Hysteresis in condensed matters: Three examples.

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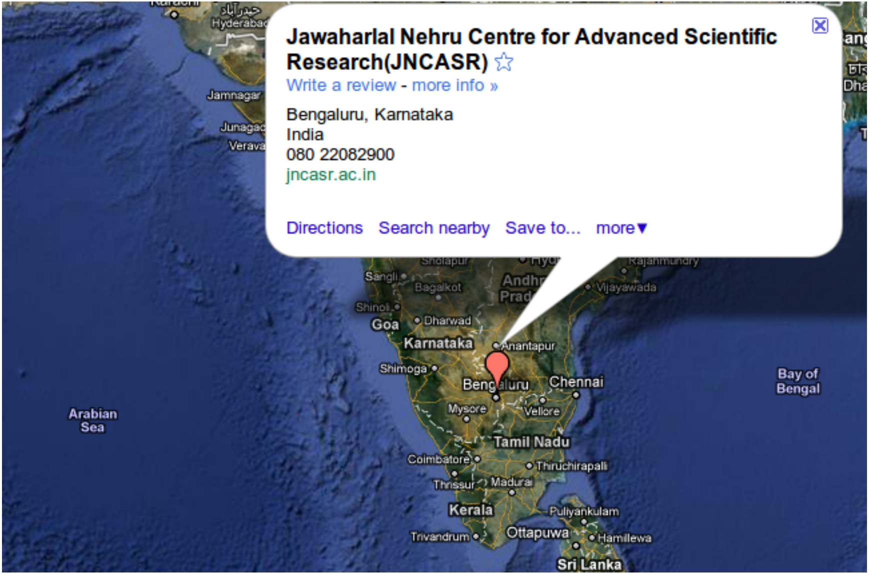
My Place



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Arabian Sea
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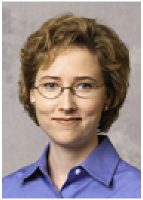
People I have been working with

Ph.D. supervisor: Dr. N. S. Vidhyadhiraja (JNCASR)

Collaborators: Prof. Erica W. Carlson (Purdue), Prof. Karin A. Dahmen (UIUC)

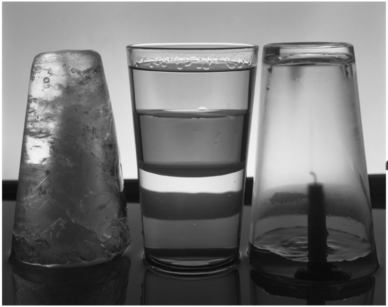


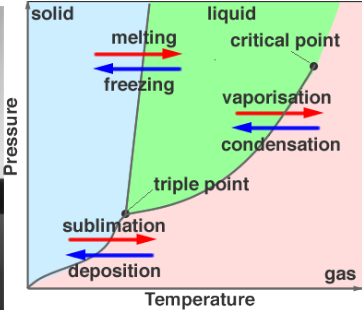
Quick outline

1. Hysteresis in three phases: Liquid-gas-solid, Ferromagnets, Metal-Insulator (Mott)
2. Qualitative explanation
3. Further investigation: Avalanches

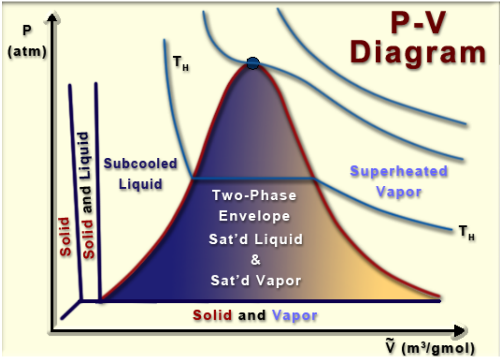
Liquid-gas-solid

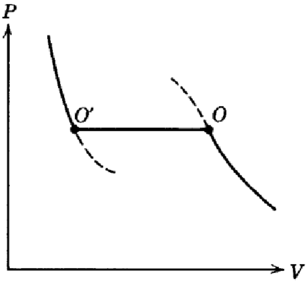
Phase diagram



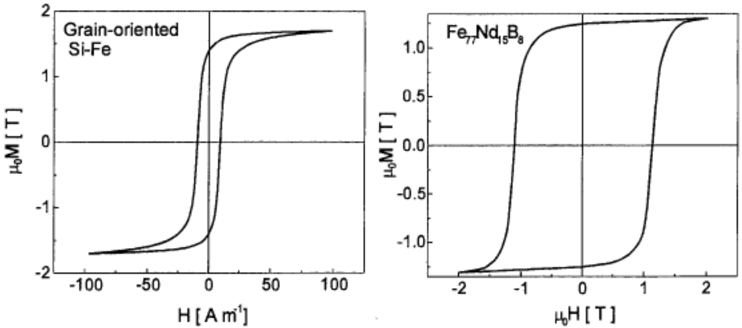


Liquid-gas-solid





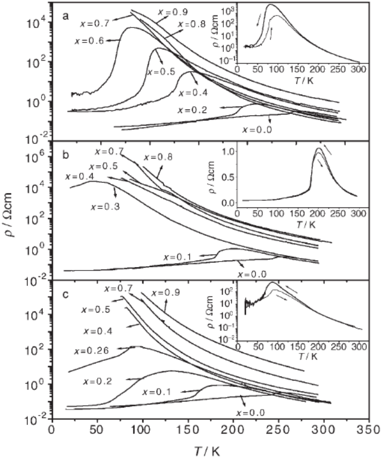
Ferromagnets



Ref. *Giorgio Bertotti, HYSTERESIS IN MAGNETISM*

Metal-insulator transition

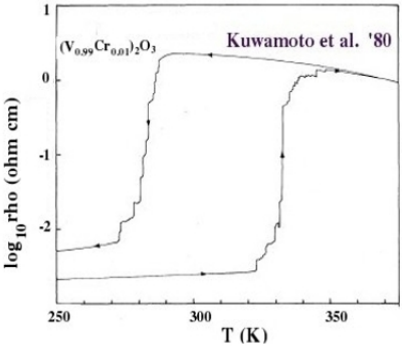
Manganites: $(La_xLn_{1-x})_0.7Ca_{0.3}MnO_3$)0.7Ca0.3MnO3

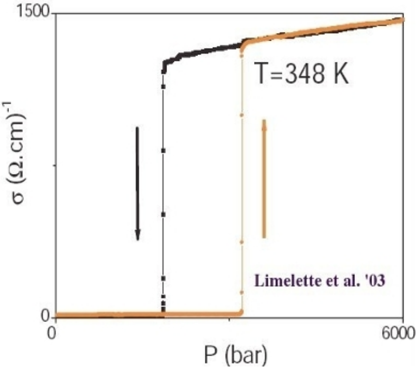


Shenoy, Sharma, Rao, ChemPhysChem 7, 2053 ('06)

Metal-insulator transition

V_2O_3: Contribution from Purdue University, *J. M. Honig's group*

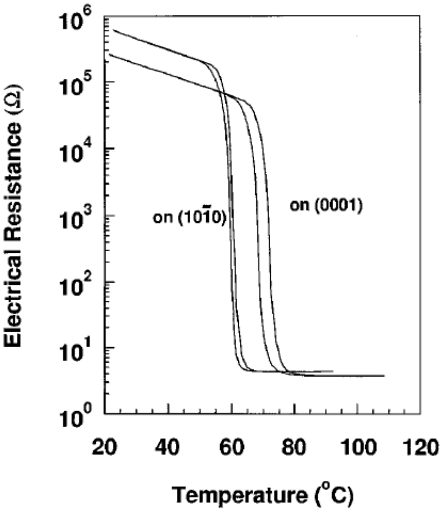




Temperature and pressure driven hysteresis

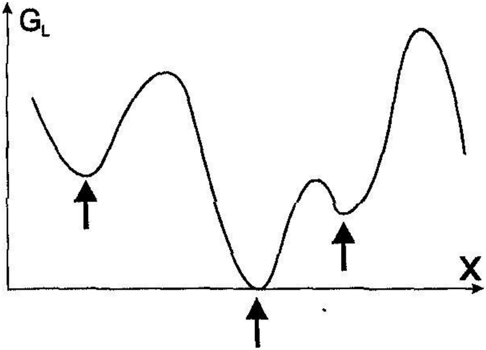
Metal-insulator transition

VO_2: Kim and Kwok, APL ('94)



General theory for hysteresis

Metastable states in free energy profile

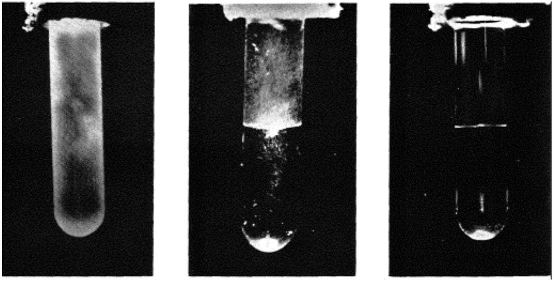


Universality ?

Can think of Ising-universality when we have two-state phases:
Liquid and Gas $\leftrightarrow$ Spin-$\uparrow$ FM and Spin-$\downarrow$ FM $\leftrightarrow$ Metal and Insulator
However, liquid-gas may differ since surface tension is an additional driving force.
Why thermal hysteresis is not common in ferromagnets?

Two-phase state: Evidence for coexistence

Liquid-gas



Ref. *E. G. Stanley, INTRO. TO PHASE TRANSITION AND CRITICAL PHENOMENA*

Two-phase state: Evidence for coexistence

Ferromagnet

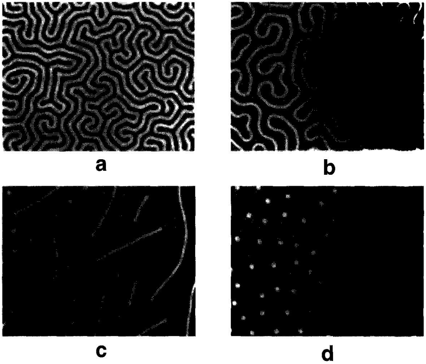
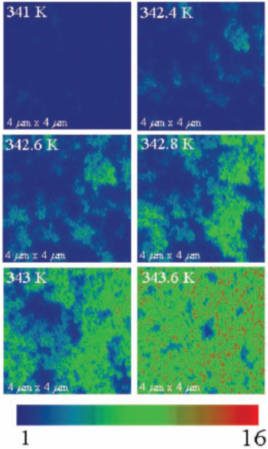


FIGURE 7.14. Domains in epitaxial garnet crystal 6 μm thick, observed by Faraday effect. (a) Stripe domains under zero field. (b) Stripe domains under an external field perpendicular to the plane of the film. (c) and (d) Formation of bubble domains. Magnification is 300x (after [B.87], p. 166, Fig. 4.31, reprinted with kind permission from Academic Press).

Ref. *Giorgio Bertotti, HYSTERESIS IN MAGNETISM*

Two-phase state: Evidence for coexistence

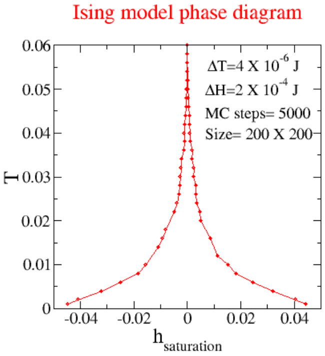
VO_2: Near-field Infra-red spectroscopy

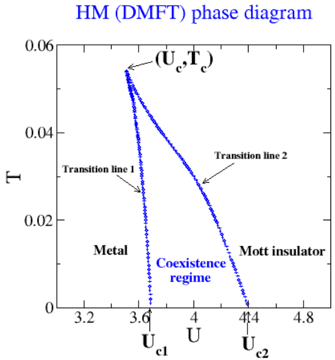


Ref. *Qazilbash et al., Science 318, 1750 ('07)*

Thermal hysteresis: Role of phase geometry

Ising model Vs Hubbard model (Dynamical mean-field th. scheme, Barman and Vidhyadhiraja, http://arxiv.org/abs/1011.4478)

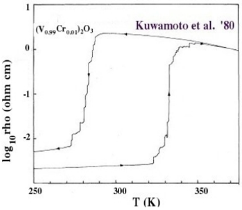


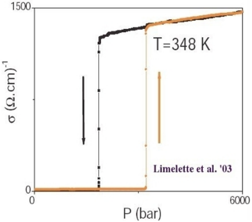


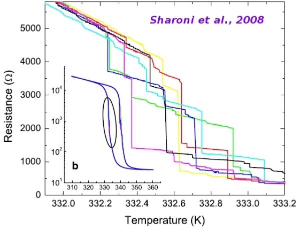
Hysteresis occurs only when both spinodal lines are crossed.

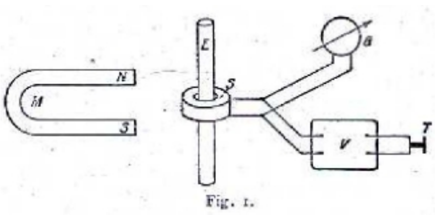
More with hysteresis: Avalanches

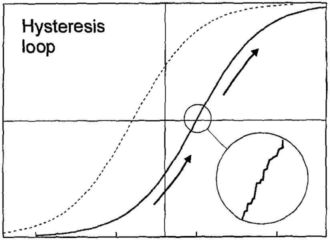
Avalanches, Barkhausen noise











More with hysteresis: Avalanches

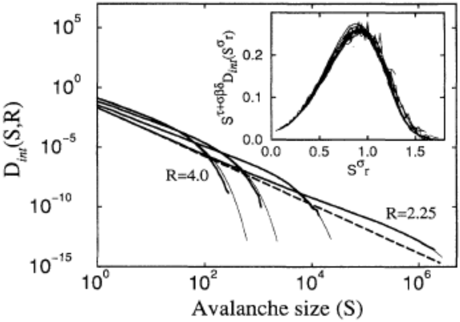
- Requires a theory that include domains and pinning disorder.
- Random field Ising model: RFIM (J. P. Sethna, K. A. Dahmen, E. W. Carlson).

$$H = -J \sum_{ij} S_i S_j - \sum_i (h + h_i) S_i \tag{1}$$

- RFIM can model for Barkhausen noise, for avalanches in MIT system we need a mapping or connection.

Barkhausen noise: RFIM

Olga, Dahmen, Sethna, PRL 75, 4528 ('95)



Barkhausen noise: RFIM

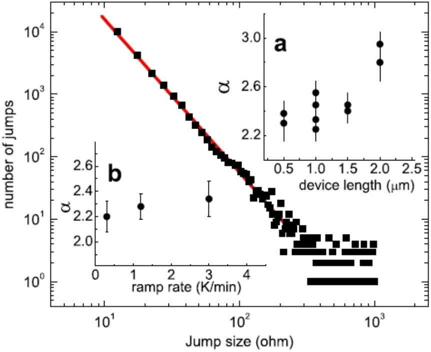
Olga, Dahmen, Sethna, PRL 75, 4528 ('95)

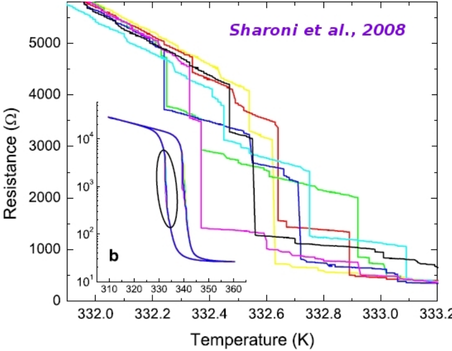
Exponents	Simulation in 3 dimensions	Experiments in 3 dimensions
τ	1.6 ± 0.06	1.74, 1.78, 1.88 [2];
		1.5 ± 0.5 [4];
		1.33 [10];
		1.5–1.7 [5]
$\tau + \sigma\beta\delta$	2.03 ± 0.03	1.73–2.1 [8]
$(\tau - 1)/\sigma\nu z + 1$	2.05 ± 0.12	1.64, 2.1, 1.82 [2];
		1.7–2 [5]
$(\tau + \sigma\beta\delta - 1)/\sigma\nu z + 1$	2.81 ± 0.11	2.28 [8]
$(3 - \tau)/\sigma\nu z$	2.46 ± 0.17	Around 2 [2,9]
$[3 - (\tau + \sigma\beta\delta)]/\sigma\nu z$	1.70 ± 0.10	1.6 [6,7]; 1.8 [11]
$(\tau - 1)/(2 - \sigma\nu z) + 1$	1.42 ± 0.04	1.44, 1.58, 1.60 [2]

VO_2 *experiment*

Jump (avalanche) size distribution

Sharoni et al., PRL 101, 026404 ('08)





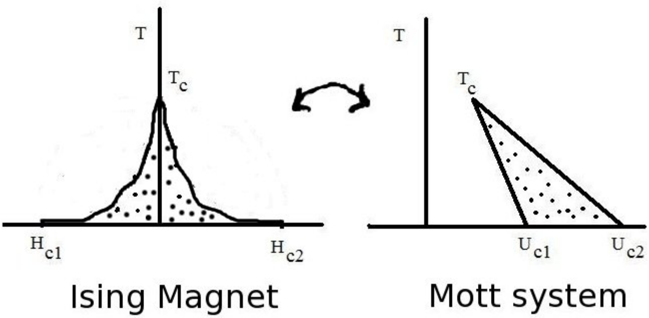
Power law: exponent, $\alpha = 2 : 48 \pm 0 : 05$

Avalanches in MIT: How to model?

Two ways !

Method 1

A canonical transformation from $U-T$ to $h-T$ phase diagram



For simplicity we can think of

$$h(U,T) = a(T)U + bT + c$$

Avalanches in MIT: How to model?

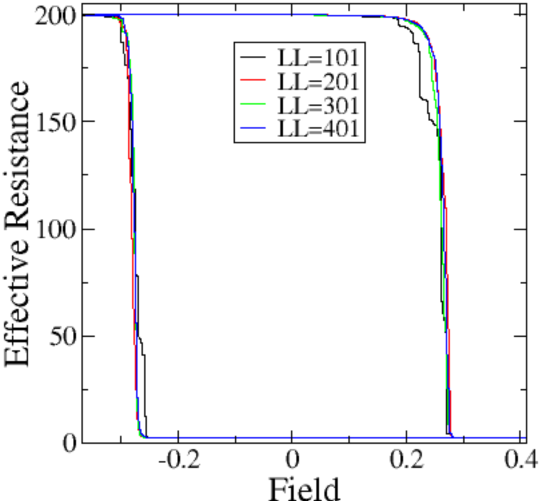
Method 2: Percolation picture

- A lattice-gas argument for the M-I domains
- Erica's method: Nematic Stripes $\rightarrow$ Random field Ising model (RFIM) $\rightarrow$ Resistor network (RN); *Carlson et al., PRL 96, 097003 ('06)*
- Similarly Lattice-gas model (M-I) $\rightarrow$ RFIM $\rightarrow$ RN

- However, percolation picture does not hold near the critical pt.
  M-I contrast ratio $\rightarrow 1$
- Need to have tunable resistances in the resistor network.

Avalanches in MIT: Finite Size effect

Avalanche size decreases as system size increases



Quick Summary

- Hysteresis is common feature in many condensed matter systems.
- Thermal hysteresis in Metal-Insulator systems, e.g. V_2O_3, VO_2 can be explained by the phase-diagram geometry.
- RFIM can be suitable for realizing the statistics in the avalanches phenomenon.
- A resistor network model should be connected to the RFIM for the MIT systems.
- The contrast ratio between metallic and insulating resistances should be tuned as the critical point is approached.

Acknowledgement

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Thanks for your kind attention !