Paramagnet NMR of MnF_2 & electric control by hyperfine field

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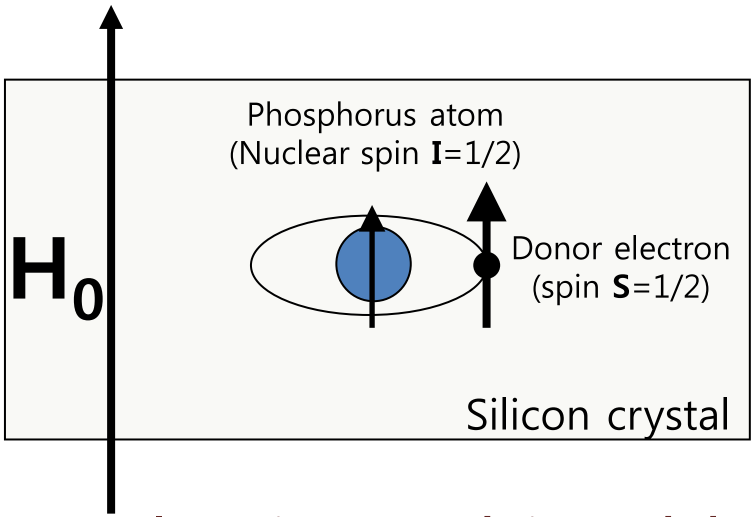
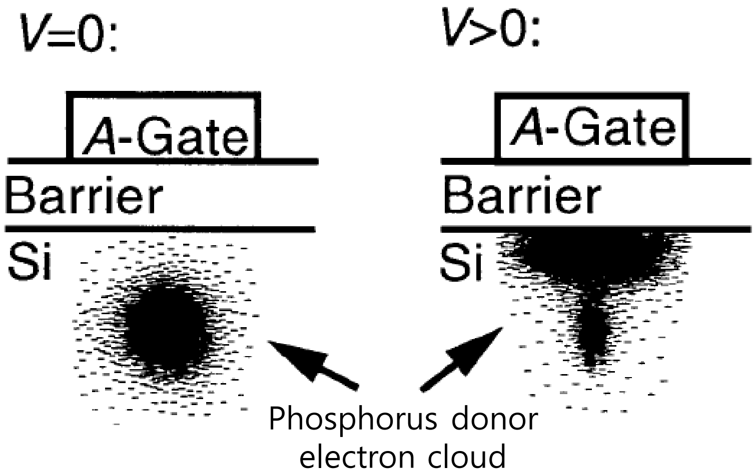
Contents

- Motivation
  - Kane's Model
- MnF_2
- Antiferromagnet MnF2
  - NMR frequency stark effect
  - Selective qubit addressing - Song's Experiment
- CW-NMR of paramagnet MnF_2
- Angle dependence
- Experimental Data
- Summary

Motivation-Kane's qubit model

- Qubit in Kane's Si:P Model
  - Nuclear spin

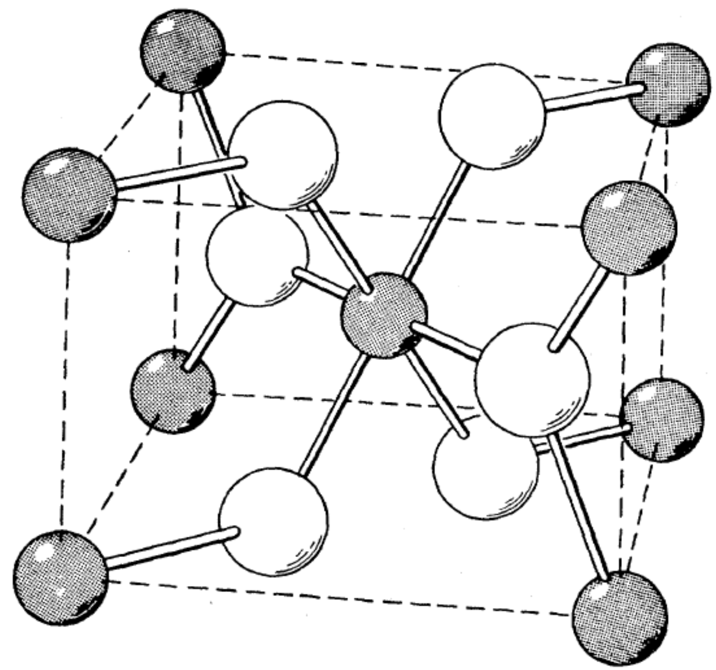




  - Selective qubit addressing
    - Electrically change of hyperfine interaction

MnF_2

- Rutile structure
- Antiferromagnet
  - Neel Temp. : 68K
- ^{19}F NMR
  - γ: 40.056MHz/T



Stark effect of NMR inMnF_2

- Pershan & Bloembergen
  - ^{19}F cw-NMR, 0T, *f* = 159.97MHz, 4.2K, ***E***//[100]

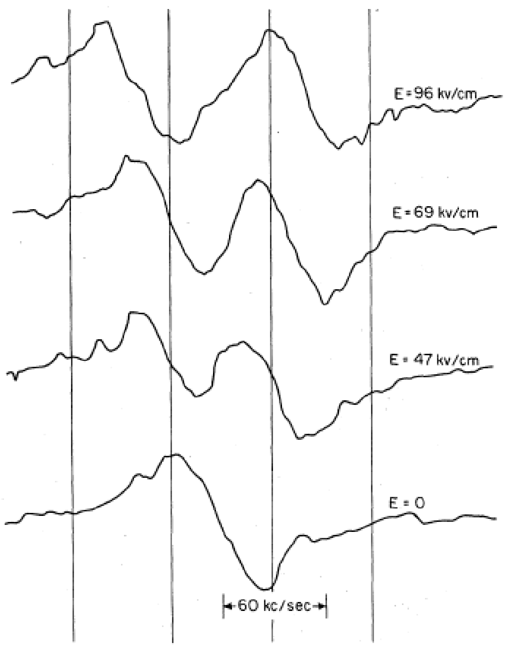


FIG. 1. The absorption derivation of the F^{19} resonance in MnF_2 at 4.2°K in zero magnetic field. An electric field of variable strength is applied along the [100] crystallographic axis.

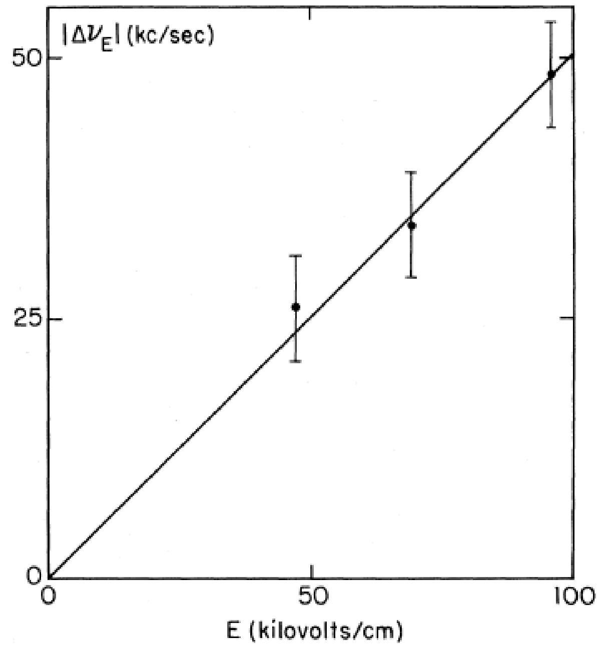
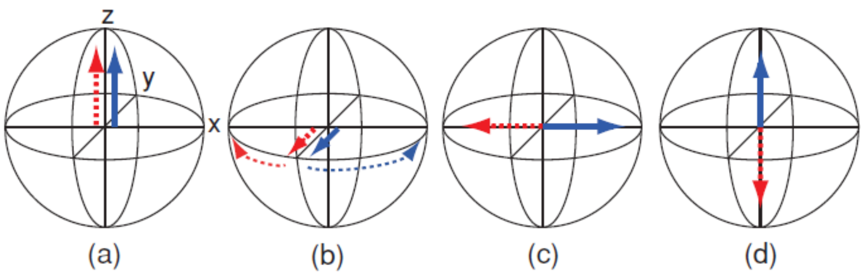


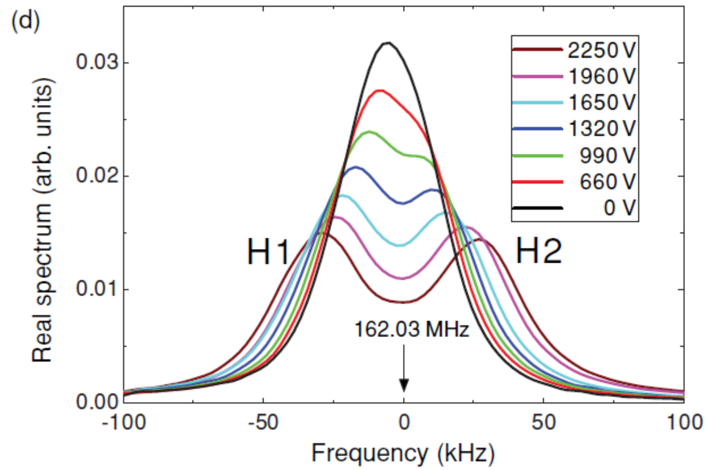
FIG. 2. The absolute shift of the F^{19} resonance versus applied electric field strength along [100]. The "electric doublet splitting" is twice the shift and amounts to 1 cps/(volt/cm).

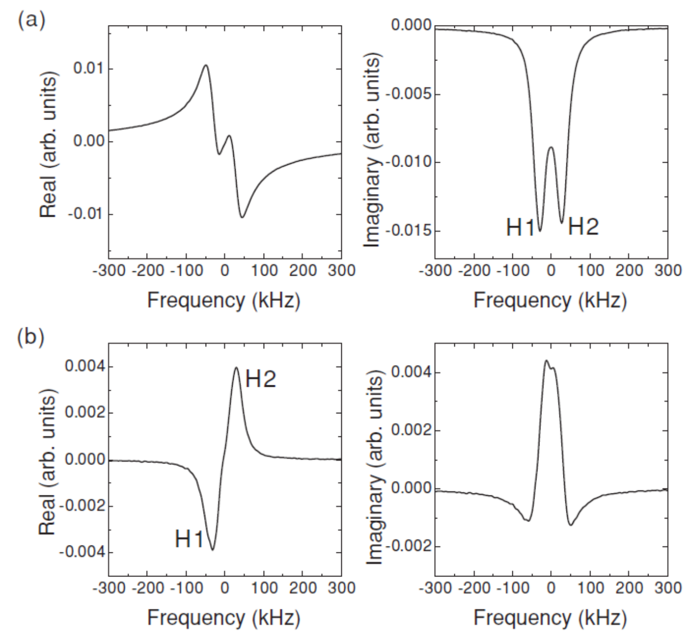
Song's experiment

- Splitting frequency
  - $\boldsymbol{E}//[110]$
  - 56kHz for 3.4V/μm
  - Hyperfine field: 4T
- Selective operation

$$R^{H_1}_{x,\text{composite}}(\pi) = R^{H_1,H_2}_{-y}\left(\frac{\pi}{2}\right) D\left(\frac{\pi}{2}\right) R^{H_1,H_2}_{x}\left(\frac{\pi}{2}\right)$$







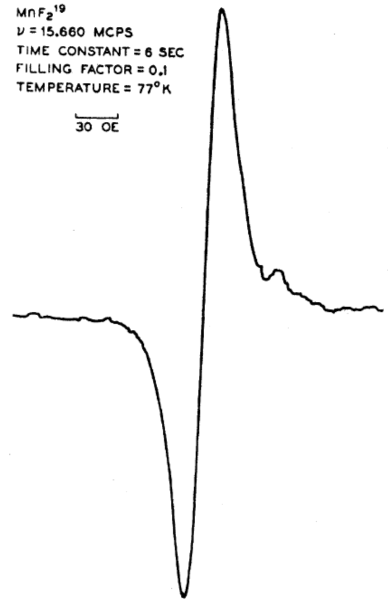
Comparison

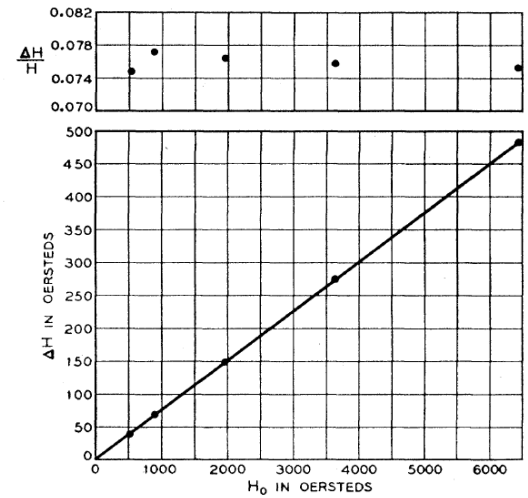
- Similarity
  - Electrical control of hyperfine field for splitting NMR frequency
- Difference

	Kane's Si:P model	Song's MnF_2
Spin system	Paramagnet	Antiferromagnet
Hyperfine Interaction	Direct Contact H.I.	Transferred H.I.

Paramagnetic NMR

- Shulman & Jaccarino
  - ^{19}F cw-NMR
  - H_0~0.363T // [001]
  - f = 15.66MHz
  - 77K

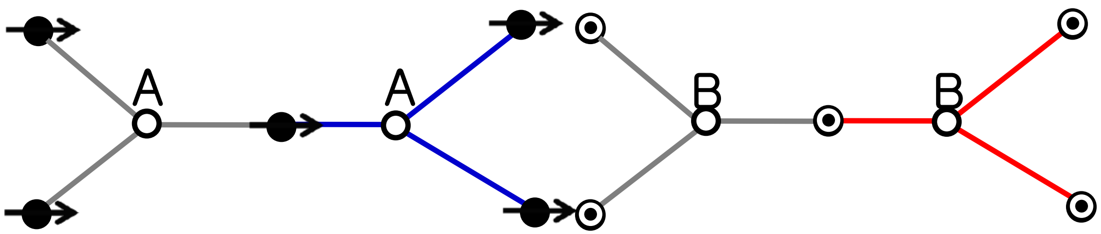


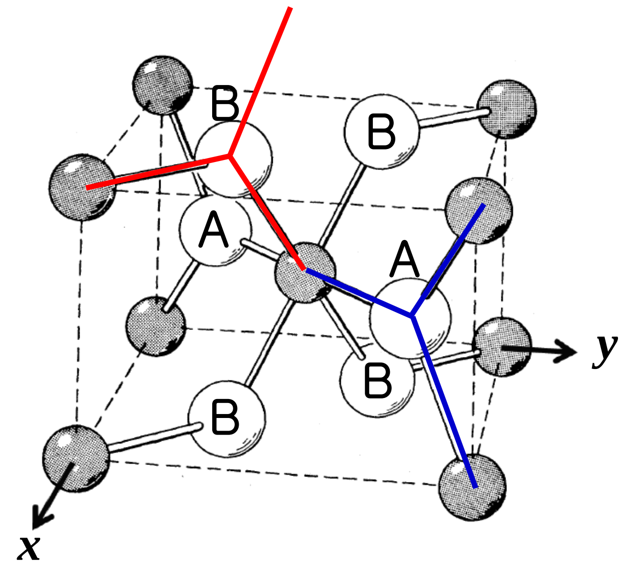


- Paramagnetic shift
  - ΔH/H = 0.0735 after demagnetization correction
  - $f = \gamma(H+\Delta H) = \gamma(1+\Delta H/H)H = \gamma' H$
  - γ' = 42.997MHz/T cf) γ_{proton}=42.577MHz/T

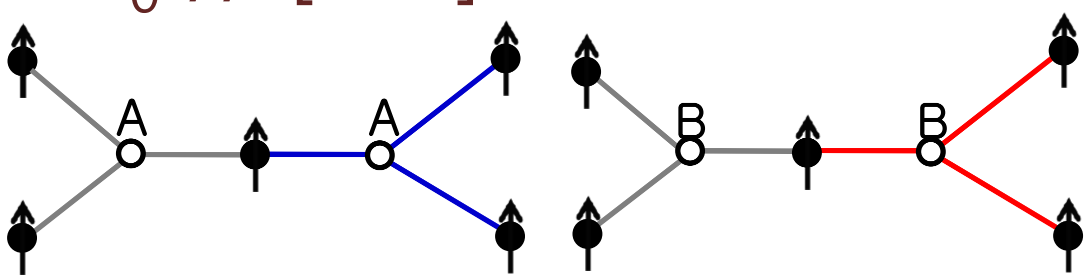
Angle dependence

- H_0 // [110]



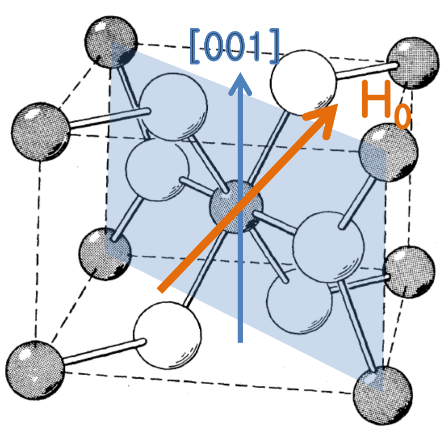


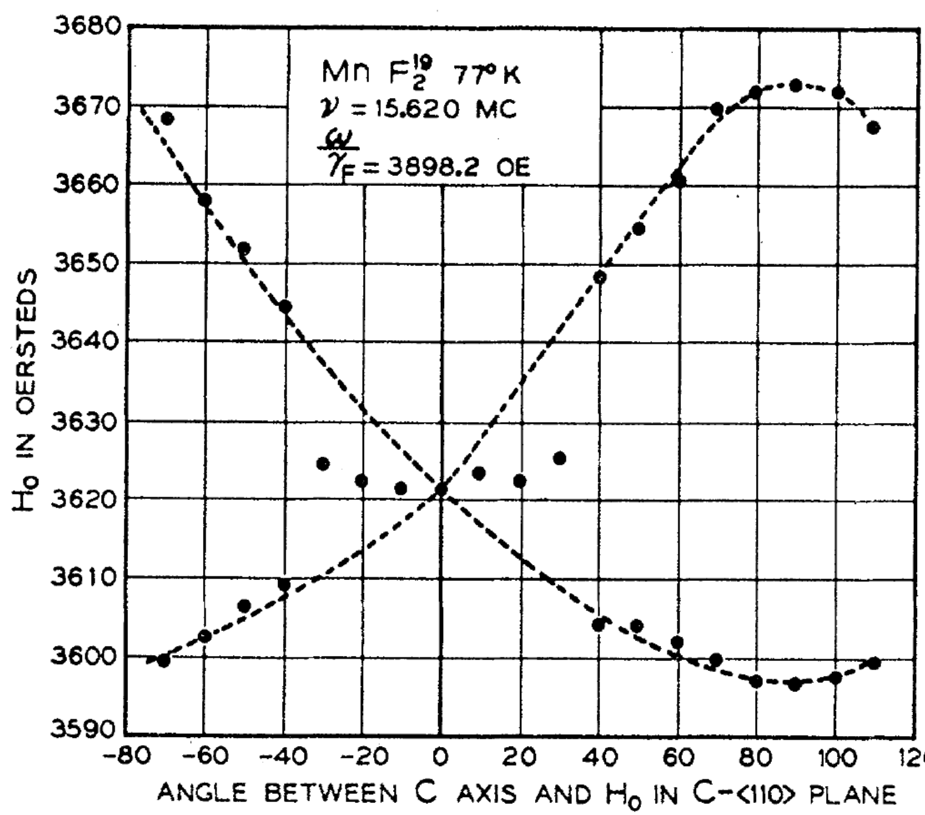
- H_0 // [001]



Angle dependence

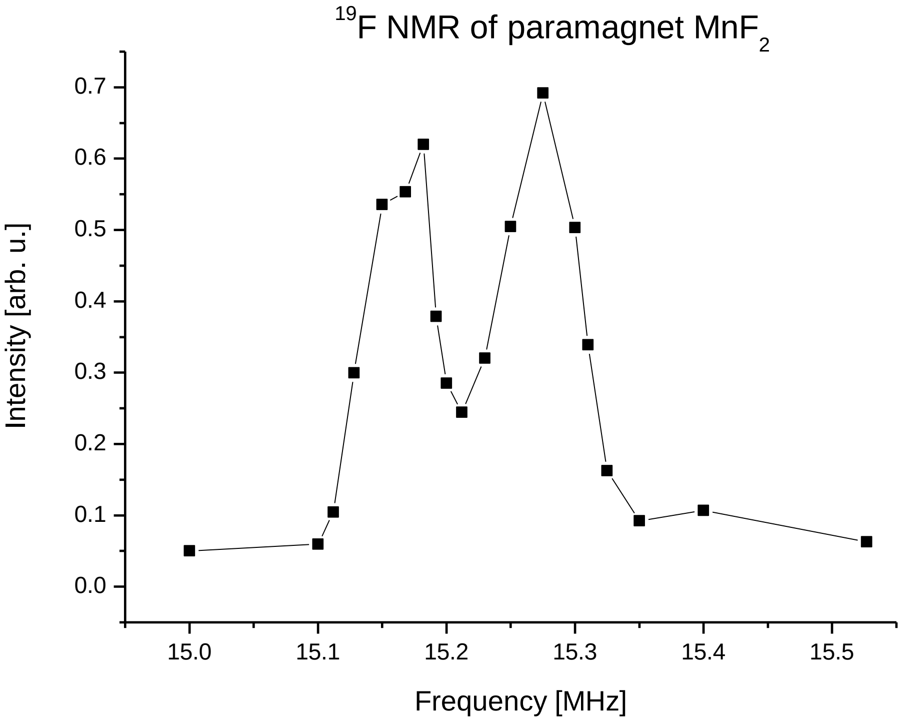
- In (110) plane, angle between [001] & H_0
  - For 0°
    - γ'= 43.13MHz/T
  - For 90°
    - γ_1'= 42.54MHz/T
    - γ_2'= 43.43MHz/T





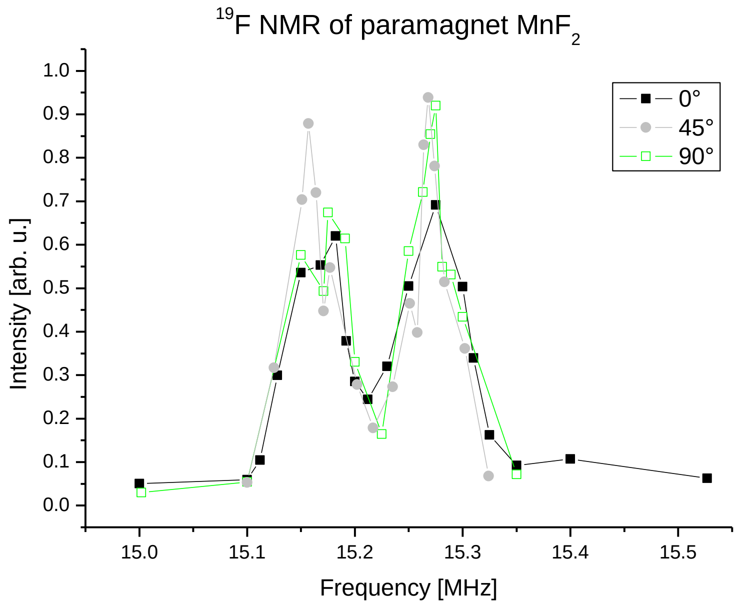
Experiment- signal?

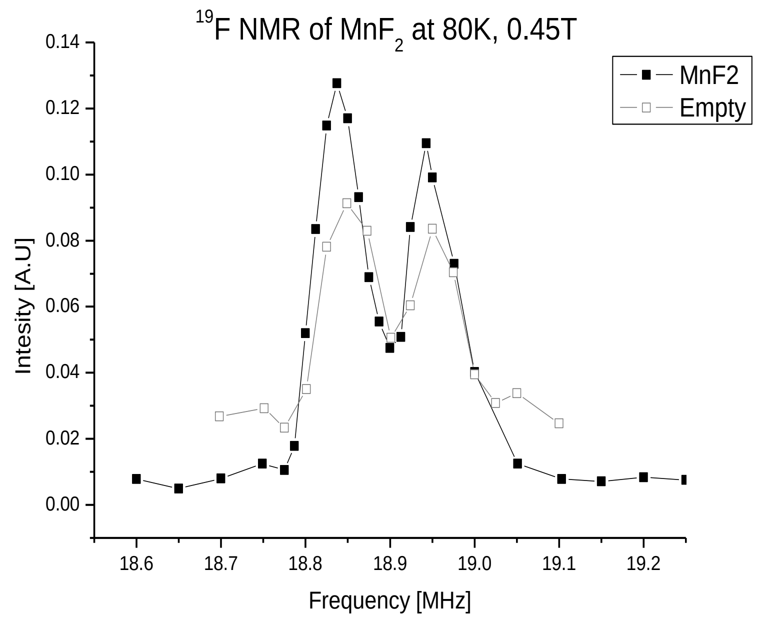
- At 82K, 0.3575T
  - $\gamma_1' = 42.45$MHz/T
  - $\gamma_2' = 42.73$MHz/T



Experiment

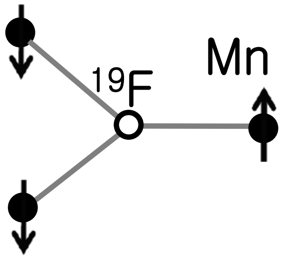
- Angle dependence
- At 80K, 0.45T



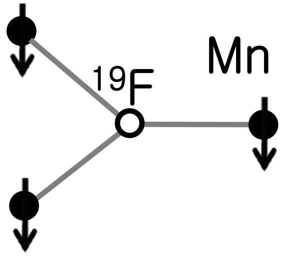


Expected electric field effect

- Song's Experiment
  - Hyperfine field: 4T
  - Splitting freq. 56kHz by 3.4V/μm
  - Non-symmetric spin environment



- Paramagnetic shift ΔH/H : 0.0735 for 77K
  - At 7T, ΔH = 0.515T, f ~300MHz → 7.2kHz by 3.4V/μm
  - Symmetric environment → smaller



Summary

- Failure of realization of Kane's Si:P Model
- Song's demonstration of qubit addressing in antiferromagnet MnF2
- Paramagnetic NMR of MnF2
  - Small paramagnetic shift compared with hyperfine field of antiferromagnet state
  - Angle depended properties
- There is signal but it can't be sure
- Expected electrical splitting of NMR frequency is very small