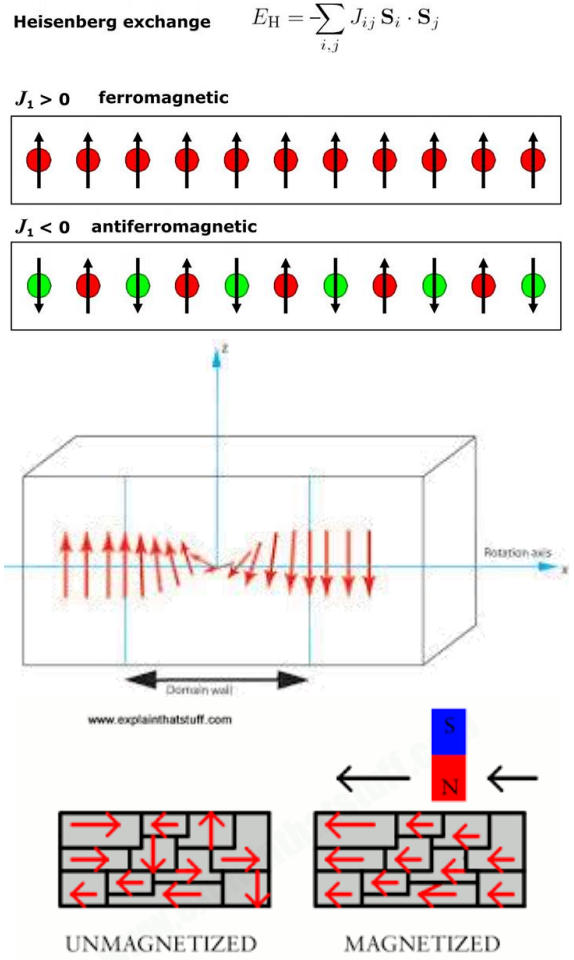
Preisach model for magnetic hysteresis

Xiaoshan Xu

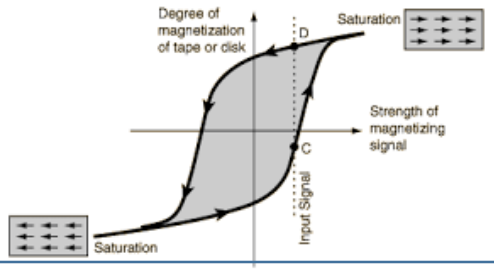
2016/08/25

Levels of details for ferromagnets

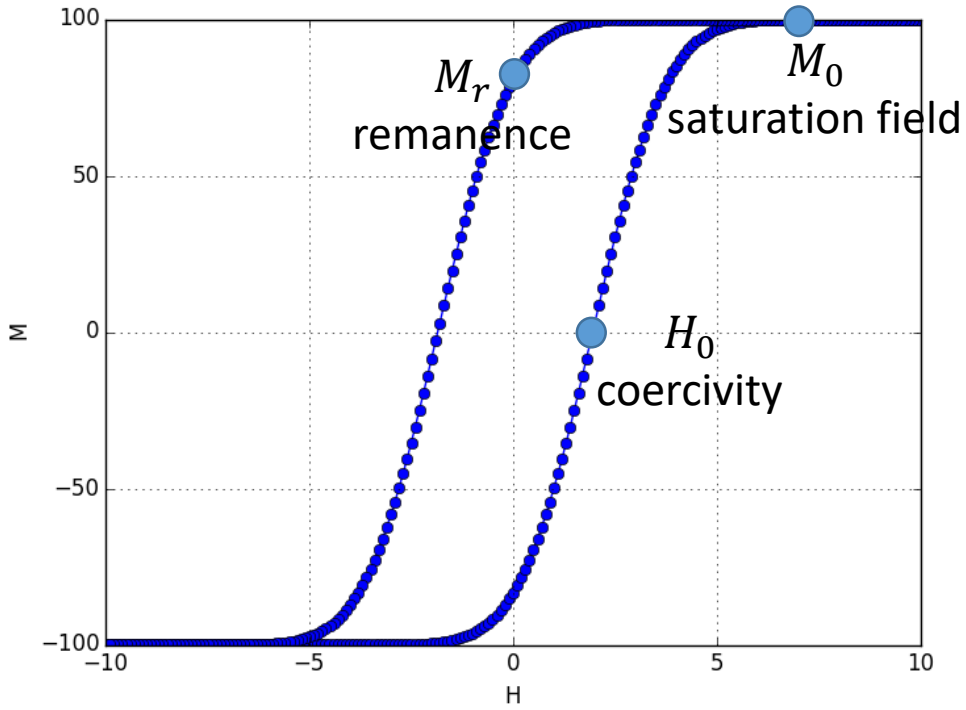
- Atomic level:
  - Exchange interaction that aligns atomic moments $\mathrm{J}_{ij}\overrightarrow{S_i} \cdot \overrightarrow{S_j}$
- Micromagnetic level
  - Smear the individual atoms into continuum, see magnetization as a function of position (domain wall)
- Domain level
  - Domains are separated by walls of zero thickness



- Nonlinear level
  - Average magnetization of the entire magnet



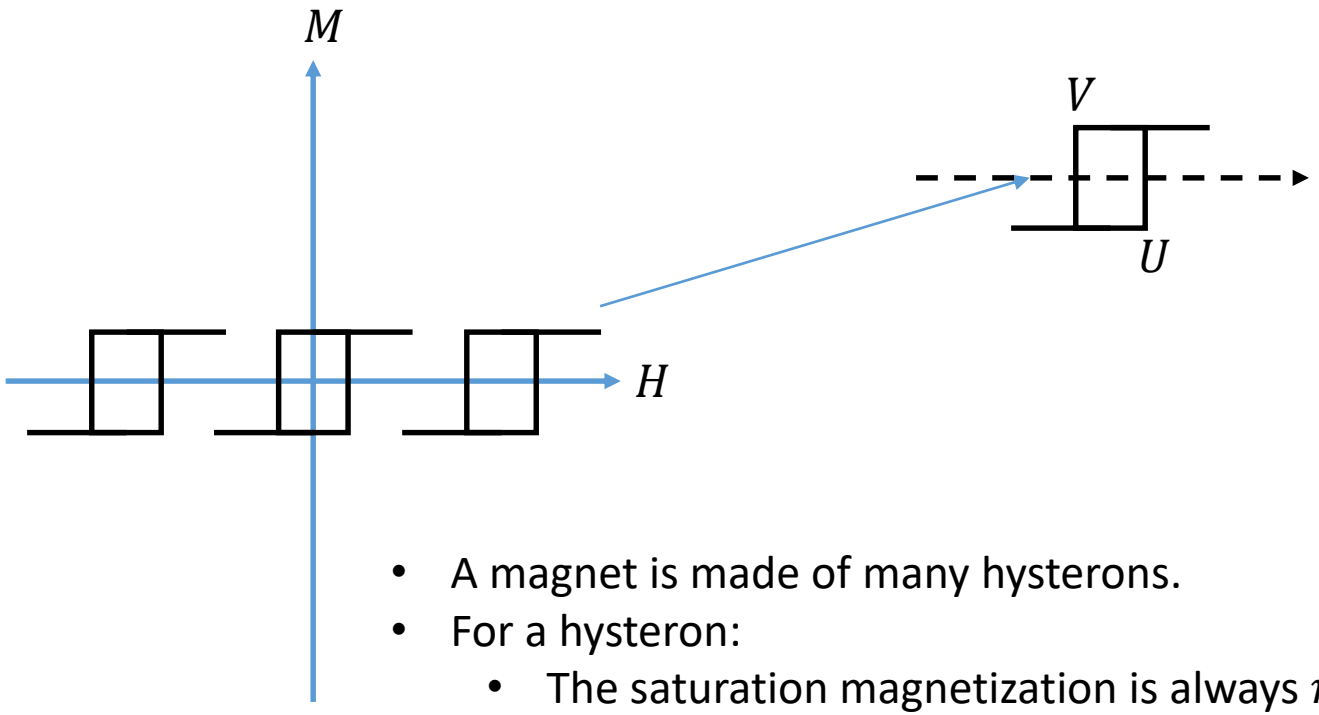
Why Perisach model



- We describe hysteresis using a few parameters M_r, M_0, H_0
- But, how to understand the shape analytically?

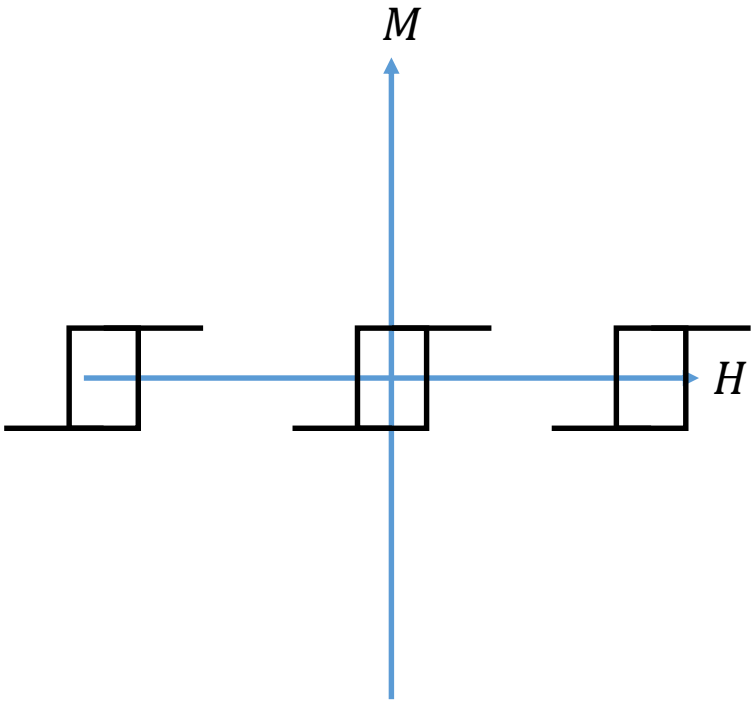
Magnetic hysteresis, Edward Della Torre, IEEE Press (New York) ,1999

Hysteron



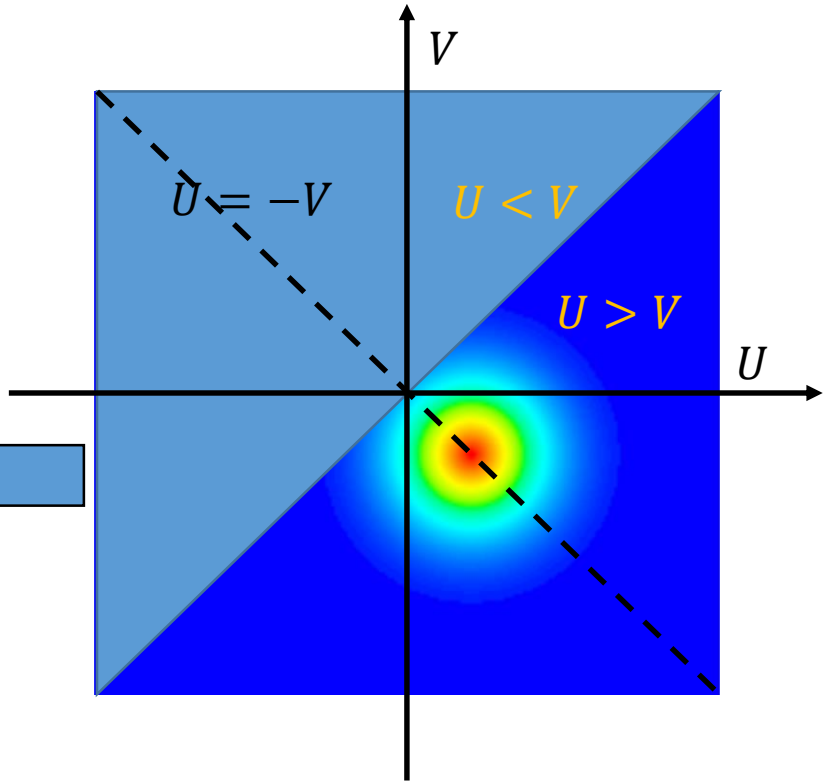
- A magnet is made of many hysterons.
- For a hysteron:
  - The saturation magnetization is always m_0
  - Can be described by two parameters, the coercive fields: U, V
  - The coercive fields are not necessarily asymmetric: ($U \neq -V$).

Hysteron distribution and mapping



$P(U,V)$

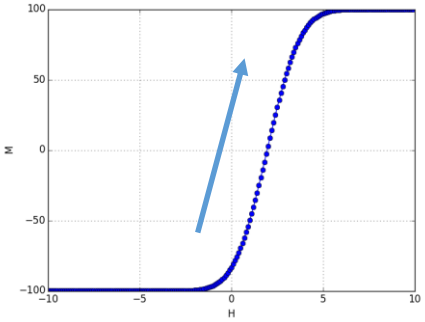
Probability of have a hysteron of two coercive fields U and V.

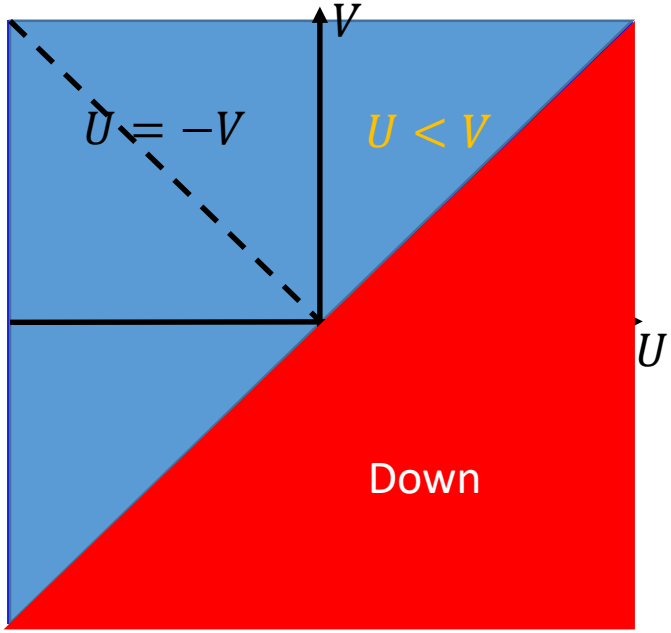


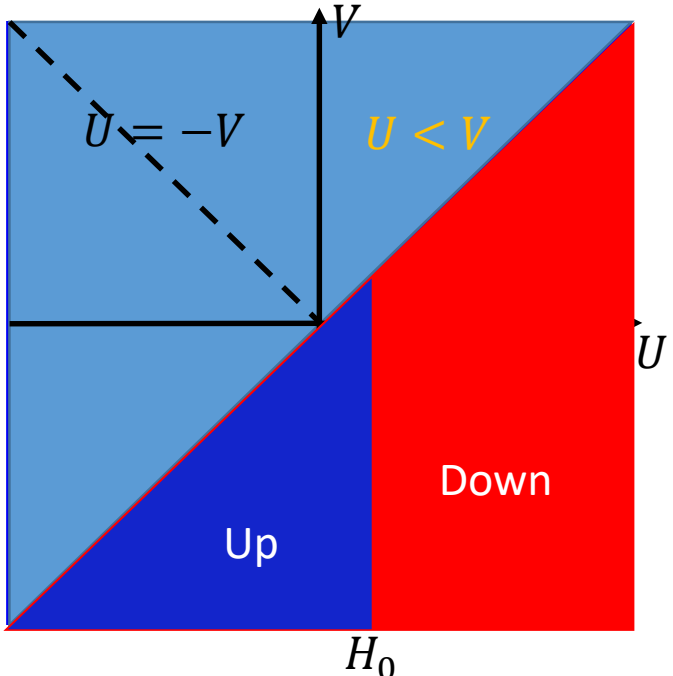
By definition, the probability is zero if $U < V$.

Calculate magnetization from the hysteron map

Large negative field to full saturate the magnetic in the down position





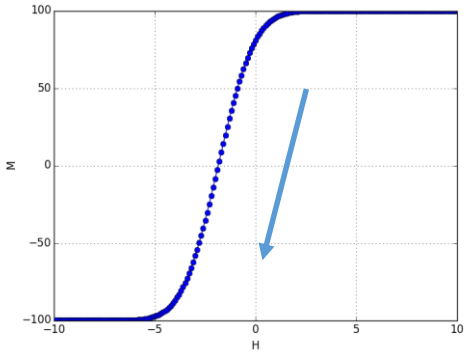


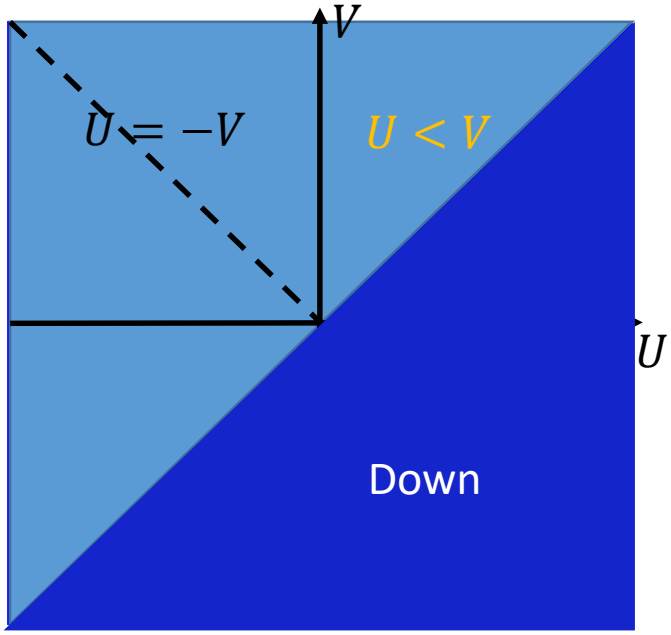
Increase the field to H_0 to flip some of the hysteron up

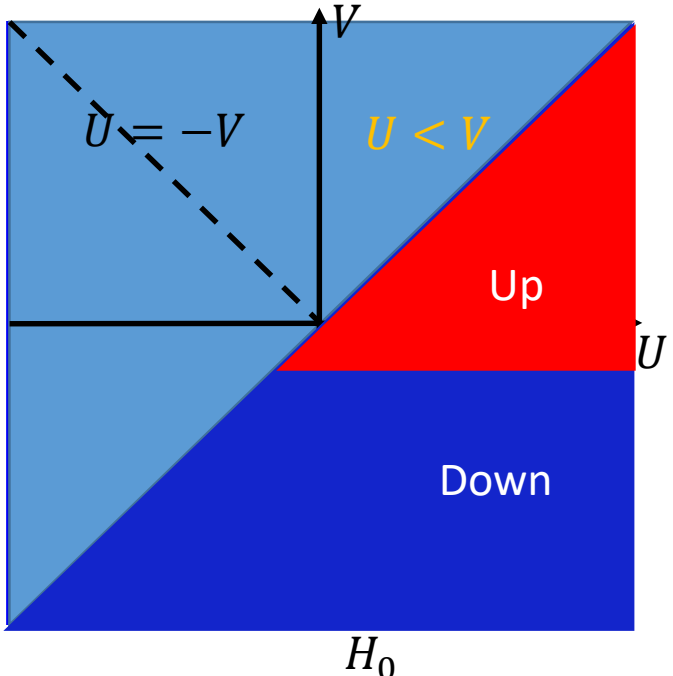
$$M = -M_0 + \int_{-\infty}^{H_0} dU \int_{-\infty}^{U} P(U,V)dV$$

Calculate magnetization from the hysteron map

Large positive field to full saturate the magnetic in the up position







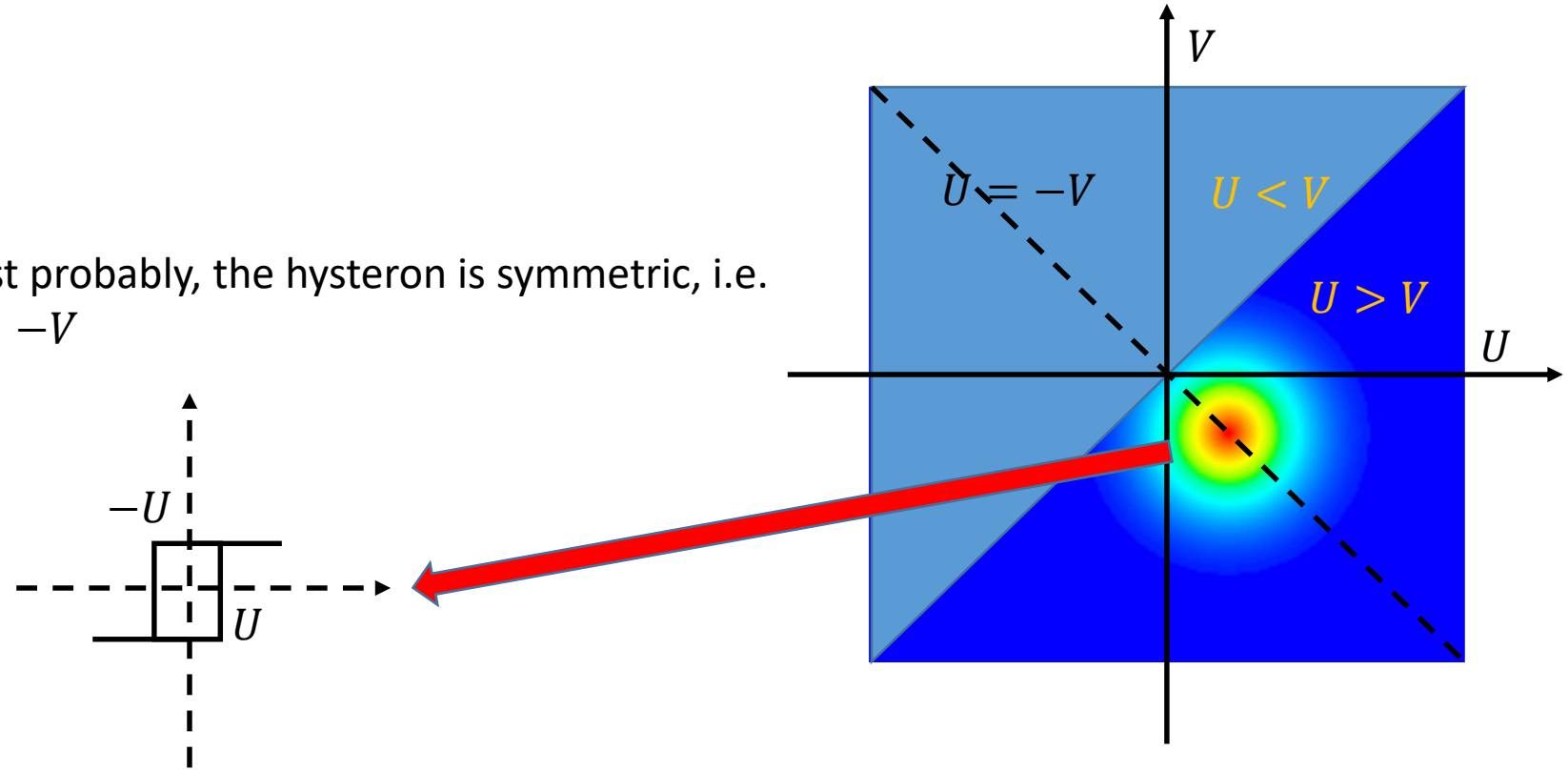
Decrease the field to H_1 to flip some of the hysteron down

$$M = M_0 - \int_{-\infty}^{H_0} dU \int_{-\infty}^{U} P(U,V)dV$$

A typical hysteron distribution

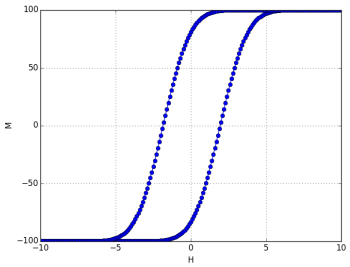
- $P(U,V) = \frac{1}{4\pi\sigma_i\sigma_k}\exp\left(\frac{\sigma_i^2(U-V-2h_k)^2+\sigma_k^2(U+V)^2}{8\sigma_i^2\sigma_k^2}\right)$

- Most probably, the hysteron is symmetric, i.e. $U = -V$

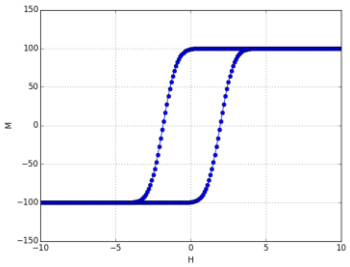


Full hysteresis and parameters

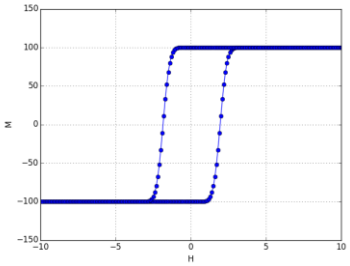
$$P(U,V) = \frac{1}{4\pi\sigma_i\sigma_k}\exp\left(\frac{\sigma_i^2(U-V-2h_k)^2 + \sigma_k^2(U+V)^2}{8\sigma_i^2\sigma_k^2}\right)$$



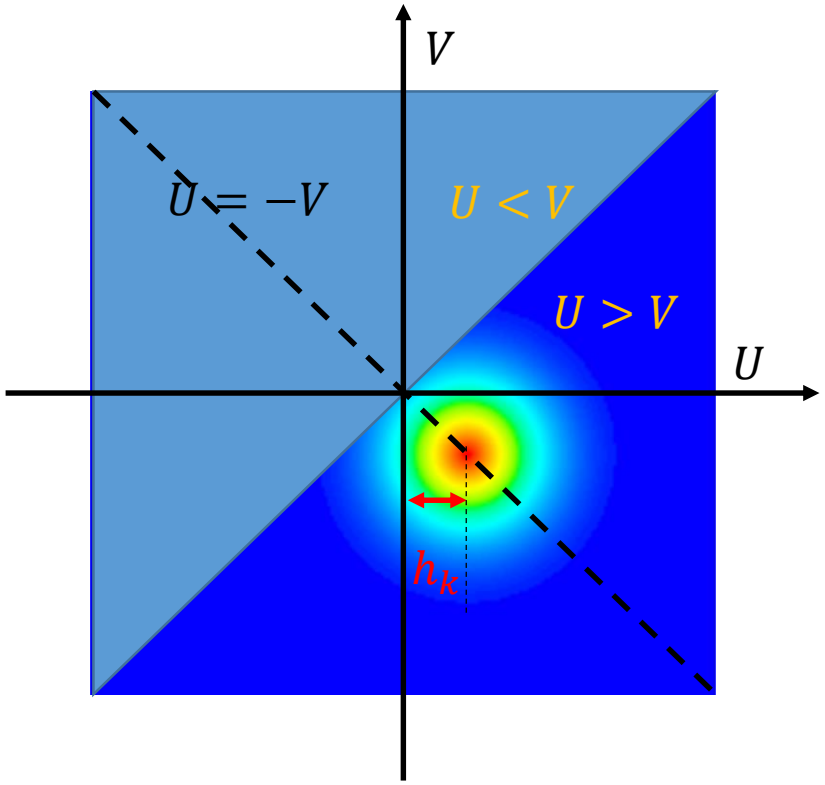
$h_k = 2\sigma_i = 2\sigma_k$



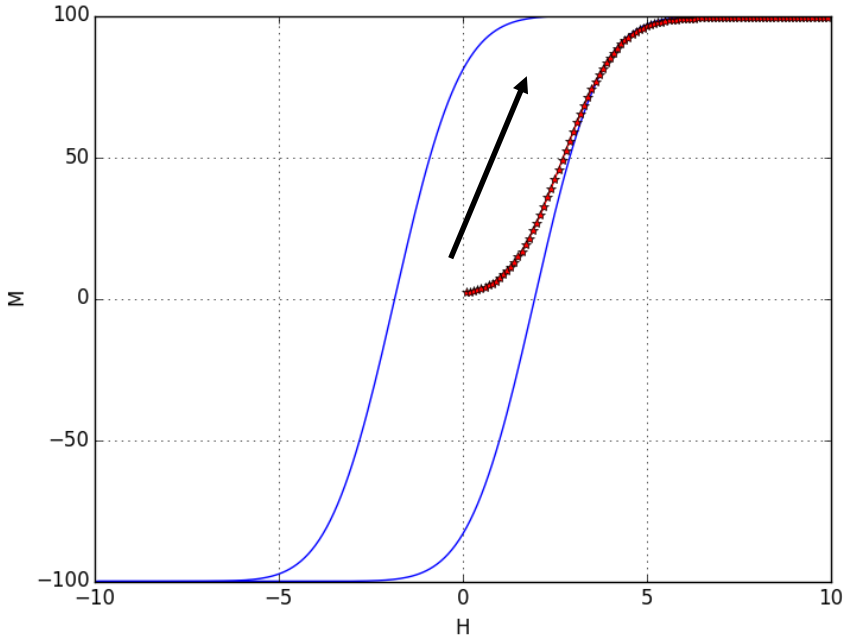
$h_k = 4\sigma_i = 4\sigma_k$

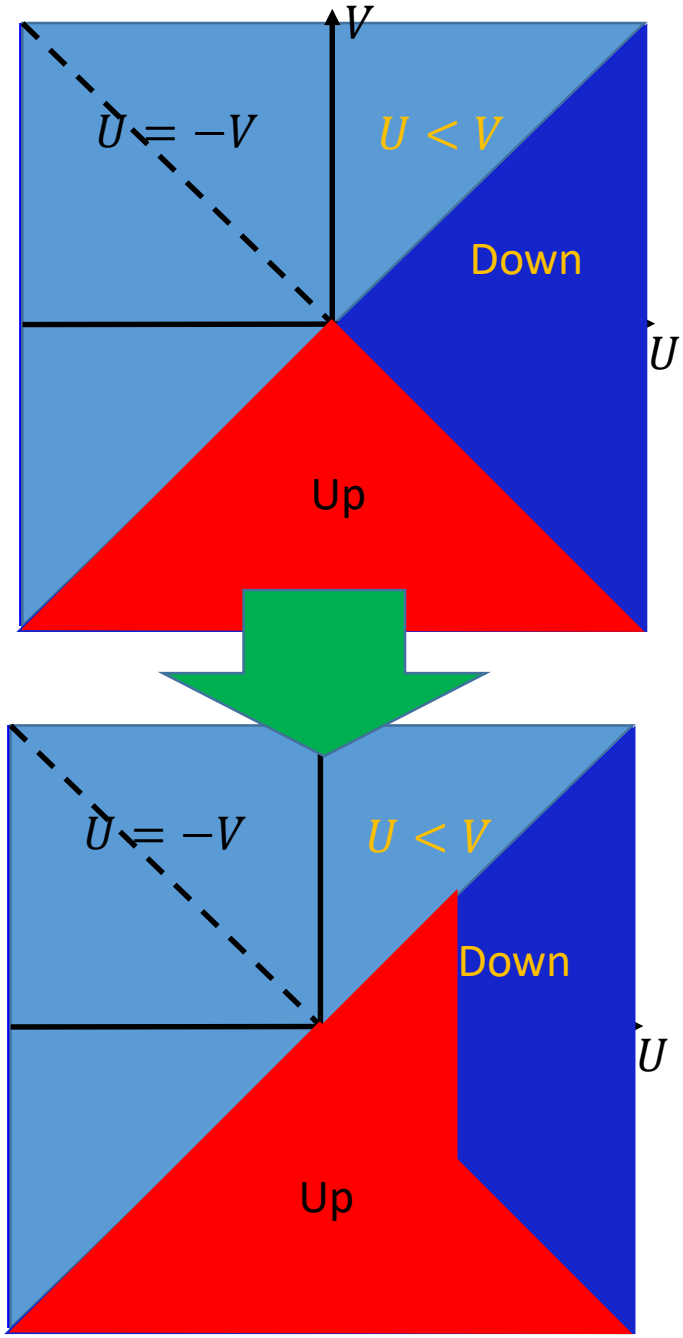


$h_k = 8\sigma_i = 8\sigma_k$

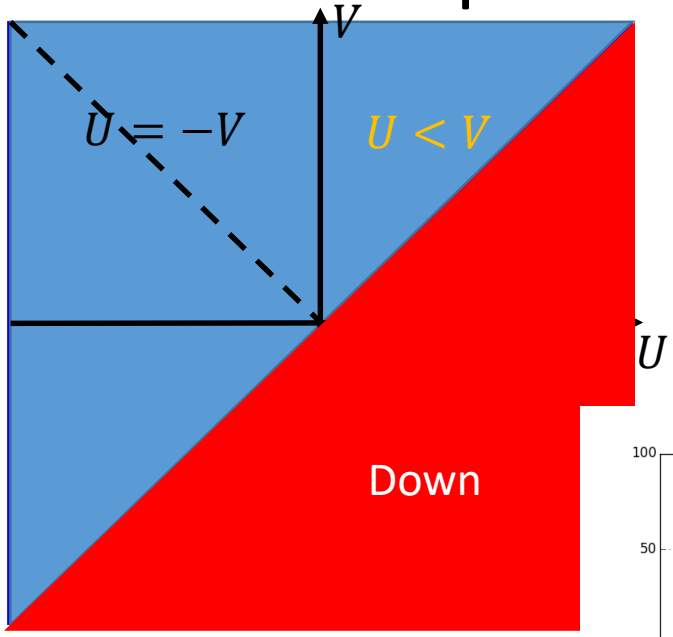


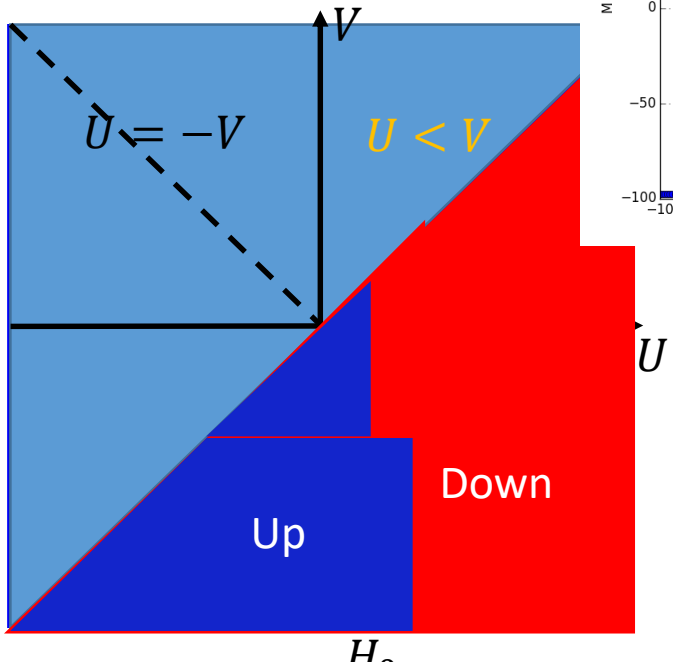
Initial magnetization

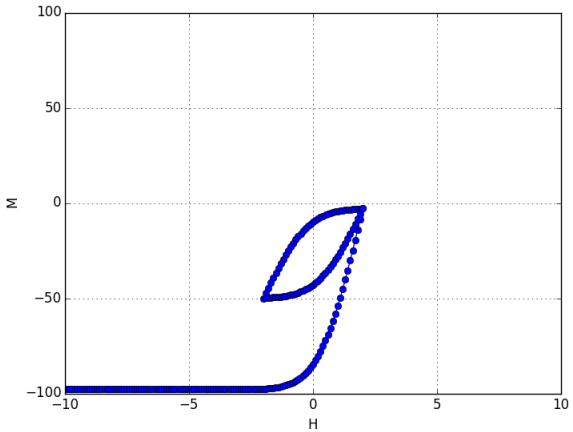


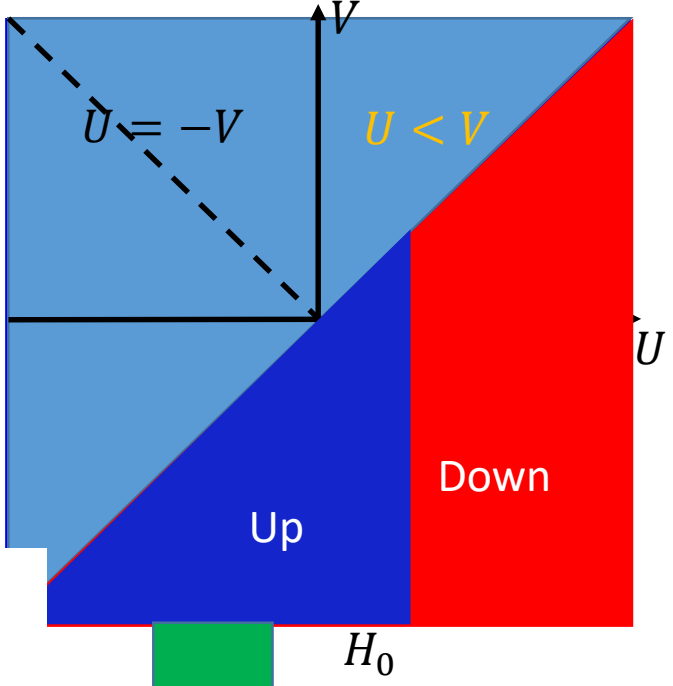


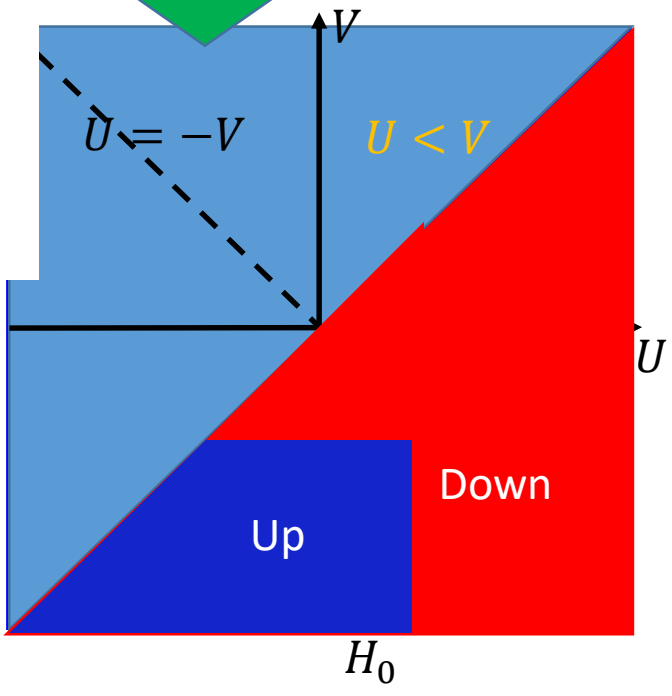
Minor loop


V
$U = -V$
$U < V$
U
Down


V
$U = -V$
$U < V$
U
Up
Down
H_0


100
50
0
−50
−100
M
−10
−5
0
5
10
H


V
$U = -V$
$U < V$
U
Up
Down
H_0


V
$U = -V$
$U < V$
U
Up
Down
H_0

Conclusion

- Preisach model can be used to describe the magnetic hysteresis using a distribution of hysterons
- It explains full-loop, minor loop, initial magnetization
- The real magnetization can be modeled with a modified Preisach model