Molecular Magnets and Quantum Resonant Tunneling

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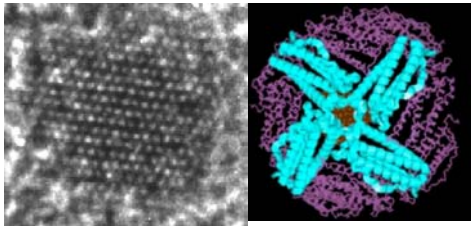
Solid State Physics II

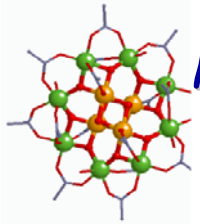
Magnetism at Different Scales

permanent magnets | micron particles | nanoparticles | clusters | molecular Magnets | Individual spins

100 nm | 10 nm | 1 nm

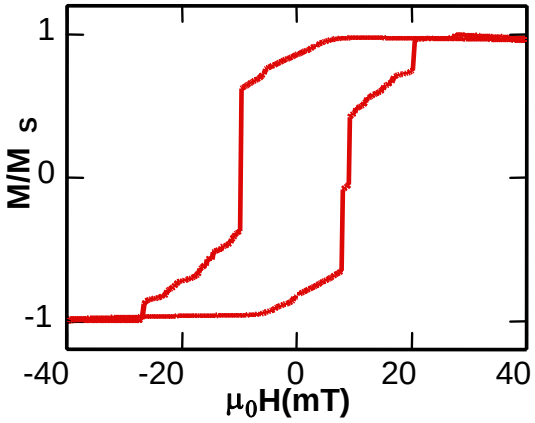
$S = 10^{23}$ 10^{10} 10^{8} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10 1





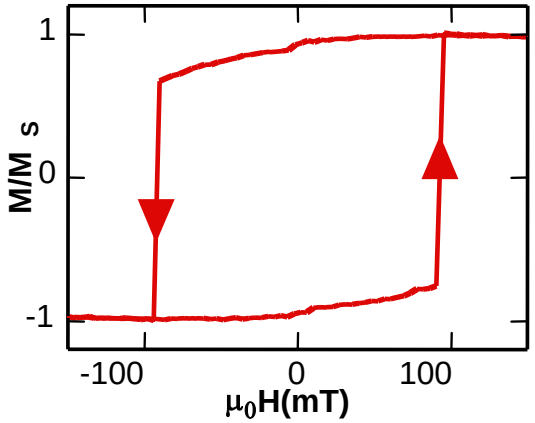
multi - domain

Motion of domain walls



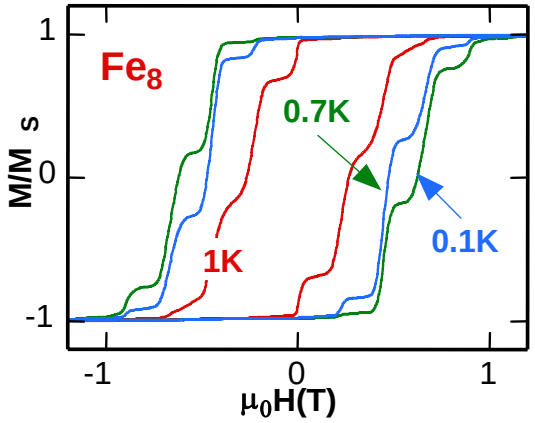
single - domain

uniform rotation



single molecule

quantum tunneling

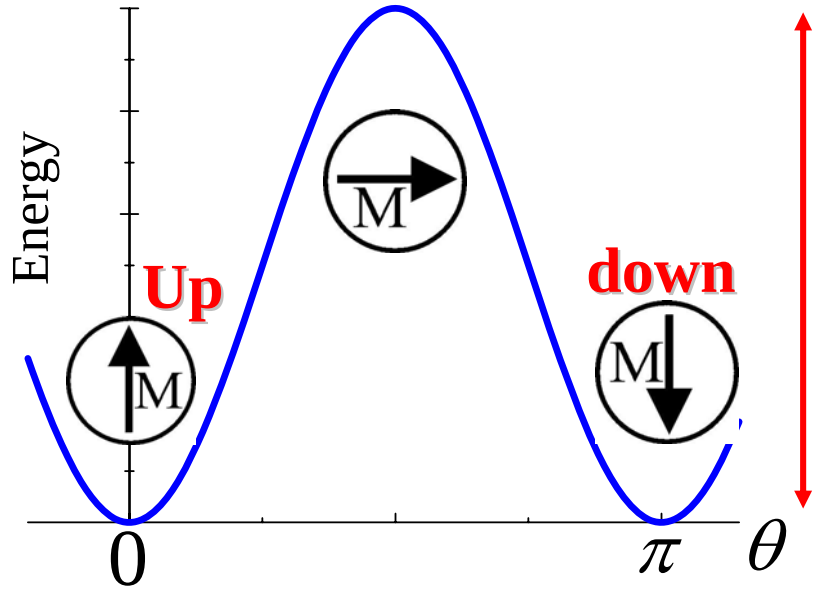


Single-Domain Nanomagnets: Classical Stoner Partiles

- **Origin of Hysteresis: Irreversibility**

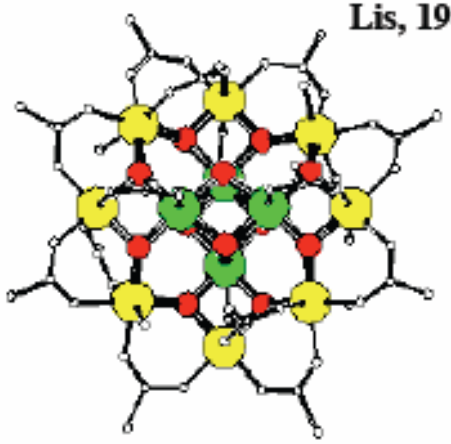
Macroscopic Magnets:
Crystal disorder

Single-Domain Nanoparticles:
Bi-stability from anisotropy



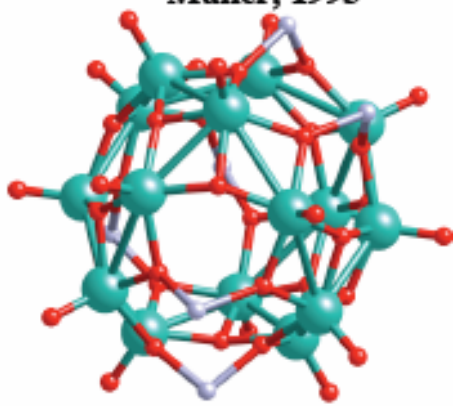
Molecular Magnets

Lis, 1980

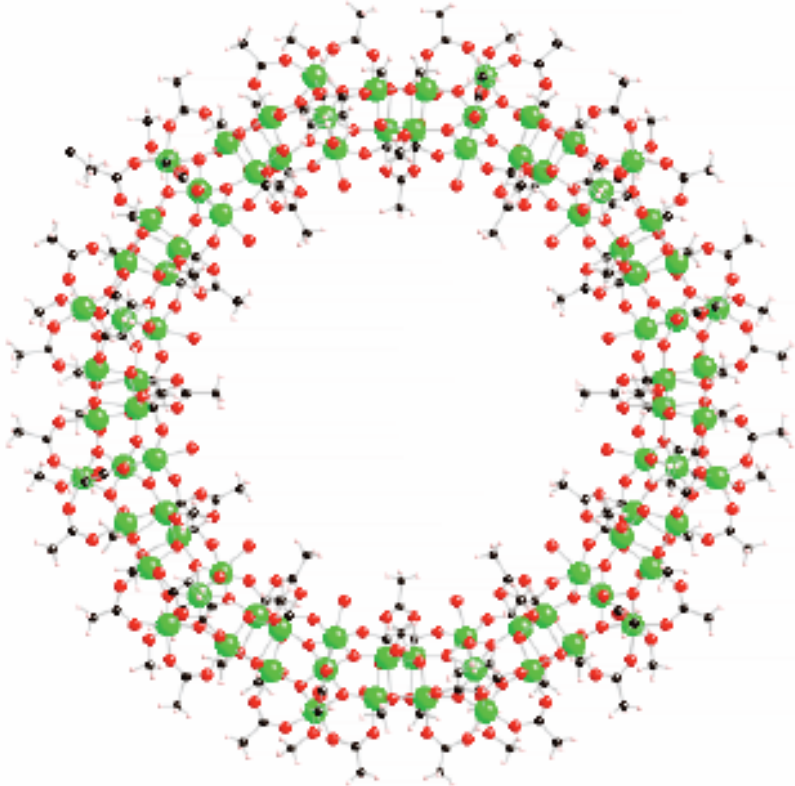


Mn_{12} S = 10

Müller, 1993



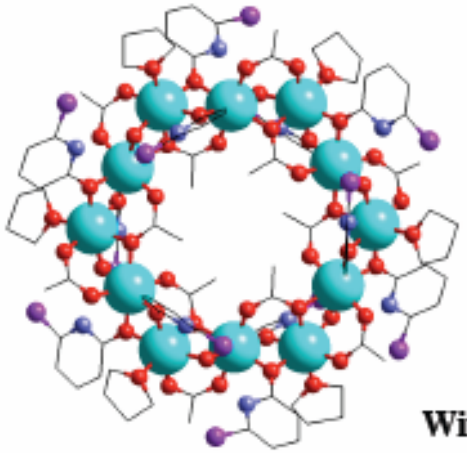
V_{15} S = 1/2



Christou, 2004

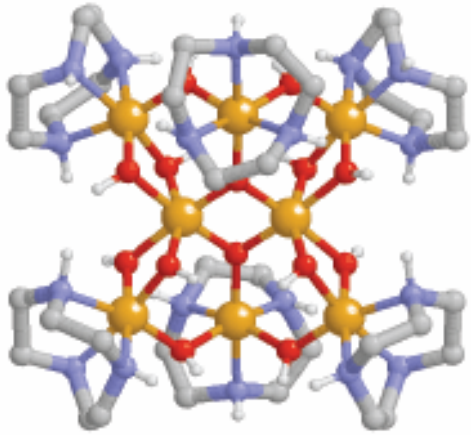
Mn_{84}
S ≈ 6

Ni_{12} S = 12



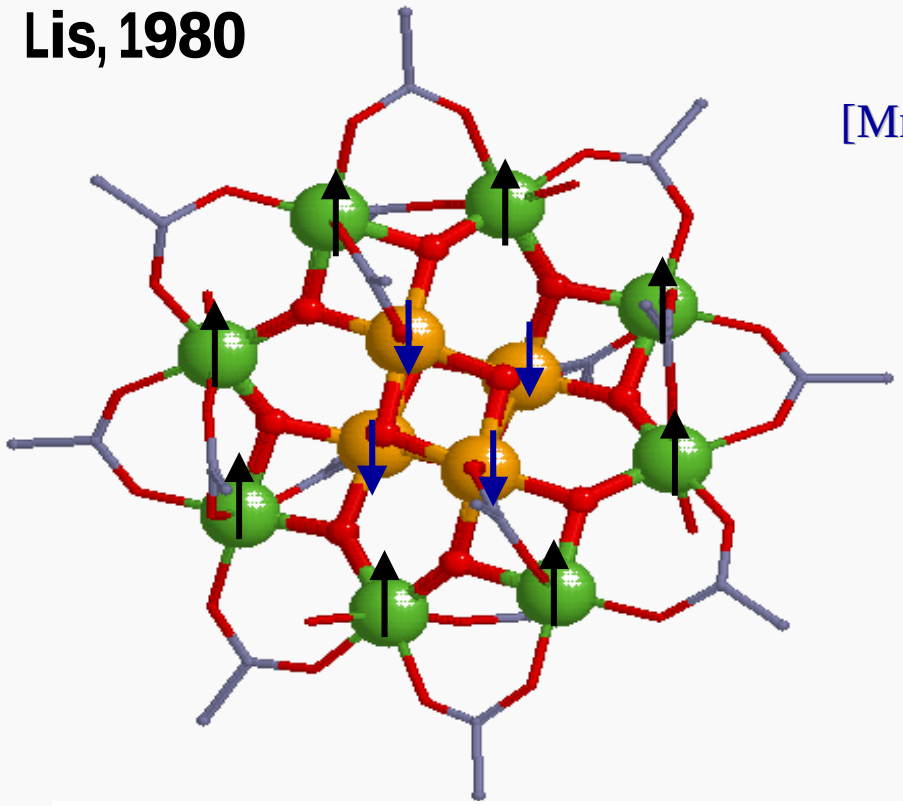
Winpenny, 1999

Fe_8 S = 10



Wiegart, 1984

The First Single Molecule Magnet: Mn_{12}-acetate



$[Mn_{12}O_{12}(CH_3COO)_{16}(H_2O)_4]\cdot 2CH_3COOH\cdot 4H_20$

Mn^{3+} **S = 2**

Mn^{4+} **S = 3/2**

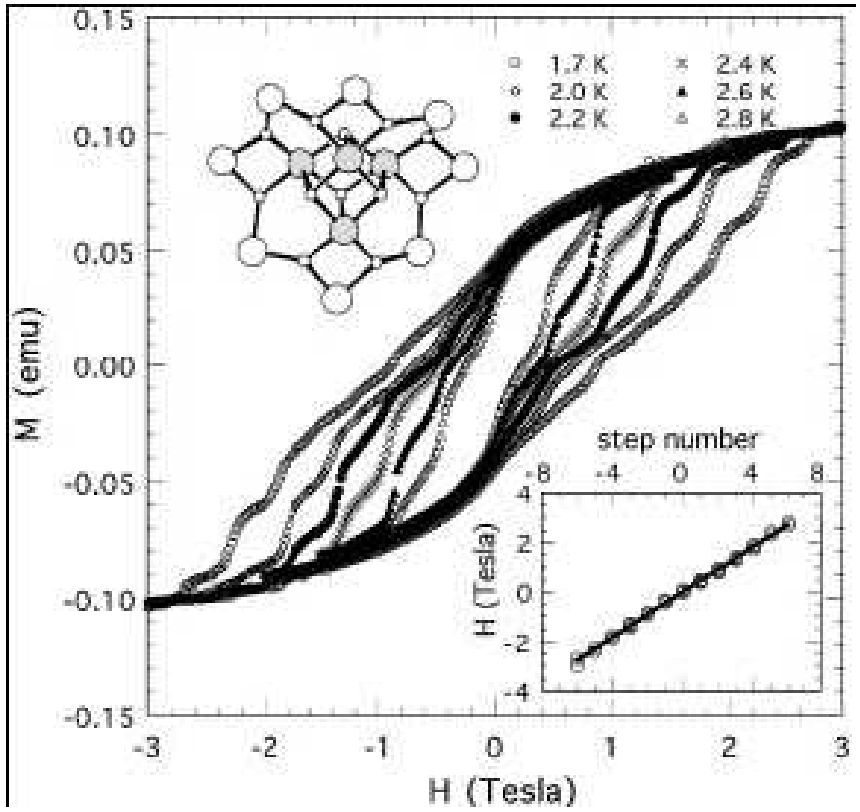
Oxygen

Carbon

Well defined giant spin (S = 10) at low temperatures (T < 35 K)

Strongly superexchange-coupled through oxygen bridges (J~100 K)

Uncommon Hysteresisc



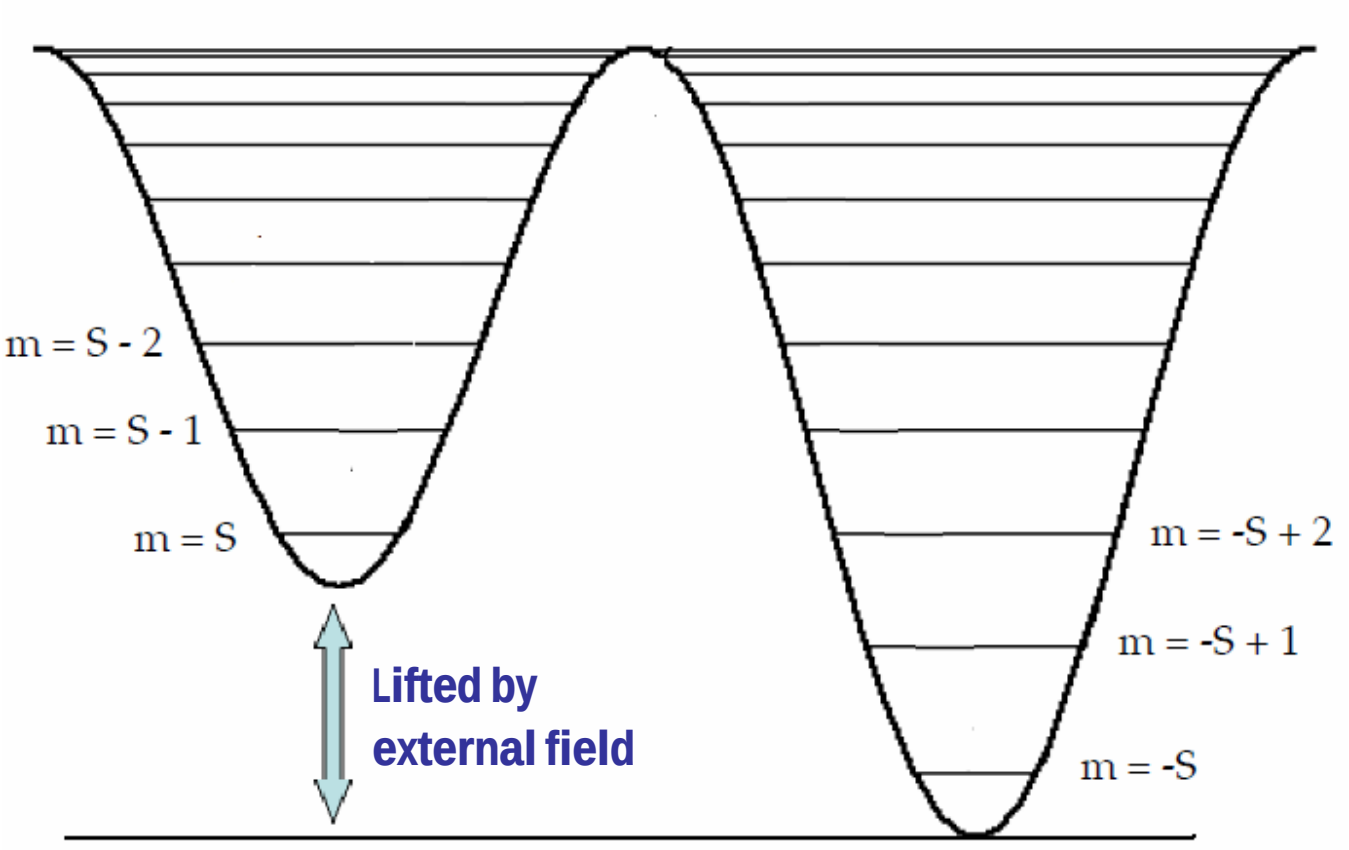
- Magnetization versus applied field. Inset shows values of field where jumps in the magnetization are observed.
- J. R. Friedman, et al., *Phys. Rev. Lett.* 76, 3830 (1996).

Steps !?

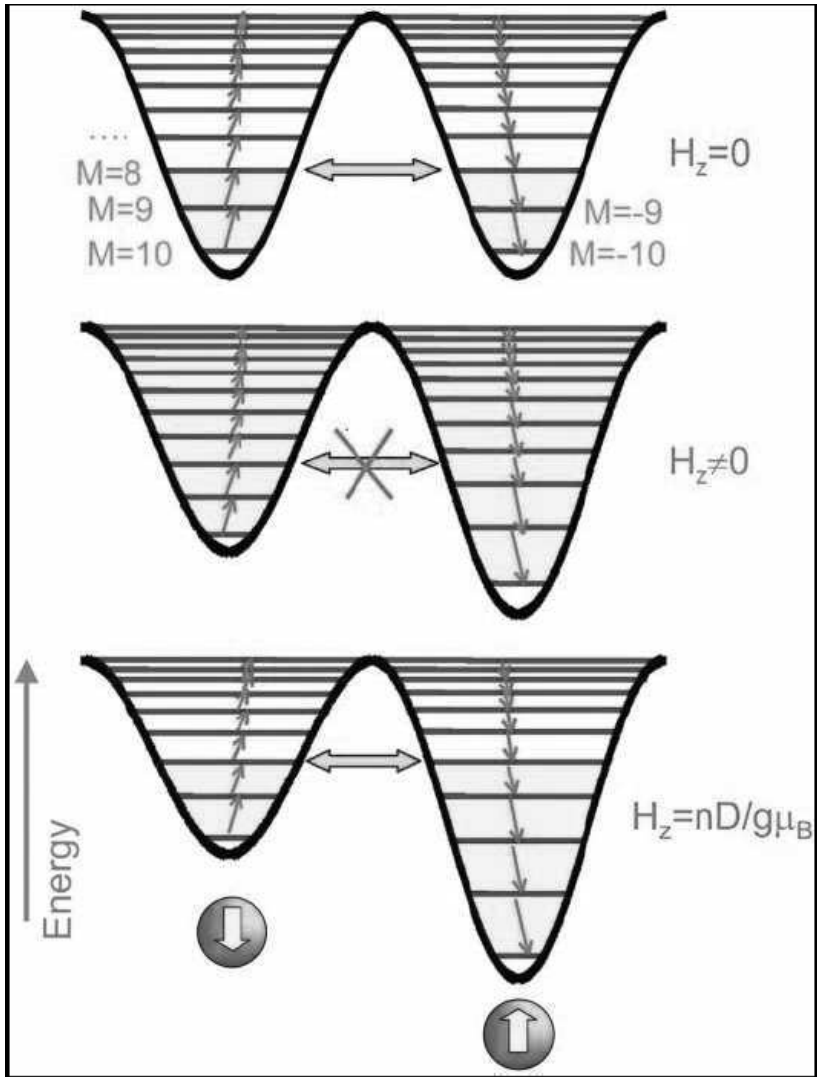
Macrospin Model

$$H = -DS_z^2 - g\mu_B S_z H_z + H'$$

Anisotropy Zeeman Tunneling

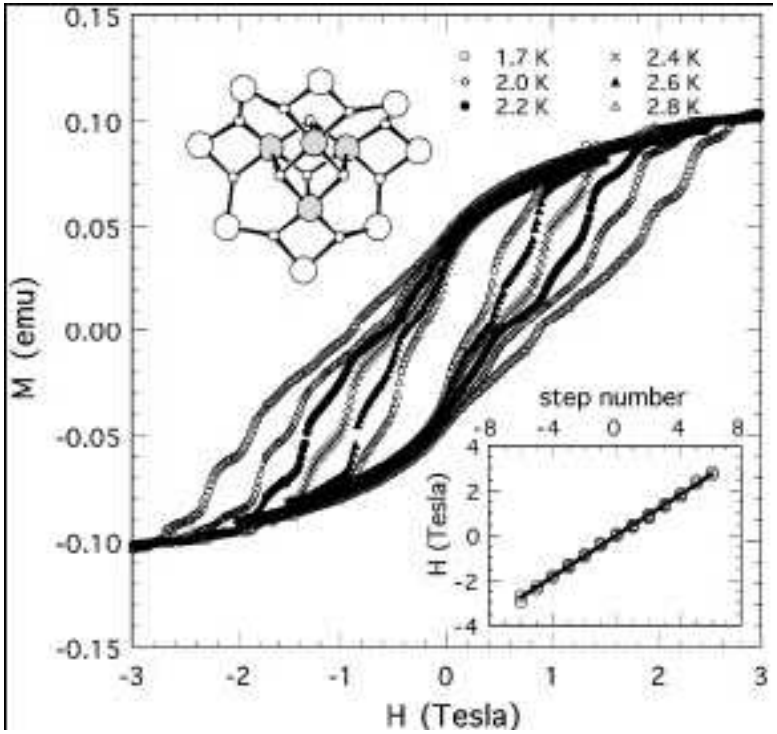


Origin of Steps: Resonant Tunneling



$$H = -DS_z^2 - g\mu_B S_z H_z + H'$$

$$H_z = -Dn/g\mu_B$$



What Causes Tunneling?

$$H = -DS_z^2 - g\mu_B S_z H_z + H'$$

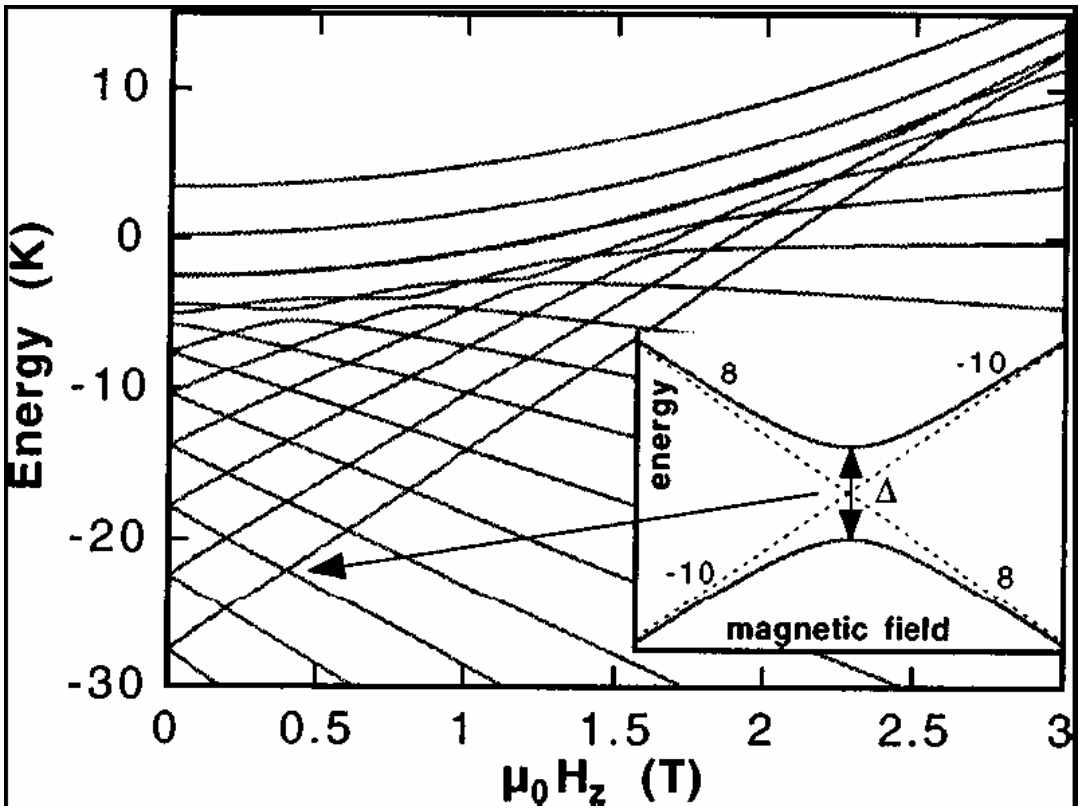
What is this?

- For Fe_8 : Transverse anisotropy energy

$$H' = E(S_x^2 - S_y^2)$$

- For Mn_{12} : Not clear

Energy Spectrum of Fe_8



Probability of NO Crossing:

Landau-Zener formula

$$P = 1 - exp(-\frac{\pi \Delta^2}{\beta})$$

No Crossing Means Tunneling

W. Wernsdorfer, et al., *J. App. Phys* 87, 5481 (2000)

Possible Origins of Tunneling in Mn_{12}

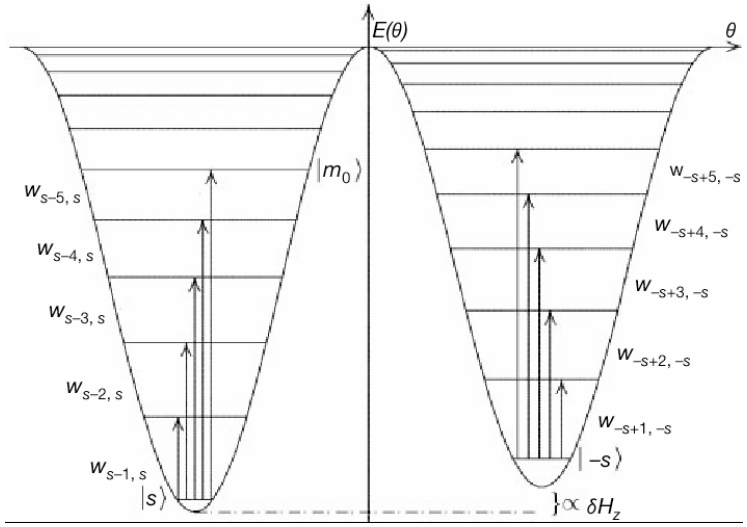
- Transverse external field
- Fourth order transverse anisotropy
- Spin-phonon interaction
- Dipolar interactions between neighboring molecules
- Hyperfine interaction with the Mn and other nuclei in the system
- ....

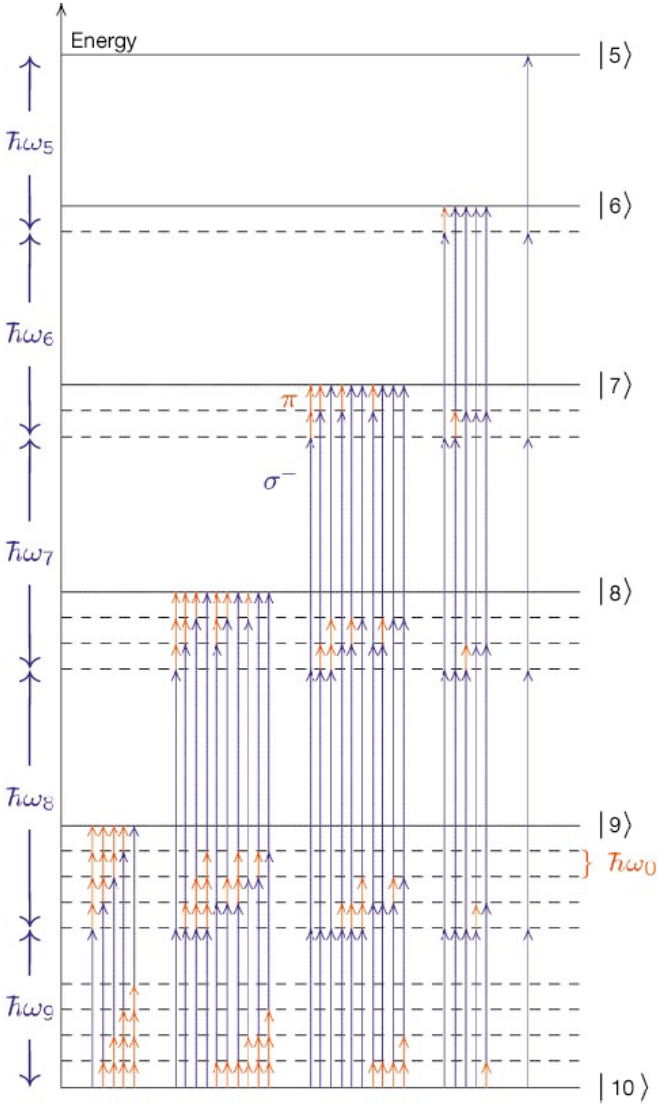
One Possible Application: Quantum Computing

Michael N. Leuenberger & Daniel Loss

NATURE, **410**, 791 (2001)

- implementation of Grover's algorithm
- storage unit of a dynamic random access memory device.
- fast electron spin resonance pulses can be used to decode and read out stored numbers of up to 10^5 with access times as short as 0.1 nanoseconds.





Thank You