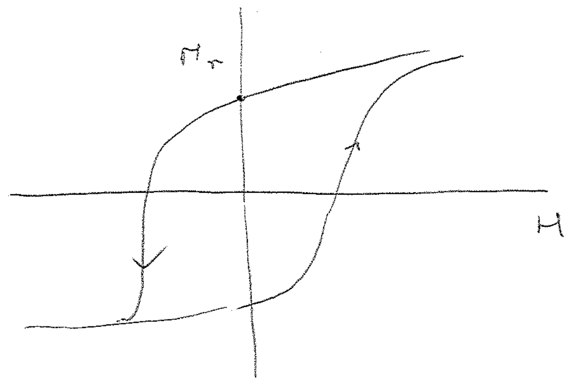
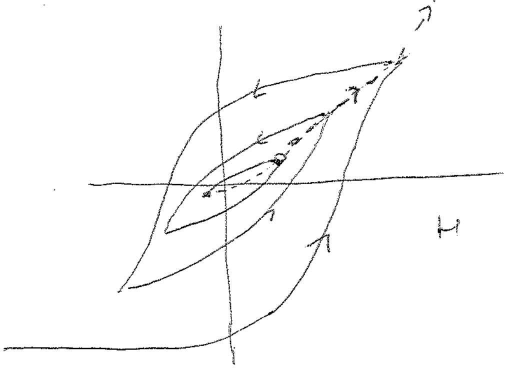
Hysteresis in magnets:

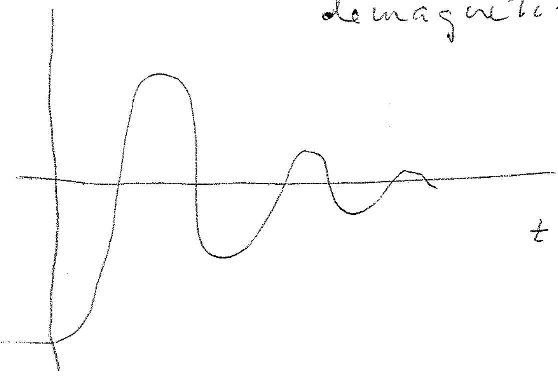


$T < T_c$

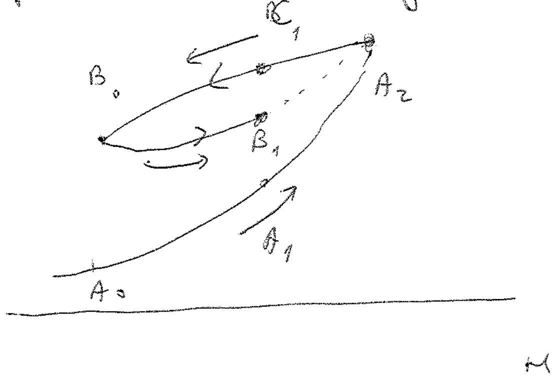
minor hysteresis loops



demagnetization



return point memory



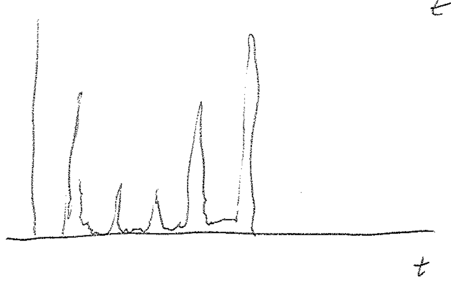
Barkhausen noise: $H \sim \alpha \cdot t$

$\frac{d\phi}{dt} \sim \dot{M}$

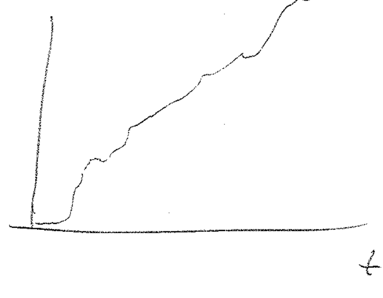
← avalanches!

$M \sim \phi$

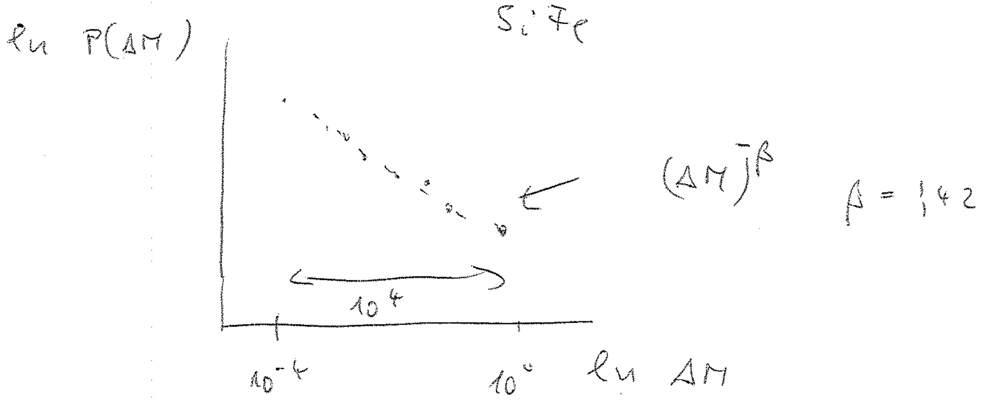
⇒



⇒

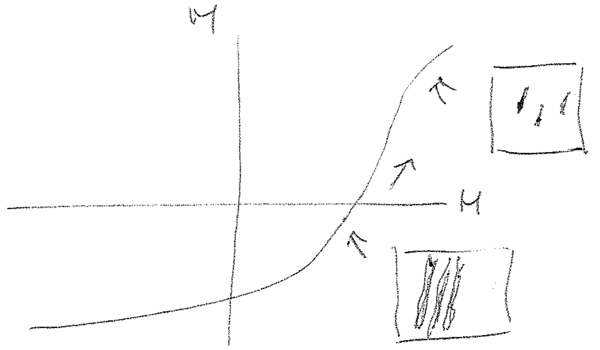


Si Fe



Disorder !

Domain structure ?



long relaxation times:

$$M = M_0 - S \ln \frac{t}{t_0}$$

"viscosity"

← stretched exponential

$$M = M_0 \, e^{-\alpha \ln^{\beta}\left(\frac{t}{t_0}+1\right)}$$

multiple time scales ~ glasses ?

Origin:

← domain wall pinning ?

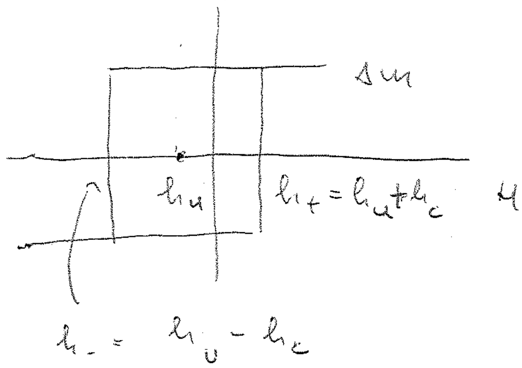
← vicinity to critical point ?

← dynamical criticality ?

← long-ranged interactions, glasses ?

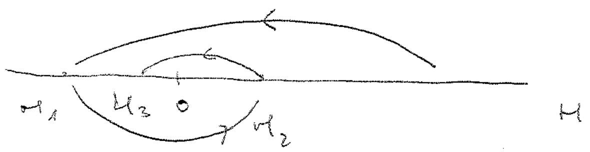
Preisach model:

hysteron

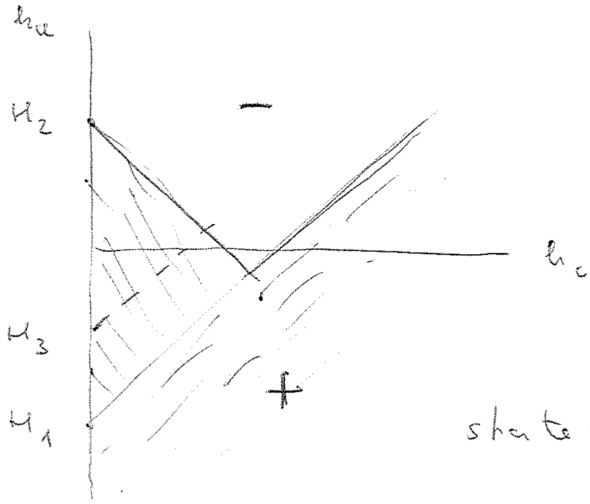


$\Rightarrow p(h_u, h_c)$

make sweep:



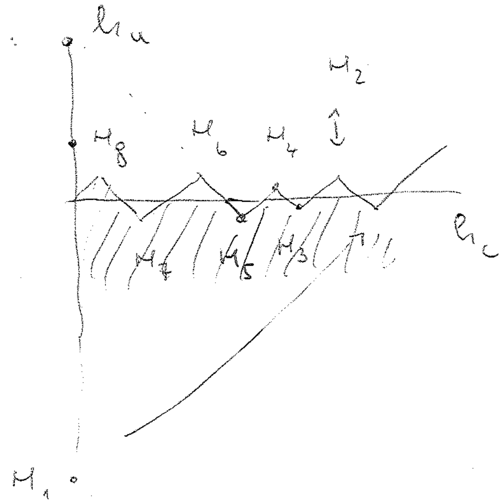
- down sweep: flip down if $H < h_u - h_c$
  $(H + h_c < h_u)$



- sweep up:
  flip up if
  $H > h_u + h_c$

  $h_u < H - h_c$

state:



increase now $H \to \frac{dM}{dH}$ changes as $H \to H_8 \to H_6$

state ~ line between ups and downs ..

return point memory! ✓

The random field Ising model:

$$\mathcal{H} = -\sum_{ij} J_{ij} s_i s_j - \sum_i (f_i s_i + H s_i)$$

effective field $F_i = \sum_j J_{ij} s_j + f_i + H$

flip occurs if $F_i > 0$

$P(f) \sim e^{-\frac{f^2}{2R^2}}$

return point memory

$\underline{s} = \{s_1, \dots, s_N\} \geq \underline{r} \equiv \{r_1 \dots r_N\}$ if

$s_i \geq r_i$

No passing:
consider $H_s(t) \geq H_r(t)$ and $\underline{s}(0) \geq \underline{r}(0)$

$\Rightarrow \underline{s}(t) \geq \underline{r}(t)$

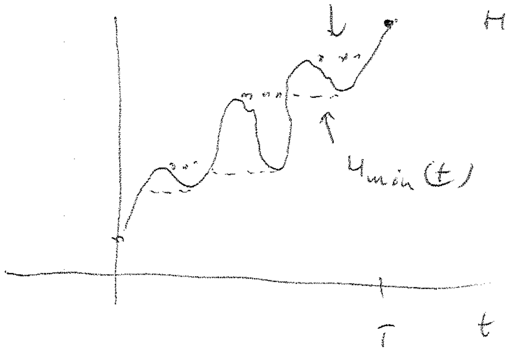
Proof:
suppose $\exists\, t$ such that $\exists\, j$ $r_j > s_j$

but $s_i \geq r_i$ for all $i \neq j$.

$\Rightarrow F_j^s \geq F_j^r > 0 \Rightarrow s_j$ must be also flipped $\Rightarrow s_j \geq r_j$

R.P.M:

$H_{max}(t)$



$H_{min}(t)$

$H(0) \leq H(t) \leq H(T)$

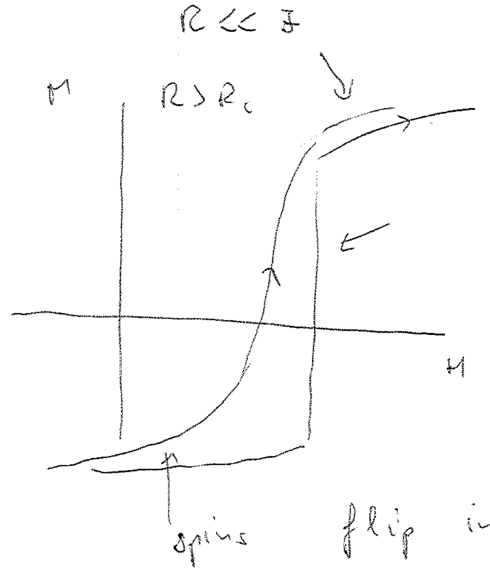
$\Rightarrow$ initial state fixed

$\Rightarrow$ final state is indep. of hystory!

$\underline{s}^{max}(t) \geq \underline{s}(t) \geq \underline{s}^{min}(t)$

$H^{min/max}$ monotonous $\Rightarrow$ final states are the same!

Avalanches — first order hysteresis



avalanche $\sim N$

critical point $H = H_c(R_c)$ $R = R_c$

$$\Rightarrow \quad P(s) \sim s^{-\tau} \, D_{\pm}\left(\frac{s}{|r|^{1/\sigma}}, \frac{h}{|r|^{\beta\delta}} \right)$$

mean field $\tau = 3/2$ $\sigma = \frac{1}{2}$ $\beta = \frac{1}{2}$ $\delta = 3$

Mean field:

$$J_{ij} \to \frac{J}{N} \qquad M = \frac{1}{N} \sum_i s_i$$

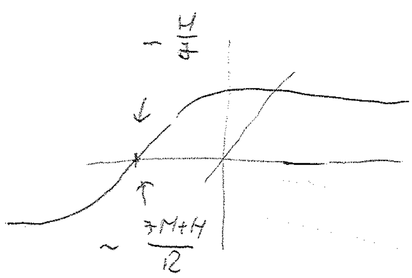
$$F_i = J \cdot M + f_i + H$$

$s_i = 1$ / $= -1$ if $F \gtrless 0$ $\Rightarrow$ f $> -(JM + H)$ / $< -JM - H$

$$M = \int_{-(JM+H)}^{\infty} \rho(f)\,df - \int_{-\infty}^{-(JM+H)} \rho(f)\,df =$$

$$= 1 - 2 \int_{-\infty}^{-(JM+H)} \rho(f)\,df$$

$$\frac{1}{\sqrt{2\pi}\,R} \, e^{-\frac{f^2}{2 \cdot R^2}}$$



$\Rightarrow$ multiple solution

multiple solutions exist if $R < R_c$

$\Rightarrow \quad 2J \cdot \rho(0) = 1$

critical behavior of magnetization jump

$R \sim T \quad \Rightarrow \quad M(r, h) = |r|^{\beta} \mathcal{M}_{\pm}\left(\frac{h}{|r|^{\beta \cdot \delta}}\right)$