Magnetic Sensor (3B)

- Magnetism
- Hall Effect
- AMR Effect
- GMR Effect

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Magnetism

Ferro-magnetic material

- **Permanent magnet**

Ferri-magnetic material

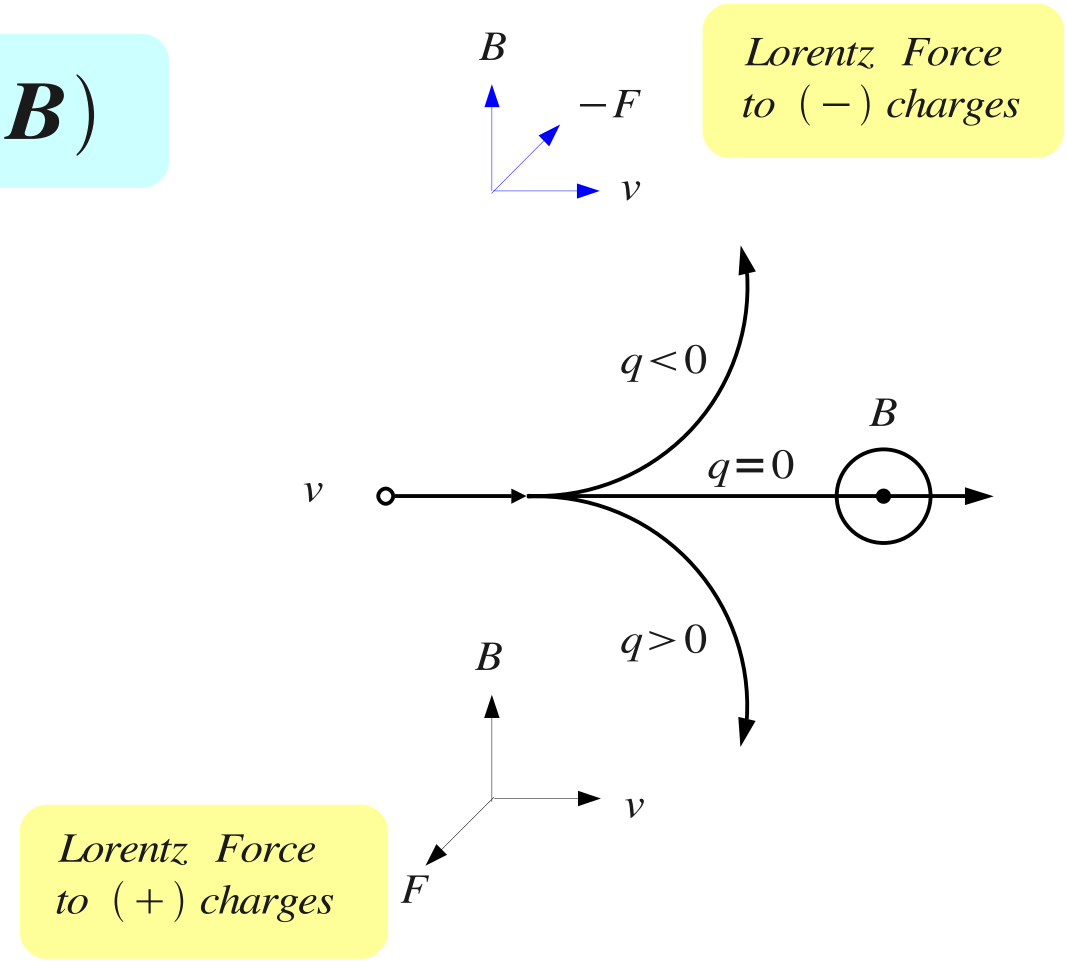
- **Below Curie Temp: like ferromagnets**
- **Above Curie Temp: like paramagnets**

Para-magnetic material

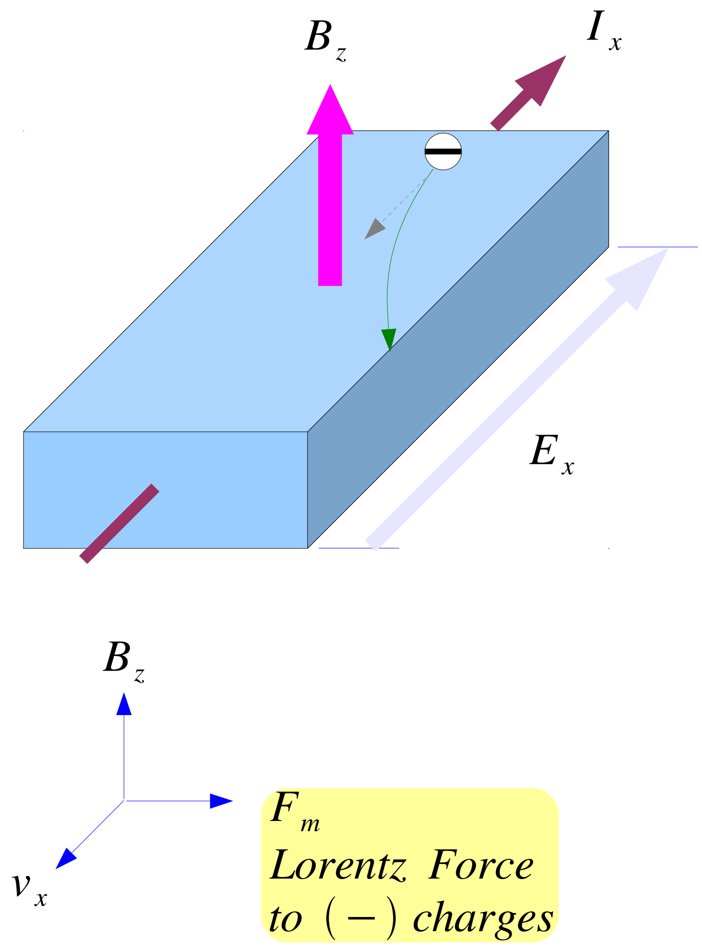
- **DC Josephson: $I > I_c$ then in the resistiv**

Lorentz Force

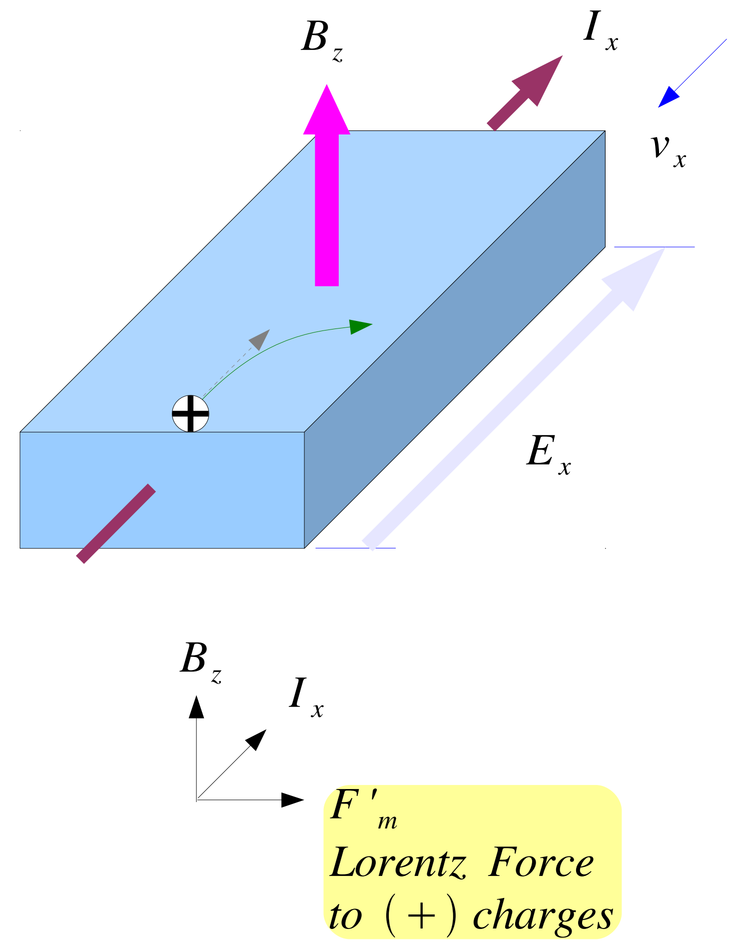
$$\boldsymbol{F} = q\,(\boldsymbol{v} \times \boldsymbol{B})$$



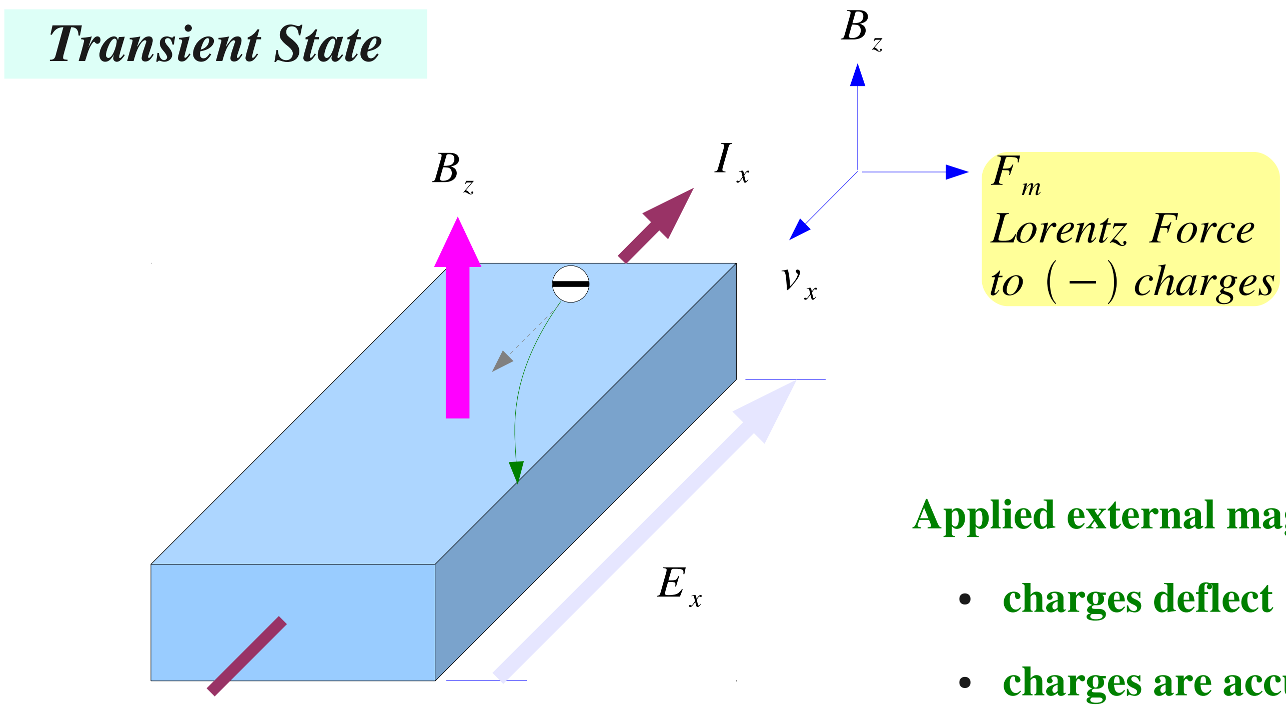
Negative Carrier



Positive Carrier



Hall Effect (2)



Applied external magnetic field

- **charges deflect**
- **charges are accumulated**
- **electrical potential (E_H) are created**

As E_H increases, new (+) and (–) charges are repelled by those previously accumulated charges. (balancing effect)

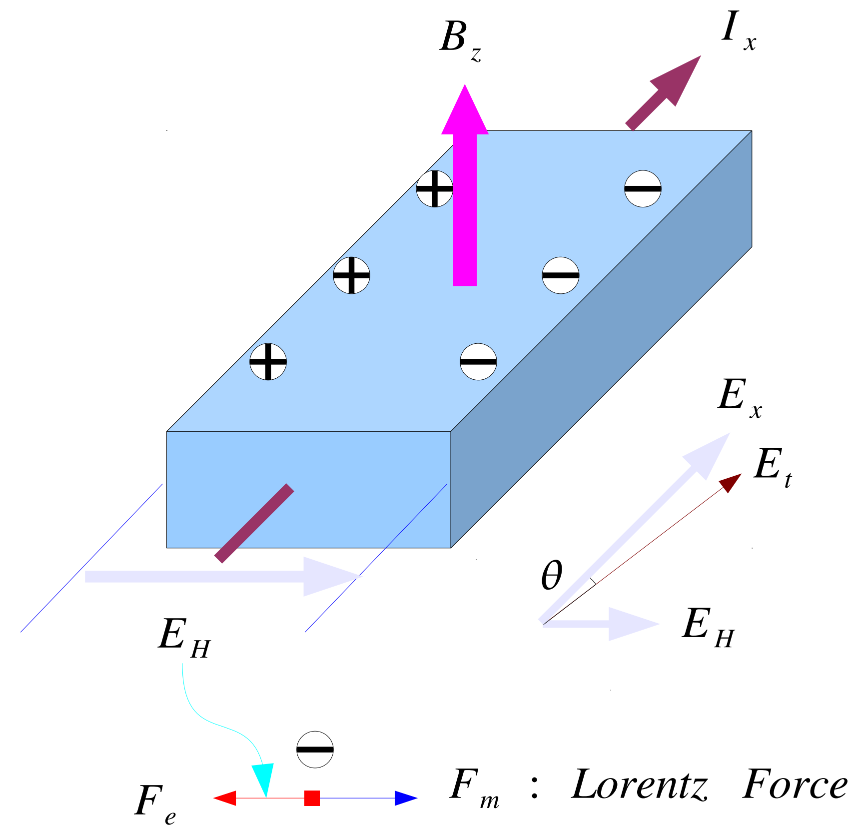
Hall Effect (3)

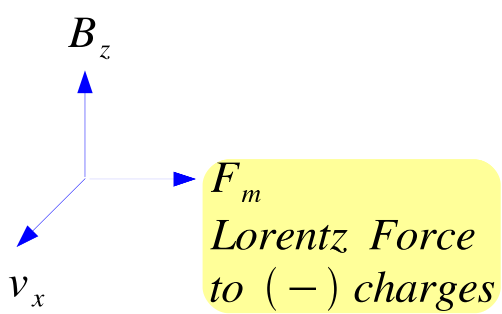
The force Fe counteracts Fm.

- F_e : due to E_H
- F_m: due to external magnetic field B_z

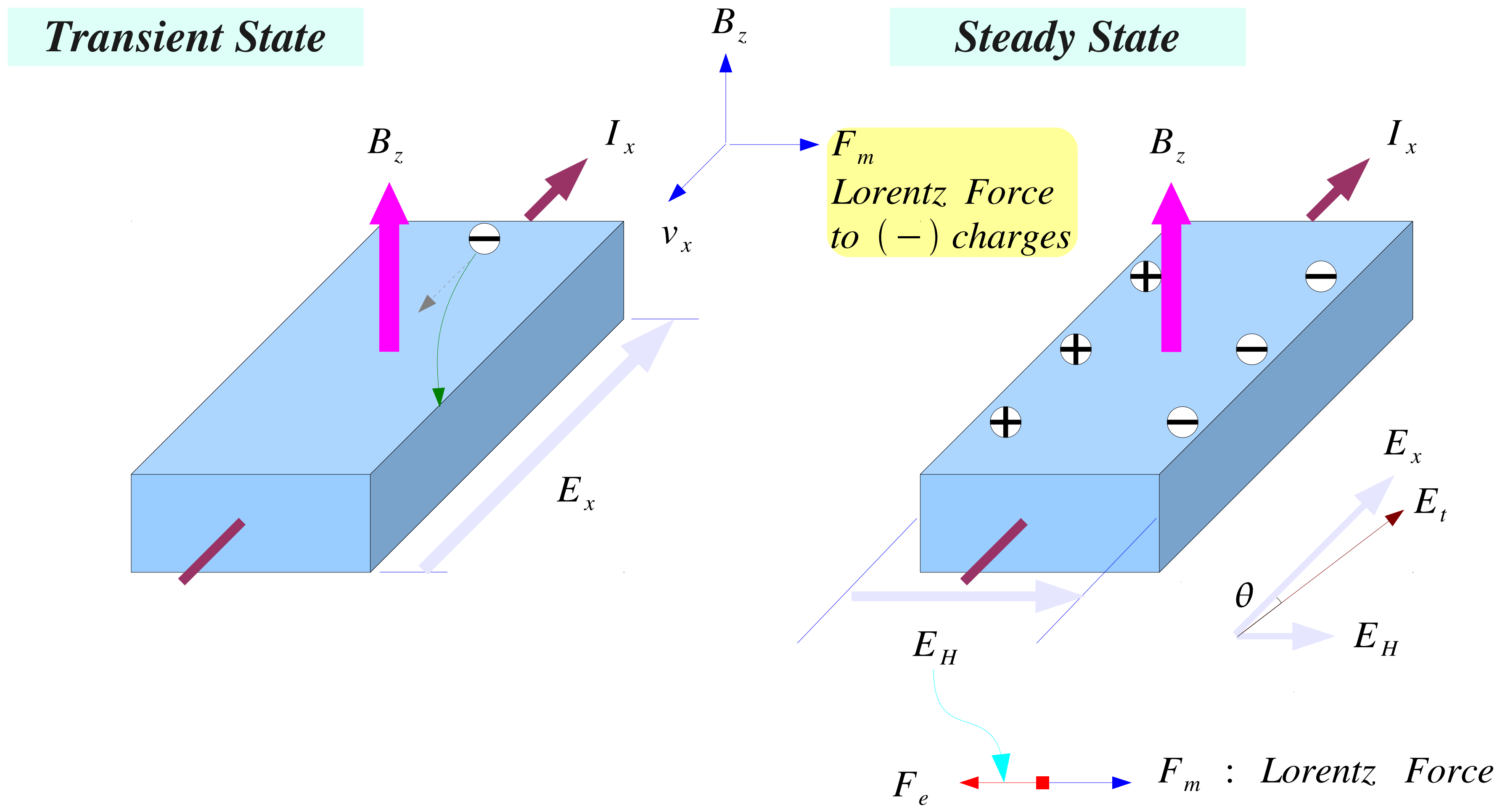
Again charges travels straight, but with the Hall angle θ.

Steady State





Hall Effect (4)

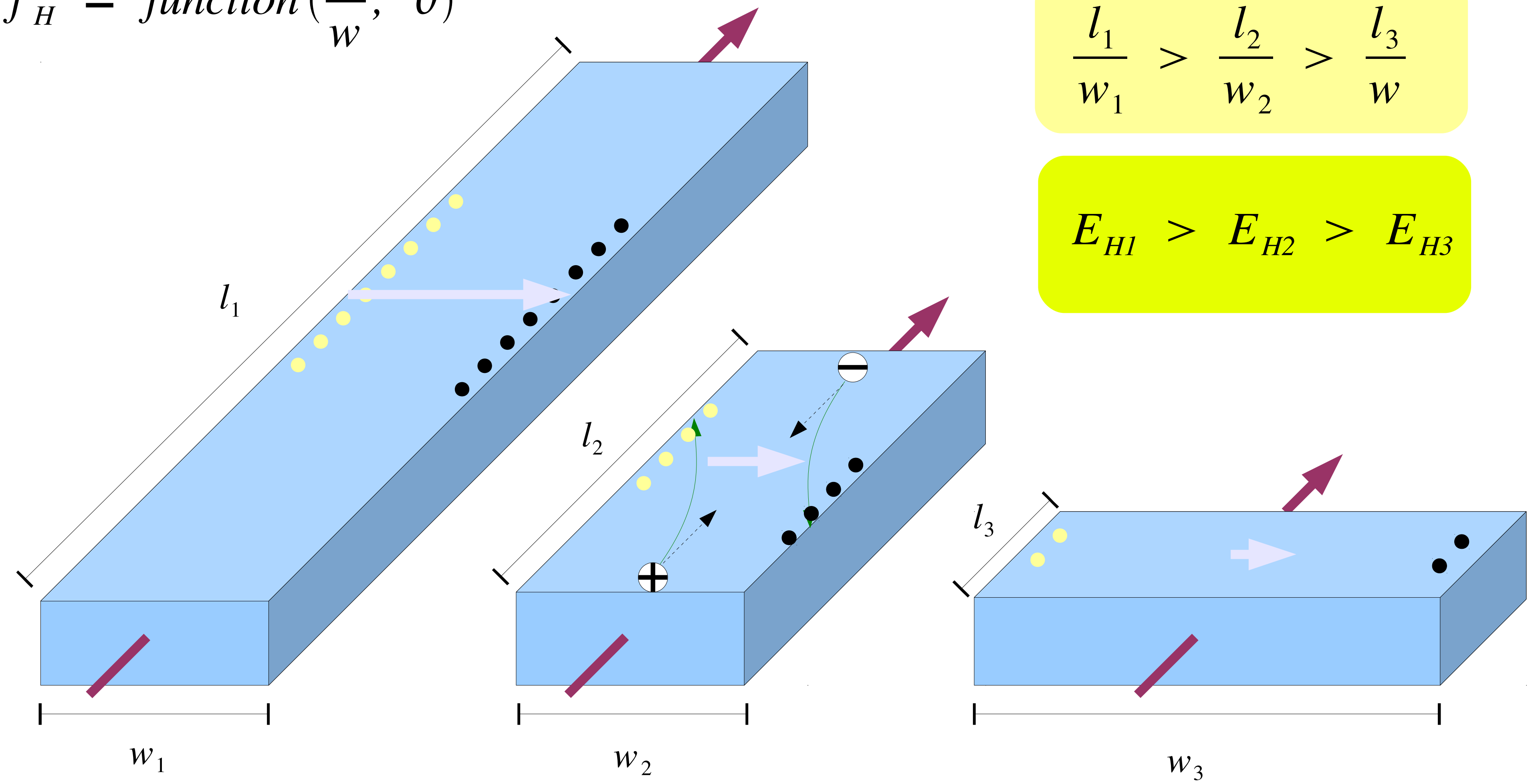


Hall Effect – Geometric Factor (1)

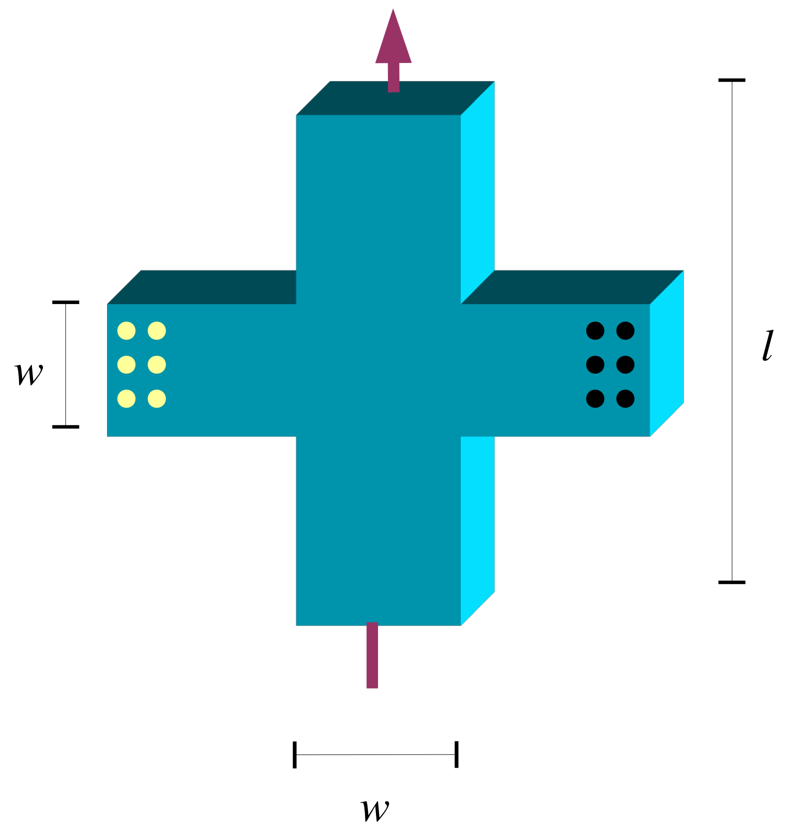
$$f_H = function\left(\frac{l}{w},\ \theta\right)$$

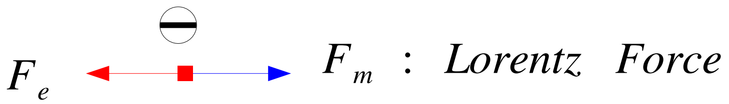
$$\frac{l_1}{w_1} > \frac{l_2}{w_2} > \frac{l_3}{w}$$

$$E_{H1} > E_{H2} > E_{H3}$$



Hall Effect – Geometric Factor (2)





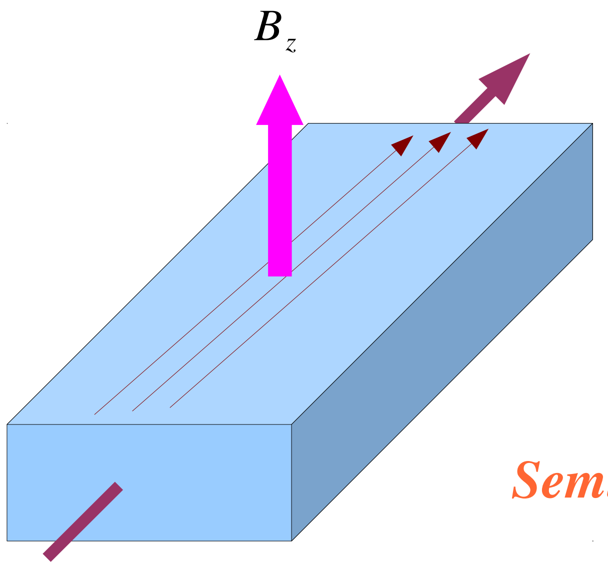
The force Fe counteracts Fm.

- **F_e : due to E_H**
- **F_m : due to external magnetic field B_z**

More charges are accumulated at the both ends until they repel other new charges.

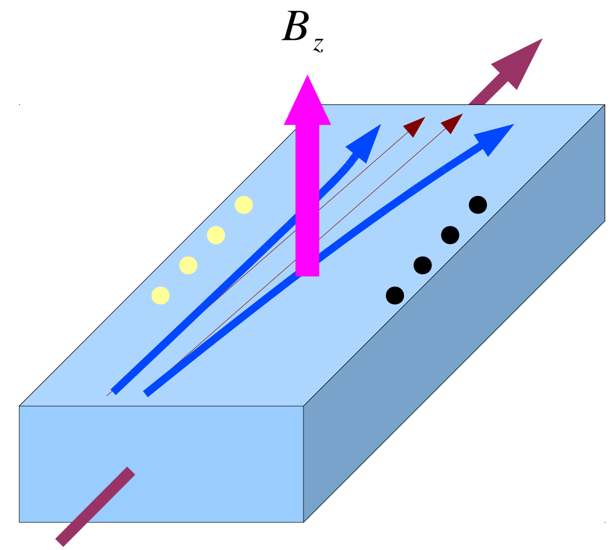
Physical Magneto-resistance Effect

Ideal Case



Semiconductor

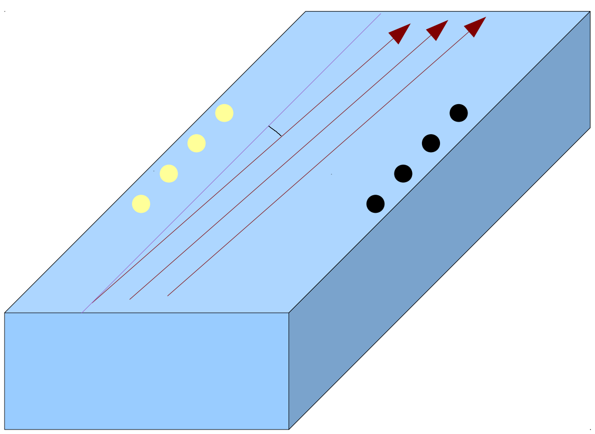
Real Case



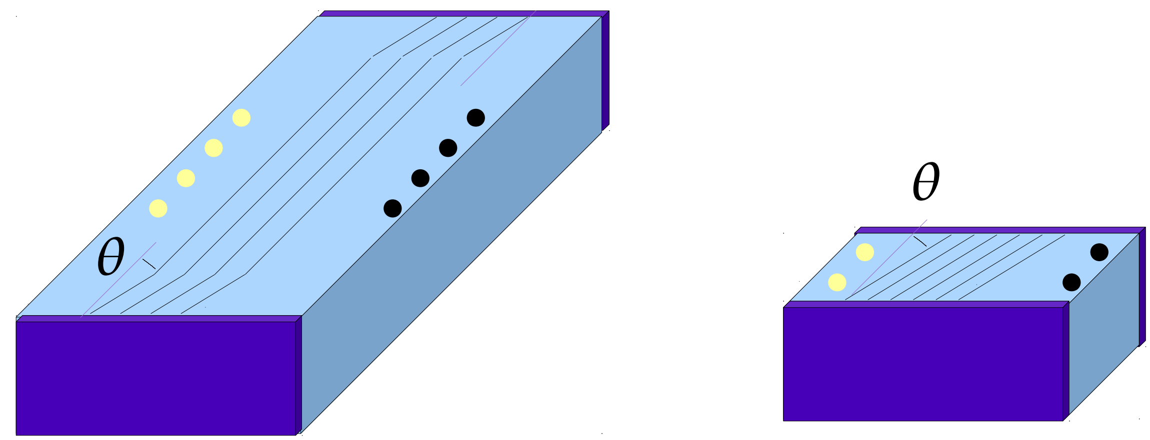
- **Different Lorentz Force to each charge**
- **Different charges travel different paths**
- **The total length of paths is increased**
- **The resistance increases slightly**

Geometrical Magneto-resistance Effect (1)

Ideal Case



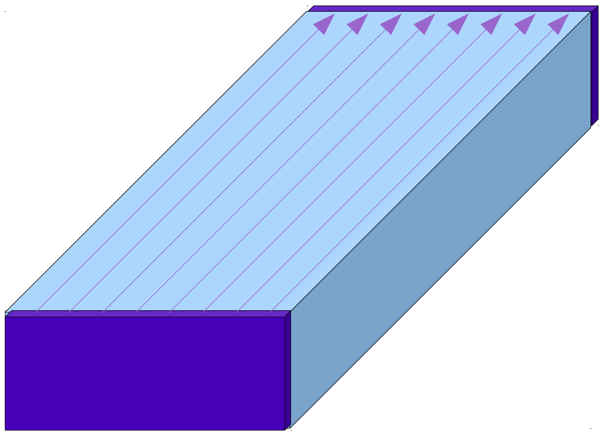
Real Cases



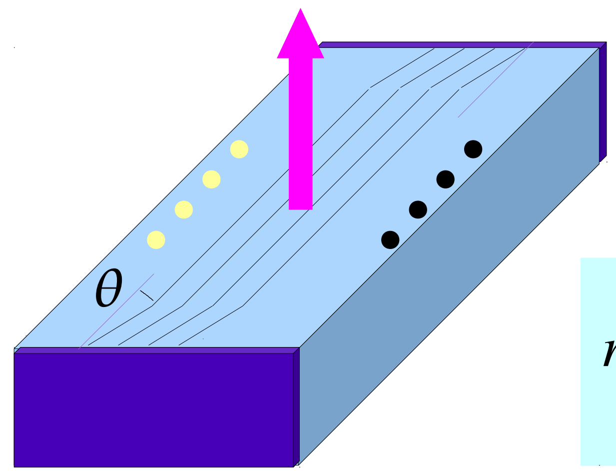
Metal Electrode Contact

Geometrical Magneto-resistance Effect (2)

Min $\boldsymbol{R_1}$

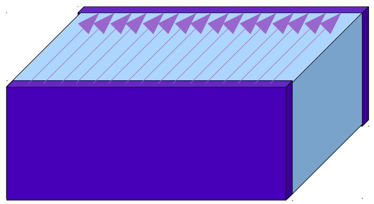


$\boldsymbol{B_z}$**:** ***Max*** $\boldsymbol{R_1}$

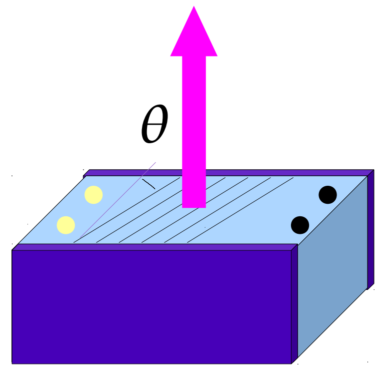


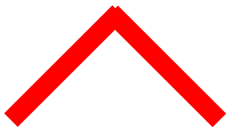
$$\text{ratio} \quad \frac{R}{R_o} = \frac{\max\ R_1}{\min\ R_1}$$

Min $\boldsymbol{R_2}$



$\boldsymbol{B_z}$**:** ***Max*** $\boldsymbol{R_2}$





$$\text{ratio} \quad \frac{R}{R_o} = \frac{\max\ R_2}{\min\ R_2}$$

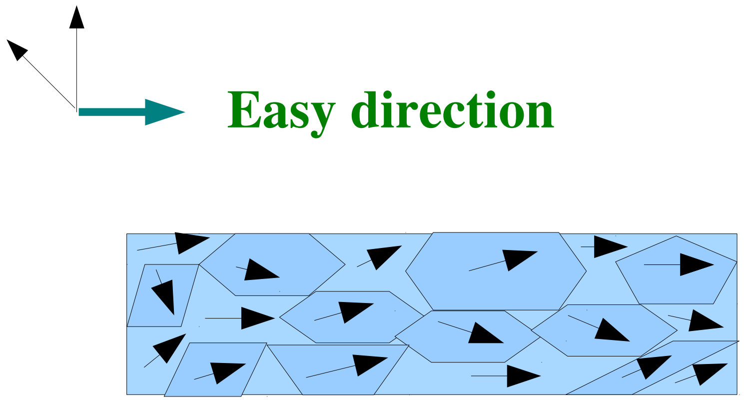
Magnetic Anisotropy (1)

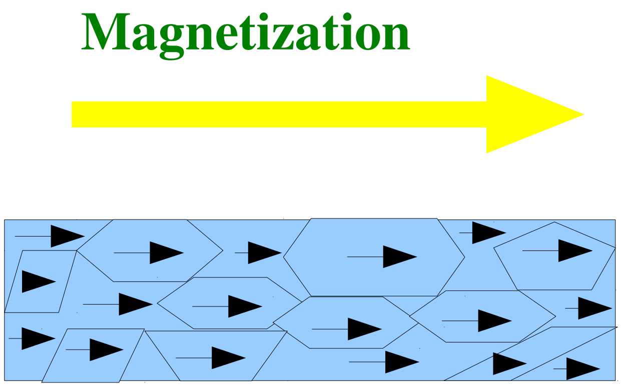
Magneto-crystalline Anisotropy

- **An intrinsic property of a ferri-magnet**
- **Magnetization curve along different crystal directions**

- **Easy direction**
- **Hard direction**
- **Intermediate direction**

Magnetic Anisotropy (2)

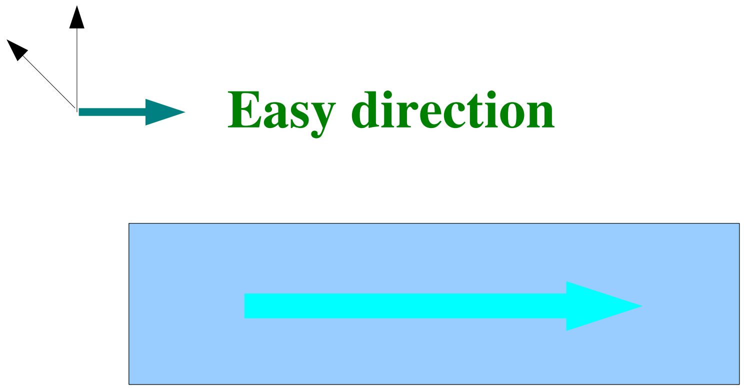




Permalloy Resistor

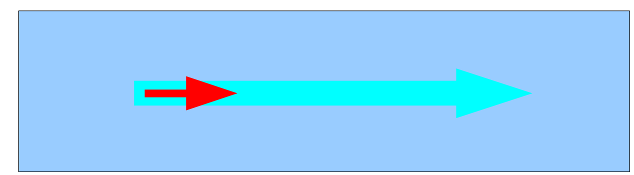
: NiFe (ferri-magnet)

Permalloy Resistor (1)



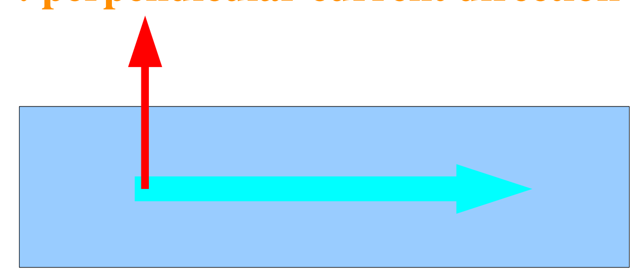
R_{max} : small current

: parallel current direction

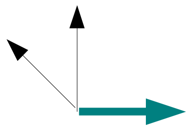


R_{min} : large current

: perpendicular current direction

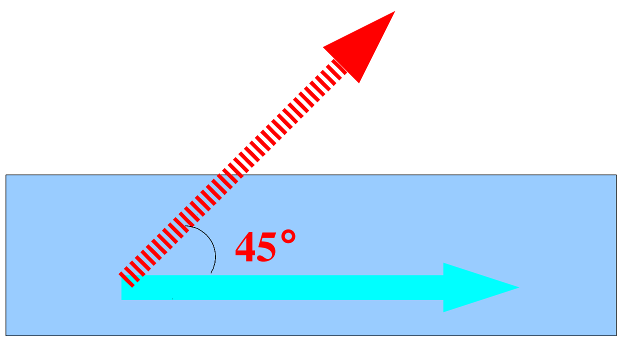


Permalloy Resistor (2)



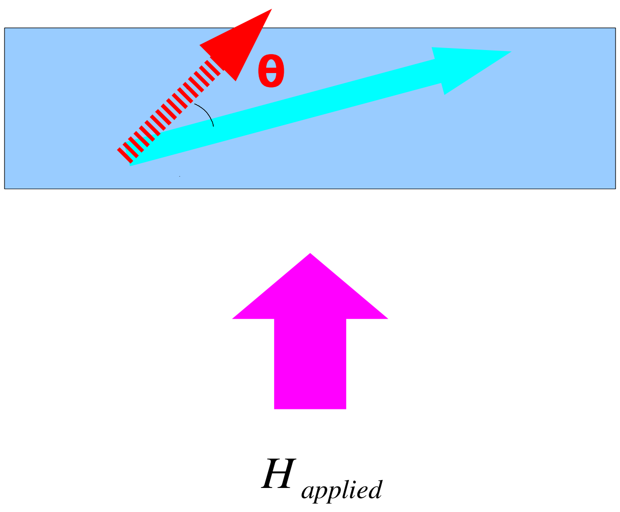
Easy direction

Fix the direction of current



External Magnetic Field changes

- **the magnetization direction of permalloy**
- **the resistance**
- **the current**



AMR Sensor (1)

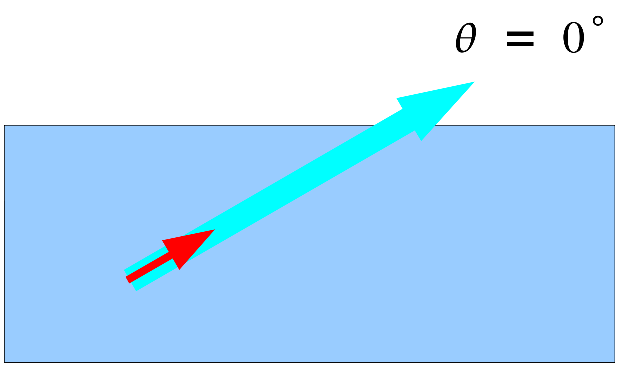
The current direction is fixed

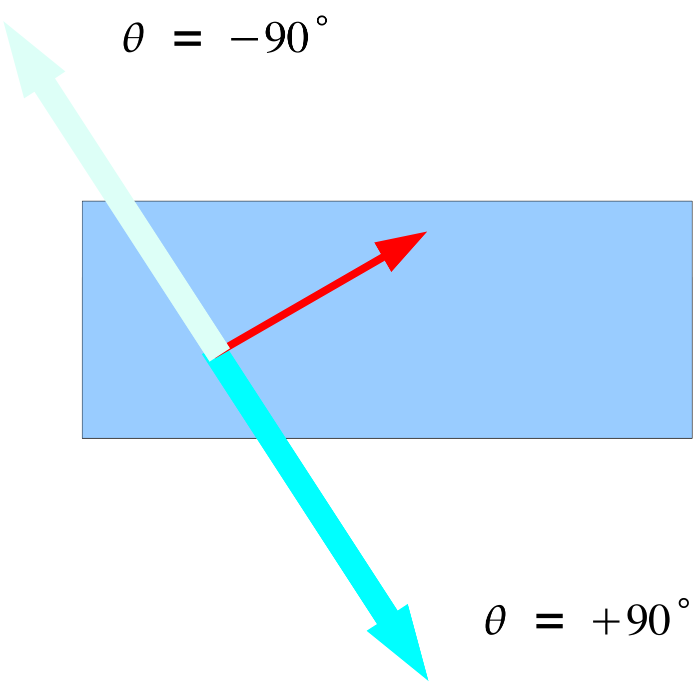
R_{max} : small current

: parallel current direction

R_{min} : large current

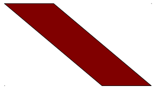
: perpendicular current direction





AMR Sensor (2)

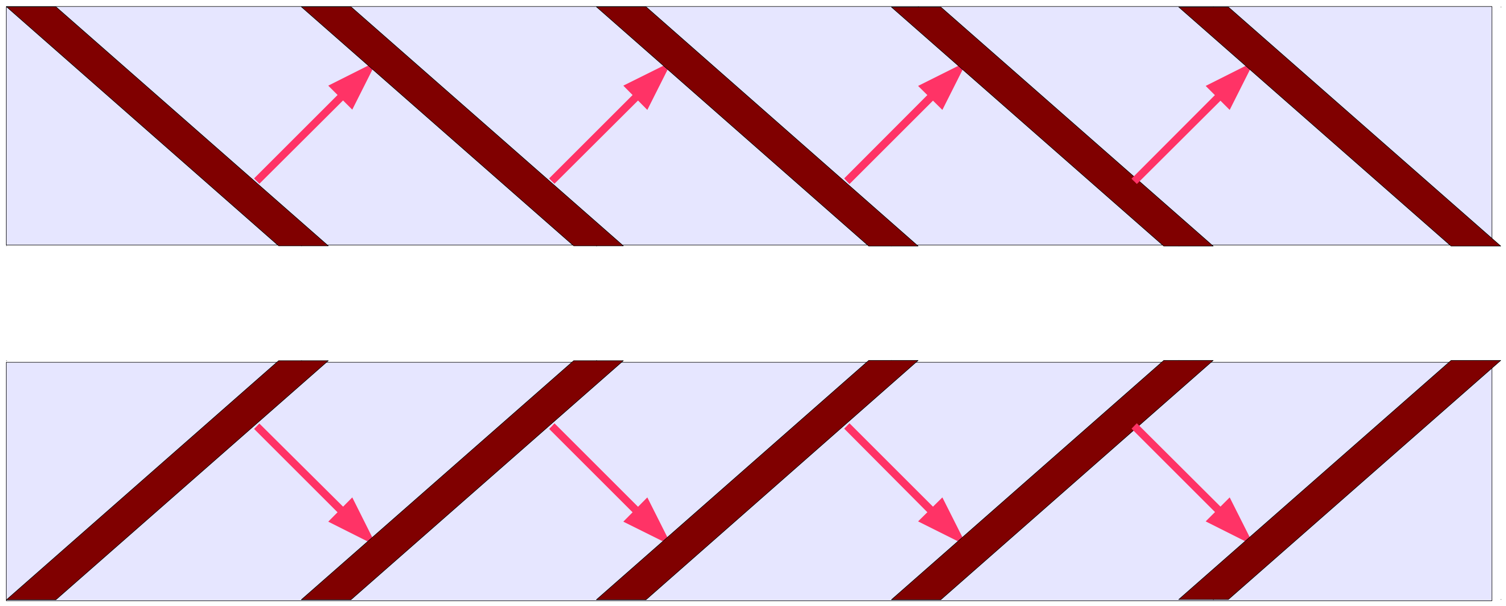
How the current direction is <u>fixed</u>?



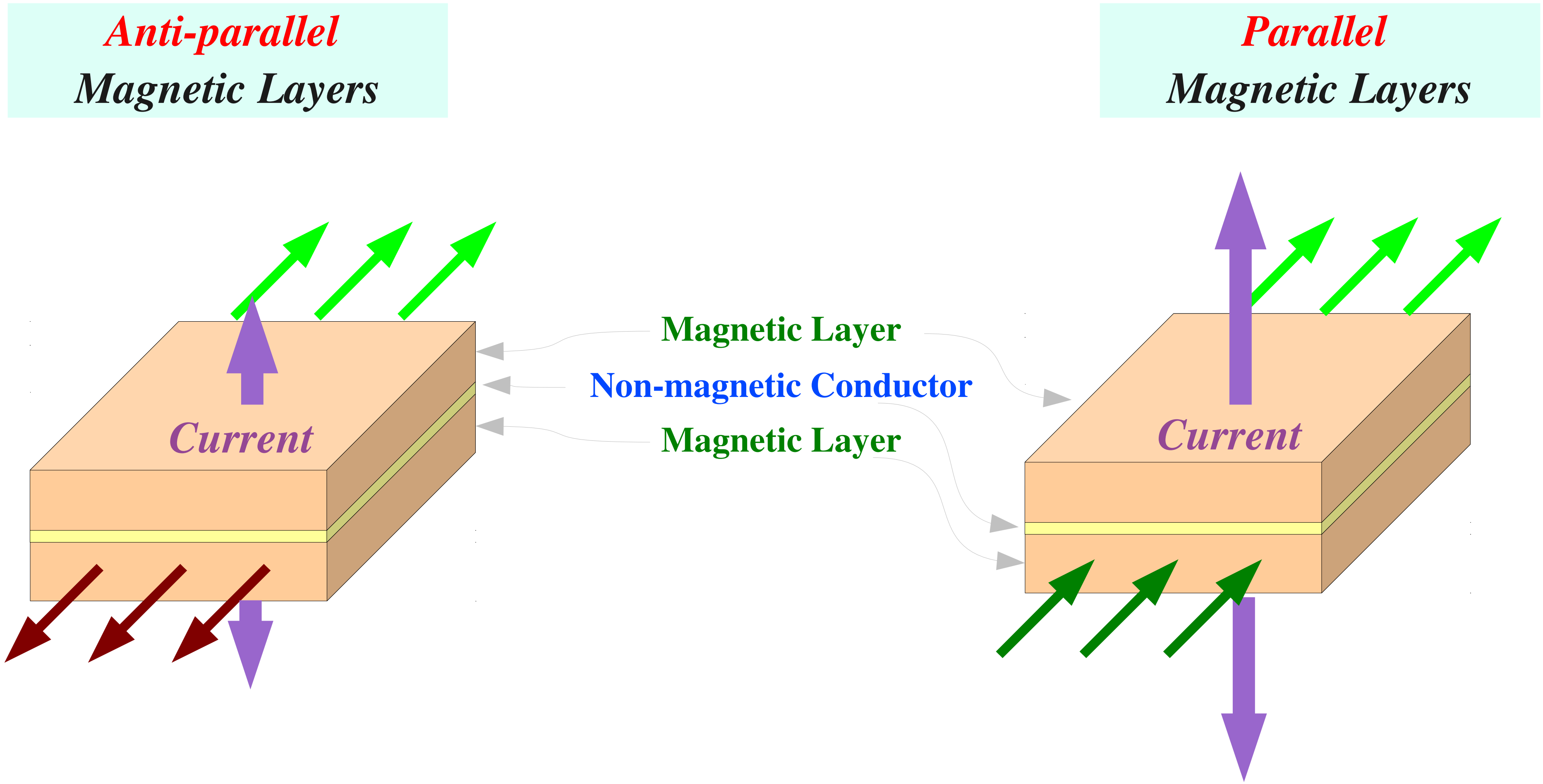
Shortening Bars

Barber Pole Biasing

: the shortest path



Giant Magneto-resistance Effect



High Interface Scattering

: R_{max}

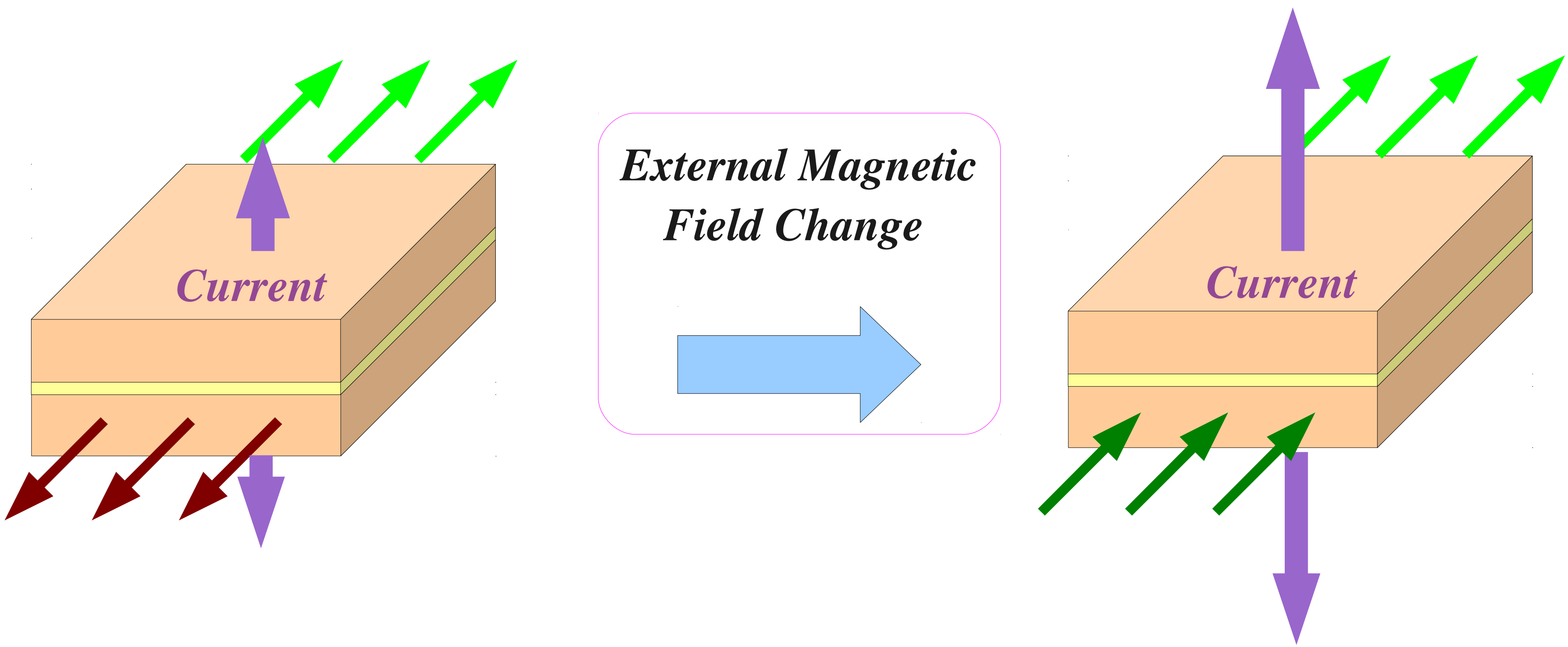
Low Interface Scattering

: R_{min}

GMR Sensor

***Anti-parallel* Magnetic Layers**

***Parallel* Magnetic Layers**



<u>High</u> Interface Scattering

: R_{max}

<u>Low</u> Interface Scattering

: R_{min}

References

[1] http://en.wikipedia.org/
[2] Nam Ki Min, Sensor Electronics, Dong-il Press
[3] http://www.sensorsmag.com/ articles