PEKING UNIVERSITY

Thermoelectric spin voltage in graphene

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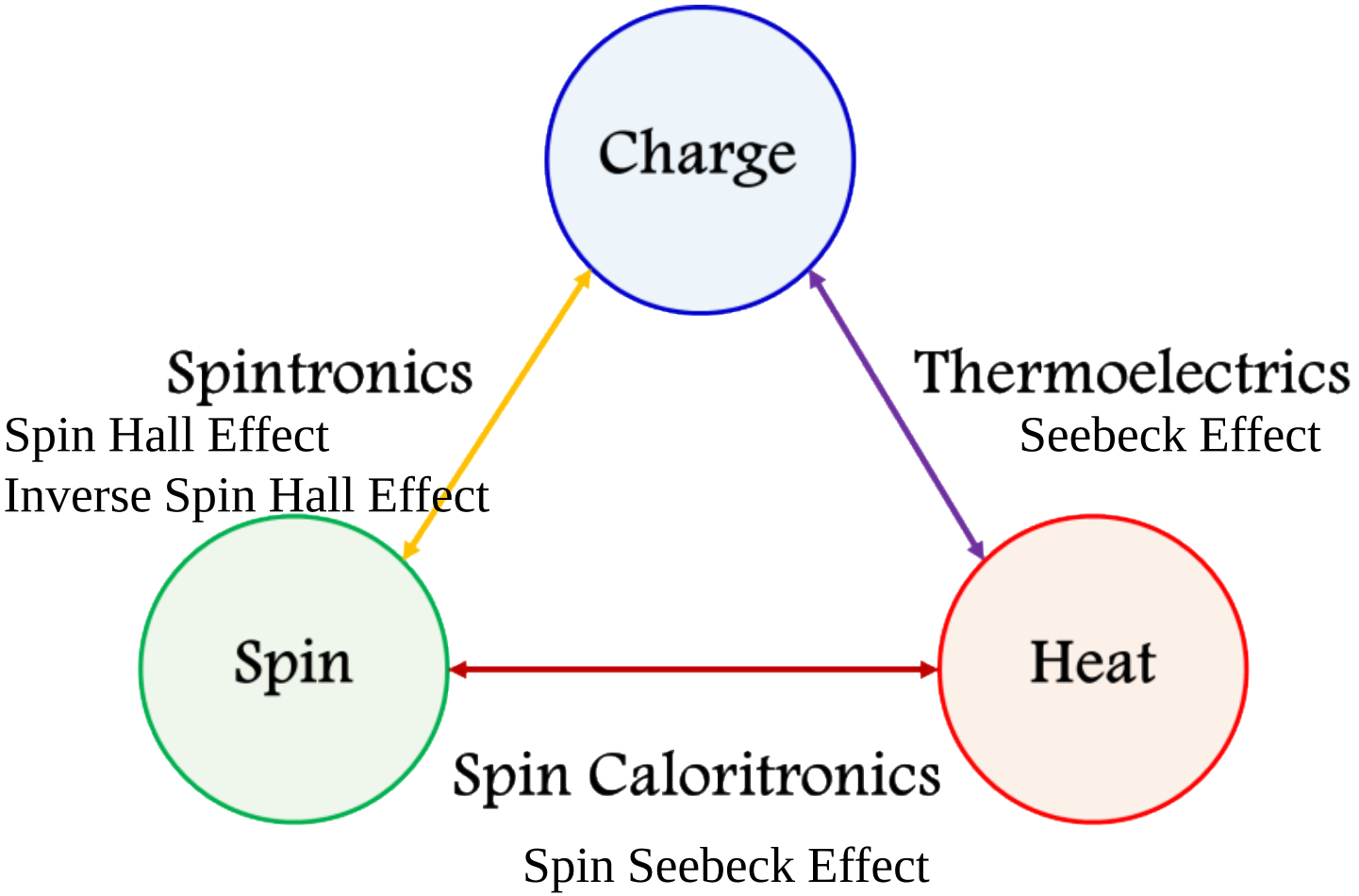
Outline

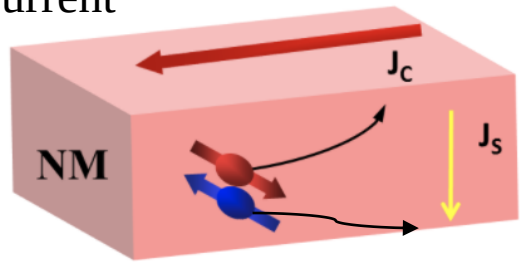

Charge
Spintronics
Spin Hall Effect
Inverse Spin Hall Effect
Thermoelectrics
Seebeck Effect
Spin
Heat
Spin Caloritronics
Spin Seebeck Effect

Spin Hall Effect & Inverse Spin Hall Effect

(a)

Spin Hall effect

Input charge current

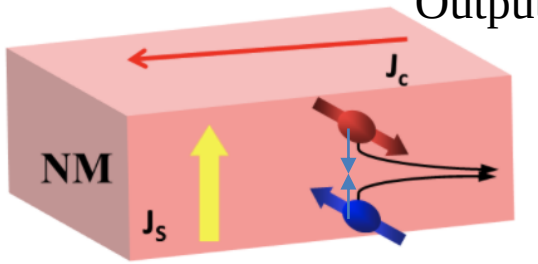


Output spin current

(b)

Inverse spin Hall effect

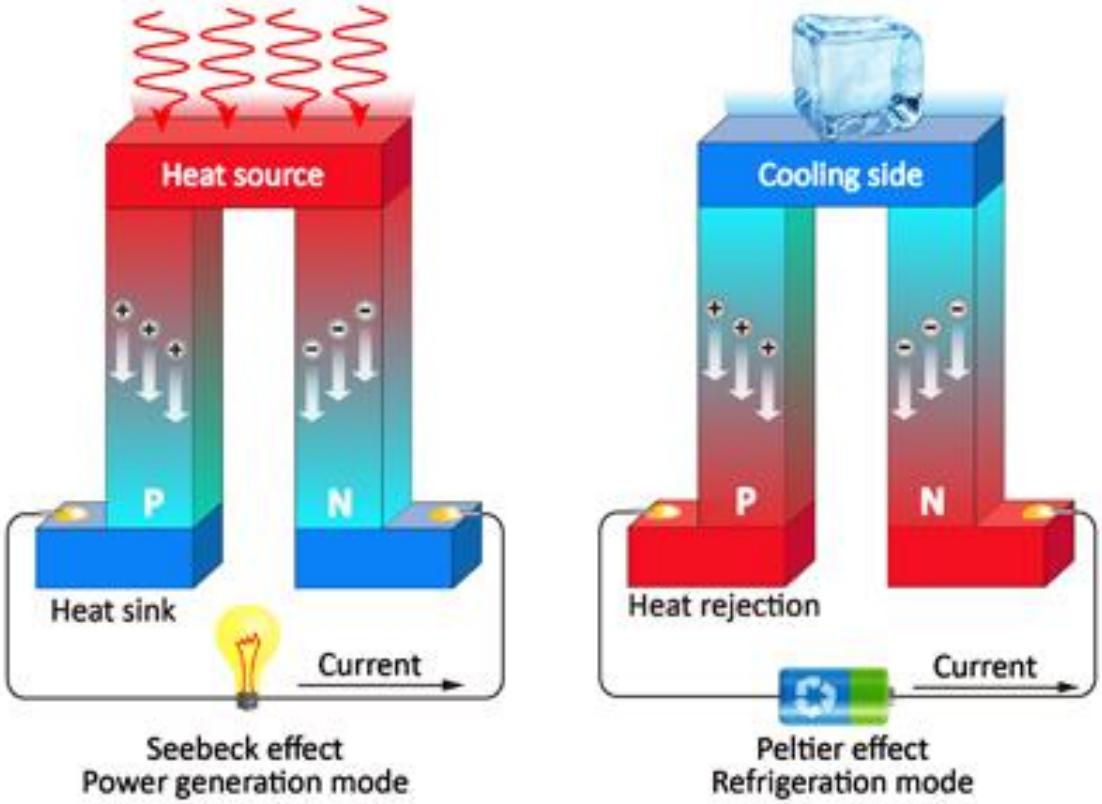
Output charge current



Input spin current

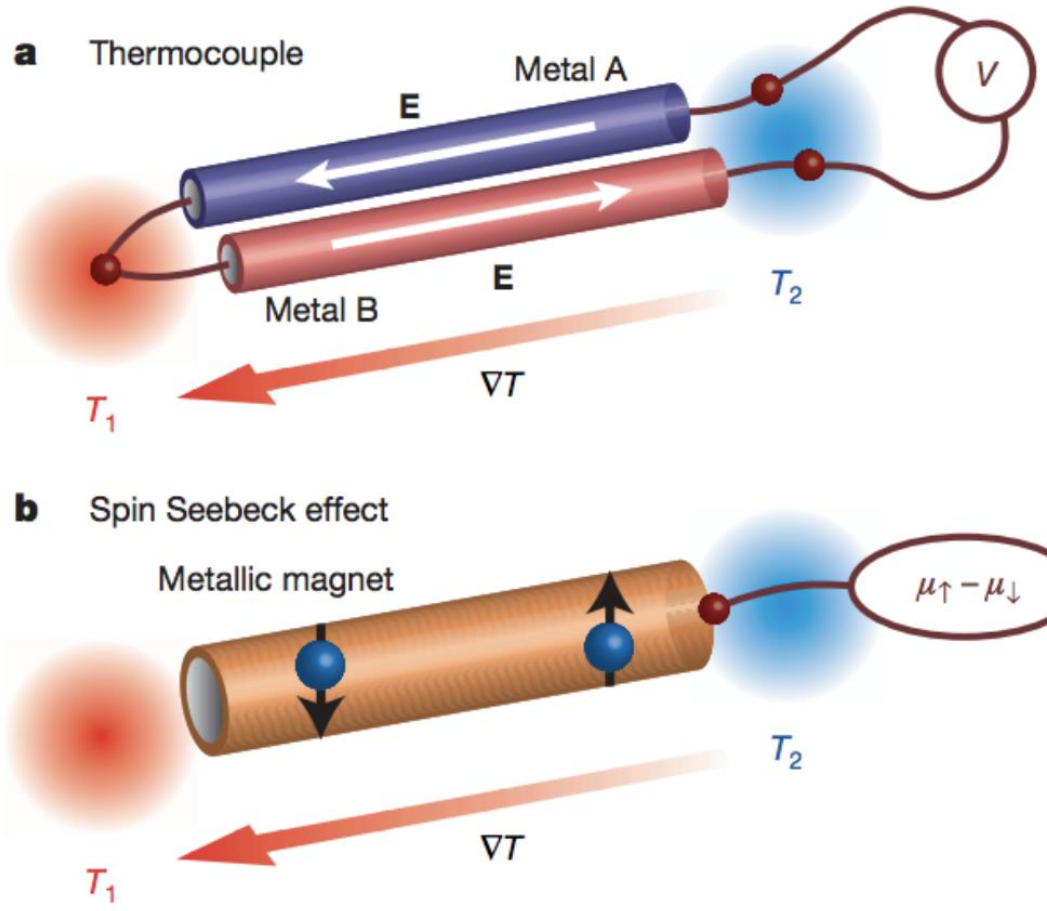
$$\mathbf{E}_{\mathrm{SHE}} = D_{\mathrm{ISHE}}\mathbf{J}_{\mathrm{S}} \times \boldsymbol{\sigma}$$

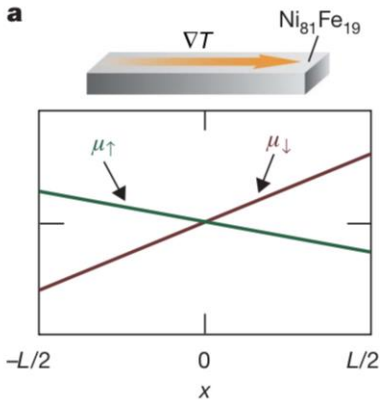
Seebeck Effect



Seebeck coefficient $S = -\frac{\Delta V}{\Delta T}$

Spin Seebeck Effect

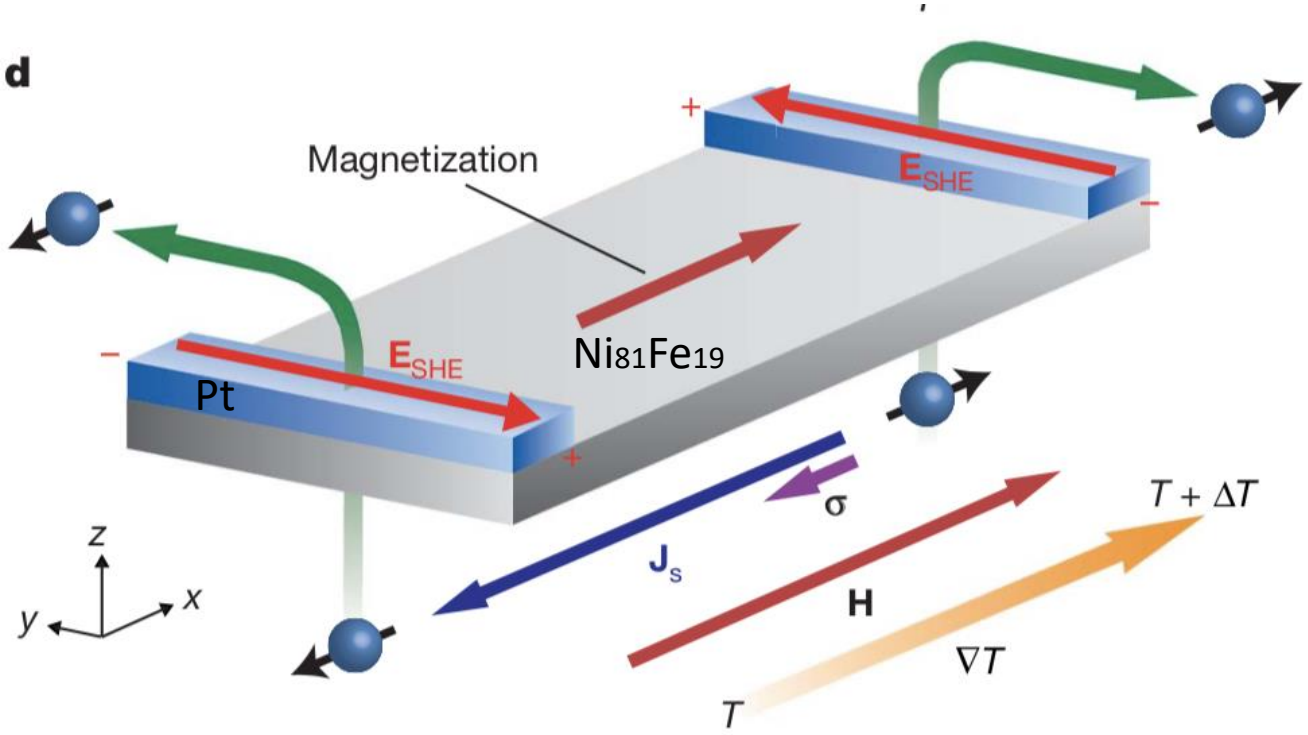




Scenario for the spin Seebeck effect:
In the spin sector, a magnet works in the same way as a thermocouple

Uchida et al. **Nature** 2008

Spin Seebeck Effect



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

Uchida et al. **Nature** 2008

Thermoelectric spin voltage in graphene

nature nanotechnology

LETTERS

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Thermoelectric spin voltage in graphene

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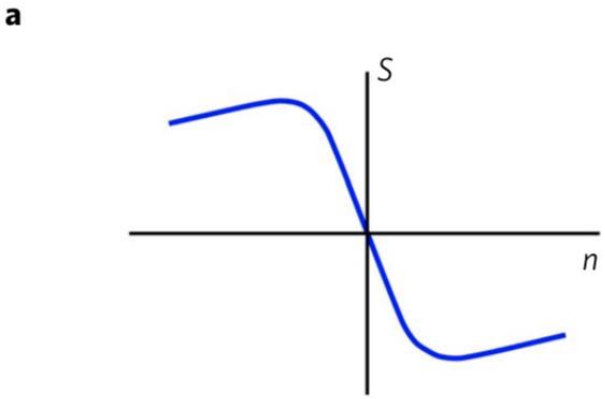
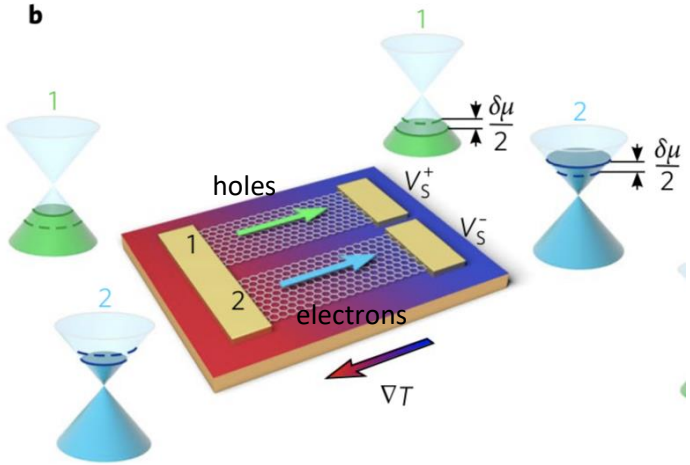
Thermoelectric spin voltage in graphene





$$\Delta S = S_2(n_2) - S_1(n_1)$$

$$V_S = V_S^+ - V_S^- = -\Delta S \Delta T = -(S_2 - S_1)\,\Delta T$$

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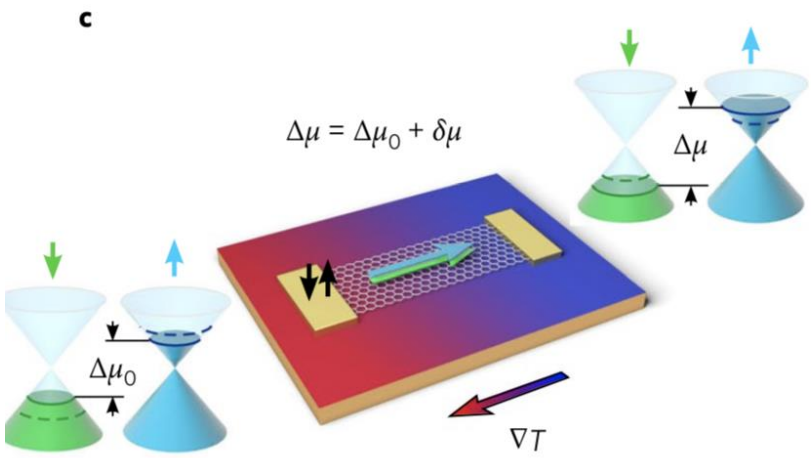
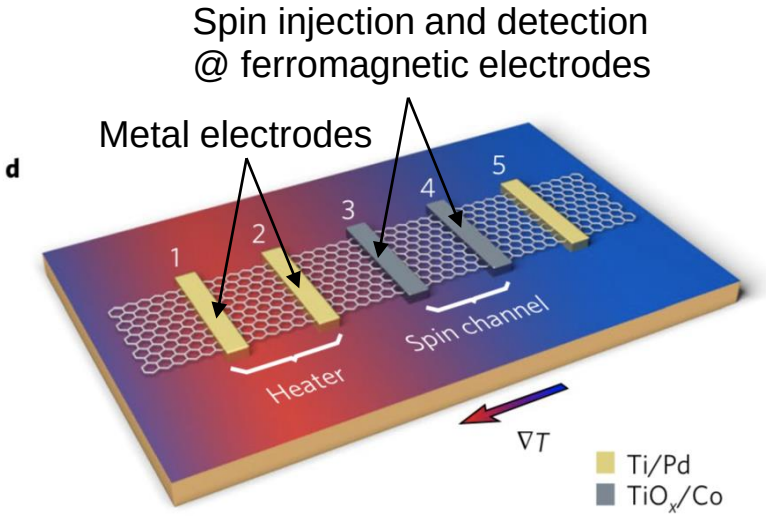
Thermoelectric spin voltage in graphene





$$\Delta\mu_0 = \mu^{\uparrow} - \mu^{\downarrow}$$
$$\delta\mu/e \approx -(S^{\uparrow} - S^{\downarrow})\Delta T$$

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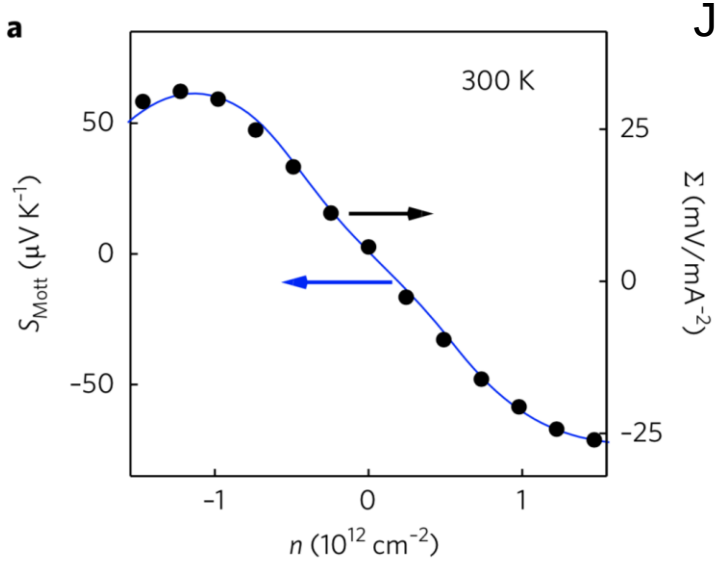
Thermoelectric spin voltage in graphene

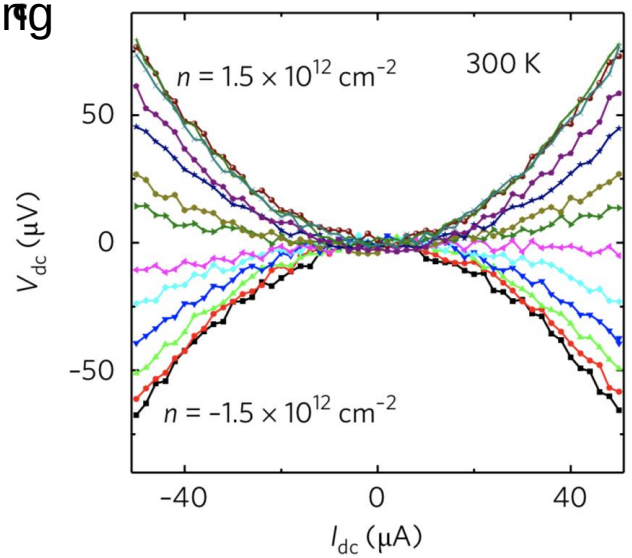
$$S_{\mathrm{Mott}} = \frac{\pi^2 k_B^2 T}{3e} \frac{\mathrm{d}\ \ln R}{\mathrm{d}\mu}\Big|_{\mu=\mu_F}$$

$$V_{dc} = -S\Delta T = -\Sigma I_{dc}^2 \qquad \Delta T = \alpha I_{dc}^2$$ Joule heating

$$\Sigma \approx \alpha S_{\mathrm{Mott}}$$

Joule heating





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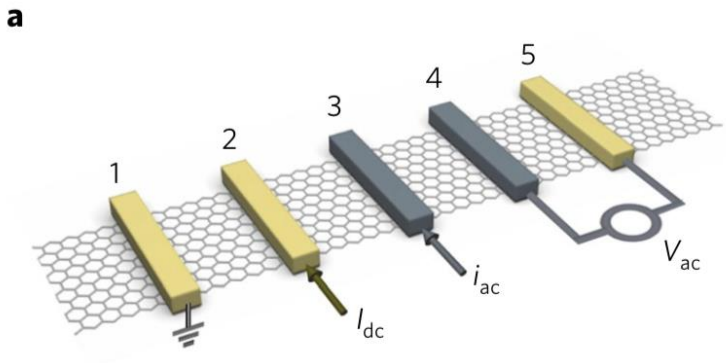
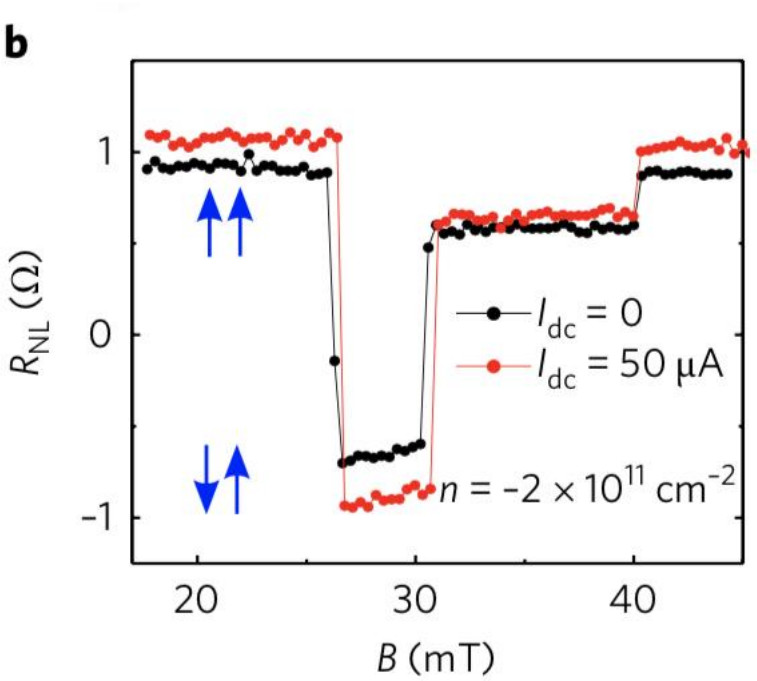
Thermoelectric spin voltage detection



$$R_{NL} = V_{ac}/i_{ac}$$



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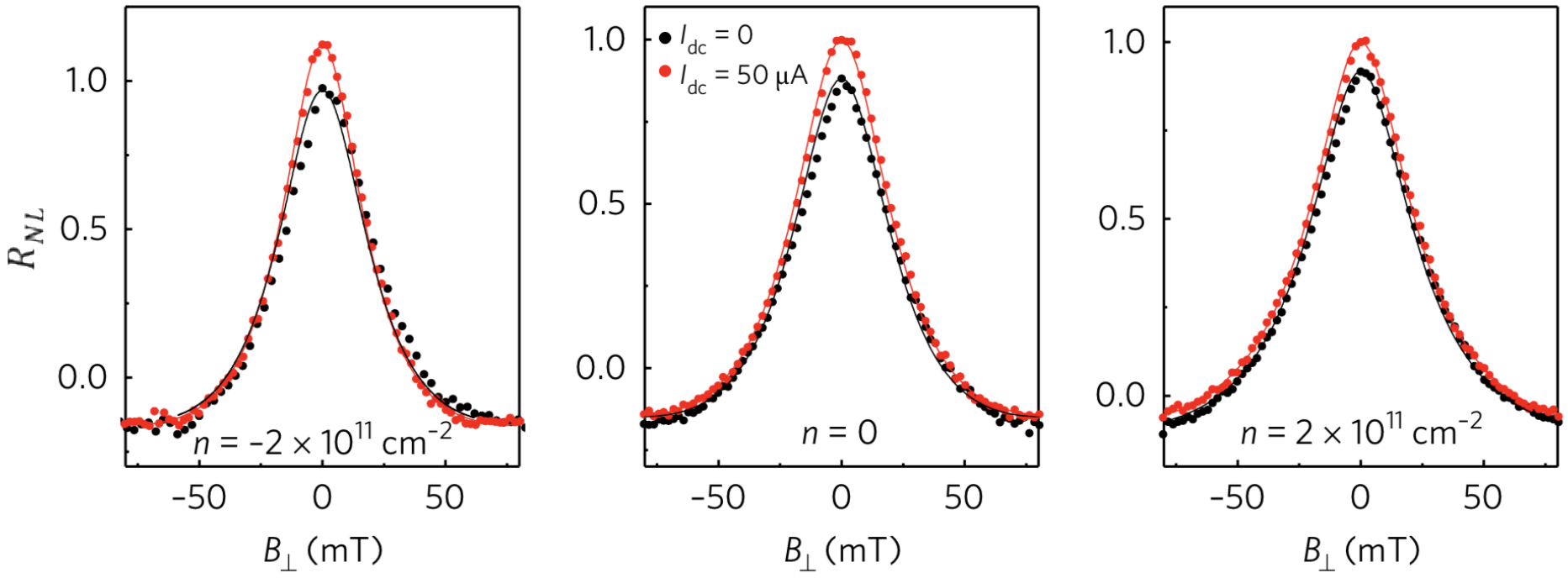
Out-of-plane magnetic field



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Thanks