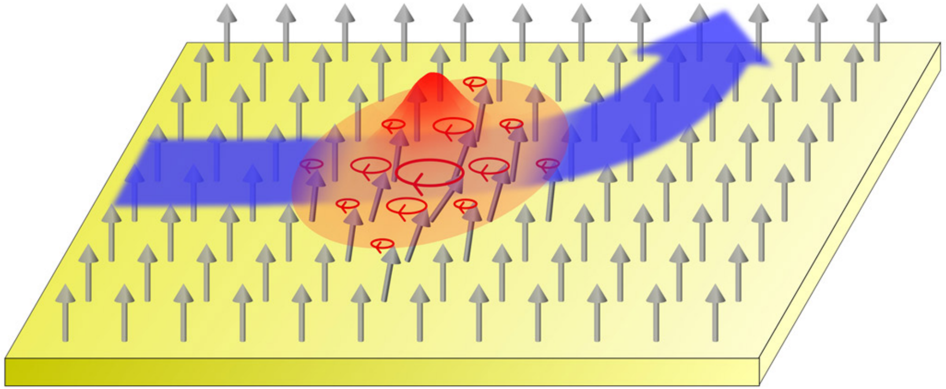
Thermal Hall effect incorporating magnon damping in localized spin systems

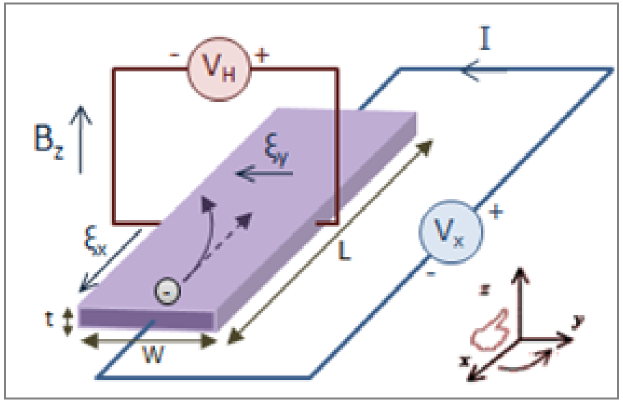
Shinnosuke Koyama[1] and Joji Nasu[1]

[1]*Department of Physics, Tohoku University, Sendai, Miyagi 980-8578, Japan*

(Dated: March 14, 2024)



Hall effect



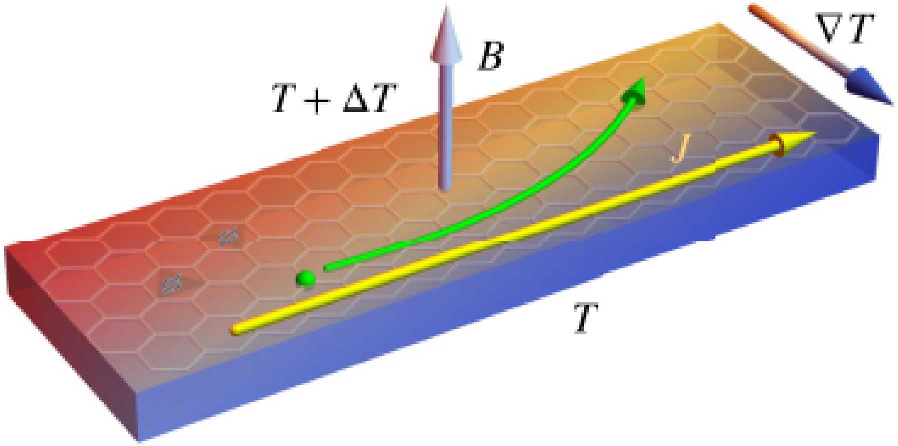
Hall effect – tensor

$$\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \end{pmatrix} = \begin{pmatrix} \rho_{xx} & \rho_{xy} \\ \rho_{yx} & \rho_{yy} \end{pmatrix} \begin{pmatrix} j_x \\ j_y \end{pmatrix};$$

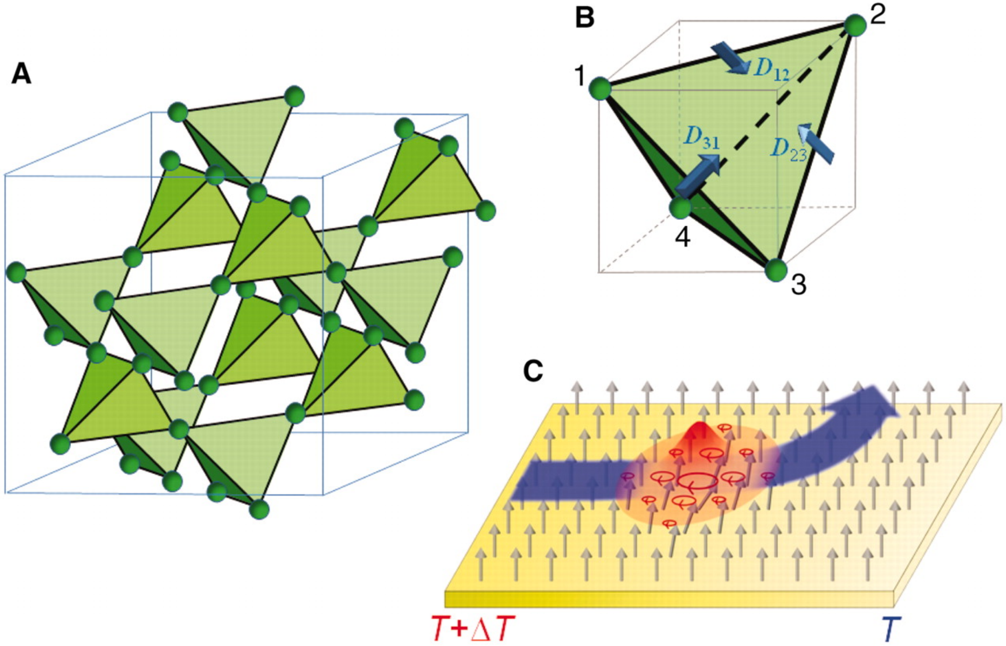
$$\begin{pmatrix} j_x \\ j_y \end{pmatrix} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{pmatrix} \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \end{pmatrix};$$

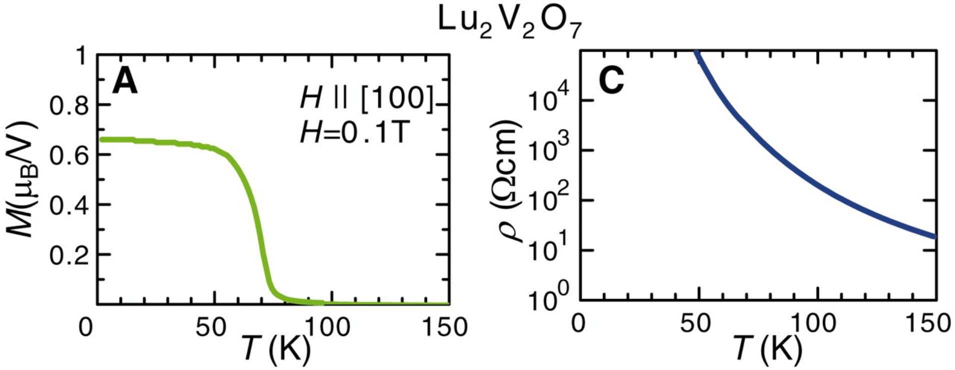
Thermal Hall effect (Righi–Leduc effect)

$$\frac{\partial T}{\partial y} = R_{\mathrm{TH}} B \frac{\partial T}{\partial x}$$



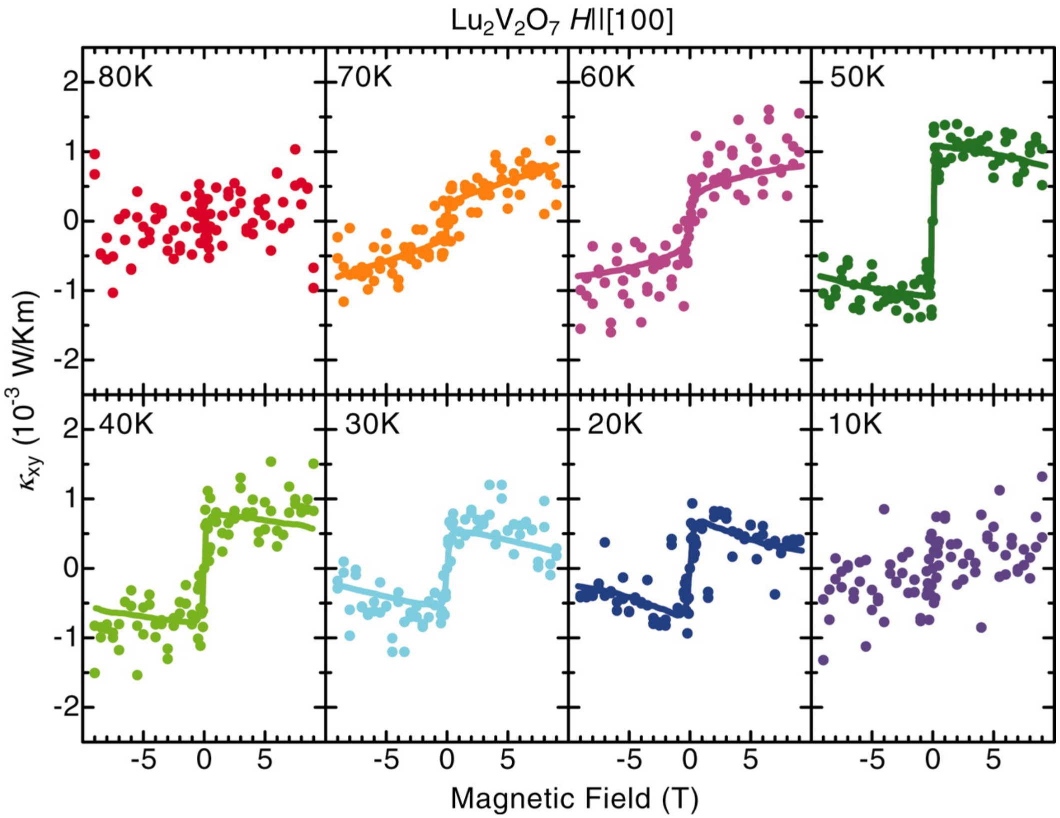
Magnon THE





Y. Onose et al. ,Observation of the Magnon Hall Effect.Science329,297-299(2010)

Magnon THE



Y. Onose et al. ,Observation of the Magnon Hall Effect.Science329,297-299(2010)

Magnon THE theory

$$H_{\mathrm{eff}} = \sum_{\langle ij \rangle} -J\vec{S}_i \cdot \vec{S}_j + \vec{D}_{ij} \cdot (\vec{S}_i \times \vec{S}_j) - g\mu_B \vec{H} \cdot \sum_i \vec{S}_i,$$

$$< i| - J\vec{S}_i \cdot \vec{S}_j + \vec{D}_{ij} \cdot (\vec{S}_i \times \vec{S}_j)|j >$$

$$=< i\,| - \frac{J}{2}(S_i^+ S_j^- + S_i^- S_j^+) + \frac{iD_{ij}}{2}(S_i^+ S_j^- - S_i^- S_j^+)\,|\,j >= -\frac{\widetilde{J}}{2} e^{i\phi_{ij}}$$

$$\widetilde{J} e^{i\phi_{ij}} = J + iD_{ij}$$

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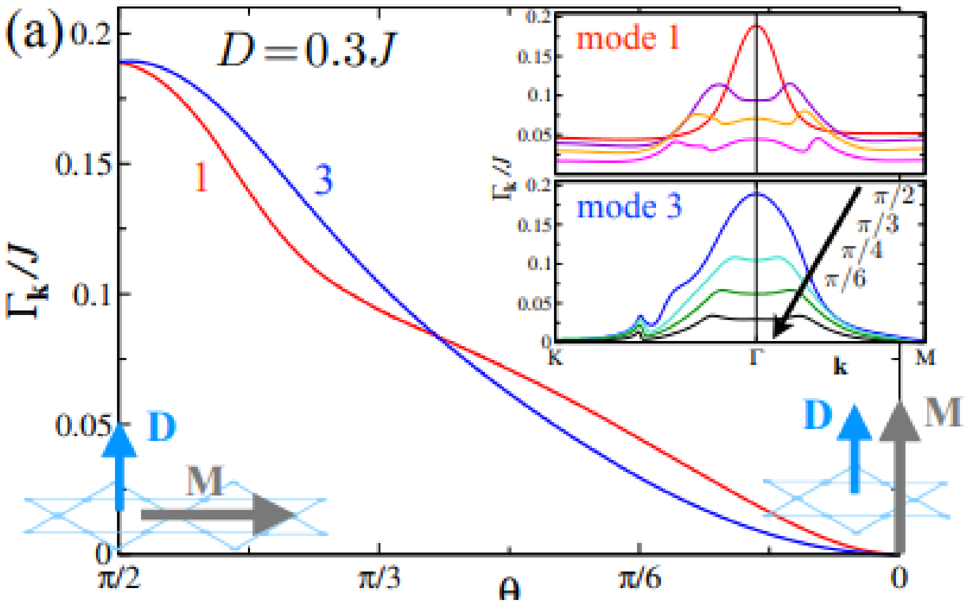
Magnon THE theory

$$\kappa^{xy} = -\frac{k_B^2 T}{\hbar V}\sum_{n,\boldsymbol{k}} c_2(\rho_n)\Omega_{n,z}(\boldsymbol{k}).$$

the Berry curvature is defined by $\Omega_n^z = \partial_{q_x} A_{ny} - \partial_{q_y} A_{nx}$, with $\boldsymbol{A}_n = i\langle\Psi_{n\boldsymbol{q}}|\mathcal{J}\partial_{\boldsymbol{q}}|\Psi_{n\boldsymbol{q}}\rangle/\langle\Psi_{n\boldsymbol{q}}|\mathcal{J}|\Psi_{n\boldsymbol{q}}\rangle$ being the Berry connection.

Magnon interactions



$$\Gamma_{\boldsymbol{k},\eta}(\omega) = -\mathrm{Im}\Sigma^{R}_{\boldsymbol{k},\eta}(\omega),$$

$$\hat{\mathcal{H}} = -J\sum_{\langle ij\rangle}\mathbf{S}_i\cdot\mathbf{S}_j + \sum_{\langle ij\rangle}\mathbf{D}_{ij}\cdot(\mathbf{S}_i\times\mathbf{S}_j),$$

$$\hat{\mathcal{H}}_{\mathrm{DM}} = \frac{D}{2}\sum_{\langle ij\rangle}\left[\left(S_i^+ + S_i^-\right)S_j^z - S_i^z\left(S_j^+ + S_j^-\right)\right]$$

$$\hat{\mathcal{H}}^{(3)}_{DM} = \frac{D}{2!}\sqrt{\frac{2S}{N}}\sum_{\mathbf{k},\mathbf{q}}\sum_{\nu\mu\eta}\widetilde{\Phi}^{\nu\mu\eta}_{\mathbf{qk;p}}\, b^\dagger_{\nu,\mathbf{q}} b^\dagger_{\mu,\mathbf{k}} b_{\eta,\mathbf{p}} + \mathrm{H.c.},$$

Phys. Rev. Lett. 117, 187203

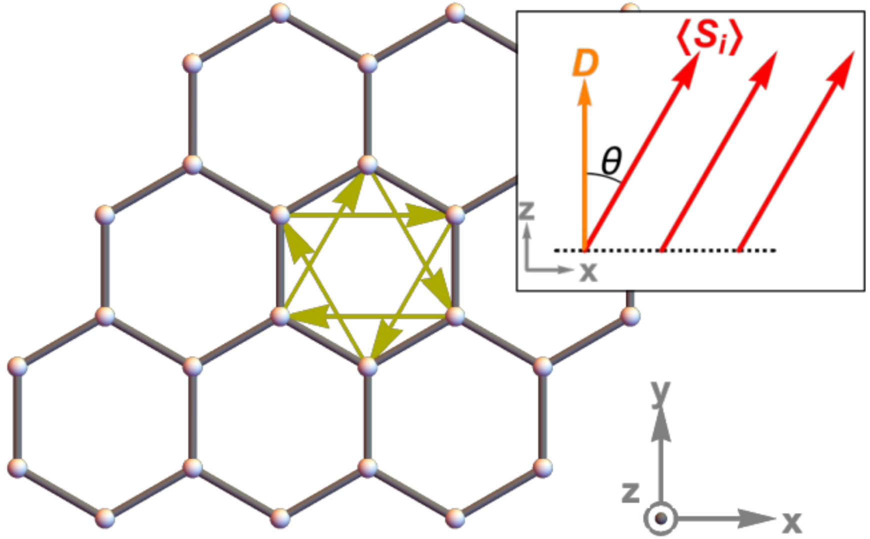
Theory for interacting magnons

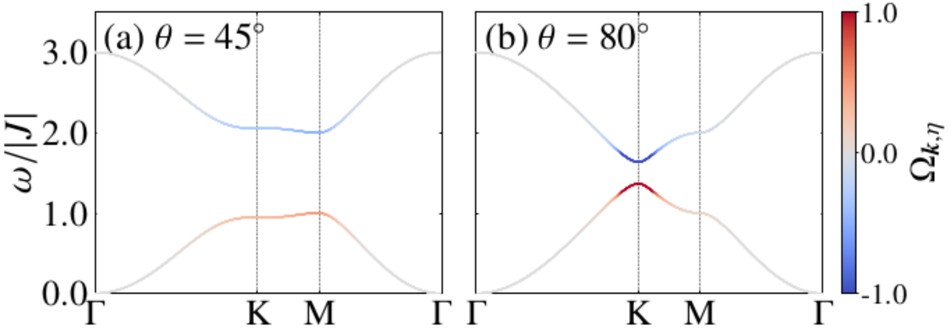
$$\kappa^{xy} = -\frac{k_{\mathrm{B}}^2 T}{\hbar V} \sum_{n,\boldsymbol{k}} c_2(\rho_n) \Omega_{n,z}(\boldsymbol{k}).$$

→

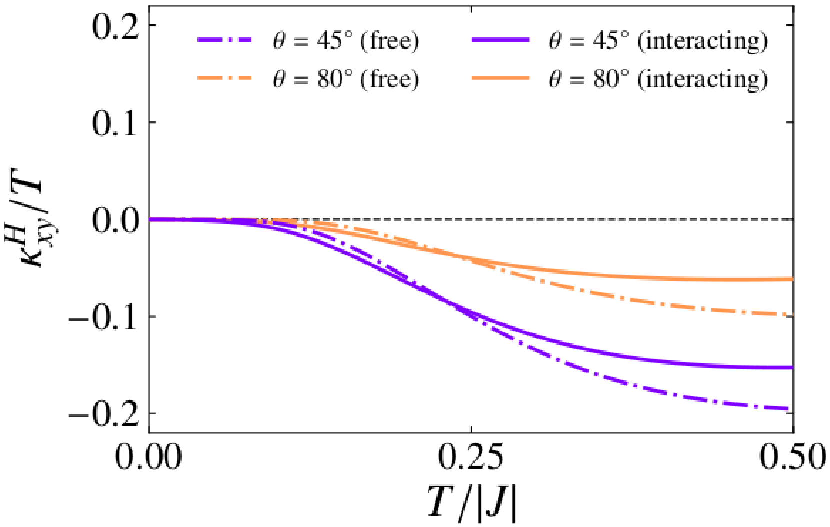
$$\kappa^H_{\lambda\lambda'} \simeq -\frac{k_B^2 T}{\hbar V} \sum_{\lambda''} \sum_{\eta}^{N} \sum_{\boldsymbol{k}} \varepsilon_{\lambda\lambda'\lambda''} \Omega^{\lambda''}_{\boldsymbol{k},\eta} \times \int_{-\infty}^{\infty} d\omega \tilde{\rho}_{\boldsymbol{k},\eta}(\omega) c_2(g(\beta\omega)).$$

Results

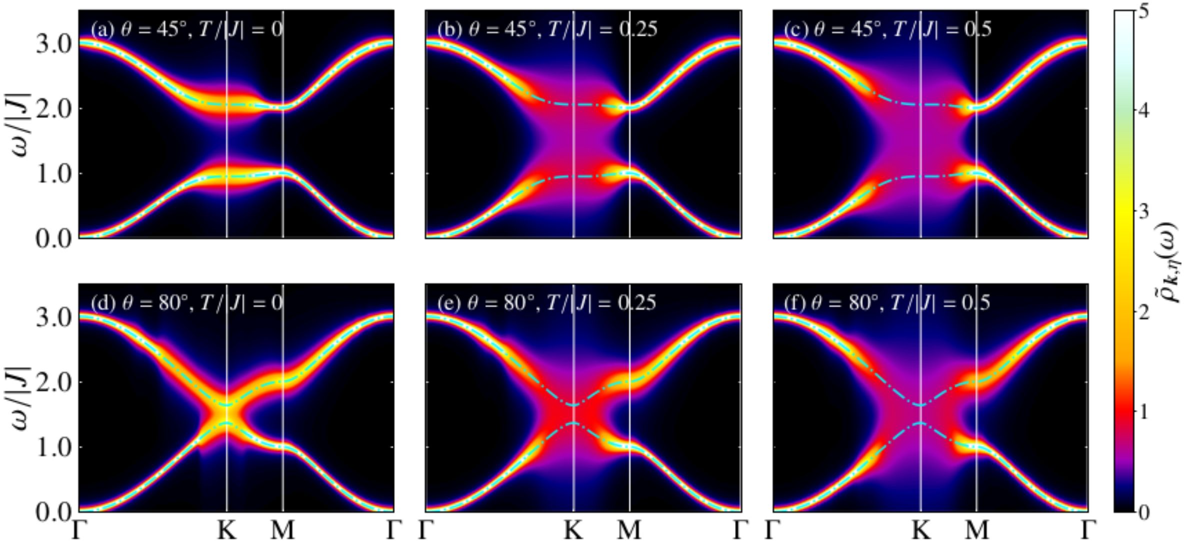




Results



θ = 45° (free)
θ = 45° (interacting)
θ = 80° (free)
θ = 80° (interacting)
κ^H_{xy}/T
$T/|J|$



(a) θ = 45°, $T/|J|$ = 0
(b) θ = 45°, $T/|J|$ = 0.25
(c) θ = 45°, $T/|J|$ = 0.5
(d) θ = 80°, $T/|J|$ = 0
(e) θ = 80°, $T/|J|$ = 0.25
(f) θ = 80°, $T/|J|$ = 0.5
$\omega/|J|$
Γ K M Γ
$\tilde{\rho}_{k,\eta}(\omega)$