DM HELICES AND MAGNETIC FIELD

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PNPI

SPIN HELIX

$$\mathbf{S_R} = S[(\mathbf{A}e^{i\mathbf{k}\cdot\mathbf{R}} + \mathbf{A}^* e^{-i\mathbf{k}\cdot\mathbf{R}})\cos\alpha + \hat{c}\sin\alpha],$$

$$\mathbf{A} = (\hat{a} - i\hat{b})/2,\ \hat{a}^2 = \hat{b}^2 = 1,\ (\hat{a}\cdot\hat{b}) = 0,$$

$$\hat{c} = [\hat{a}\times\hat{b}],\ \alpha \to \text{cone angle..}$$

FELIX STRUCTURE

Helical strucure: Wave vector $\mathbf{k}$

$\hat{c}$ is perprndicular to spin rotatio

Two main cases:

$\hat{c}||\mathbf{k}$ B20 magnets.

$\hat{c} \perp \mathbf{k}$ cycloid (Multifrttoiks). .

DMI 1

Spins are rotated by DMI:

$$V_{DM} = \mathbf{D} \cdot [\mathbf{S}_1 \times \mathbf{S}_2] = DS^2 \sin\theta_{12}.$$

DMI appears due to inversion symmetry breacking in the center of the bond $\mathbf{b}$ connecting two spins (Moroya theorem).

DMI 2

Three breacking ways.

i. $Mn - Si - Mn$ bond along $\hat{x}$.

Si shifting $||\hat{x}$: $L_{MnSi} < L_{Si-Mn}$, $\mathbf{D} \sim [\hat{y} \times \hat{z}]||\hat{x}$.

$\mathbf{k}|| \pm \hat{c}$, Simple heliz.

ii. $Mn - O - Mn$ bond. O shifting along y or z :

$\mathbf{D} \sim [\hat{x} \times \hat{y}]||\hat{z}$ or $[\hat{x} \times \hat{z}]||\hat{y}$

$\mathbf{k} \perp \hat{c} \rightarrow$Cycloids.

iii. Mirror symmetry breacking $\hat{z} \neq -\hat{z}$

$\mathbf{D} \sim [\hat{z} \times \mathbf{b}]$. Cycloid.

ENERGY

Exchange and DM interactions

+ magnetic field

$$H = (1/2)\sum[J_{\mathbf{R},\mathbf{R}'}(\mathbf{S}_{\mathbf{R}} \cdot \mathbf{S}_{\mathbf{R}'}) + (\mathbf{D}_{\mathbf{R},\mathbf{R}'} \cdot [\mathbf{S}_{\mathbf{R}} \times \mathbf{S}_{\mathbf{R}'})] + \sum(\mathbf{H} \cdot \mathbf{S}_{\mathbf{R}}),$$

$$\mathbf{D}_{\mathbf{R}',\mathbf{R}} = -\mathbf{D}_{\mathbf{R},\mathbf{R}'}.$$

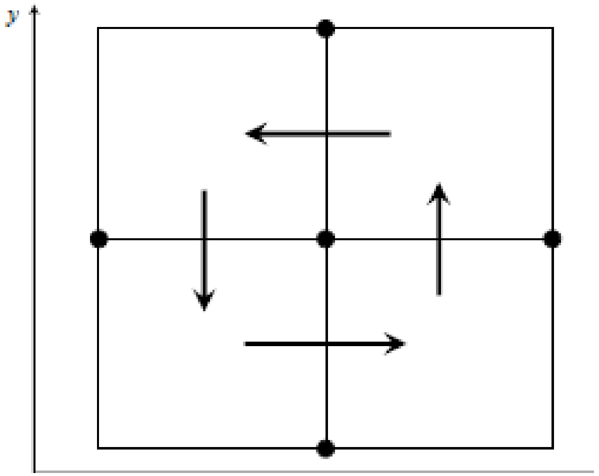
HELIX ENERGY

$$E = S^2\{J_0 \sin^2\alpha + [J_{\mathbf{k}} + i(\mathbf{D}_{\mathbf{k}} \cdot \hat{c})]\}\cos^2\alpha + S(\mathbf{H} \cdot \hat{c}).$$

$$J_{\mathbf{k}} = \sum_{\mathbf{b}} J_{\mathbf{b}} \cos \mathbf{k} \cdot \mathbf{b},$$

$$\mathbf{D}_{\mathbf{k}} = i \sum_{\mathbf{b}} d_{\mathbf{b}} [\hat{z} \times \hat{b}] \sin \mathbf{k} \cdot \mathbf{b}$$

SQUARE SURFACE LAYYR



Arrows are DM vectors

$$\mathbf{D}_x = d[\hat{y} \times \hat{z}],\ \mathbf{D}_y = d[-\hat{x} \times \hat{z}]$$

$$J_{\mathbf{k}} = 2J(\cos k_x + \cos k_y),$$

$$\mathbf{D}_{\mathbf{k}} = 2id(-\sin k_y, \sin k_x) \sim 2id[\hat{z} \times \mathbf{k}$$

AF LATTICE

$$\mathbf{k} \to \mathbf{k} + \pi(1,1)$$

$$\tan k_x = k\hat{c}_y, \; ; \tan k_y = -k\hat{c}_x, \;\; k = d/J$$

$$\sin\alpha = -\frac{(\mathbf{H}\cdot\hat{c})}{H_c}, \;\; H_c = \simeq 4SJ_0, \;\; J_0 = 4J.$$

H_c-spin flip field.

In-Plane FIELD

$$E = -S^2 J_0 \left\{ 1 + \frac{k^2}{4} - \frac{k^4}{8}[\sin^4\phi + \cos^4\phi) - W\cos^2(\phi - \Phi)] \right\},$$

$$\hat{c} = (\cos\phi, \sin\phi),\ \mathbf{H} = H(\cos\Phi, \sin\Phi)\ W = (H/4H_c k^2)^2.$$

TERMS: 1.AF energy. 2. Helix part.

3. DMI anisotropy. 4. Field energy.

CHIRAL DOMAINS 1

$H = 0$ Energy minima along square

diagonals (easy $\hat{c}$ directions).

Maxima along ridges (hard directions).

Four chiral domains:

$\mathbf{k} \perp \hat{c}$ CYCLOIDS.

$H \gg H_c k^2 \to \hat{c} || \pm \mathbf{H}$ Two domains.

CHIRAL DOMAINS 2

Strong field $H > H_d = H_c k^2/2\sqrt{2}$: $\hat{c} || \pm \mathbf{H}$.

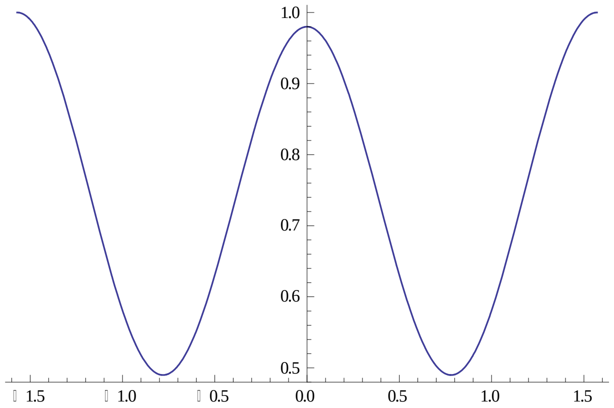
Weak field $H < H_d$. H —— (1,0).$\pm\pi/4$ domaims ro

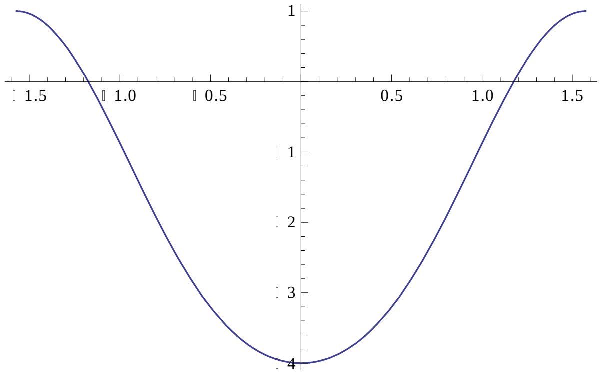
$\mathbf{H}||(1,1), H < H_d$. Both $\pm\pi/4$ are in their places.

$H = H_d$. $-\pi/4$ dolain jumps to plus place.

This state is stable below H_d.

FIELD ||(1,0)

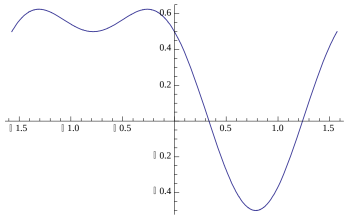




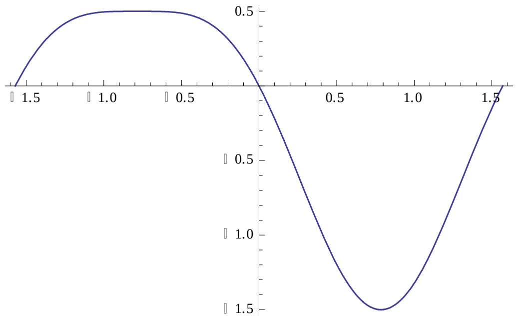
$$H = 0$$

$$H \gg H_d$$

FIELD || (1,1)



$H = H_d/\sqrt{2}$



$H = H_d$

Out-of--plane FIELD 1

$$(\mathbf{H} \cdot \hat{z}) = H \cos \Theta,$$

$$\hat{c} = (\cos\phi \sin\theta, \sin\phi \sin\theta, \cos\theta).$$

$$k_x = -k \sin\phi \sin\theta, \; k_y = k \cos\phi \sin\theta. \quad .$$

$$E = -S^2 J_0(k^2/4) \sin^2\theta - (SH^2/2H_c) \cos^2(\theta - \Theta).$$

$$\tan 2\theta = -\frac{(H/H_{sf})^2 \sin 2}{1-(H/H_{sf})^2 \cos 2\Theta}, \; H_{sf} = H_c k/2\sqrt{2} \gg H_d.$$

Out-of- PLANE FIELD 2

i. $(H/H_{sf})^2 \cos 2\Theta = 1,\ \mathbf{k}^2 = k^2/2.$

ii. $\Theta = 0$, H$|||\hat{z}$.

$E = -S^2 J_0 - SH^2/2H_c + \Delta E.$

$\Delta E \sim (H^2 - H_{sf}^2)\sin^2\theta.$

$H < H_{sf}\ \ \theta = \pi/2$, Helix.

$H > H_{sf}, \theta = 0$, AF in flop state.

RESULTS

In-plane field rotates $(\hat{c}, \mathbf{k})$ cross.

Strong field $\hat{c}||\mathbf{H}$.

Two chiral domains.

Out-of-plane field.

(k$decreasing$.

Strong field.

Helix $\rightarrow$ Antiferromagnet.

3-D GENERALIZATION

GGGGGGGGGGGGGGGGG

= 0: $(\hat{c}, \mathbf{k})$ plane, $[\hat{c} \times \mathbf{k}]$ direction.

plane field. Rotation of $\mathbf{K} \pm \mathbf{k}$ reflections (

main transitions.

larization: $\Delta\sigma \sim (\hat{c} \cdot \mathbf{K})(\mathbf{K} \cdot \mathbf{P})$ at $\mathbf{P}||\mathbf{H}$

anges with $\hat{c}$ rotation.

t-of- plane field.

decrising, AF transition.

СПАСИБО!

FM LATTICE

FM critical field $H_f = SJ_0k^2/2$.

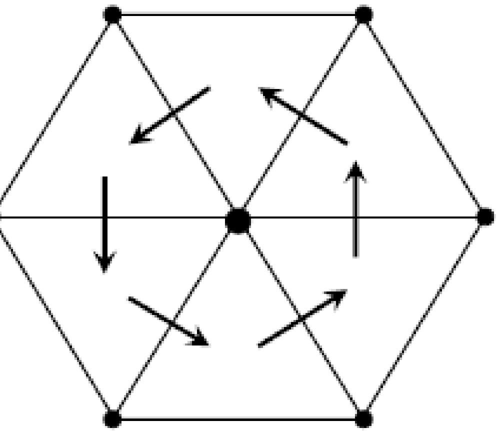
Donain rotating field

$H_{fd} = SH_fk \sim k^3 \ll H_d \sim k^2$.

Anisotropy: Dipolar interaction:

$A \to A + (g\mu_B)^2 A_1/a^3, \; A_1 \simeq 26$.

TRIANGULAR LATTICE



$$\text{Bonds } \mathbf{b}_0 = \hat{x}$$

$$\mathbf{b}_\pm = \hat{x}\cos\psi \pm \hat{y}\sin\psi, \psi = \pi/3$$

$$E = -2S^2 \sum_{j=0,\pm} \{J\cos(\mathbf{b}_j \cdot \mathbf{k}) -$$

$$d[(\hat{c} \cdot [\hat{z} \times \mathbf{b}_j])\sin(\mathbf{b}_j \cdot \mathbf{k})]\} - S(\mathbf{H} \cdot \hat{c})/2H_c,$$

K-EXPANSION 1

$$k^2 : \ \mathbf{k} \perp \hat{c} \text{ Cycloid.}$$

$$E = -S^2 J_0 \left(1 + \frac{k^2}{4}\right) - \frac{S(\mathbf{H}\cdot\hat{c})^2}{2H_c}.$$

$$k = d/J, \ J_0 = 6J,$$

$$H_a = 4SJ_0, \ H_f = SJ_0k^2/2.$$

$$\Delta E_4 = (S^2 J_0 k^4/16) \sum_{n=0\pm} \sin^4(\phi + n\pi/3) = \frac{9S^2J_0k^4}{132},$$

SIX ORDER ANISOTROPY

$$\Delta E_6 = -\frac{S^2 J_0 k^6}{144} \sum_{n=0,\pm} \sin^6(\phi + n\pi/3) \sim \cos 6\phi,$$

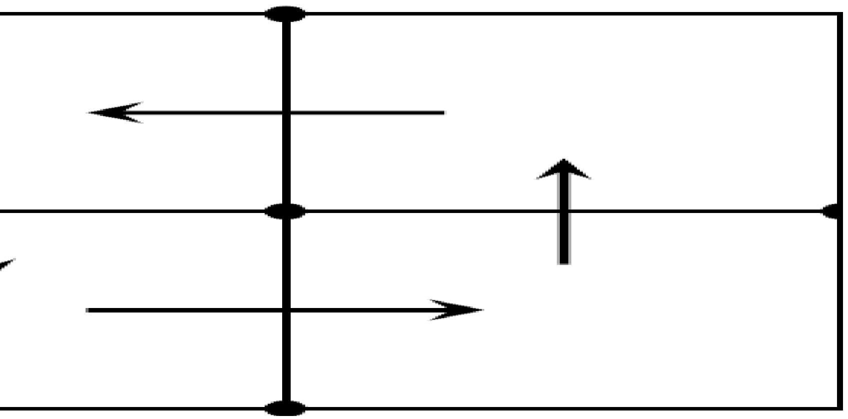
Three domain pairs.

Easy $\hat{c}$ axes: $\pm\pi/6, \pi/2$.

Domain rotating field

$$H_d = \frac{\sqrt{3} H_a k^3}{96} (AF), \; \frac{\sqrt{3/2} H_f k^4}{48} (FM).$$

RECTANGULAR LATTICE



$k_x = -\frac{d_x \hat{c}_y}{J_x}, k_y = \frac{d_y \hat{c}_x}{J_y}.$

$E = -2S^2 \left(\frac{d_x^2}{J_x} \sin^2 \phi + \frac{d_y^2}{J_y} \cos^2 \phi \right).$

tes: $\phi = 0, \ \phi = \pi/2$

$\frac{d_y^2}{J_y}, \ \hat{c}||\hat{y}, \mathbf{k}||\hat{x}..$

$E = S^2 \left(\frac{d_x^2}{J_x} - \frac{d_y^2}{J_y} \right)$ rotates $(\hat{c}, \mathbf{k})$

$\hat{c}_y) \rightarrow (\hat{c}_x)..$

LAYER POLARIZATION

Layer is at z_0 above the substrate.

Elastic energy $U(z) = -\frac{1}{2}K(z - z_0)^2$.

Helix energy $E = -S^2 d^2(z)/4J_0$.

Layer shihifting $\delta z = -S^2 dd'/2KJ_0$.

Polarization $\mathbf{P} \sim \delta z || \hat{z}$.

$$\delta z = 0 \text{ if } H_\perp > H_{sf} \sim H_c k.$$

CONCLUSIN

Magnetic field affects strongly

the DM helical structure:

It may rotate the vector $\mathbf{k}$,

Chane its value,

Supress the helix.

СПАСИБО!