Hysteresis effect in $\nu = 1$ quantum Hall system under periodic electrostatic modulation

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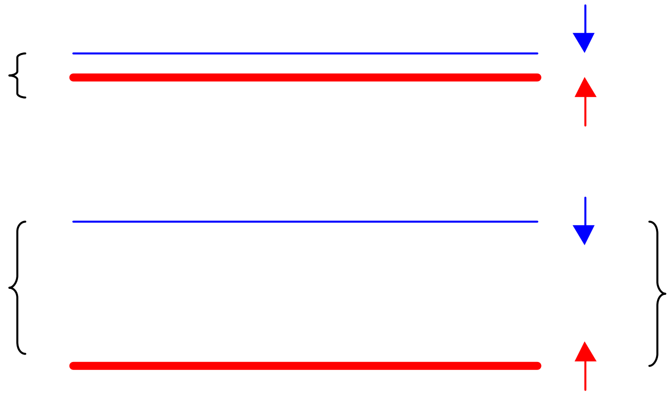
Ferromagnet in ν =1 quantum Hall system

Zeeman splitting



exchange interaction

enhanced splitting

$$\frac{e^2}{\epsilon \ell_B}\sqrt{\frac{\pi}{2}}$$

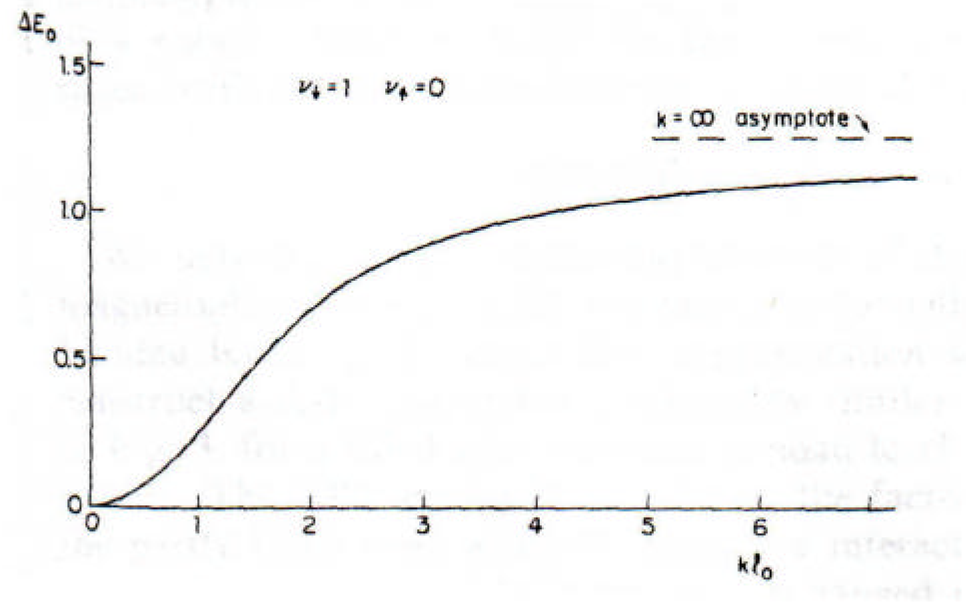
a single spin flip costs $\Sigma = (\pi/2)^{1/2} e^2/\epsilon l_B$ =125 K at 4 T

→ very stable ferromagnetic ordering

Dispersion of spin wave in ν =1 QHFM

(Bychkov, Iordanskii, and Eliashberg, JETP Lett. 1981

Kallin, Halperin, Phys. Rev. B 1984)



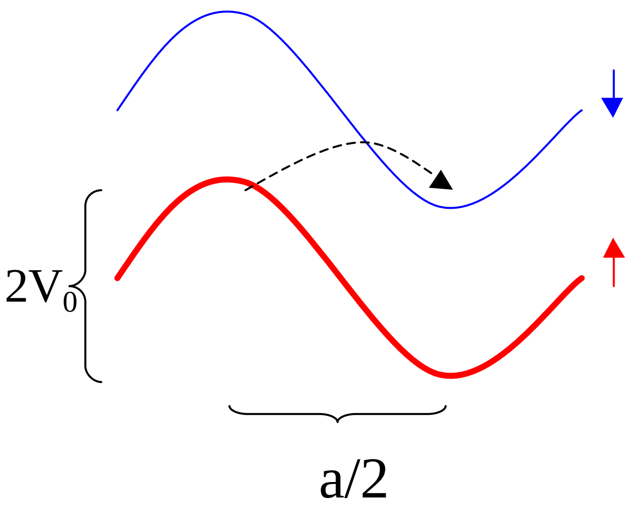
$$\frac{e^2}{e\ell_B}\sqrt{\frac{p}{2}}$$

$$E(k) = \frac{e^2}{e\ell_B}\sqrt{\frac{p}{2}}\left[1 - e^{-k^2 l_B^2/4} I_0(k^2 l_B^2/4)\right]$$

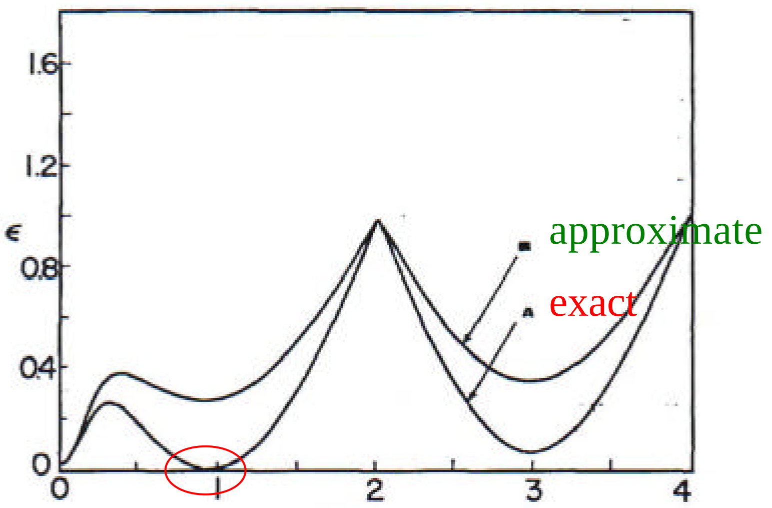
Periodically modulated QHS

(Bychkov, Maniv, Vagner, Wyder, Phys. Rev. Lett. 1994)

Semi-classical picture



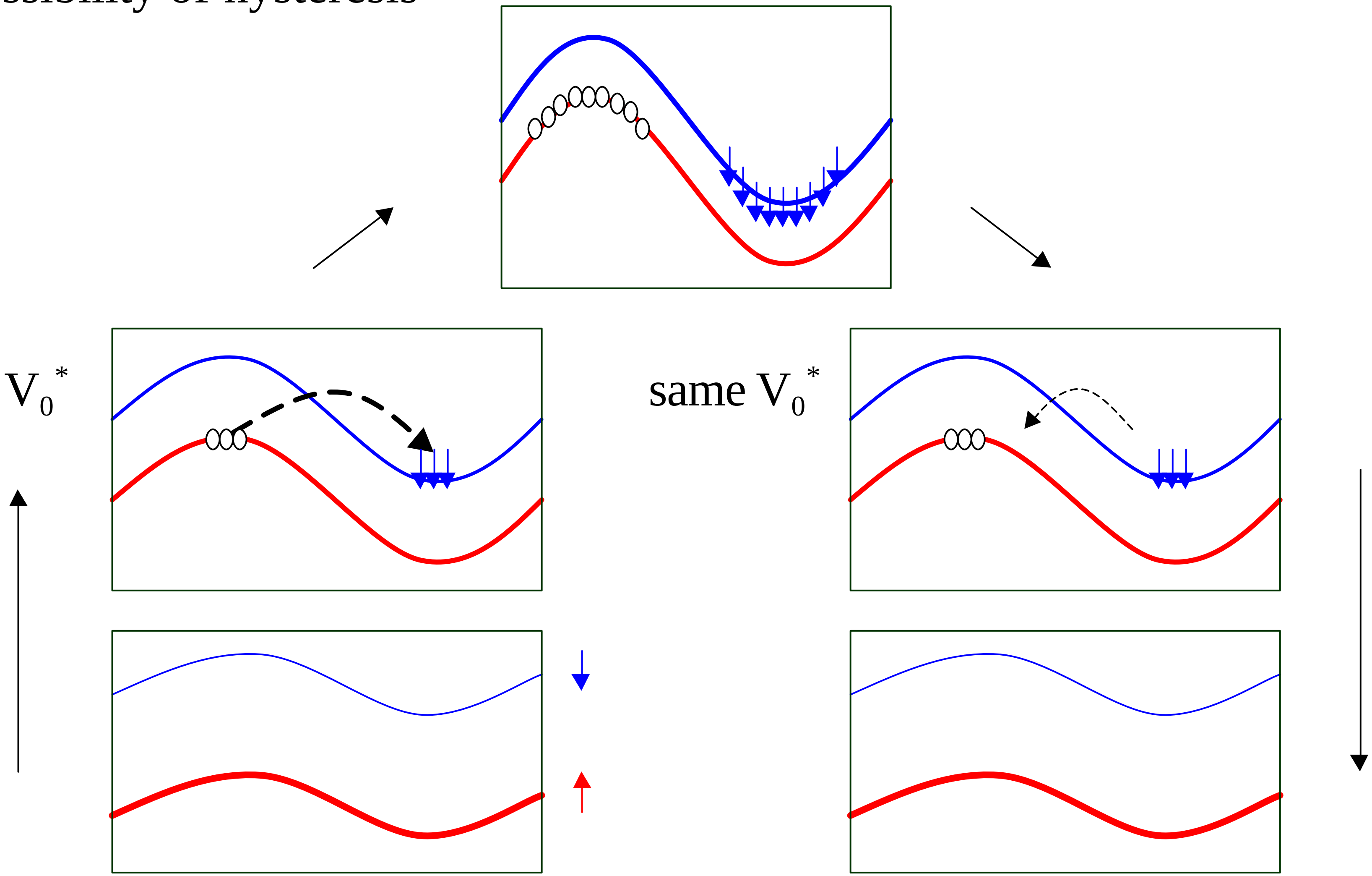
Dispersion of spin wave



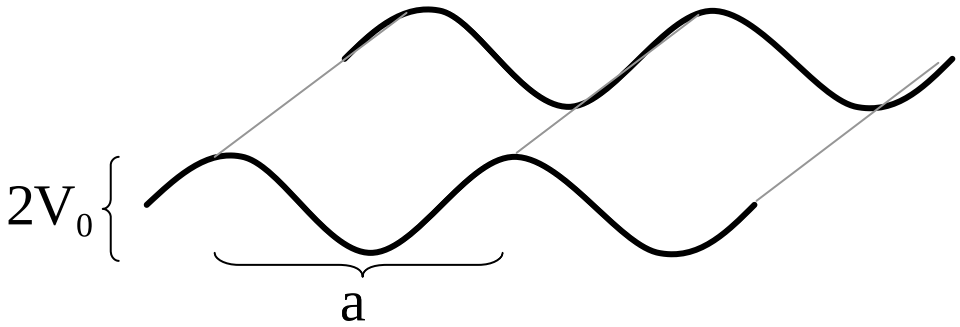
$k = a/2l_B^2$

$a = 15.7 l_B$, $V_0 = 0.58\ e^2/\varepsilon l_B$

Possibility of hysteresis



1-dim electrostatic modulation



$$H=\sum_{X,\alpha}(-\frac{\alpha}{2}\Delta_z^{(0)}-\mu)c^\dagger_{X,\alpha}c_{X,\alpha}+H_M+H_C,$$

x = guiding center coord.

a = ↑↓

Modulation part (with LLL projection)

$$H_M=\sum_{X,\alpha}V_0e^{-(G_0l)^2/4}\cos\left(G_0X\right)c^\dagger_{X,\alpha}c_{X,\alpha}\ ,$$

$G_0=2p/a$

Electron-electron interaction part

$$H_C=\frac{1}{2}\sum_{\{X_i\},\alpha,\beta}\langle X_1,X_2|v|X_3,X_4\rangle c^\dagger_{X_1,\alpha}c^\dagger_{X_2,\beta}c_{X_3,\beta}c_{X_4,\alpha}$$

Self-consistent Hartree-Fock calculation

$$H_{\mathrm{HF}} = \sum_{X,\alpha} (\varepsilon_{X,\alpha} - \mu) c^{\dagger}_{X,\alpha} c_{X,\alpha} \ ,$$

$$\varepsilon_{X,\alpha} = -\frac{\alpha}{2}\Delta_z^{(0)} + V_0 e^{-(G_0 l)^2/4} \cos(G_0 X) + \sum_{G_j} W_0^{\alpha}(G_j) e^{-iG_j X}$$

$$W_0^{\alpha}(G) = \frac{e^2}{\kappa l} \sum_{\beta} \left[H_0(G) - \delta_{\alpha,\beta} X_0(G)\right] \left\langle \rho_0^{\beta}(-G) \right\rangle$$

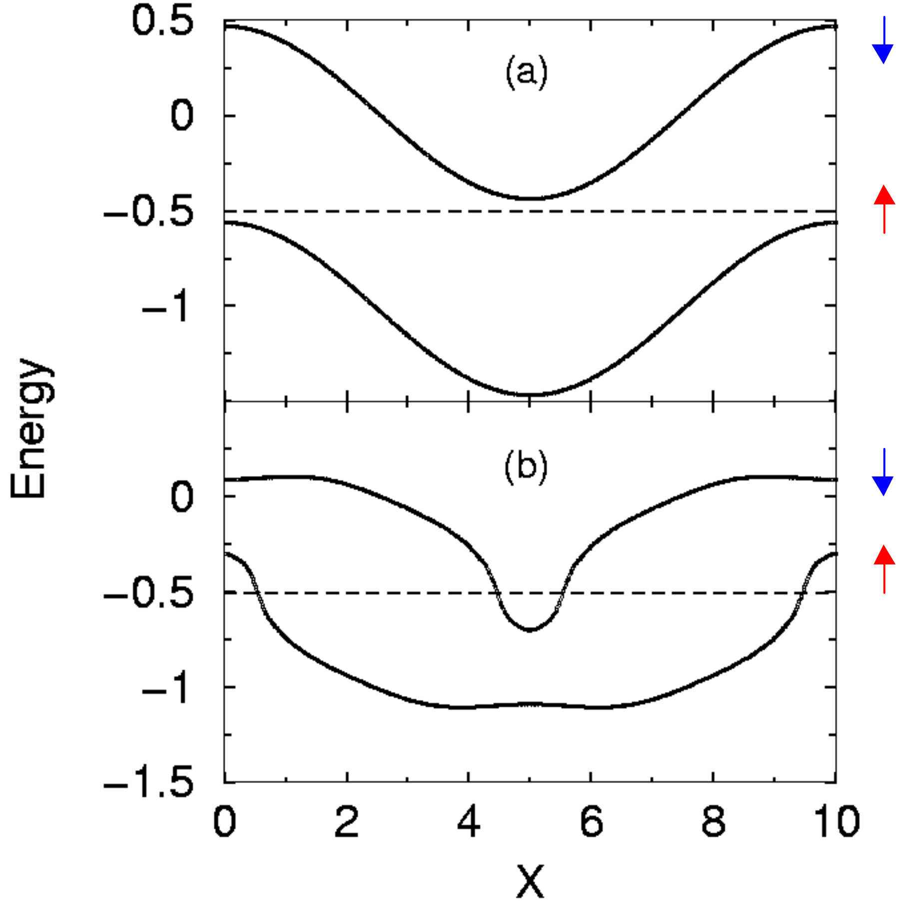
$$H_0(G) = \frac{1}{|G|} e^{-(Gl)^2/2} (1 - \delta_{G,0}),$$

$$X_0(G) = \sqrt{\frac{\pi}{2}} e^{-(Gl)^2/4} I_0 \left[\frac{(Gl)^2}{4}\right],$$

$$\left\langle \rho_0^{\beta}(-G) \right\rangle = \frac{1}{N_{\varphi}} \sum_X e^{iGX} \langle c^{\dagger}_{X,\beta} c_{X,\beta} \rangle,$$

Self-consistent band structure (?=1)

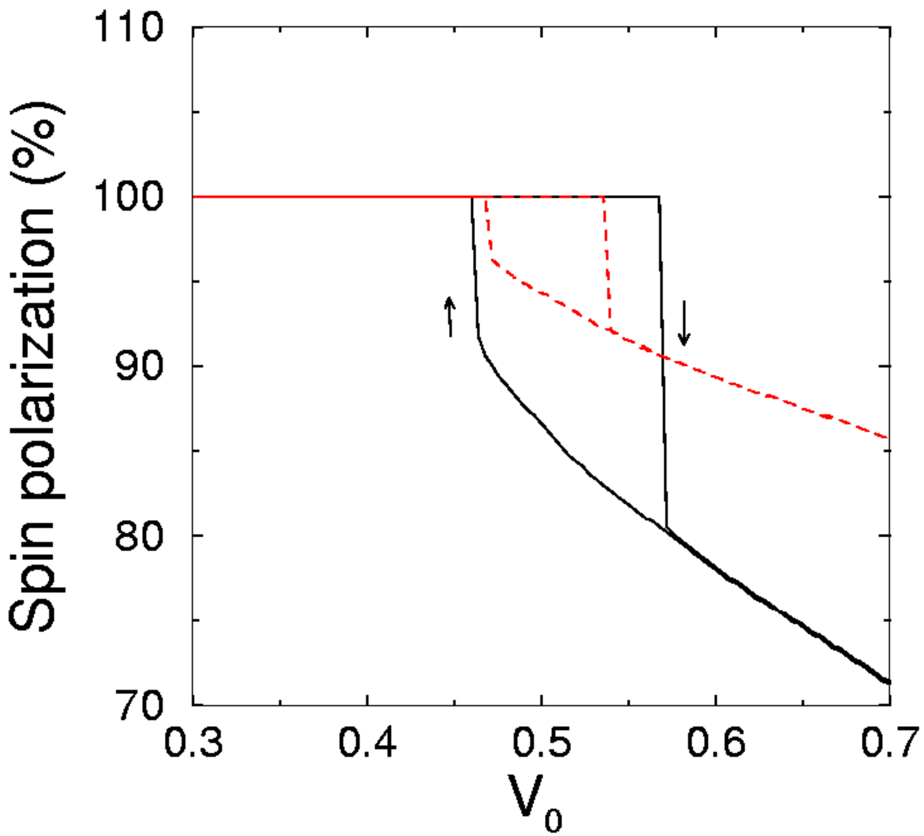
(energy in units of $e^2/\epsilon l$, period in units of l)

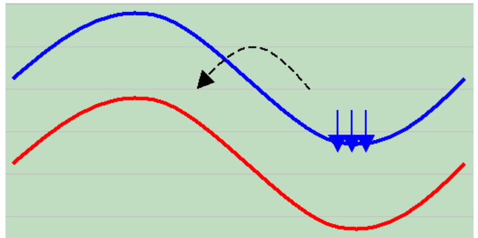


V_0=0.5, a=10

V_0=0.6, a=10

Hysteresis of spin polarization

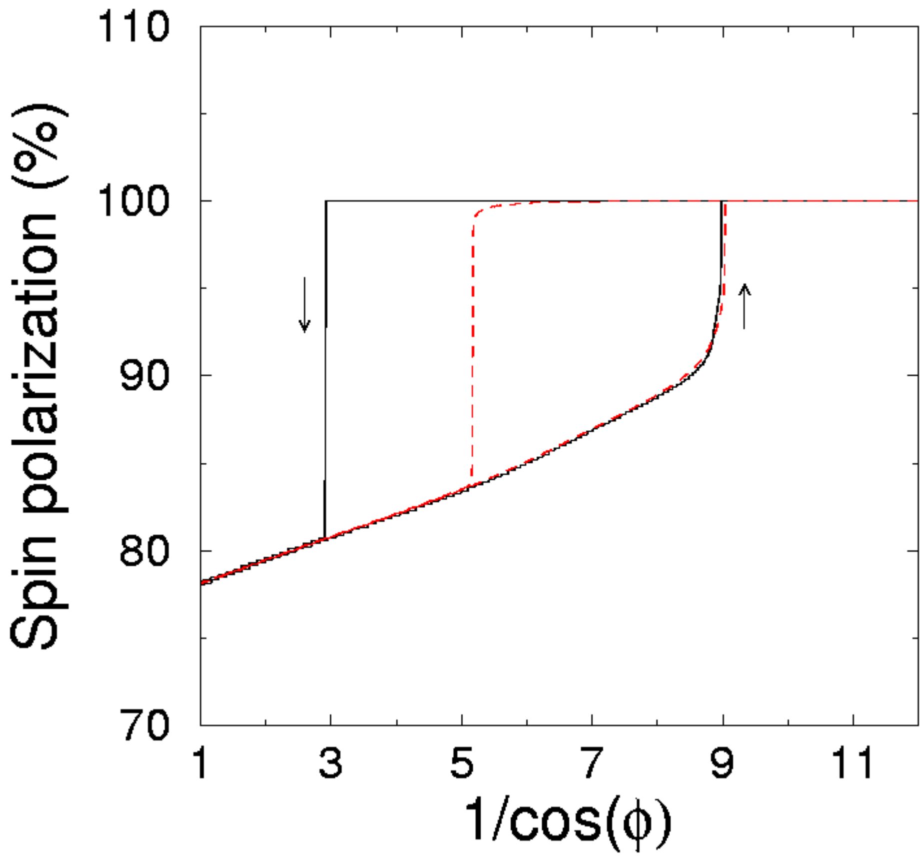


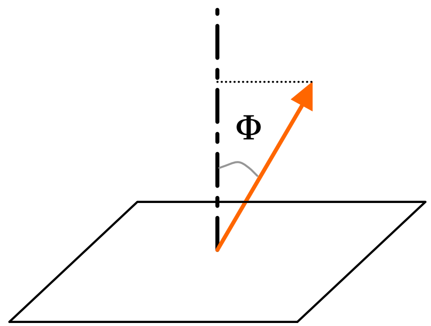


a=15.7

a=10

Changing the tilting angle of the magnetic field





kT=0, kT=0.01

Hysteresis in a ν =1 modulated QHS

- Need short period (similar conclusion from Manolescu and Gudmundsson, Phys. Rev. Rapid Comm. 2000)
- Range of parameters (for GaAs with $n=3\times10^{11}/cm^2$, $B=12.4$ T, $l_B=72.8$ A, $e^2/\varepsilon l_B=16$ meV)

  Modulation period $a = 15\, l_B \approx 110$ nm

  Modulation amplitude $V_0 = 0.5\, e^2/\varepsilon l_B \approx 8$ meV
- What have been left out in this calculation

  Landau level mixing ($h\omega_c=21.4$ meV)

  Screening and higher order correlations