Giant Magnetoresistance and Beyond

Dawn of spintronics

Pavel Baláž

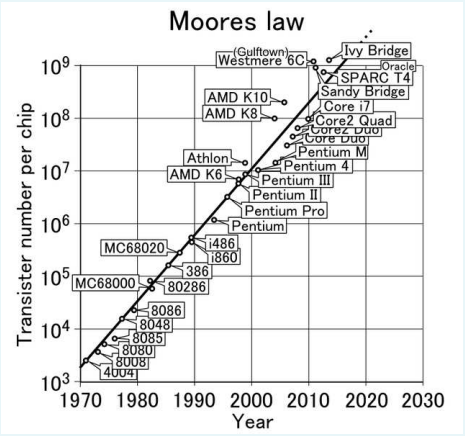
Charles University, Department of Condensed Matter Physics, **Group of Theoretical Physics**

Prague, 7 th May 2019 early in the morning

Motivation: physics and computers

Moore's law

the number of transistors
in a dense integrated circuit
doubles
about every two years



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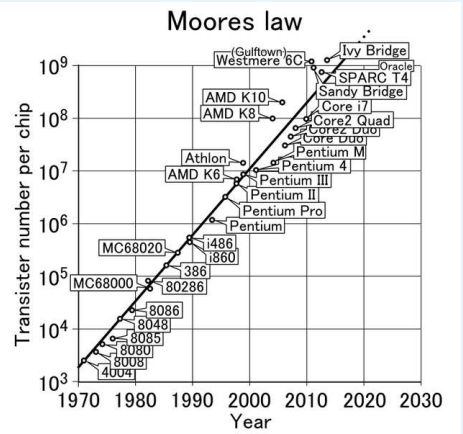


Amount of written information

amount of data and stored information
doubles
every 18 months

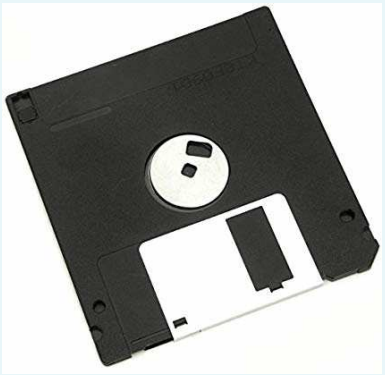
Prehistoric age of magnetic memories

1932: Magnetic drum memory

10 kB memory

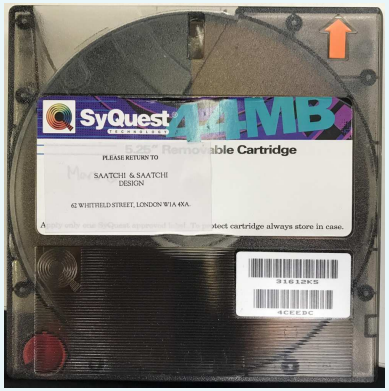
1990s: Floppy disc

1.44 MB memory



1980s: SyQuest hard disc

44 MB memory



1970s: Magnetic tape

up to 60 MB memory

Breakthrough in magnetic memories: Giant Magnetoresistance

Peter Grünberg and Albert Fert
Nobel Prize in Physics, 2007

- 1989: Giant Magnetoresistance
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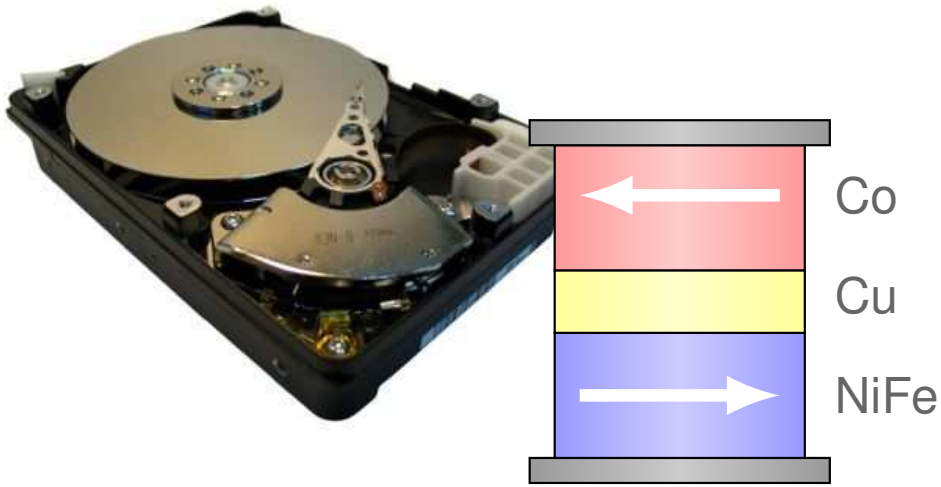

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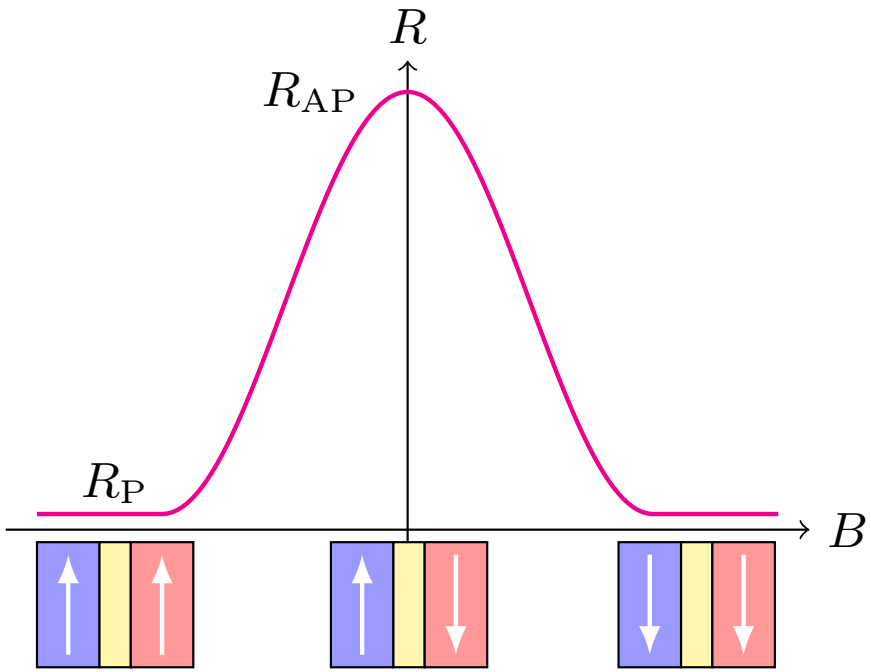

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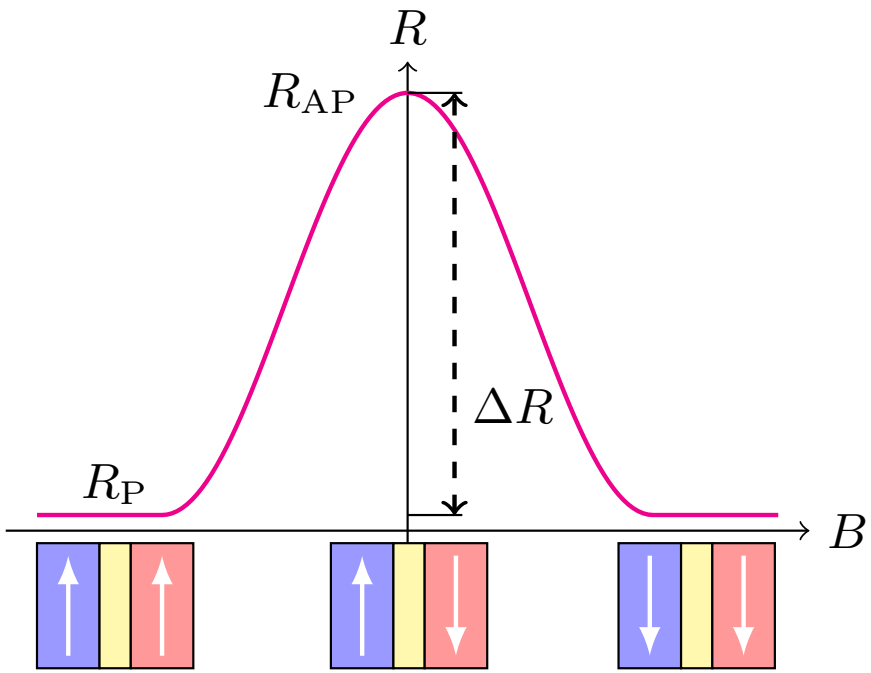

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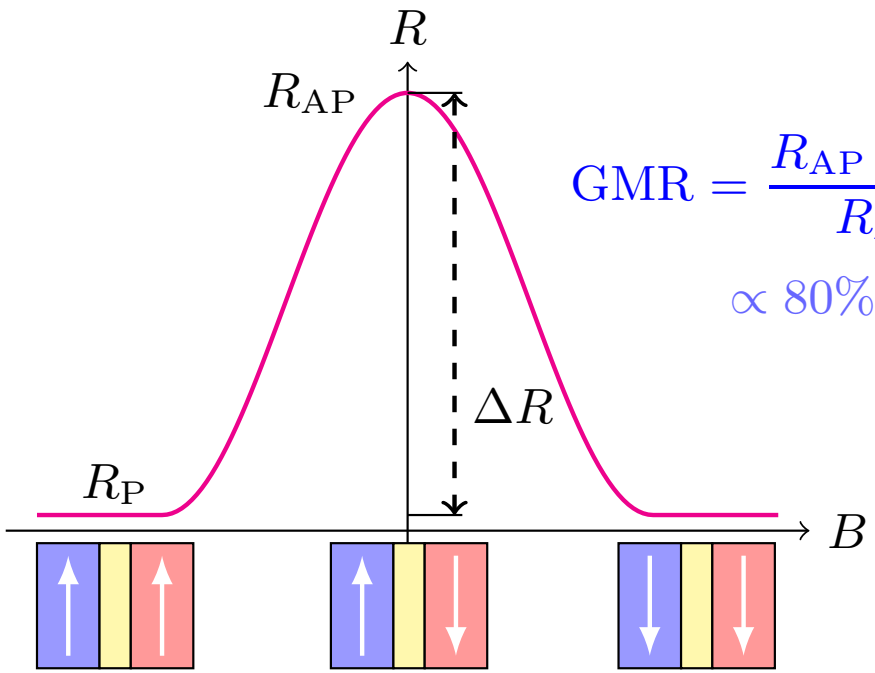

$$\mathrm{GMR} = \frac{R_{\mathrm{AP}} - R_{\mathrm{P}}}{R_{\mathrm{AP}}}$$

$\propto 80\%$

Physical principle of GMR: electon has spin

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- transport properties in each spin channel are different

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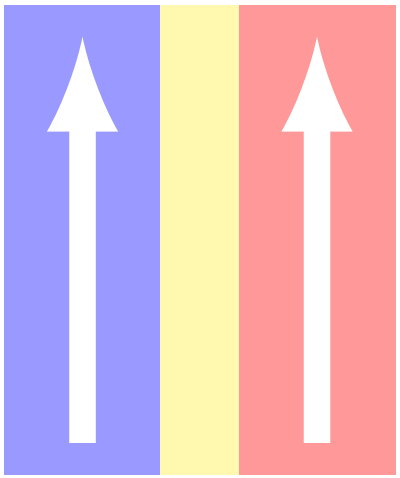

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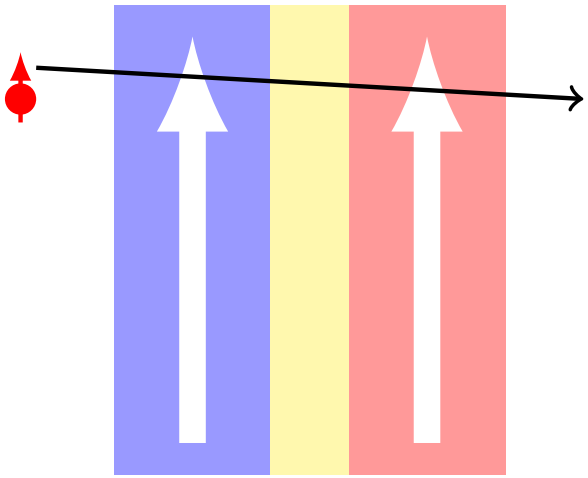

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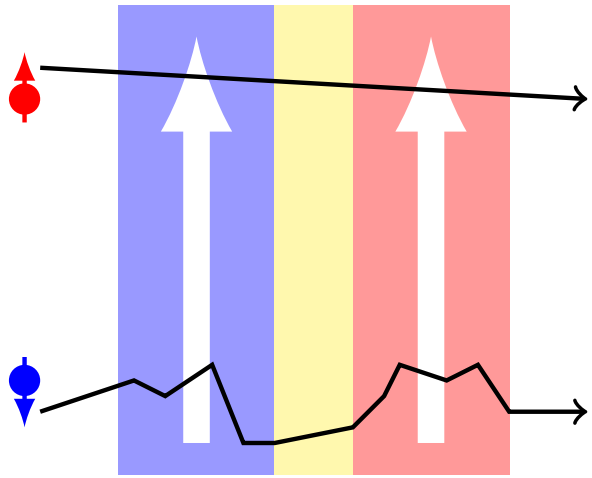

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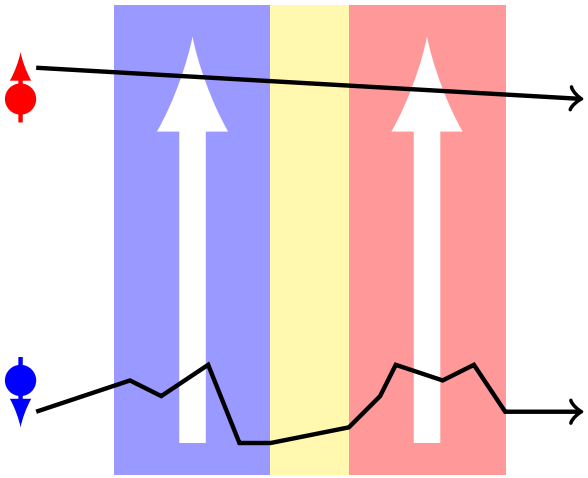

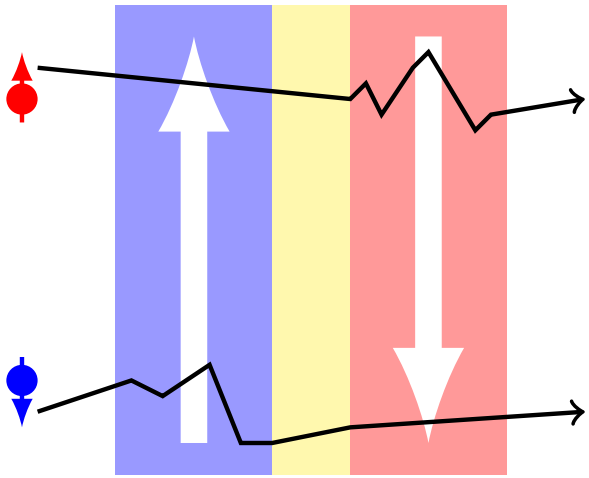

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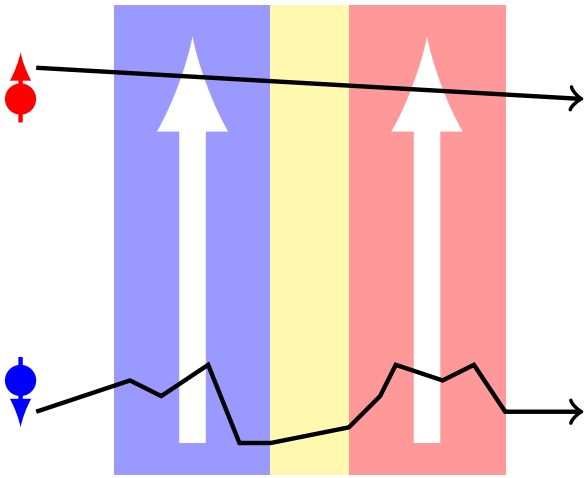

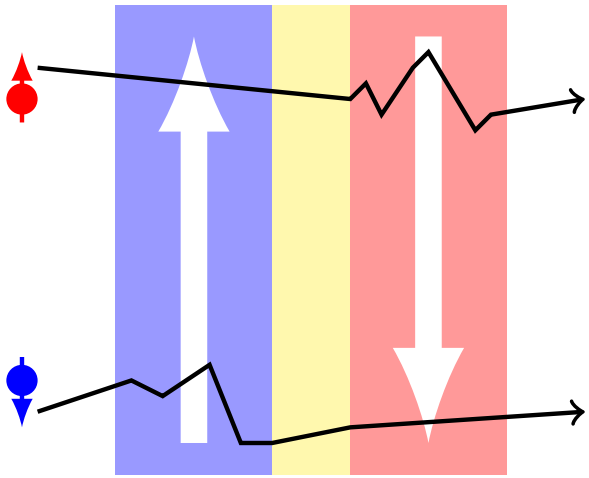

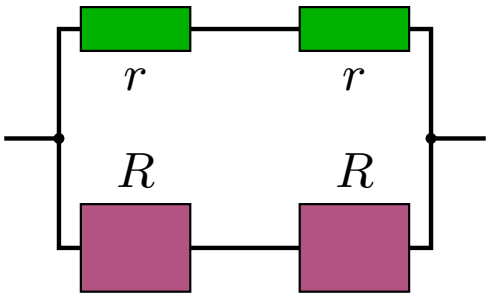

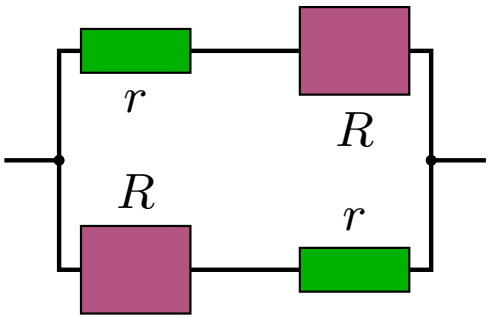

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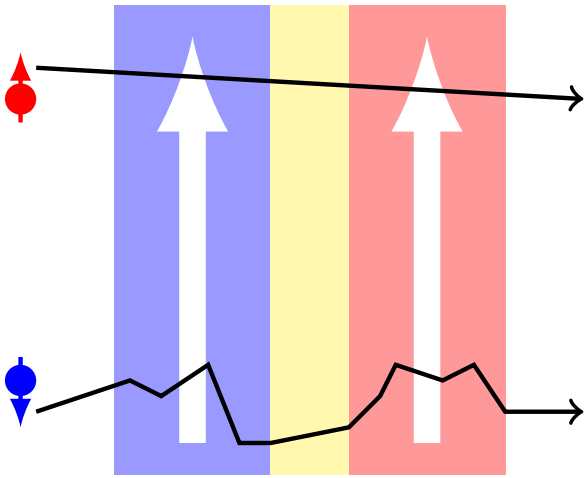
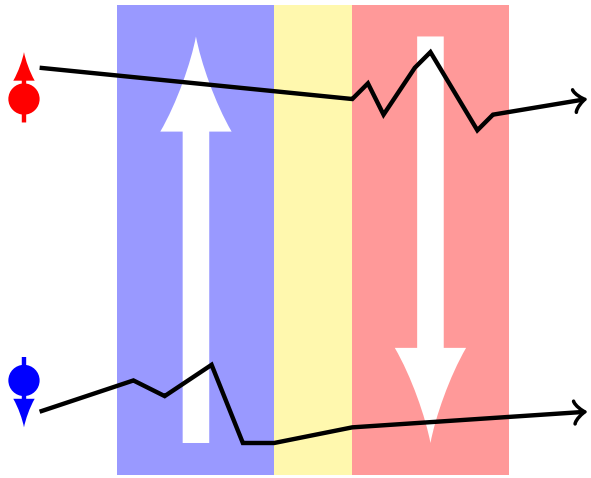
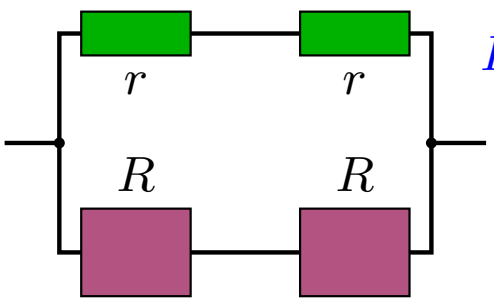
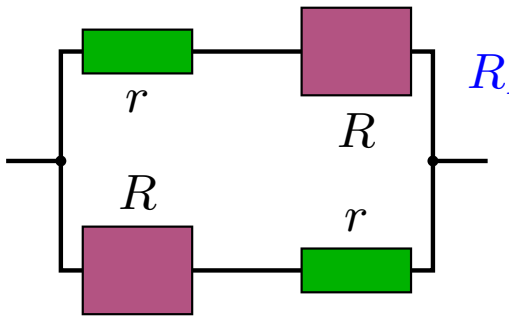




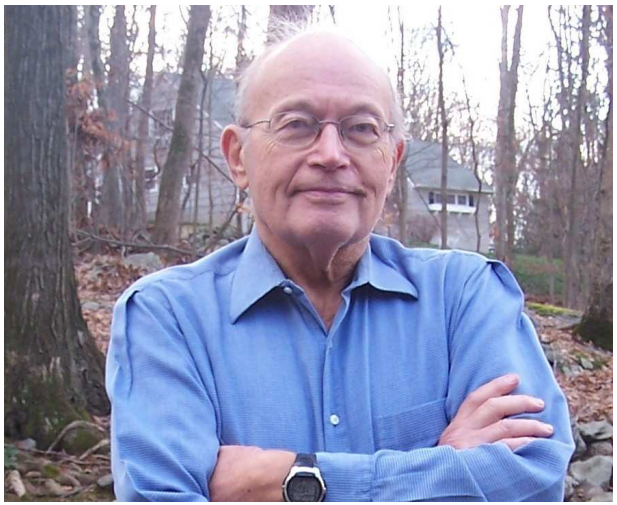


$$R_{\mathrm{P}} = \frac{r+R}{2\,r\,R}$$

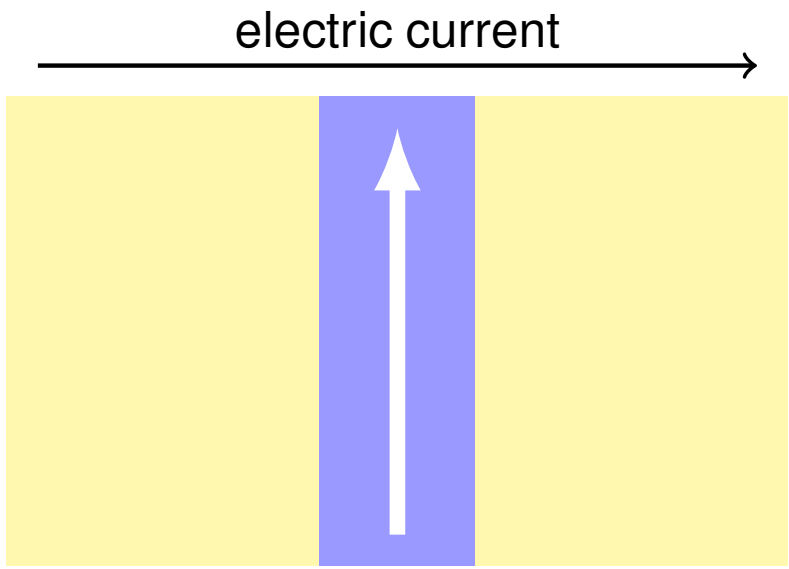


$$R_{\mathrm{AP}} = \frac{r+R}{2}$$

Start of spintronics



John Slonczewski



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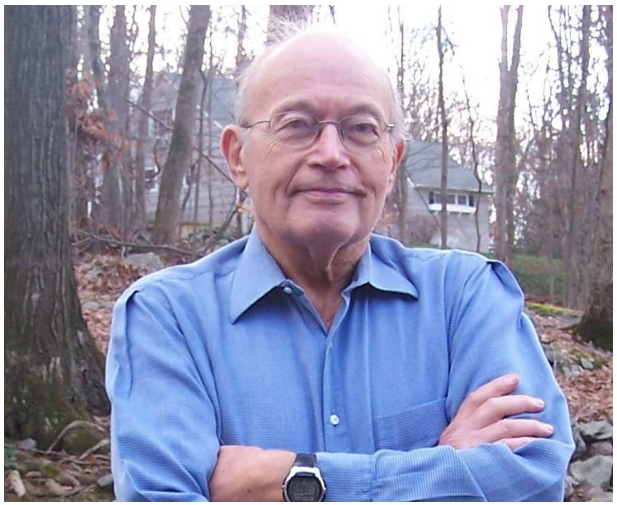

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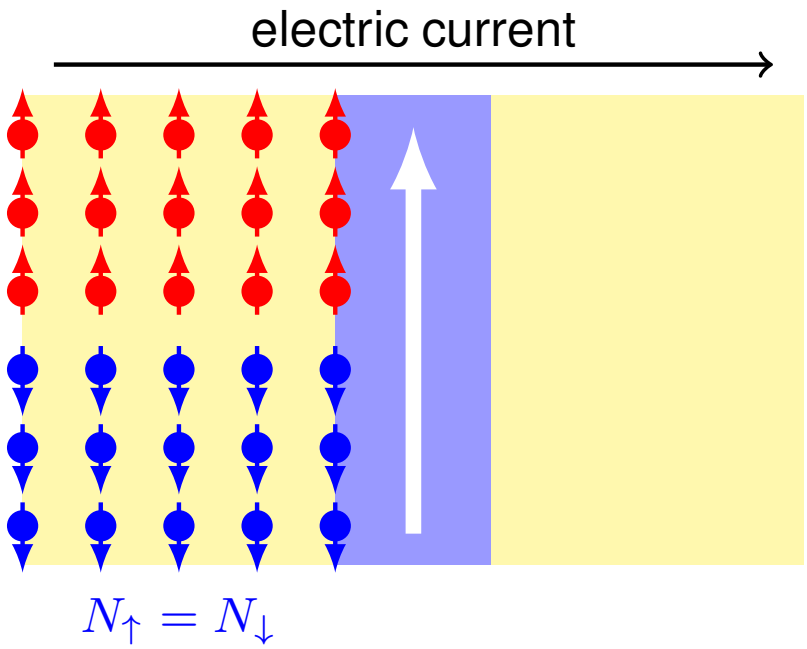

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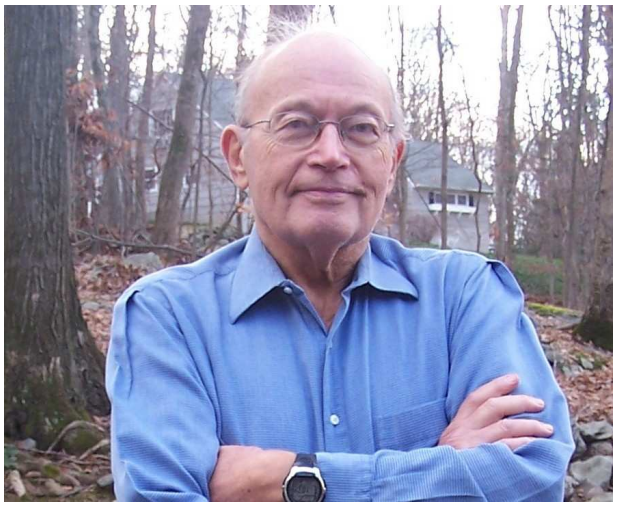

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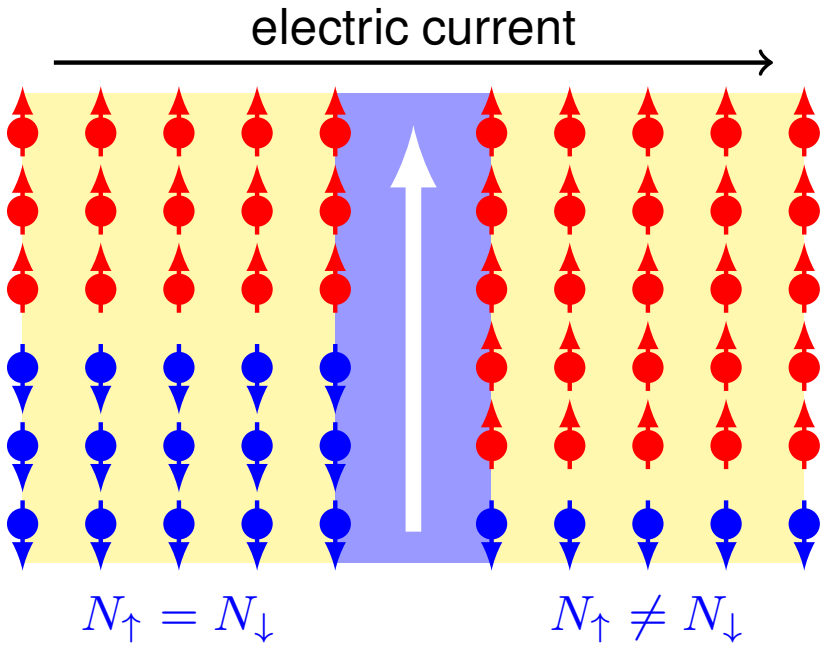

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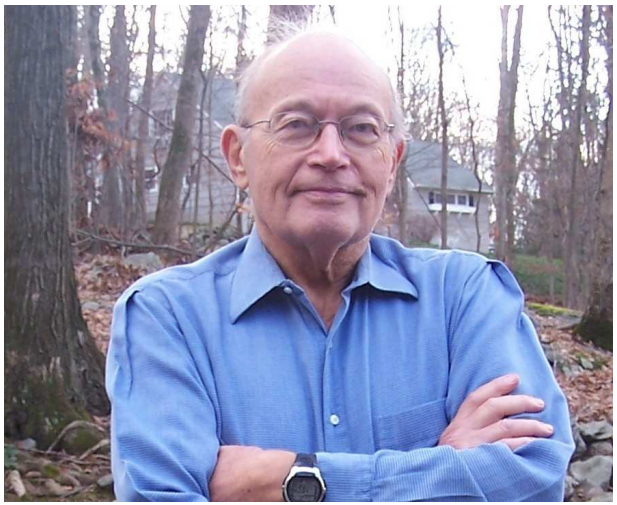

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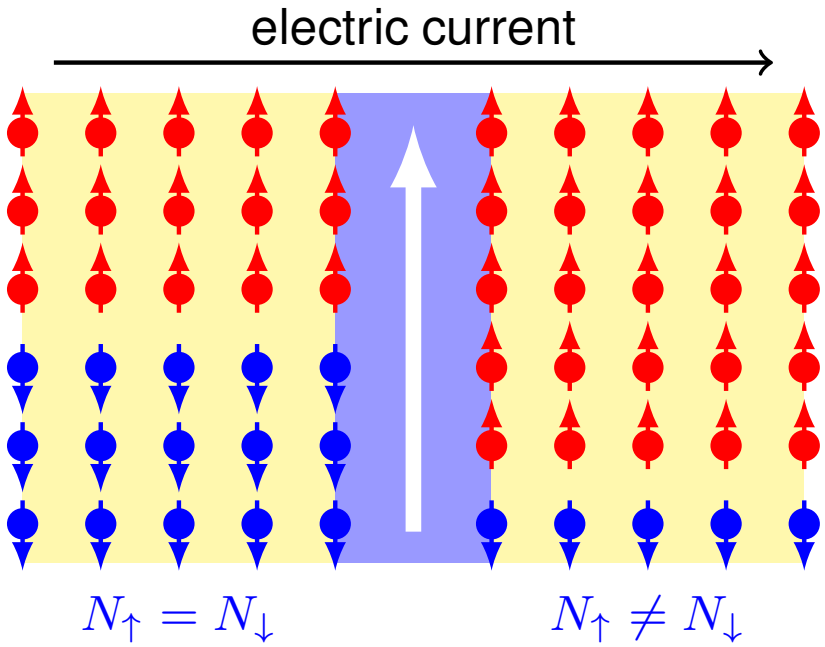

spin-polarized current

spin current

$$J_s = J_\uparrow - J_\downarrow \qquad P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$

Angular momentum transfer

- spin current carries charge and angular momentum

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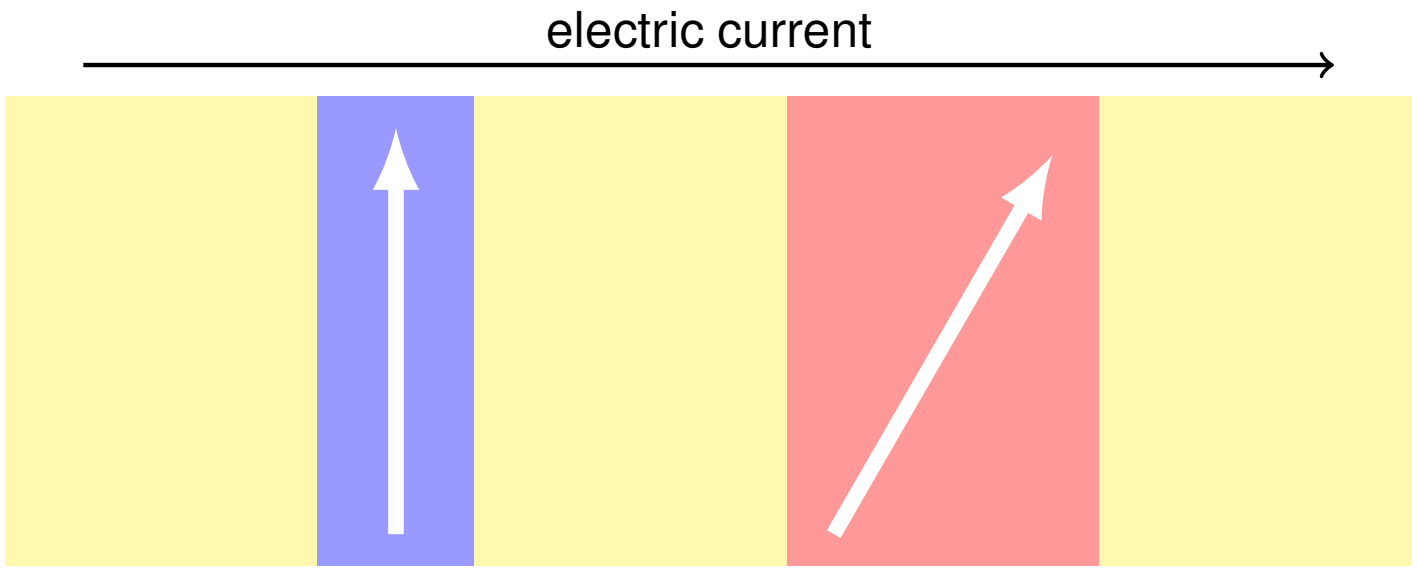

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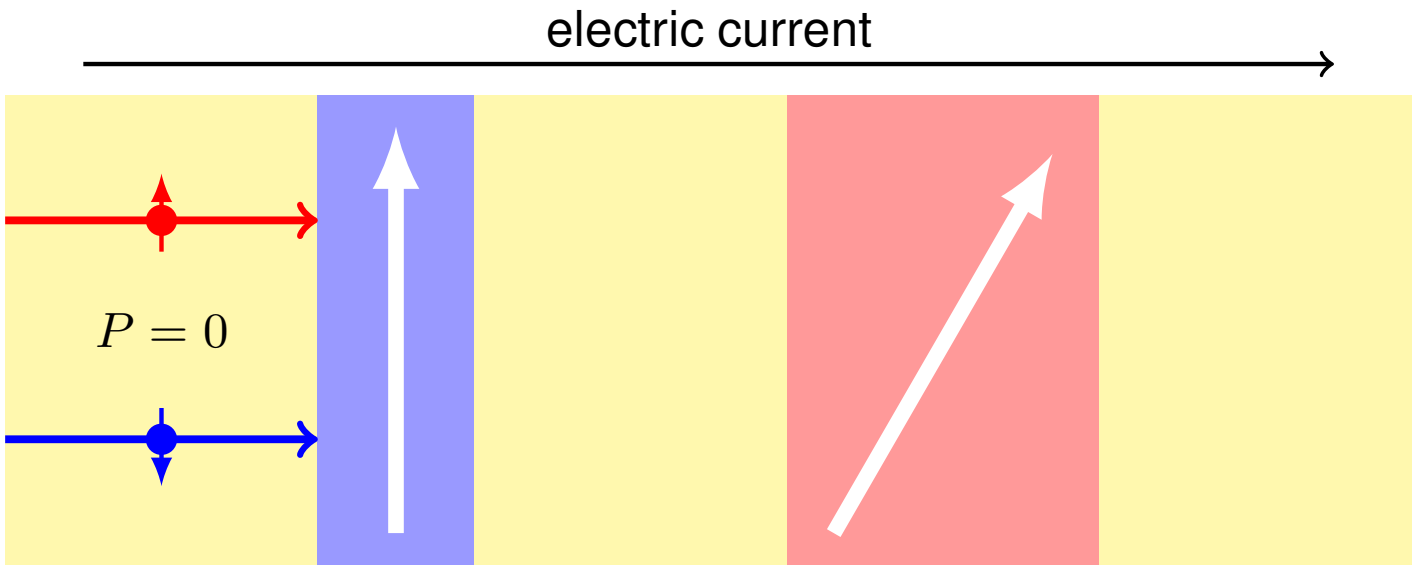

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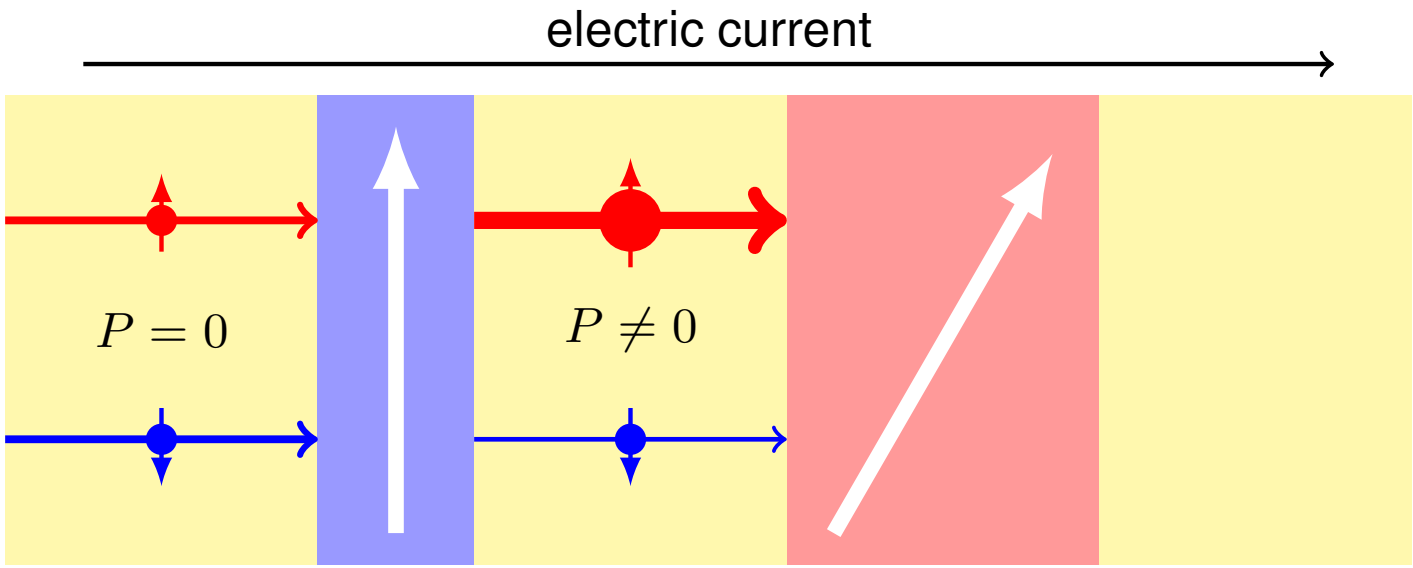

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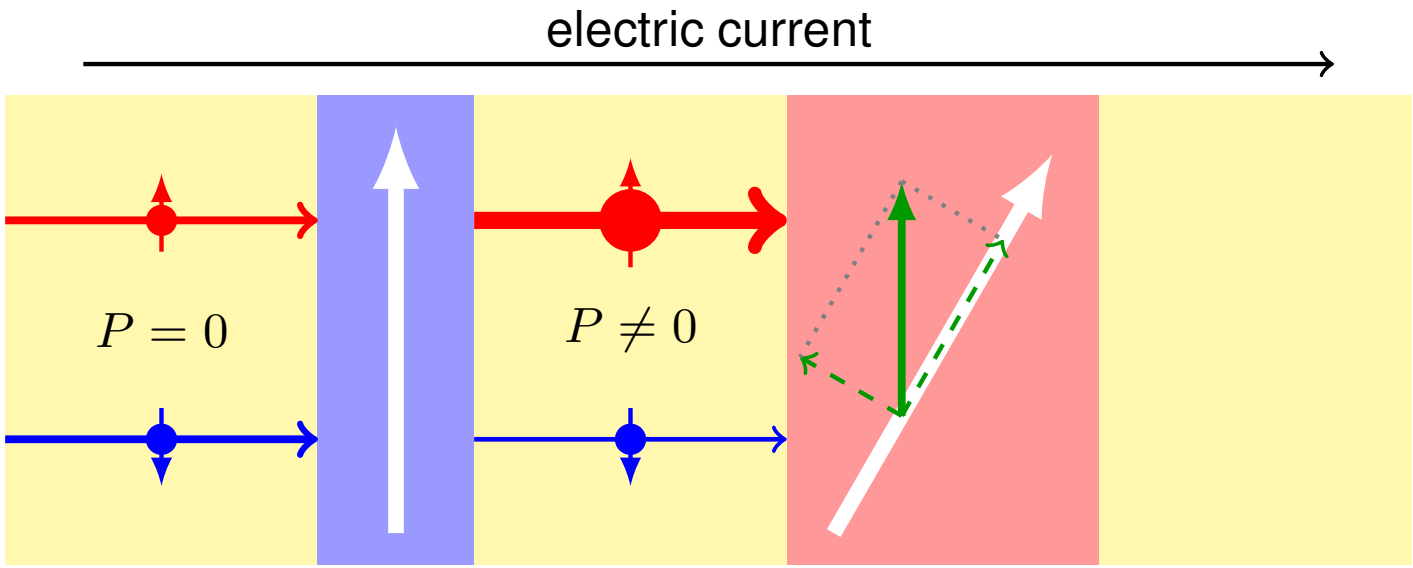

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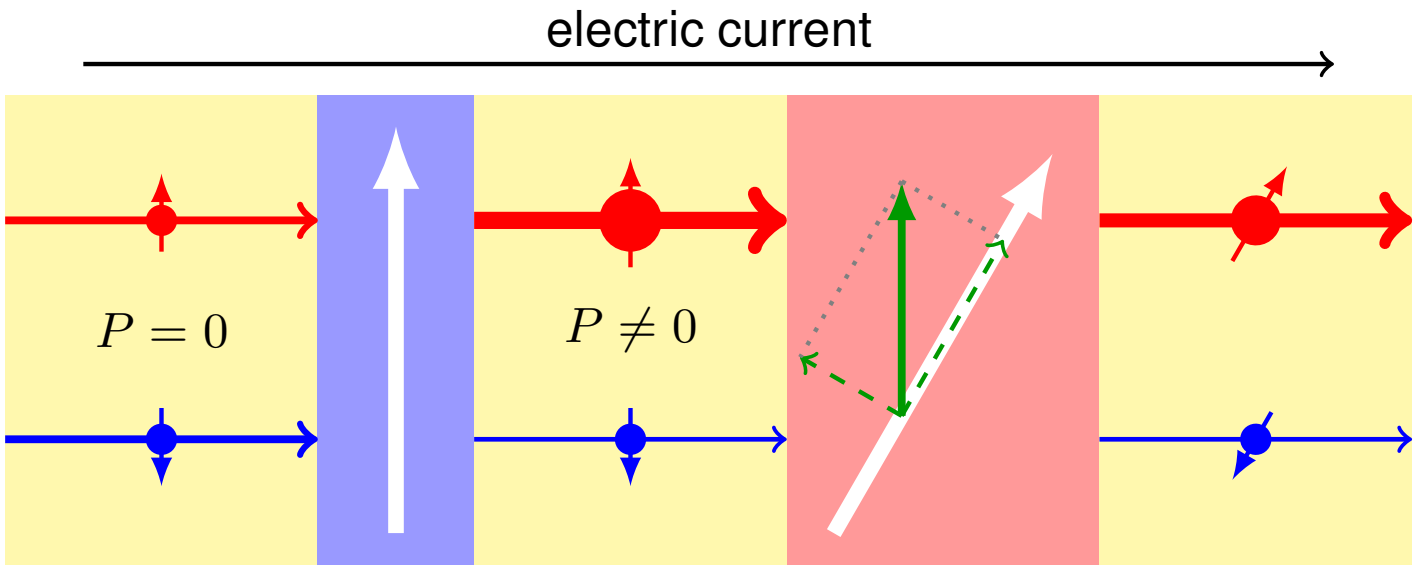
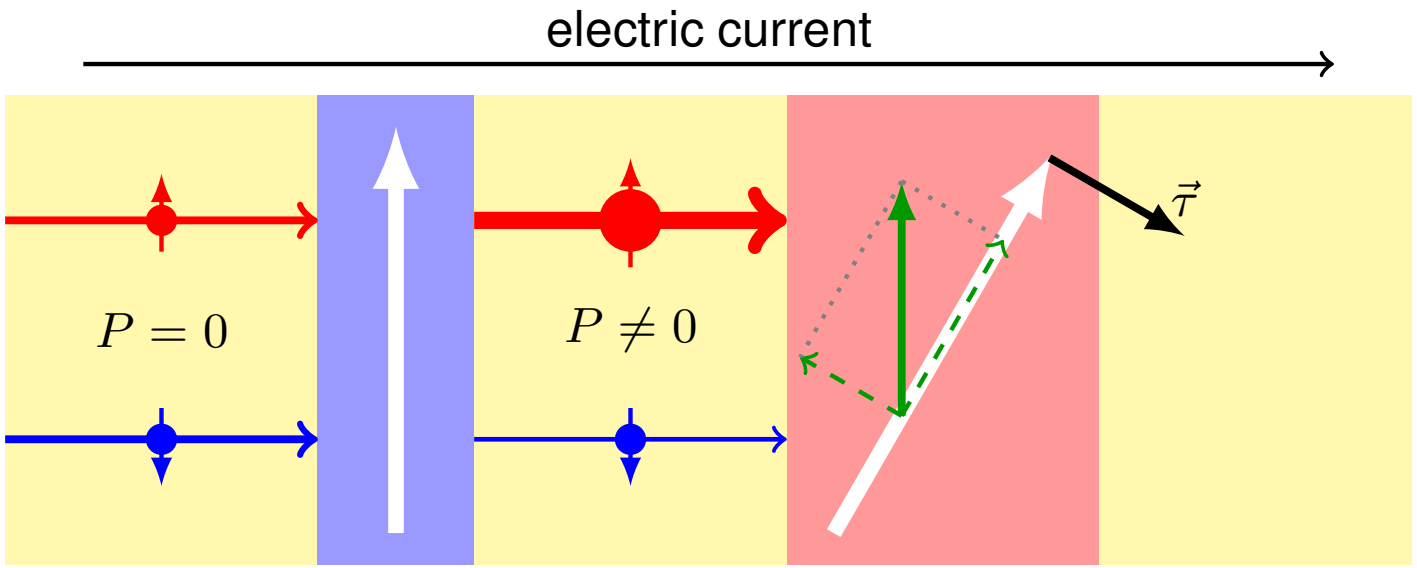


- longitudinal component passes the magnetic layer

Angular momentum transfer

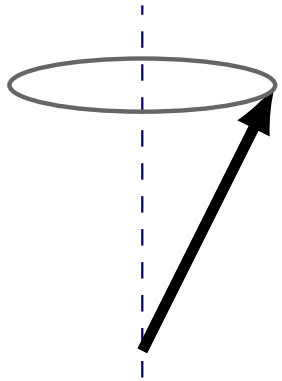
- spin current carries charge and angular momentum



- longitudinal component passes the magnetic layer
- transverse component is absorbed in the magnetic layer: spin transfer torque $\vec{\tau}$
- magnetization dynamics

Magnetization dynamics

Magnetic precessions



- spin torque oscilator
- GHz frequencies
- microwave transmitters

Magnetization dynamics

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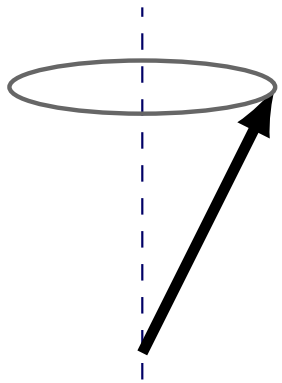

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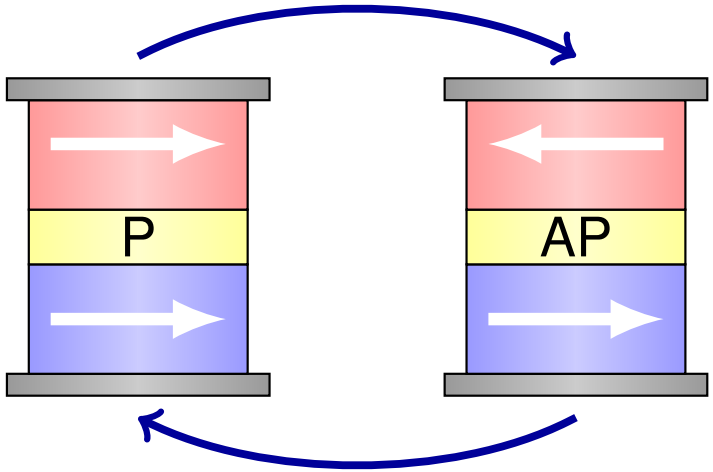
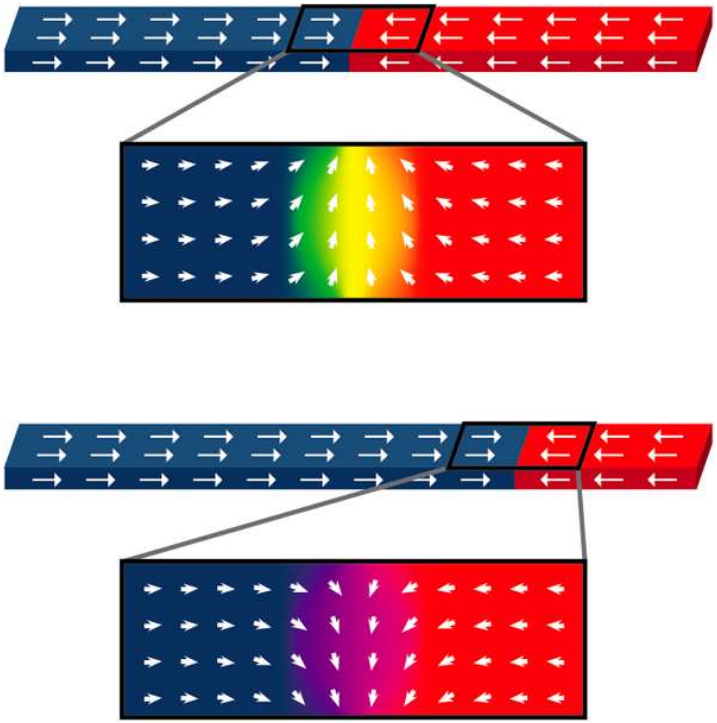
Magnetization switching



- magnetic random access memories MRAM
- faster writing rate
- higher density of the memory cells
- nonvolatility

Magnetic domain walls in nanowires

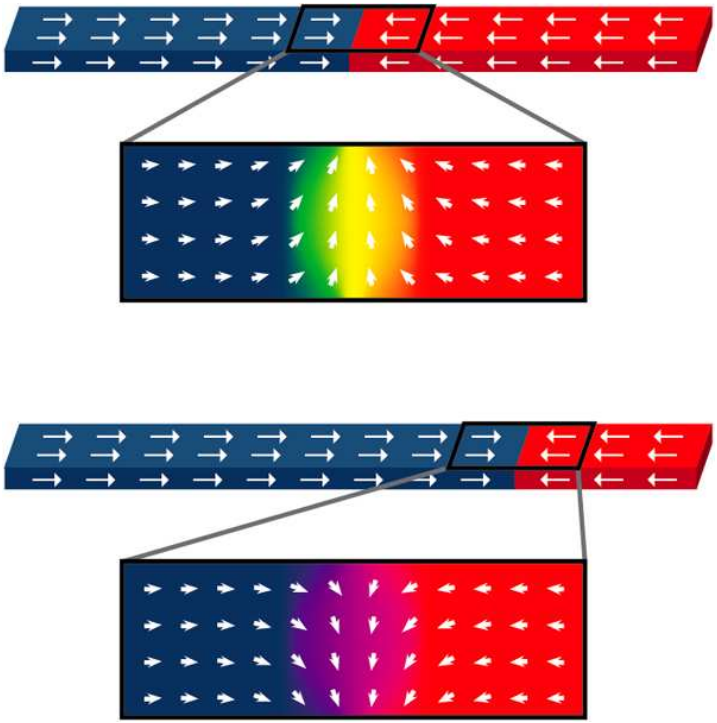


Source: Physics 1, 17 (2008)

topological defect

- domain wall contains noncollinear magnetizations
- Spin transfer torque is possible

Magnetic domain walls in nanowires



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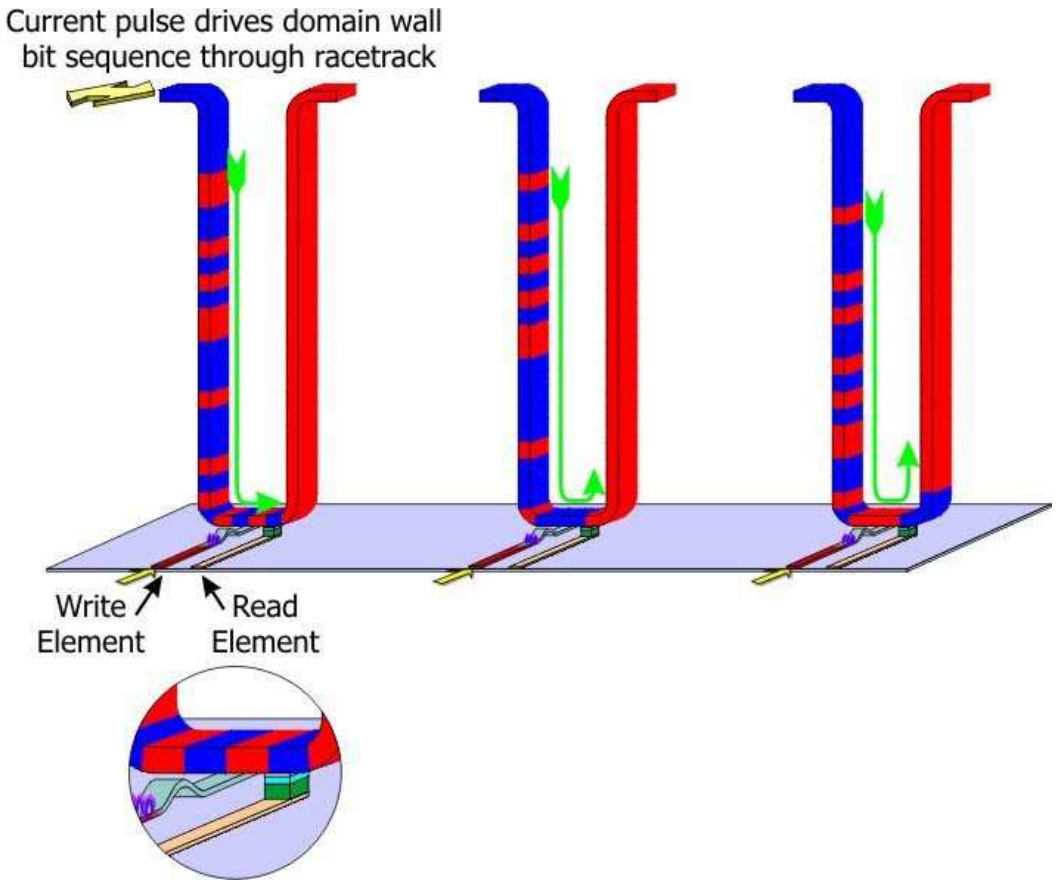
Stuart Parkin

Domain wall racetrack memory

3D magnetic memory



Source: Physics World

What is wrong with spintronics?

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Everspin 28 nm 1Gb STT-MRAM

What is wrong with spintronics?

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Major drawbacks

- to move domain wall or magnetization switching we need large currents
- high energy consumptions
- Joule heating

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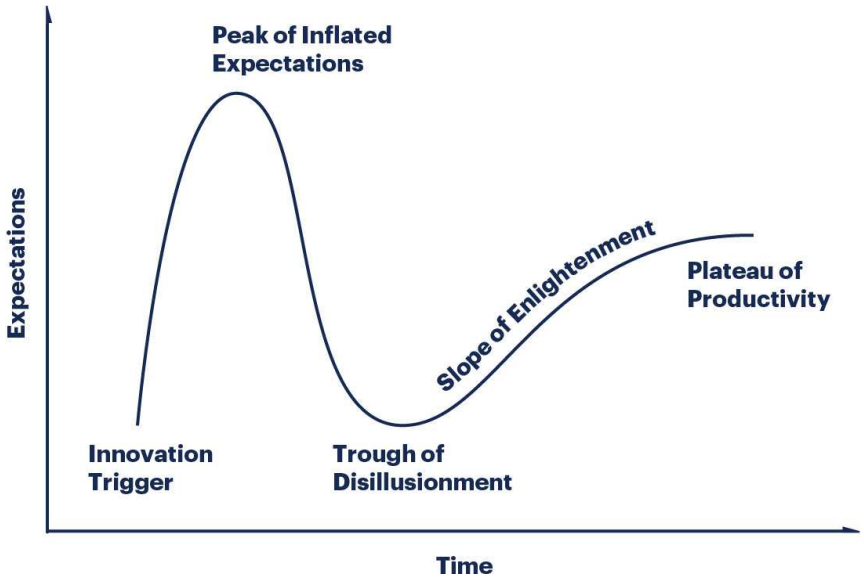

Source: gartner.com

Major drawbacks

- to move domain wall or magnetization switching we need large currents
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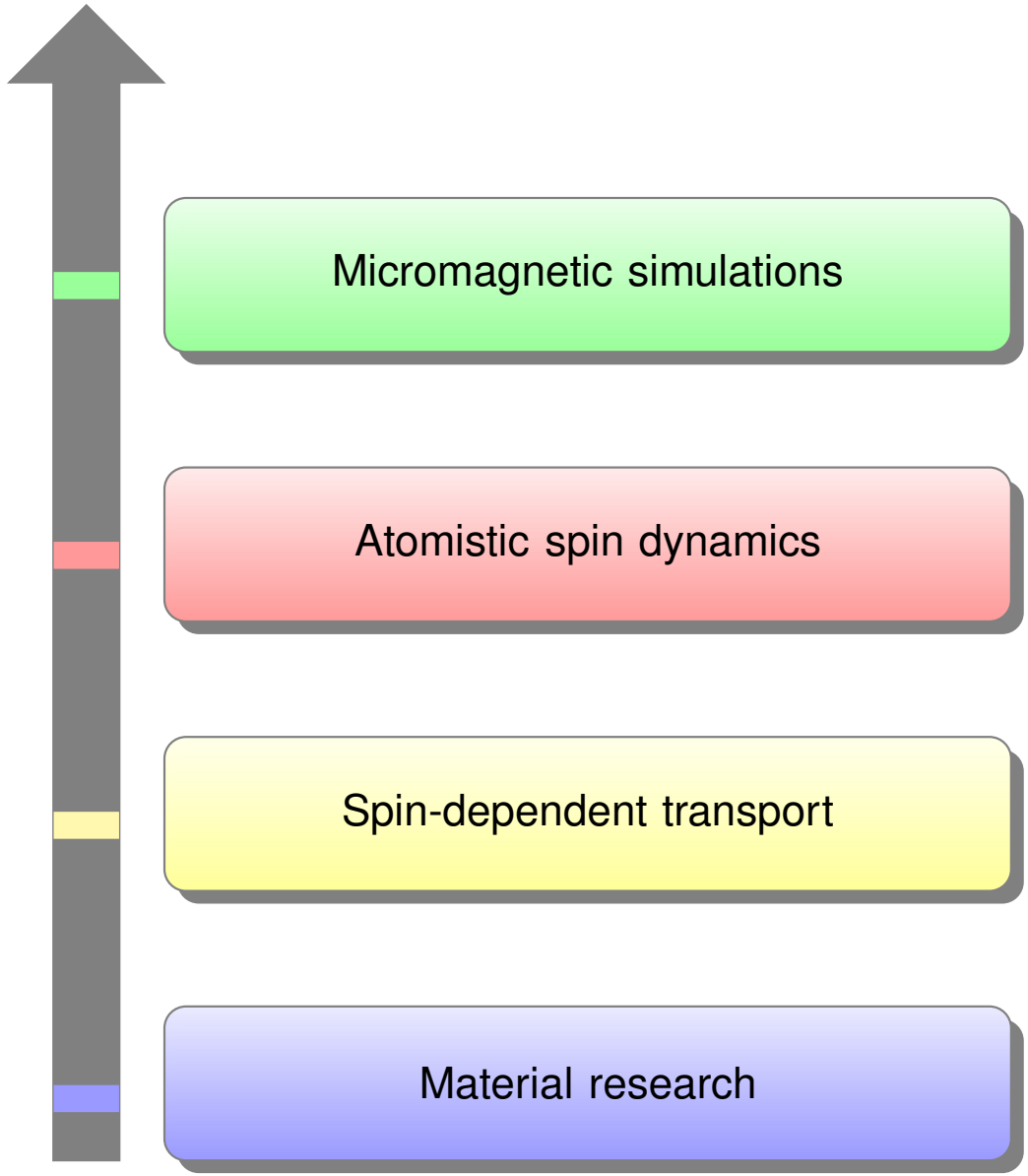
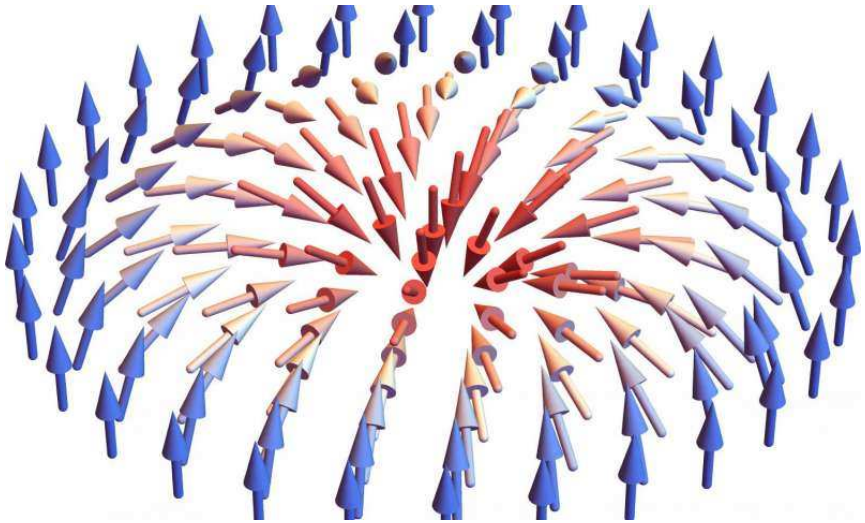
- MRAM is sliding into the trough (2018)
- requires further research
- new materials
- new ideas and approaches

Playground for physicists: multiscale approach



New trends in spintronics: skyrmions



Source: Phys.org

- topological defects in magnetic texture
- can be manipulated by current

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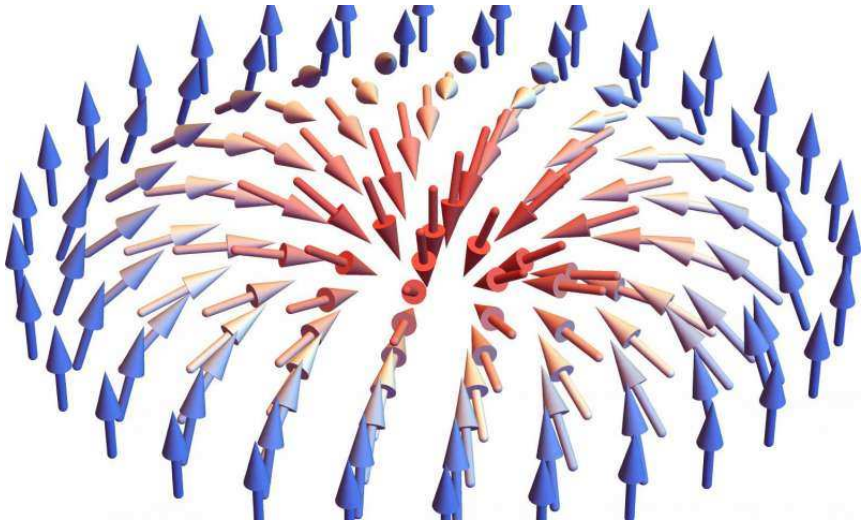

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- topological defects in magnetic texture
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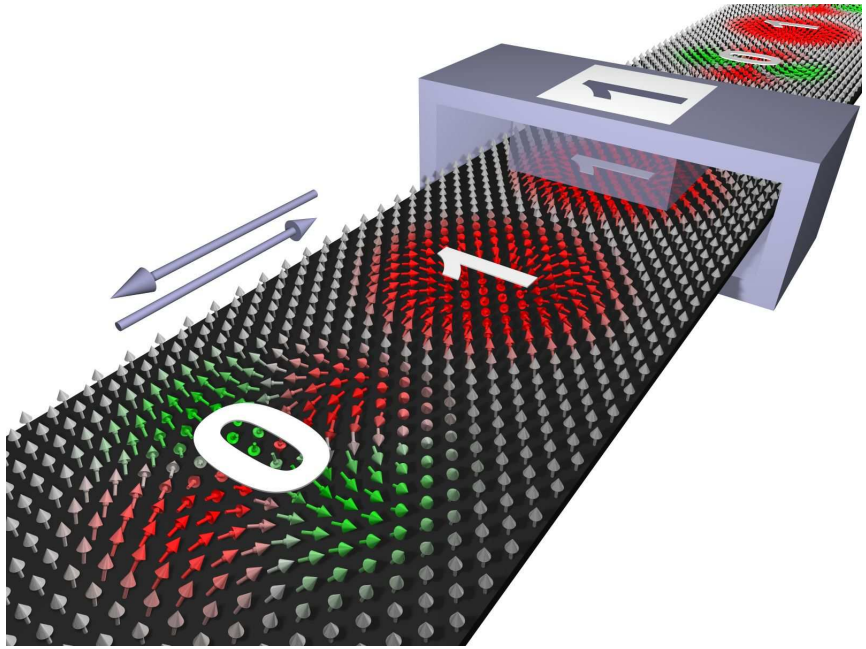
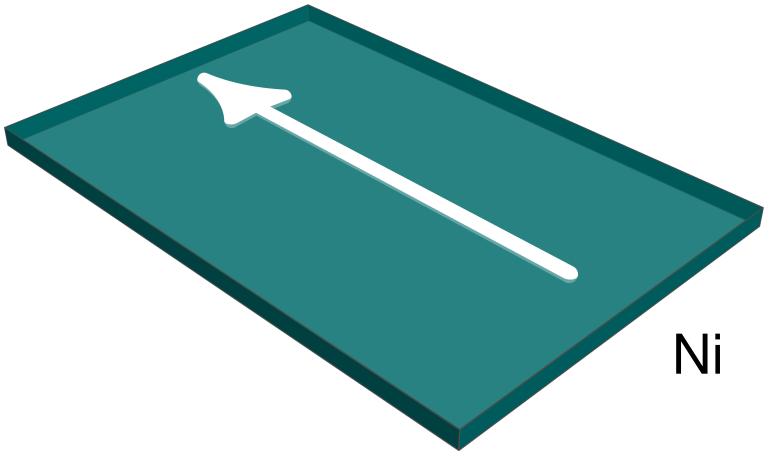
- Skyrmionic racetrack memory



Source: Forschungszentrum Jülich

New trends in spintronics: magnetism goes to ultrafast



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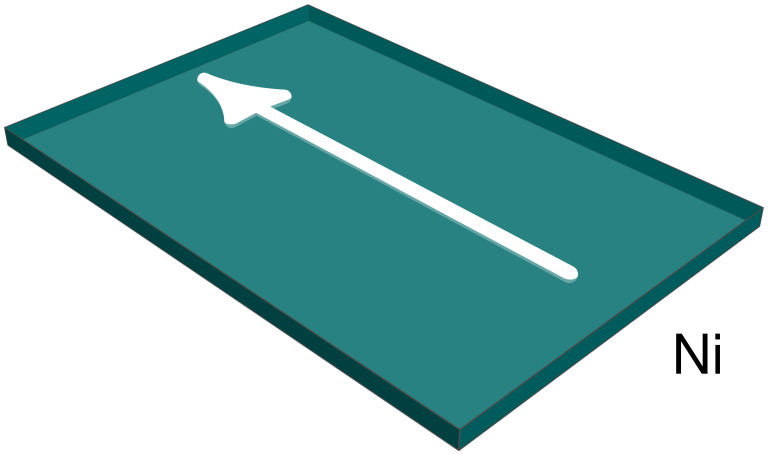

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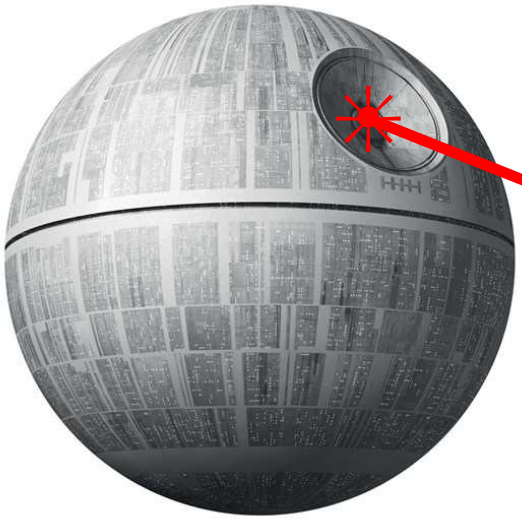
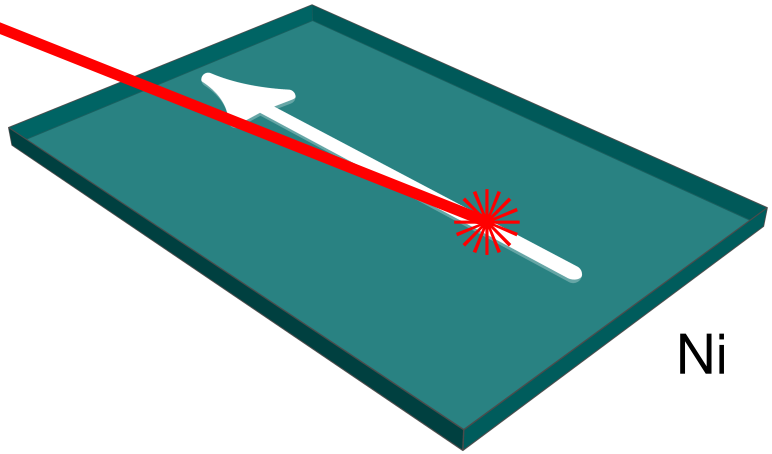


just for few femtoseconds



Ni

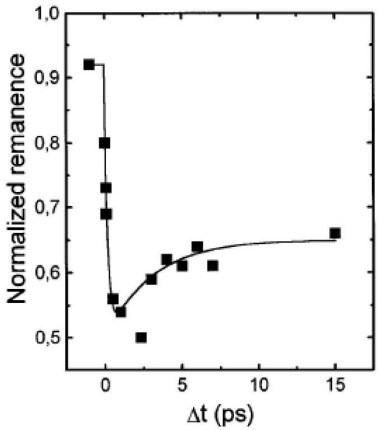
New trends in spintronics: magnetism goes to ultrafast

magnetization reduction

New trends in spintronics: magnetism goes to ultrafast

ultrafast
magnetization reduction

Ni



E. Beaurepaire *et al.*

Ultrafast Spin Dynamics in Ferromagnetic Nickel

Phys. Rev. Lett. **76**, 4250 (1996)

Thank you for your attention!

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