Absolute Quantum Tunneling Rate Measurements in NanoMagnets

Aleksandra Simicevic[1], Shunsuke Yoshii[2], Go Tanaka[2], Misaki Hayashi[2], Takaharu Tashiro[2], and Hiroyuki Nojiri[2]

[1]NanoJapan Program, Rice University, USA and Department of Civil and Environmental Engineering, Louisiana State University, USA

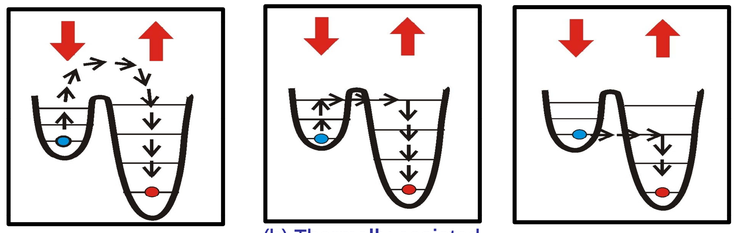
[2]Institute for Materials Research, Tohoku University, Japan

INTRODUCTION

High spin single molecule magnets

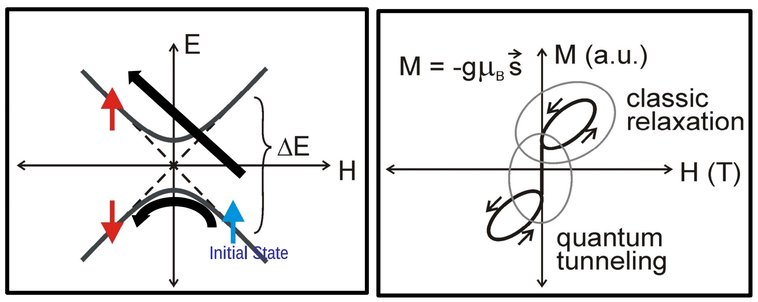
- Applications:
  - Nanoscale magnetic memory
  - Quantum computing
- Features
  - Distinct magnetization states
  - Store memory in “spin up” or “spin down” states

What is Quantum Tunneling of Magnetization (QTM)?



(a) Thermal relaxation (b) Thermally assisted tunneling (c) Quantum tunneling

- Configurations of particles described by quantum numbers. Spin quantum number defines value and orientation of spin.
- Zeeman energy level is degenerate at zero magnetic field.
- Applied magnetic field alters energy and breaks degeneration.

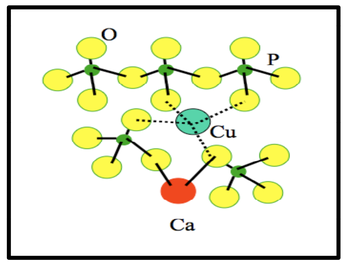


Zeeman graph shows the splitting of an energy level as a magnetic field is applied.

- *Classic physics:* An electron’s different orientations are permanently separated and are assumed to remain in the same orientation.
- *Quantum physics:* In a region, occurring around a zero magnetic field, electron may switch orientations and tunnel through the energy barrier into a different energy state. This transition is called *quantum tunneling*.

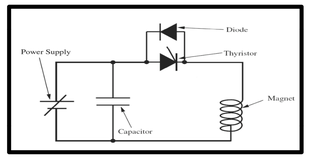
OBJECTIVE

- To determine the origin of absolute spin reversals in single molecular magnets in a two-level spin system of Cu^{2+} ions doped in a $Ca(PO_3)_2$ glass
- Use steady magnetic field and pulse field combination to find absolute reversal rate
- Variables:
  - Temperature (0.4 K -1.5 K)
  - Sweep rate (2000 T/s - 6000 T/s)
  - Density of ions (1% - 4%)

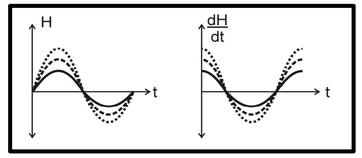


METHOD

Magnetization measurements under pulsed magnetic fields

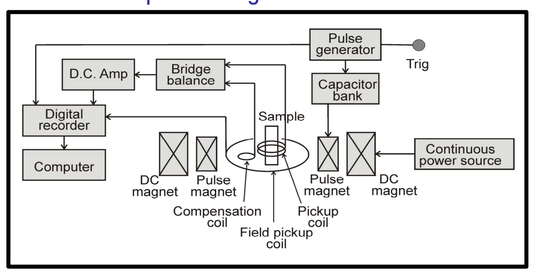


Generator of pulse fields

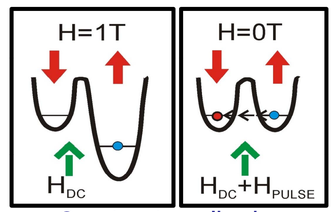


Magnetic field and sweep rate

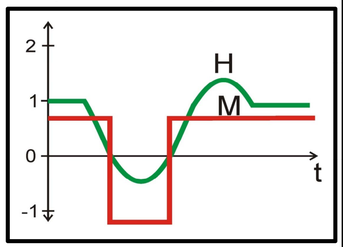
Schematic of magnetization measurements under pulsed magnetic fields



- Steps:
  - Sample concentration preparation
  - Cooling system (temperature variable cryostat with He system)
  - Signal detection (standard induction method with pick-up coils)
  - Pulsed field + steady field (to control the initial spin state) measurements



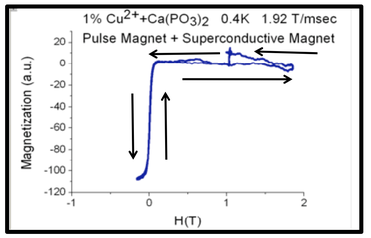
Quantum tunneling in two-level system under pulse and steady fields



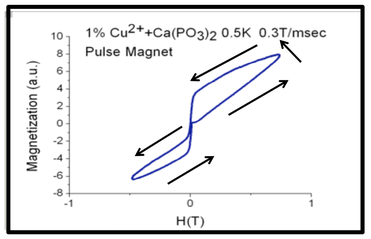
RESULTS

- Quantum tunneling found:
  - Rapid change in magnetization with zero magnetic field

Magnetization vs. magnetic field



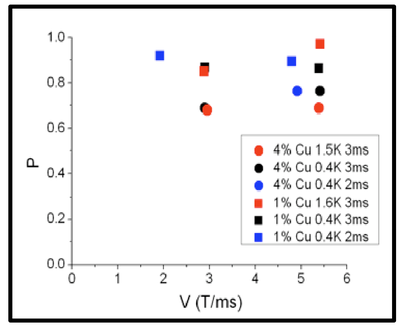
Pulse magnet + Superconductive magnet



Pulse magnet

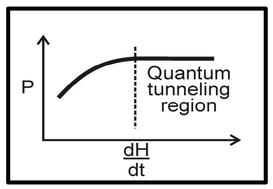
- Quenched relaxation:
  - Little hysteresis
  - Little dependency on temperature change
- Tunneling gap is 25 mk
- Large reversal rate (close to 1) occurs at 400 mK

Absolute reversal rate

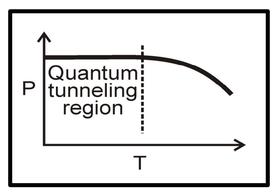


CONCLUSIONS

- In quantum tunneling-region, quantum tunneling occurs even though temperature is larger than ten times the tunneling gap
- Quantum tunneling produced by fast-sweeping fields may be possible at higher temperatures



Reversal rate vs. sweep rates



Reversal rate vs. temperature effects

ACKNOWLEDGEMENTS

Research conducted at the Institute for Materials Research in Tohoku University, Sendai, Japan

This material is based upon work supported by the National Science Foundation under Grant No. OISE-0530220