Thermal Spin Transport: Spin Seebeck Effect in Metallic Ferromagnet

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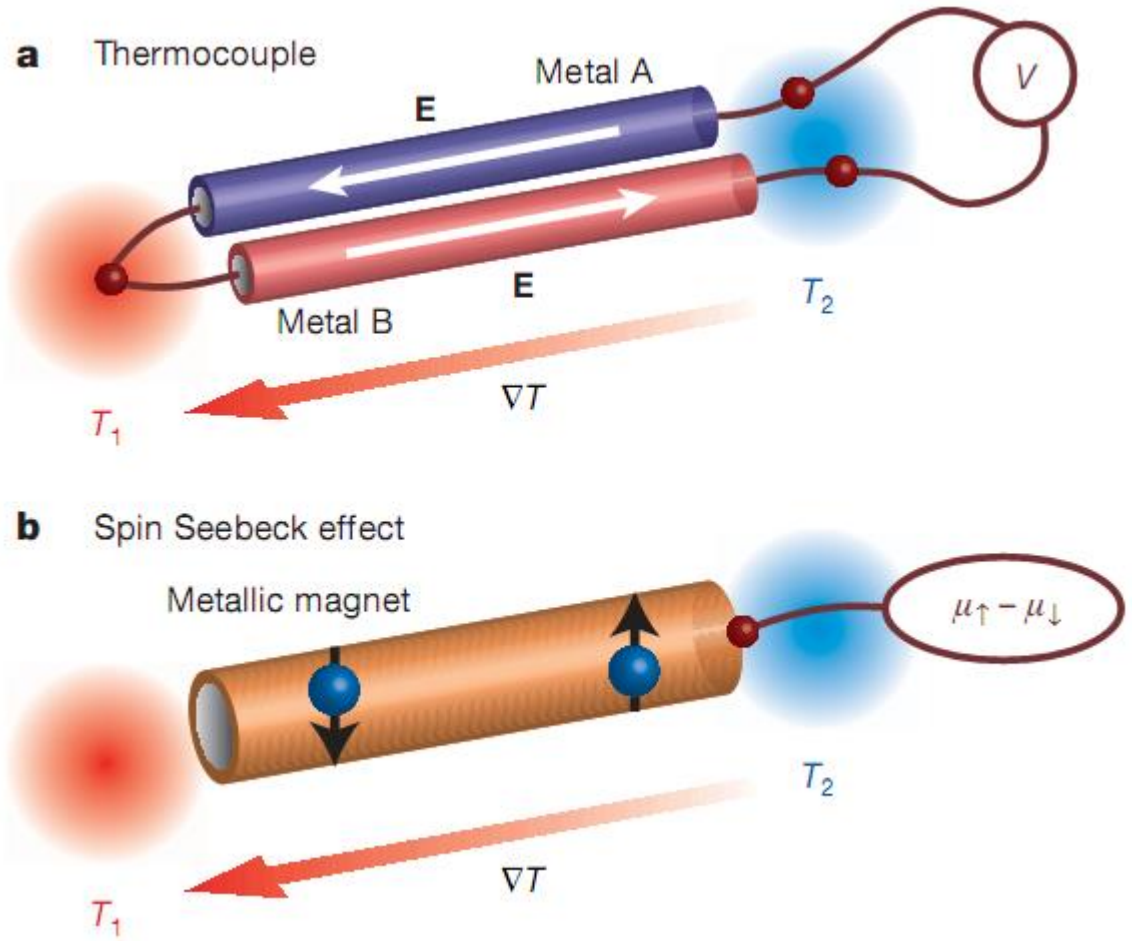
Schematics of spin Seebeck effect



$$\mu_\uparrow = \mu^c{}_\uparrow - e\phi$$

$$\nabla\mu_\uparrow = (\partial\mu^c{}_\uparrow/\partial n_\uparrow)\nabla n_\uparrow + (\partial\mu^c{}_\uparrow/\partial T)\nabla T - e\nabla\phi$$

$$\nabla(\mu_\uparrow - \mu_\downarrow) = eS_S\nabla T$$

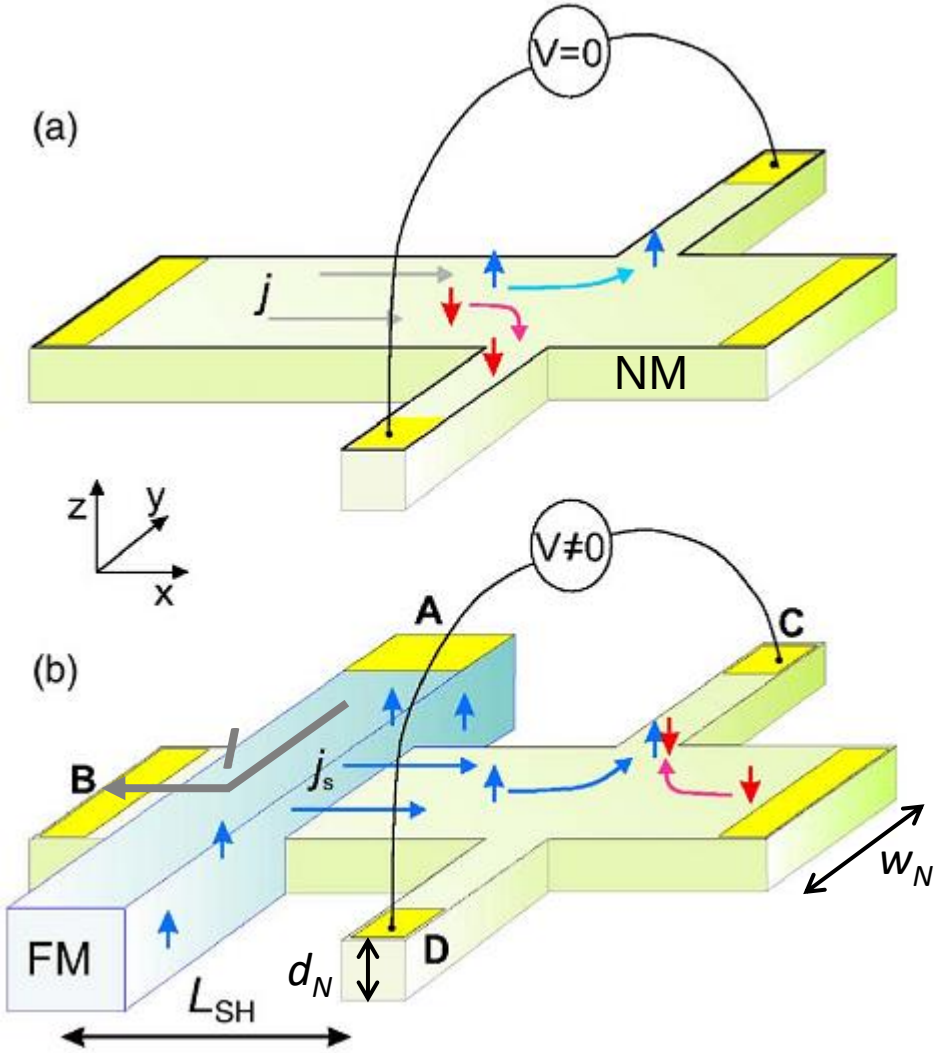
$$S_S = (1/e)[\partial\mu^c{}_\uparrow/\partial T - \partial\mu^c{}_\downarrow/\partial T]$$

$\partial\mu^c{}_\uparrow/\partial T \neq \partial\mu^c{}_\downarrow/\partial T$ for metallic ferromagnet

Creation of bulk spin accumulation by temperature gradient

K. Uchida, et al, Nature 455, 778 (2008)

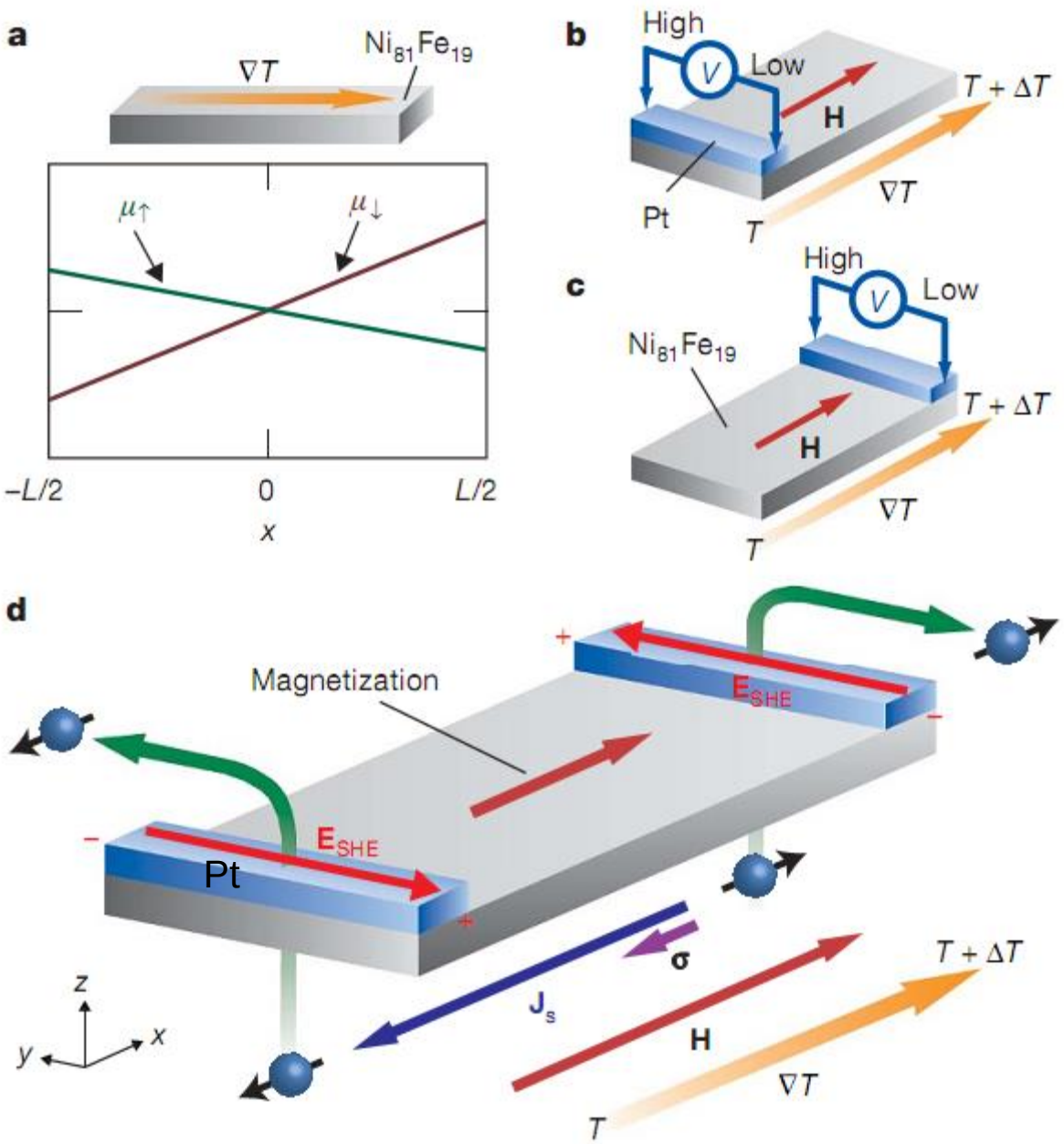
Schematics of SHE and ISHE



$$\boldsymbol{V}_c \propto \alpha_{SH}(\hat{\sigma} \times \boldsymbol{j}_s)$$

S. O. Valenzuela and M. Tinkham, JAP 101, 09B103 (2007)

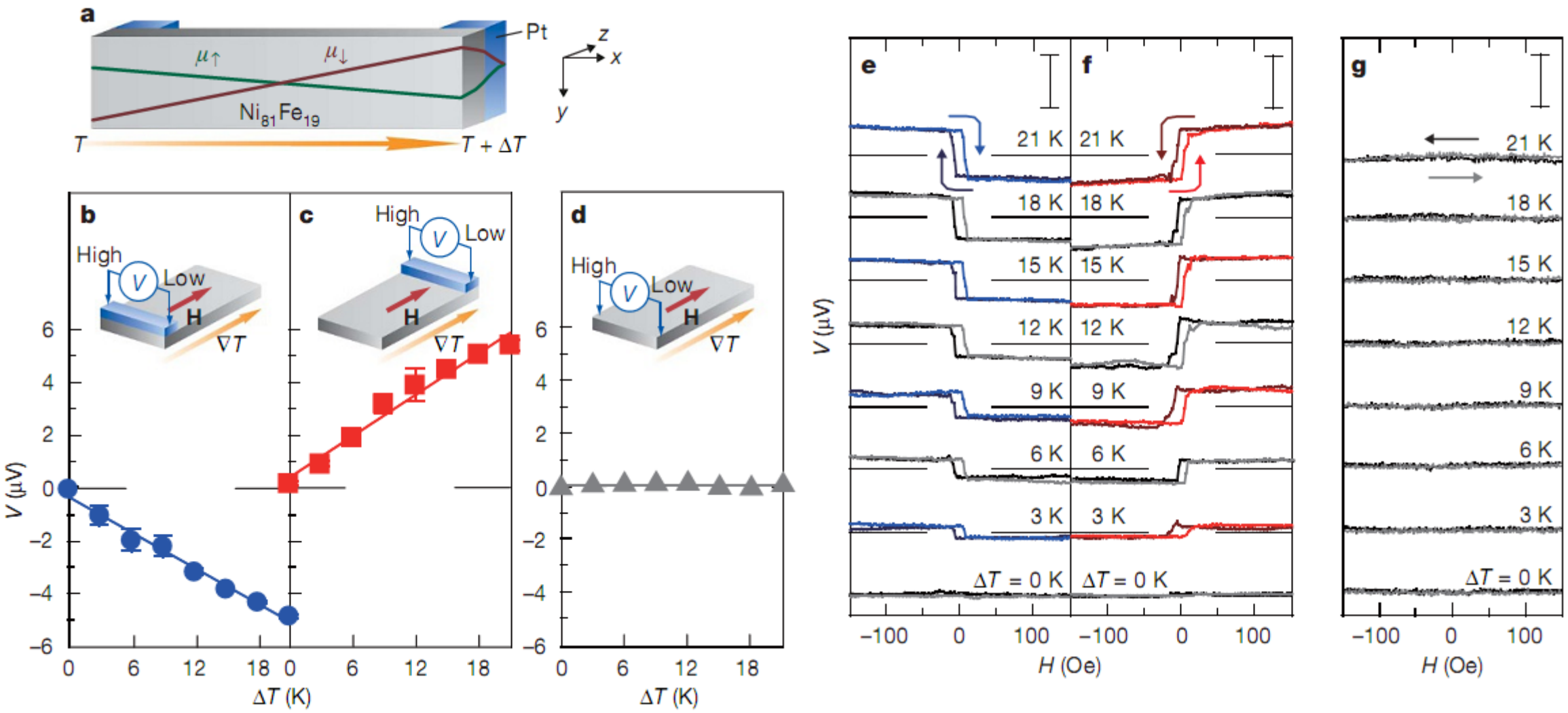
Experiment setup



$$\mathbf{E}_{SHE} = D_{ISHE}\mathbf{J}_S \times \boldsymbol{\sigma}$$

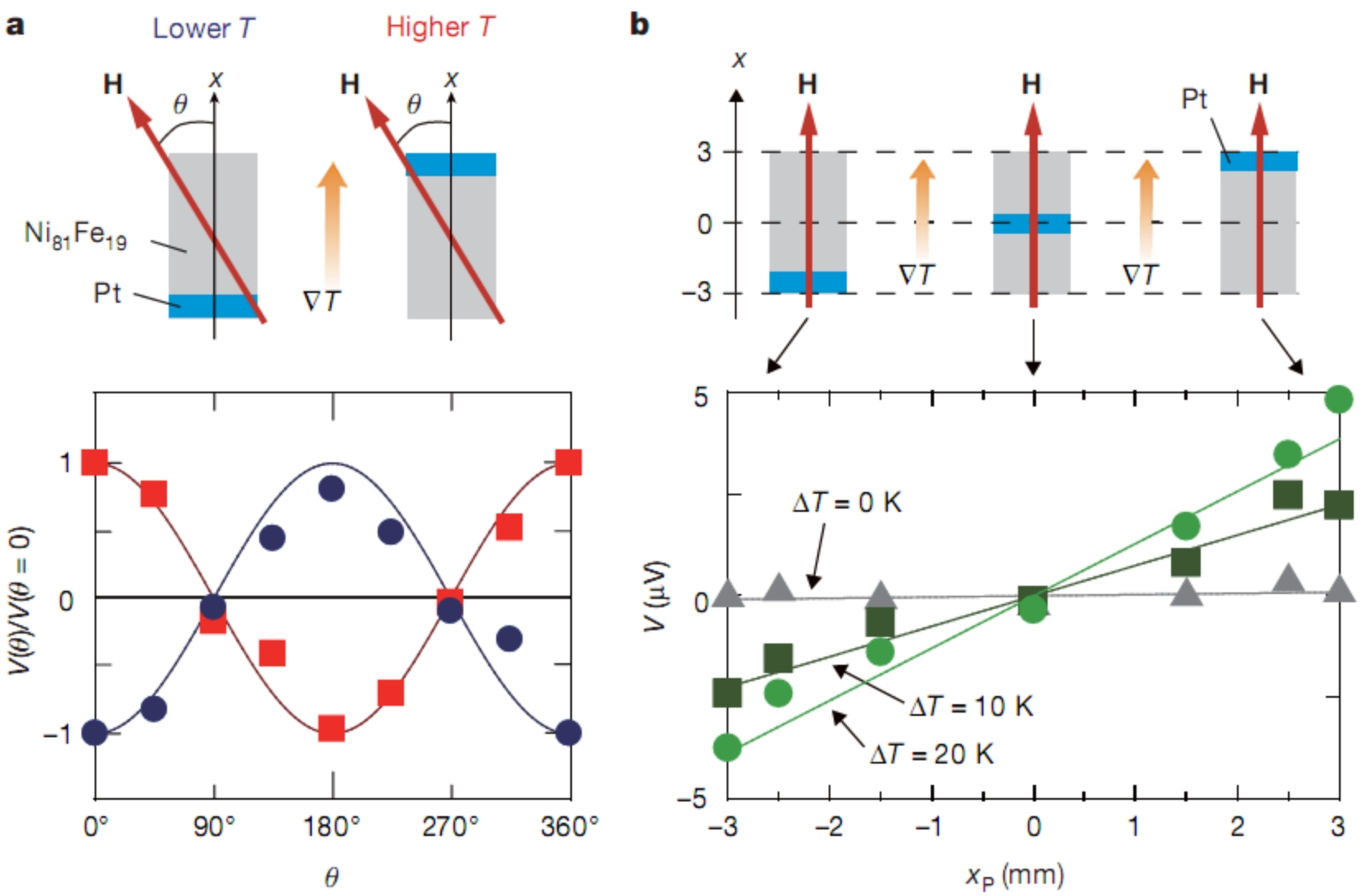
K. Uchida, et al, Nature 455, 778 (2008)

ISHE detection of thermally-driven spin current



K. Uchida, et al, Nature 455, 778 (2008)

Angle and distance dependence of ISHE signal



$$V \approx \theta_{Pt}\eta_{NiFe-Pt}(L_{Pt}/d_{Pt})S_S\Delta T/2$$

K. Uchida, et al, Nature 455, 778 (2008)