FUNDAMENTALS OF NANOELECTRONICS

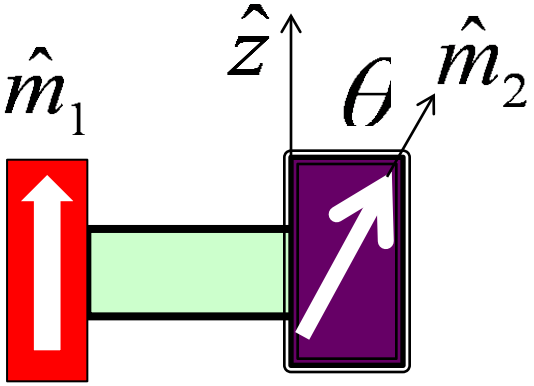
B. Quantum Transport

1. Schrodinger Equation
2. Contact-ing Schrodinger
3. More Examples

4. Spin Transport →

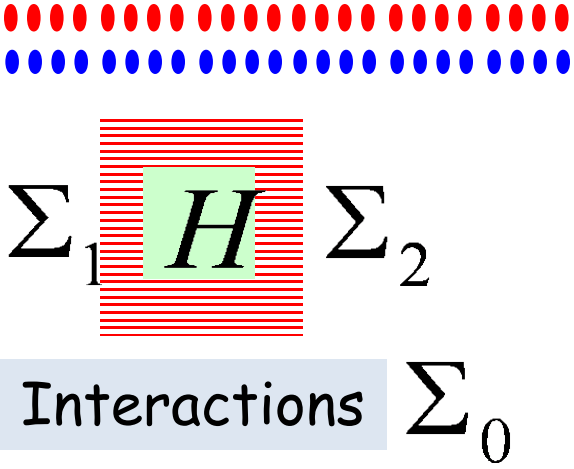
- 4.1. Introduction
- 4.2. Magnetic contacts
- 4.3. Rotating contacts
- 4.4. Vectors and spinors
- 4.5. Spin-orbit coupling
- 4.6. Spin Hamiltonian
- 4.7. Spin density/current
- 4.8. Spin voltage
- 4.9. Spin circuits
- 4.10. Summing up ..

4.9a Spin circuits



up

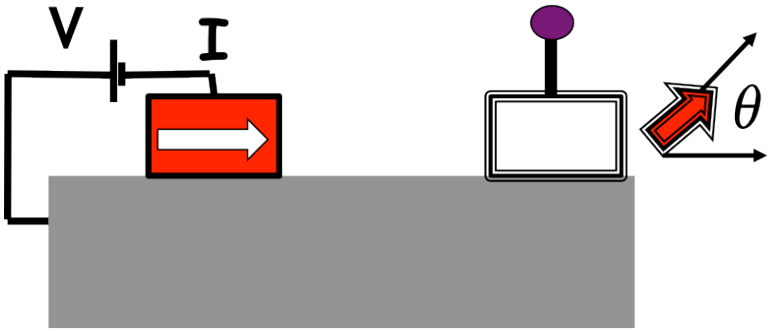
dn

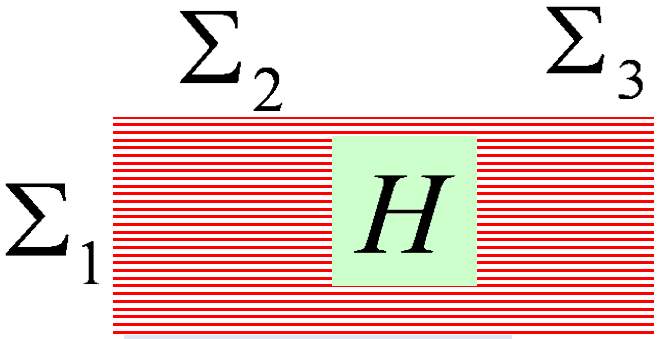


Interactions Σ_0

◆ Spin Valves

◆ Magnetic Tunnel Junctions (MTJ's)

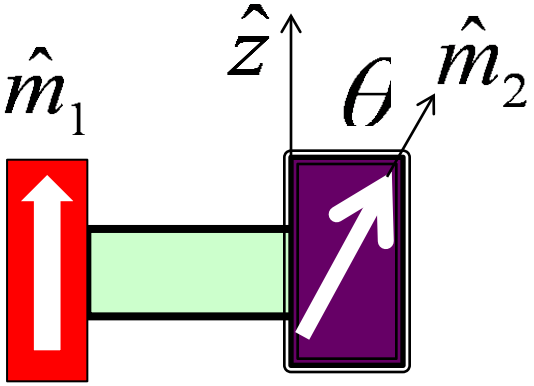


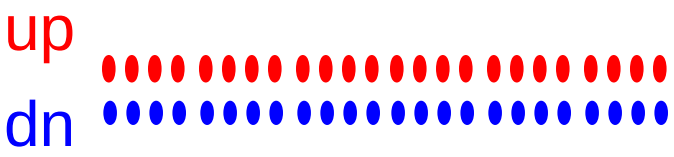


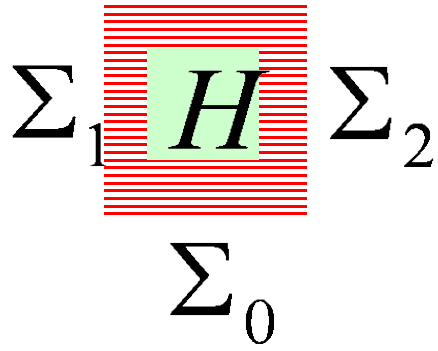
Interactions Σ_0

◆ Phase-breaking

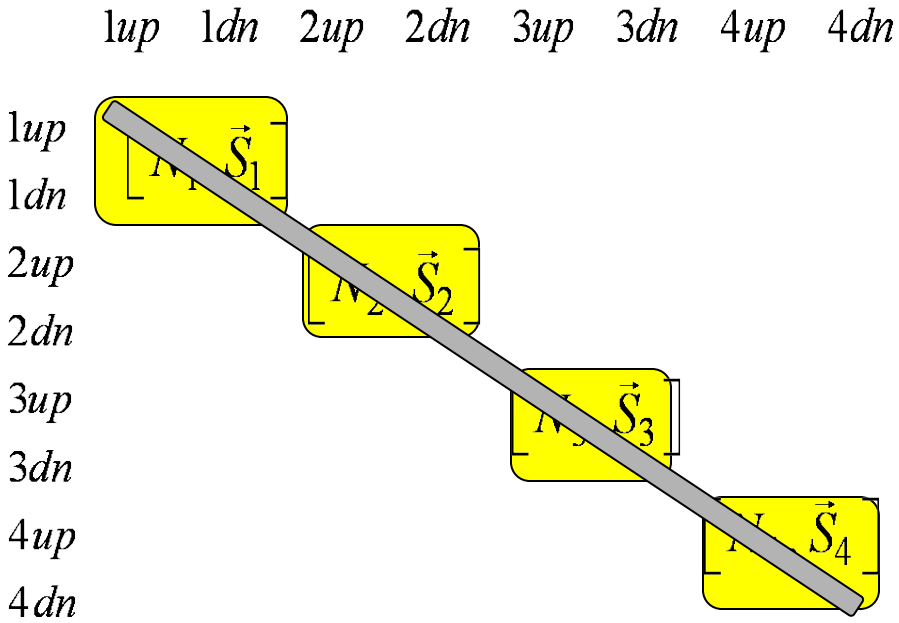
◆ Spin flip

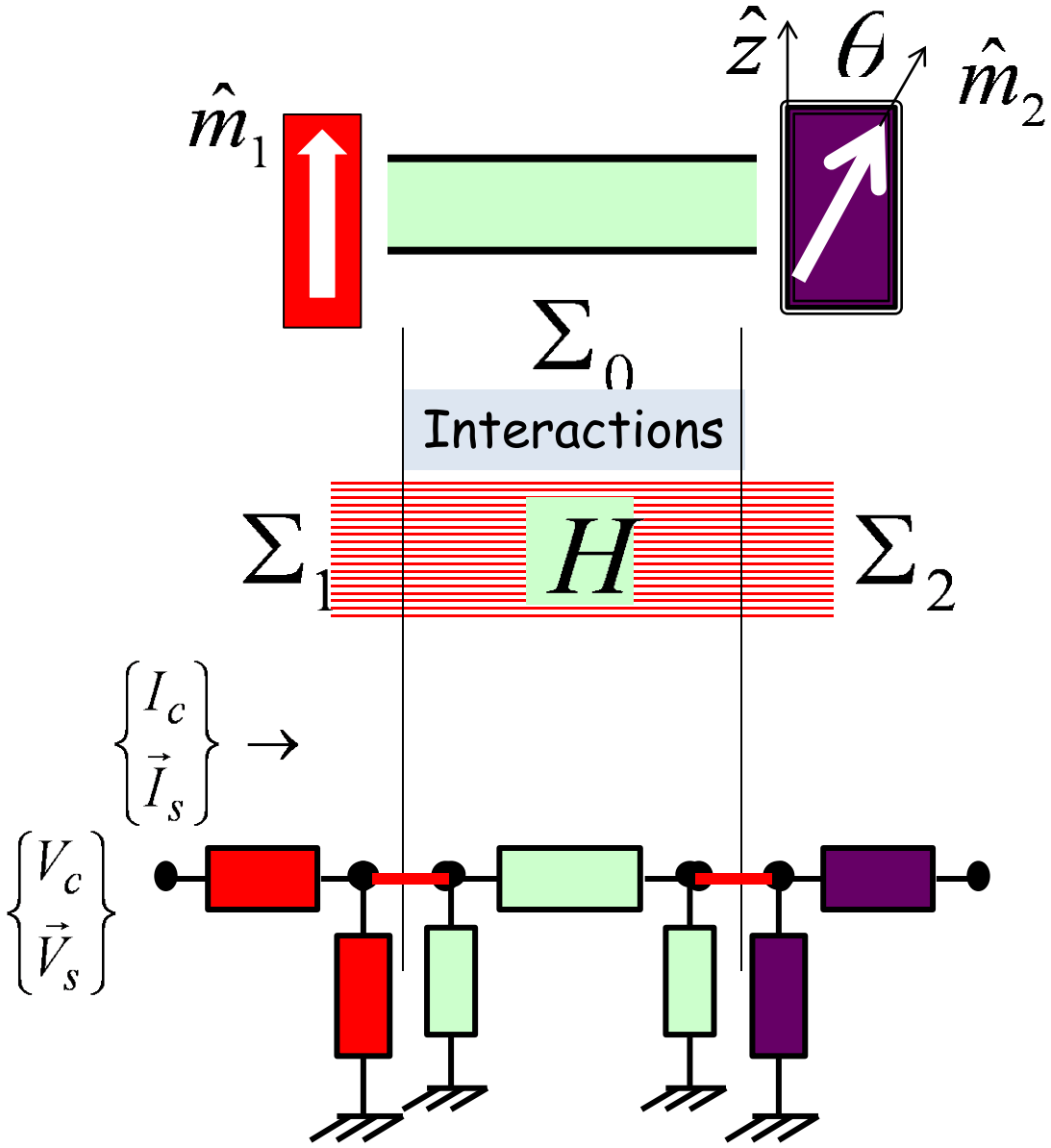


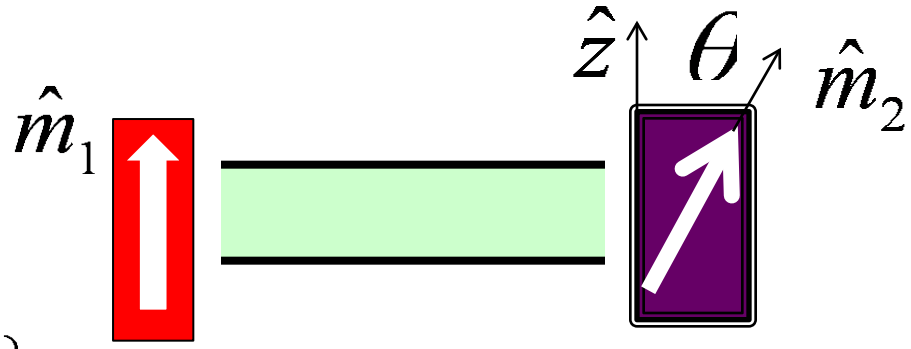




Interactions

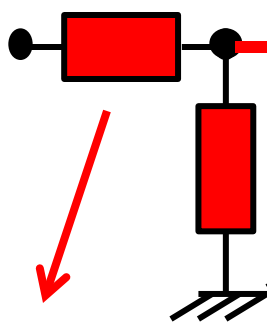



$\hat{z}$
θ
$\hat{m}_2$
$\hat{m}_1$
Σ_0
Interactions
Σ_1
H
Σ_2
$\begin{Bmatrix} I_c \\ \vec{I}_s \end{Bmatrix}$
$\begin{Bmatrix} V_c \\ \vec{V}_s \end{Bmatrix}$



$$\begin{Bmatrix} I_c \\ \vec{I}_s \end{Bmatrix} \rightarrow$$

$$\begin{Bmatrix} V_c \\ \vec{V}_s \end{Bmatrix}$$



$$c = \frac{up + dn}{2}$$

$$z = \frac{up - dn}{2}$$

$$G_0 \begin{array}{c} \\ up \\ dn \end{array} \begin{array}{c} \begin{array}{cc} up & dn \end{array} \\ \begin{bmatrix} g_1 & 0 \\ 0 & g_2 \end{bmatrix} \end{array}$$

$$G_0 = g_1 + g_2$$

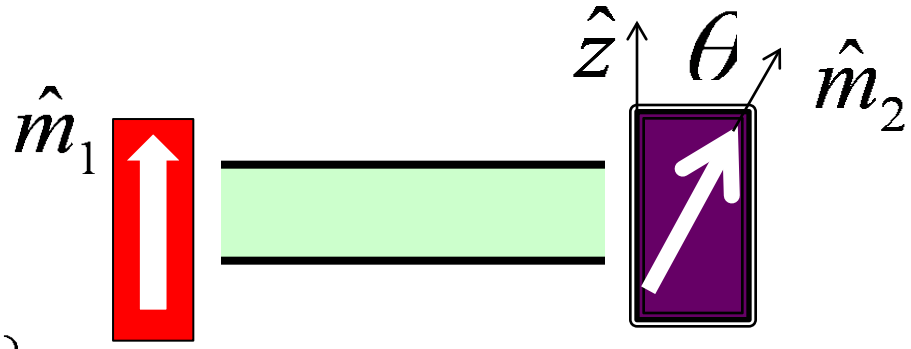
$$\Delta G = g_1 - g_2$$

$$P = \Delta G / G_0$$

$$G_0 \begin{array}{c} \\ c \\ z \\ x \\ y \end{array} \begin{array}{c} \begin{array}{cccc} c & z & x & y \end{array} \\ \left[\begin{array}{cc|cc} 1 & P & 0 & 0 \\ P & 1 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{array}\right] \end{array}$$

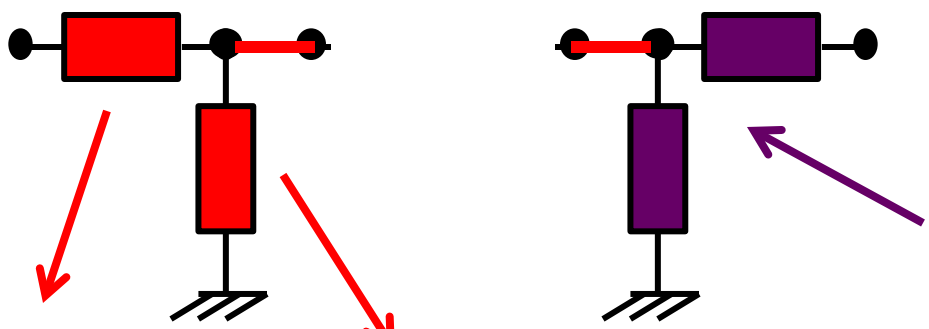
$$G_0 \begin{array}{c} \\ c \\ z \\ x \\ y \end{array} \begin{array}{c} \begin{array}{cccc} c & z & x & y \end{array} \\ \left[\begin{array}{cc|cc} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \hline 0 & 0 & a & -b \\ 0 & 0 & +b & a \end{array}\right] \end{array}$$

$$\begin{array}{c} \\ c \\ z \end{array} \begin{array}{c} \begin{array}{cc} c & z \end{array} \\ \begin{bmatrix} G_0 & \Delta G \\ \Delta G & G_0 \end{bmatrix} \end{array} \rightarrow G_0 \begin{bmatrix} 1 & P \\ P & 1 \end{bmatrix}$$



$$\begin{Bmatrix} I_c \\ \vec{I}_s \end{Bmatrix} \rightarrow$$

$$\begin{Bmatrix} V_c \\ \vec{V}_s \end{Bmatrix}$$



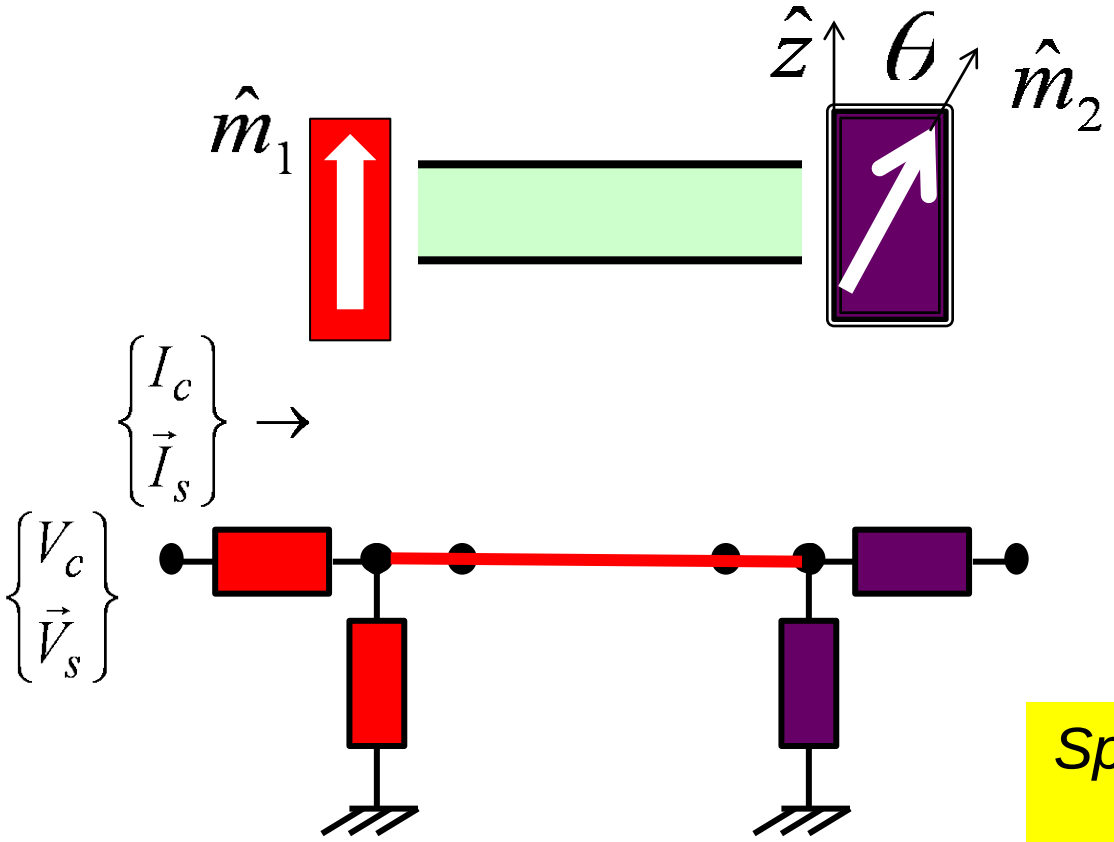
$$G_0 = \begin{array}{c} \\ c \\ z \\ x \\ y \end{array} \begin{array}{c} \begin{array}{cccc} c & z & x & y \end{array} \\ \left[\begin{array}{cc|cc} 1 & P & 0 & 0 \\ P & 1 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{array}\right] \end{array}$$

$$G_0 = \begin{array}{c} \\ c \\ z \\ x \\ y \end{array} \begin{array}{c} \begin{array}{cccc} c & z & x & y \end{array} \\ \left[\begin{array}{cc|cc} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \hline 0 & 0 & a & -b \\ 0 & 0 & +b & a \end{array}\right] \end{array}$$

$$G(\theta) = U\, G(\hat{z})\, U^{+}$$

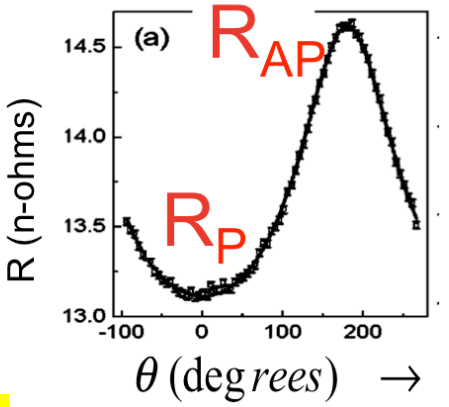
$$U = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

4.9f Spin circuits

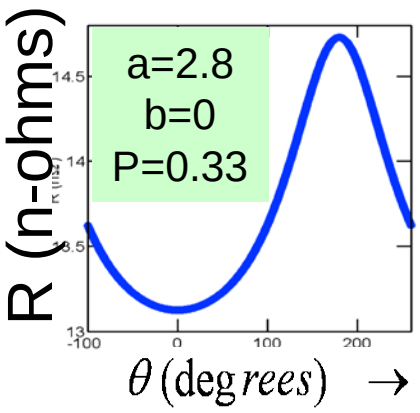


EXPERIMENT

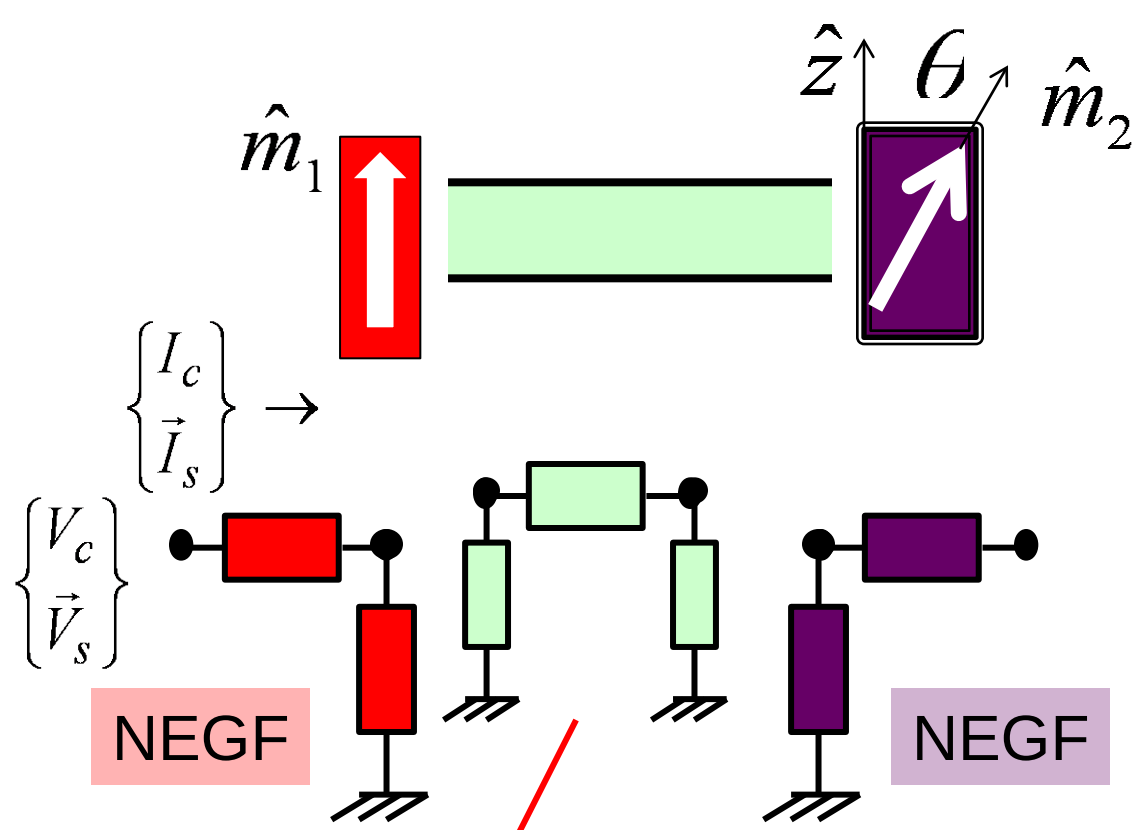
Urazhdin et al. PRB 2005



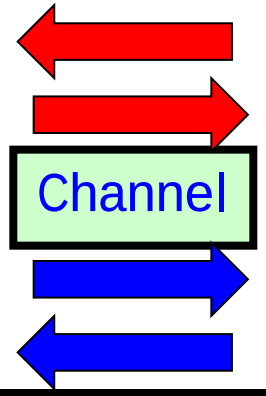
Spin circuit theory



◆ To get comparable results, NEGF would need to include dephasing processes in channel

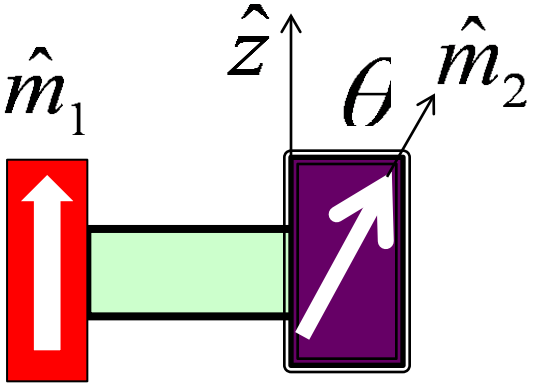


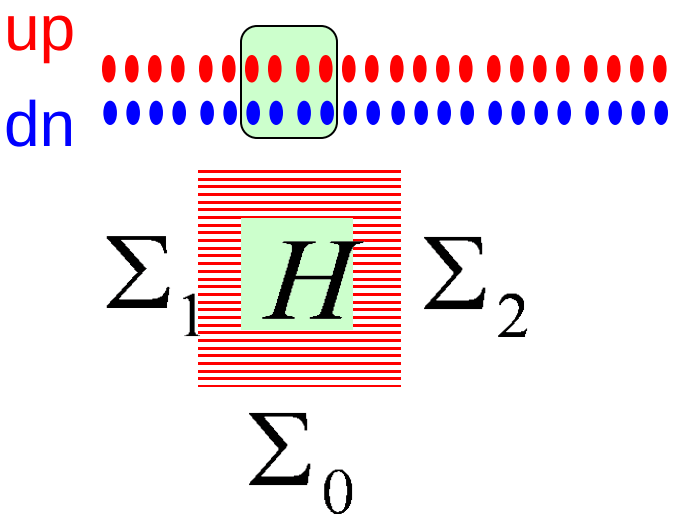
- Spin diffusion equation
- NEGF



100	100	50
100	100	100
Normal	Magnetic	Spin-orbit
100	50	50
100	50	100

4.9h Spin circuits





8-component "spin"

64-component "voltage" + "current"

	1up	1dn	2up	2dn	3up	3dn	4up	4dn
1up	$[N_1, \vec{S}_1]$							
1dn								
2up			$[N_2, \vec{S}_2]$					
2dn								
3up					$[N_3, \vec{S}_3]$			
3dn								
4up							$[N_4, \vec{S}_4]$	
4dn								

Full NEGF : $4n^2$

Spin circuit : $4n$

Full NEGF treats entire device as a "giant spin"

Coming up next ..

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4.6. Spin Hamiltonian

4.7. Spin density/current

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