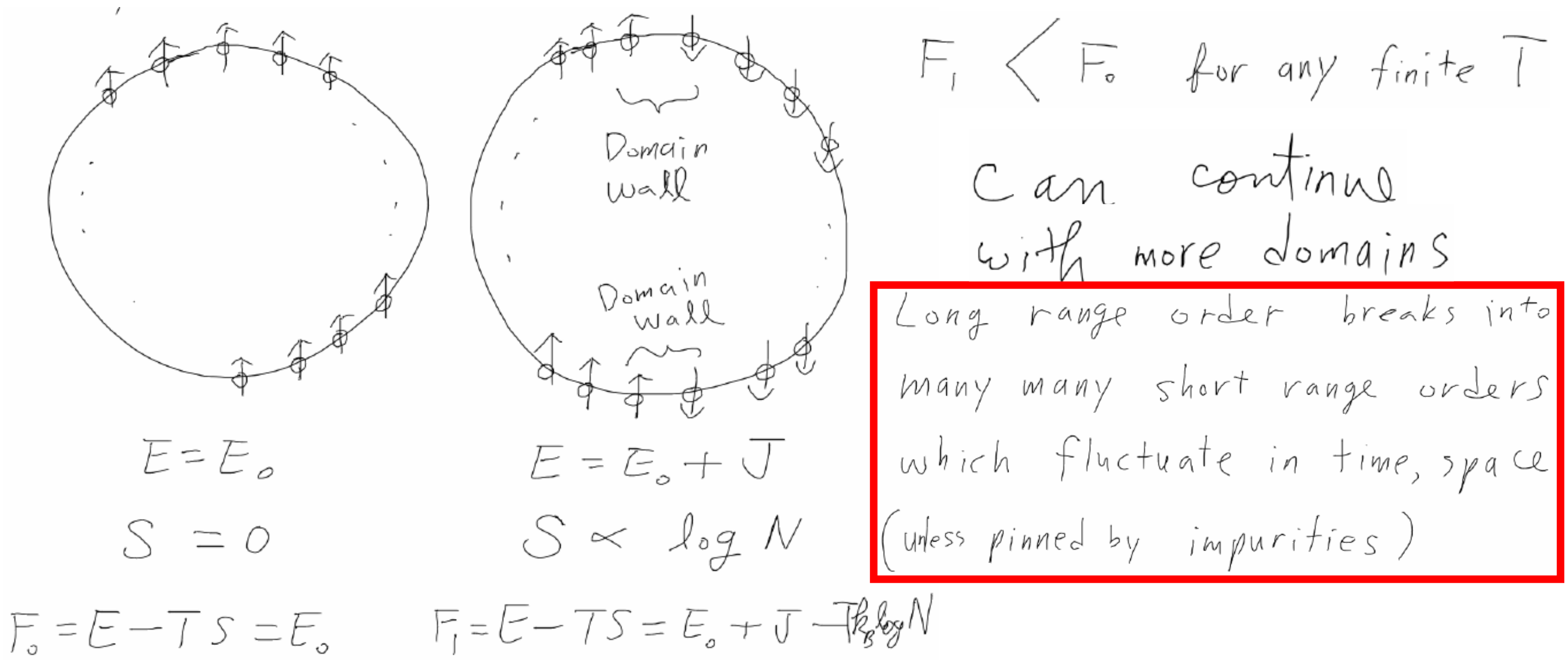
Z = Coordination # = # of n.n.

$$H = -\sum_i \vec{S}_i \cdot \left(J Z \langle \vec{S} \rangle \right) \leftarrow \text{FM}$$

$$\vec{B}_i \propto J Z \vec{M}$$

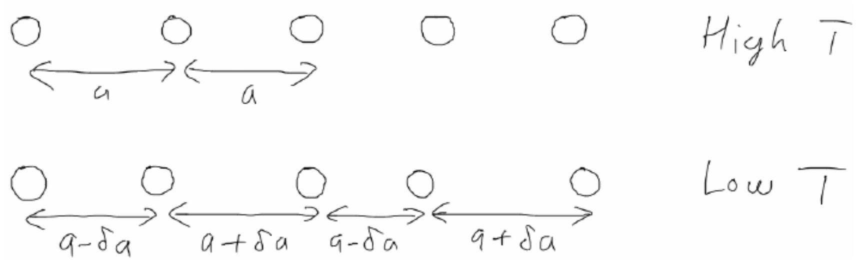
MF theory works better as the spatial dimension increases.

Why Mean-Field Theory Completely Breaks Down in One Dimension



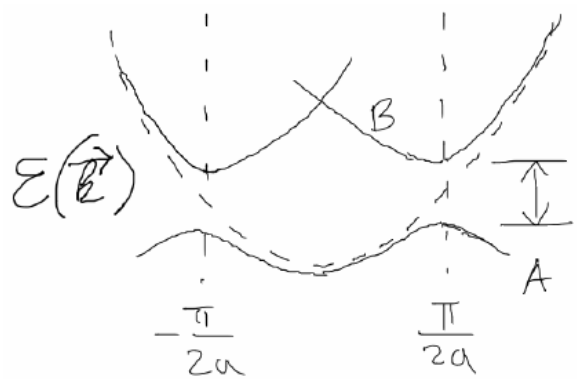
- Mermin-Wagner Theorem : No long range order (i.e. no phase transition) in 1D or 2D with short range interactions

Peierls Instability (Charge Density Wave)



mono-valent

High T : metal
Low T : insulator



$2\Delta \propto \delta a$

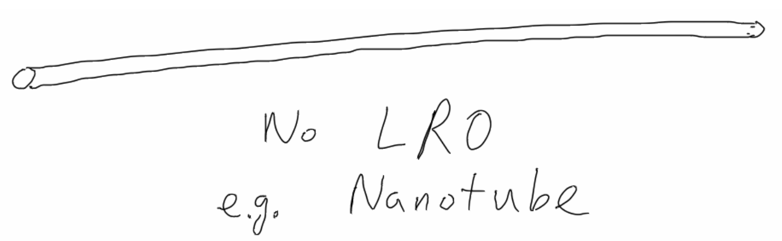
Energy lowering $\propto (\delta a)^2 \log(\delta a)$
(Kittel)

Lattice strain $\propto (\delta a)^2$

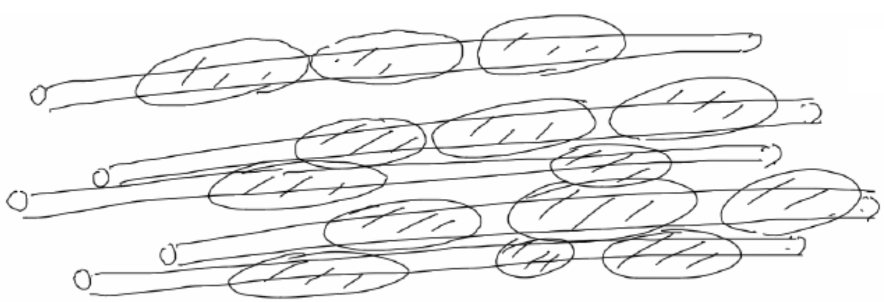
- Analogous Physics in Spin Density Wave (Cr), and Spin Peierls ($CuGeO_3$) Transitions

Wait … What Really Happens in Peierls Systems

- This was a mean-field picture! And, we did not condier Mermin-Wagner theorem.



Neutron Diffraction, X-ray Diffraction, Photoemission Spectroscopy, Pauli Susceptibility, Resistivity etc. can examine these strange behaviors on quasi-1D materials



$T \approx T_{MF}$

$T \gg T_{MF}$	Nothing
$T \approx T_{MF}$	Fluctuating SRO show up (Confined to chains)
$T \approx T_{3D}$ ($T_{3D} \ll T_{MF}$)	Real LRO Phase transition

Other Novel Nano-Scale Physics

- Spin-and-charge separation
- Luttinger liquid state of electrons
- Nanotubes, graphene, graphite
- Massless Dirac particles in graphene
- Quantized conductance
- Metal-Insulator transition
- Quantum dots – Coulomb blockade, Kondo resonance, …
- Quantum Hall Effect
- Magnetic multi-layers
- …

I was like a boy playing on the sea-shore, and diverting myself now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.