

Co to jest spin?

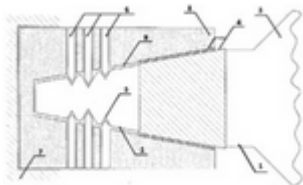
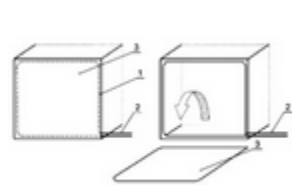
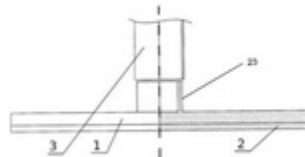
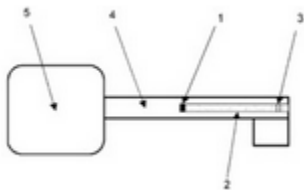
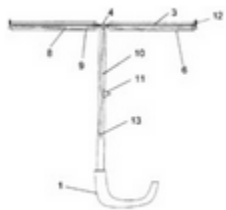


Sprawy bieżące

1. Esej na temat przyszłości – do 8 stycznia 2021! Jest SZABLON

UWAGA: Esej jest na oceny 4-5 (czyli testy są na 3-4)

2. Nowy przedmiot „**Od pomysłu do patentu - Trendy, nowe technologie i zarządzanie innowacjami**” (Jacek Szczytko, Piotr Nieżurawski) – 1100-2`TNT (2 i 3 rok FIZ), 3 ECTS

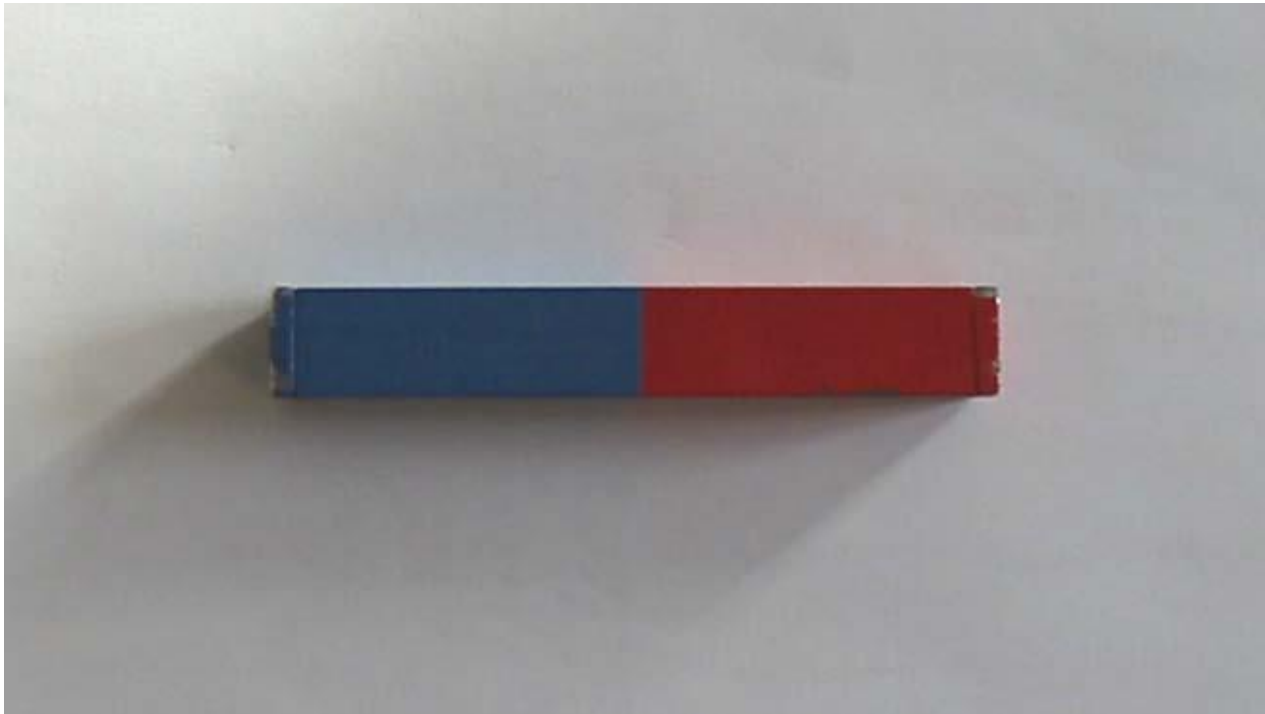


PAT: Układ czaszy parasola oraz parasol zawierający taki układ czaszy parasola				
	Numer zgłoszenia	P.421346	Numer prawa wyłącznego	Pat.231903
	Data zgłoszenia	2017-04-20	Status	Prawo w mocy
	Nazwa/Tytuł	Układ czaszy parasola oraz parasol zawierający taki układ czaszy parasola	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL
PAT: Układ klucza i zamka ze wskazaniem zamknięcia zamka oraz sposób sygnalizacji zamknięcia zamka				
	Numer zgłoszenia	P.421270	Numer prawa wyłącznego	Pat.232894
	Data zgłoszenia	2017-04-11	Status	Prawo w mocy
	Nazwa/Tytuł	Układ klucza i zamka ze wskazaniem zamknięcia zamka oraz sposób sygnalizacji zam...	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL
PAT: Urządzenie do mocowania rury między dwiema zasadniczo równoległymi do siebie płaszczyznami				
	Numer zgłoszenia	P.418588	Numer prawa wyłącznego	Pat.231433
	Data zgłoszenia	2016-09-07	Status	Prawo w mocy
	Nazwa/Tytuł	Urządzenie do mocowania rury między dwiema zasadniczo równoległymi do siebie pla...	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL
PAT: Sposób wyznaczania wartości namagnesowania nanocząstek magnetycznych oraz urządzenie do wyznaczania wartości namagnesowania nanocząstek magnetycznych				
	Numer zgłoszenia	P.402159	Numer prawa wyłącznego	Pat.222392
	Data zgłoszenia	2012-12-20	Status	Prawo wygasło (brak opłaty za ochronę)
	Nazwa/Tytuł	Sposób wyznaczania wartości namagnesowania nanocząstek magnetycznych oraz urządzt...	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL
PAT: Pojemnik i jego zastosowanie				
	Numer zgłoszenia	P.427375	Numer prawa wyłącznego	
	Data zgłoszenia	2018-10-12	Status	Postępowanie w toku
	Nazwa/Tytuł	Pojemnik i jego zastosowanie	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL
PAT: Zestaw klucza z trzmem o symetrii obrotowej i rdzenia zamka				
	Numer zgłoszenia	P.427214	Numer prawa wyłącznego	
	Data zgłoszenia	2018-09-27	Status	Postępowanie w toku
	Nazwa/Tytuł	Zestaw klucza z trzmem o symetrii obrotowej i rdzenia zamka	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL
PAT: Zestaw klucza i rdzenia zamka				
	Numer zgłoszenia	P.427215	Numer prawa wyłącznego	
	Data zgłoszenia	2018-09-27	Status	Postępowanie w toku
	Nazwa/Tytuł	Zestaw klucza i rdzenia zamka	Zgłaszający/Uprawniony	UNIwersytet Warszawski, Warszawa, PL

<https://ewyszukiwarka.pue.uprp.gov.pl/search/simple-search?lng=pl>

Co to jest spin?

Skąd się biorą magnesy?



http://lucy.troja.mff.cuni.cz/~tichy/elektross/magn_pole/stac_mp.html

Trochę historii

<1000 r. p.n.e. Mezopotamia: niektóre rudy żelaza to „żyjące kamienie”.

600 r. p.n.e. Tales z Miletu: „magnetyt ma duszę”, bo przyciąga żelazo.

98-55 r. p.n.e. Lukrecjusz (Titus Lucretius Carus) w poemacie *De Rerum Natura* użył słowa *magnes* jako nazwy dla kamienia pochodzącego z Magnezji na północy Grecji.

23-72 r. Plinusz Drugi (Gaius Plinius Secundus) napisał w *Historia Naturalis*, że według Nikadera (poety greckiego) nazwa *magnes* pochodzi od odkrywcy, niejakiego *Magnesa*, który wspinając się na górę Ida zauważył, że gwoździe jego sandałów przyczepiają się do skały.

...

ok. 1080 r. pierwszy opis magnezu w Chinach

1175 - 1183 r. pierwsze odniesienie do kompasu – Alexander Neckem, angielski mnich z St. Albans, opisuje działający kompas w dziele *De Nominibus Utensilium* (O nazwach rzeczy).

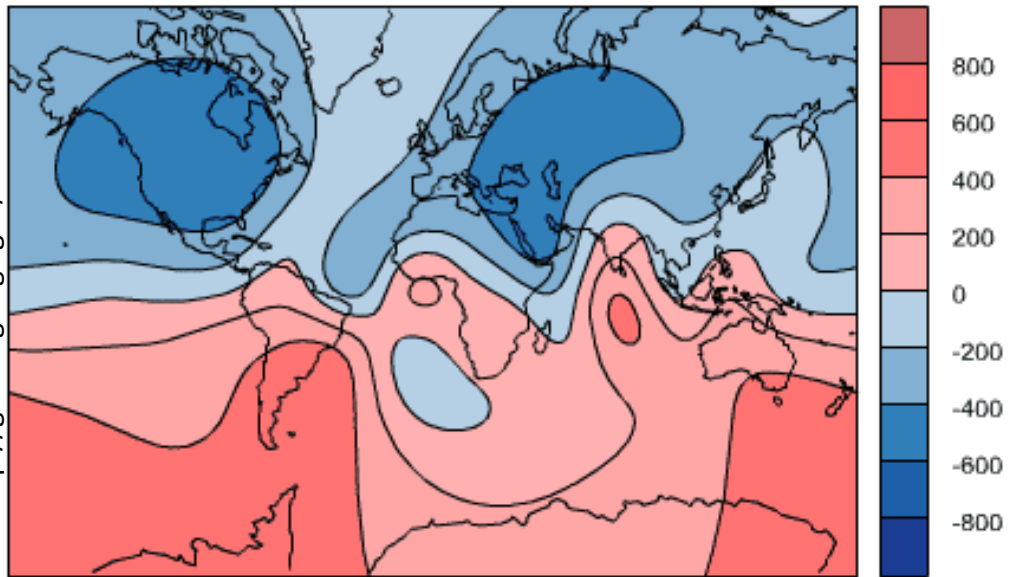
1269 – pierwszy szczegółowy opis do kompasu – Petrus Peregrinus de Marincourt, francuski krzyżowiec opisuje jak zbudowany jest kompas

Magnetyt - Fe_3O_4 , rdza – Fe_2O_3 ,

From Lodestone to Supermagnets. Alberto P. Guimarães

Trochę historii

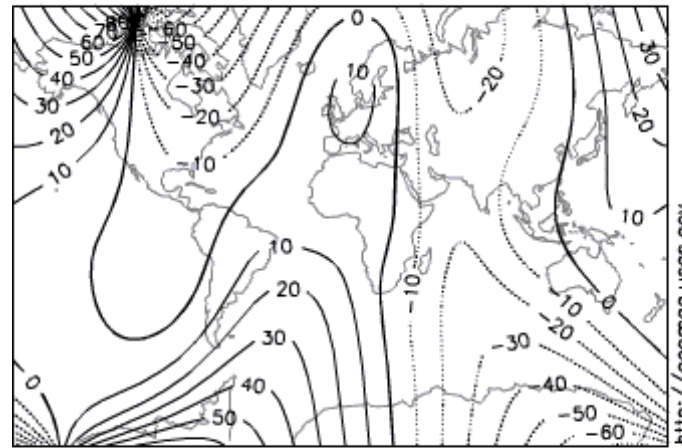
1590
Radial Core Field (relative values)



Model by A. Jackson, A. R. T. Jonkers, M. R. Walker,
Phil. Trans. R. Soc. London A (2000), 358, 957-990.

<http://geomag.usgs.gov>

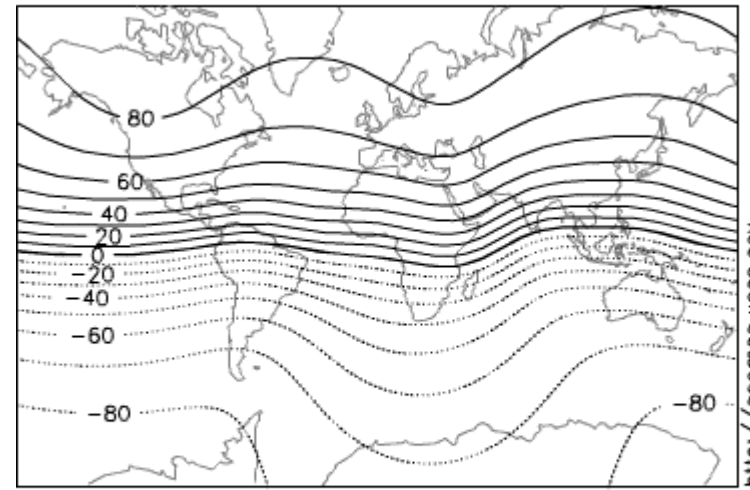
1590
Declination (degrees east)



Model by A. Jackson, A. R. T. Jonkers, M. R. Walker,
Phil. Trans. R. Soc. London A (2000), 358, 957-990.

<http://geomag.usgs.gov>

1590
Inclination (degrees down)



Model by A. Jackson, A. R. T. Jonkers, M. R. Walker,
Phil. Trans. R. Soc. London A (2000), 358, 957-990.

<http://geomag.usgs.gov>

Trochę historii

William Gilbert (1544-1603) w dziele "De magnete" zajął się magnetyzmem i m.in. napisał, że sama Ziemia jest magnesem.

1740 r. pierwszy komercyjny magnes - Gowen Knight oferuje naturalne magnesy naukowcom i navigatorom. Magnesowanie przez pocieranie.

1820 r. Hans Christian Oersted odkrył pole magnetyczne wokół przewodnika w którym płynie prąd.

1823 r. William Sturgeon zbudował pierwszy elektromagnes. Ok. 1825 solenoidy (cewki) budował także Andre Marie Ampere. M.in. odkrył, że poprzez namagnesowanie w cewce można uzyskać magnesy mocniejsze od naturalnych

1855 r. prawa indukcji Michaela Faradaya

1860 r. pierwszy silnik stałoprądowy Zenobe Theophile Gramme. Wcześniej prototypowe silniki budowali Oersted (1820), Faraday (1821), Jacobi (1834), Elias (1842), Froment (1844) oraz Pacinotti (1860)

1871 r. generator prądu stałego Z.T Gramme udoskonalony w 1872 r. przez Niemców Wernera von Siemens i Johanna Georga Halskego.

1873 - Maxwell publikuje *Treatise on Electricity and Magnetism*

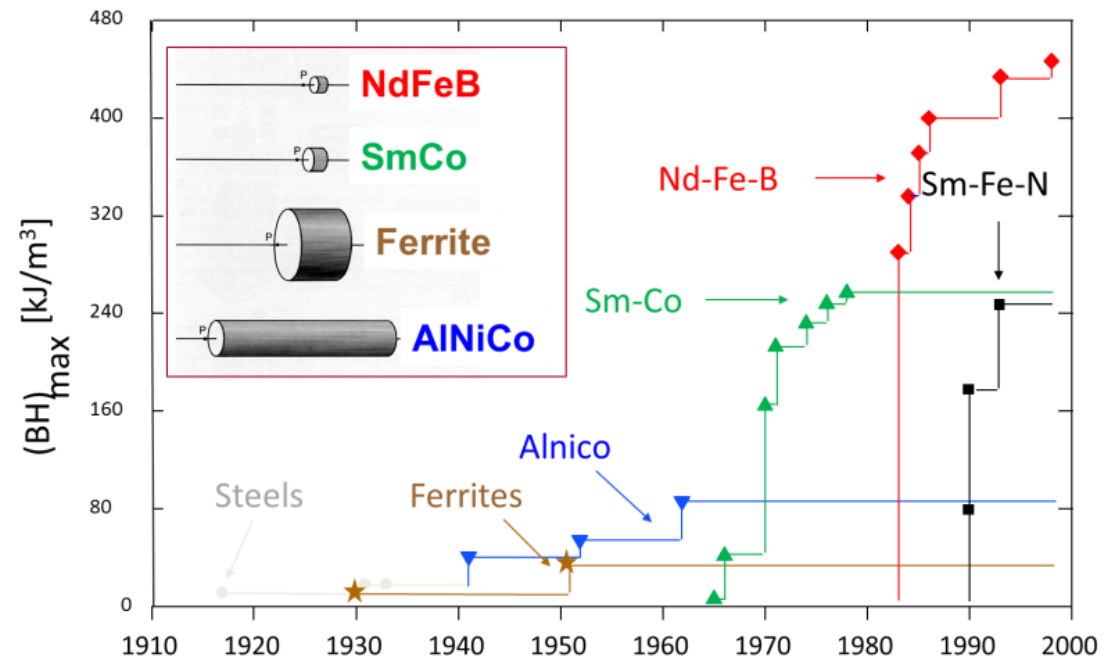
http://www.rare-earth-magnets.com/magnet_university/history_of_magnetism.htm

Trochę historii

- 1895 r. Pierre Curie odkrywa, że ferromagnetyki tracą swoje własności po przekroczeniu pewnej temperatury.
- 1917 r. magnesy kobaltowe: K. Honda and T. Takai
- 1919 r. komercyjne magnesy stalowe
- 1930 r. magnesy Alnico: I. Mishima tworzy stop Al, Ni, Fe
- 1952 r. magnesy ceramiczne Phillipsa (J.J. Went, G.W. Rathenau, E.W. Gorter, G.W. Van Oosterhout) Ba, Sr, Fe, Pb i O.
- 1966 r. magnesy z ziem rzadkich dr Karl J. Strnat z U.S. Air Force Materials Laboratory w bazie sił powietrznych Wright-Patterson odkrywa silny magnes 18 MGOe) Samar-Cobalt (SmCo_5)
- 1972 r. Zaawansowane magnesy ziem rzadkich Karl J. Strnat oraz Alden Ray (30 MGOe) Samar-Cobalt ($\text{Sm}_2\text{Co}_{17}$).
- 1983 – magnesy żelazo-neodym-bor $\text{Nd}_2\text{Fe}_{14}\text{B}$ Magnets General Motors, Sumitomo Special Metals oraz Chińska Akademia Nauk odkrywają rekordowy stop $\text{Nd}_2\text{Fe}_{14}\text{B}$ (35 MGOe).
- rekord z 2002 r. naukowcy z Vacuumschmelze GmbH uzyskali w laboratorium 55.6 MGOe Nd-Fe-B (limit teoretyczny ok. 144 MGOe)

Źródło: różne

Trochę historii



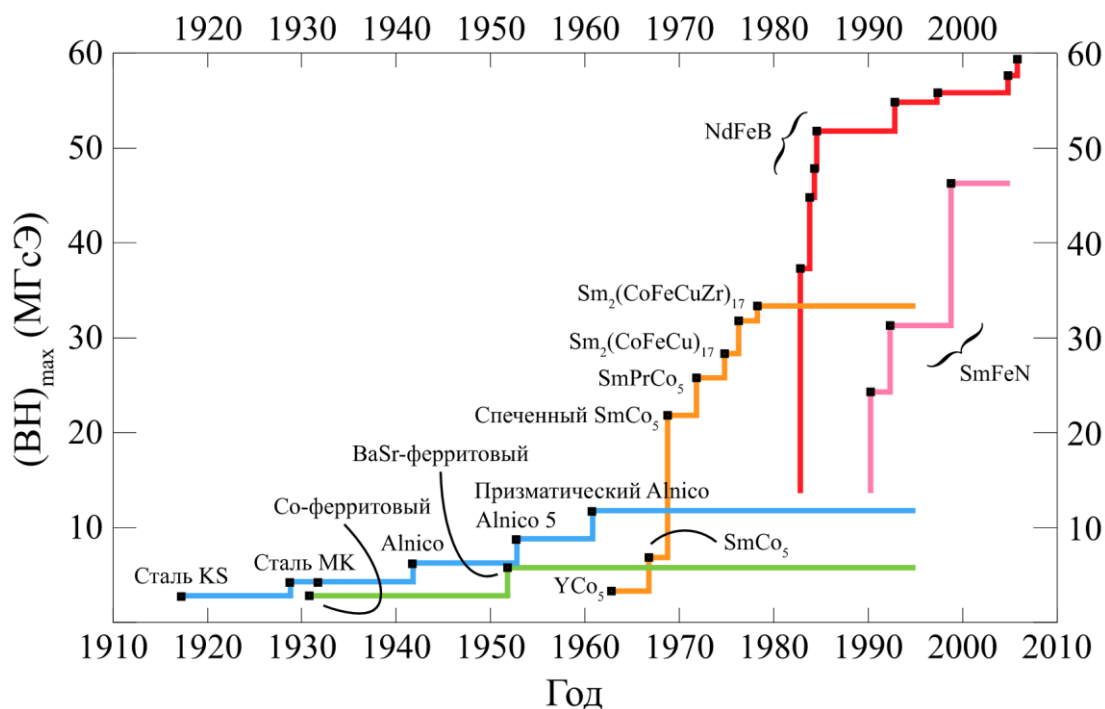
Magnetyt (z 1750 r.) typowy ferryt i magnes z ziem rzadkich. Każdy z nich o gęstości energii 1J.

https://www.mawi.tu-darmstadt.de/fm/funktionale_materialien/research_topics/permanent_magnetics/index_pm_3.en.jsp

<http://www.tcd.ie/Physics/Schools/what/materials/magnetism/seven.html>

A lodestone magnet from the 1750's and typical ferrite and rare earth used in modern appliances. Each of these produce about 1J of energy.

Trochę historii



Magnetyt (z 1750 r.) typowy ferryt i magnes z ziem rzadkich. Każdy z nich o gęstości energii 1J.

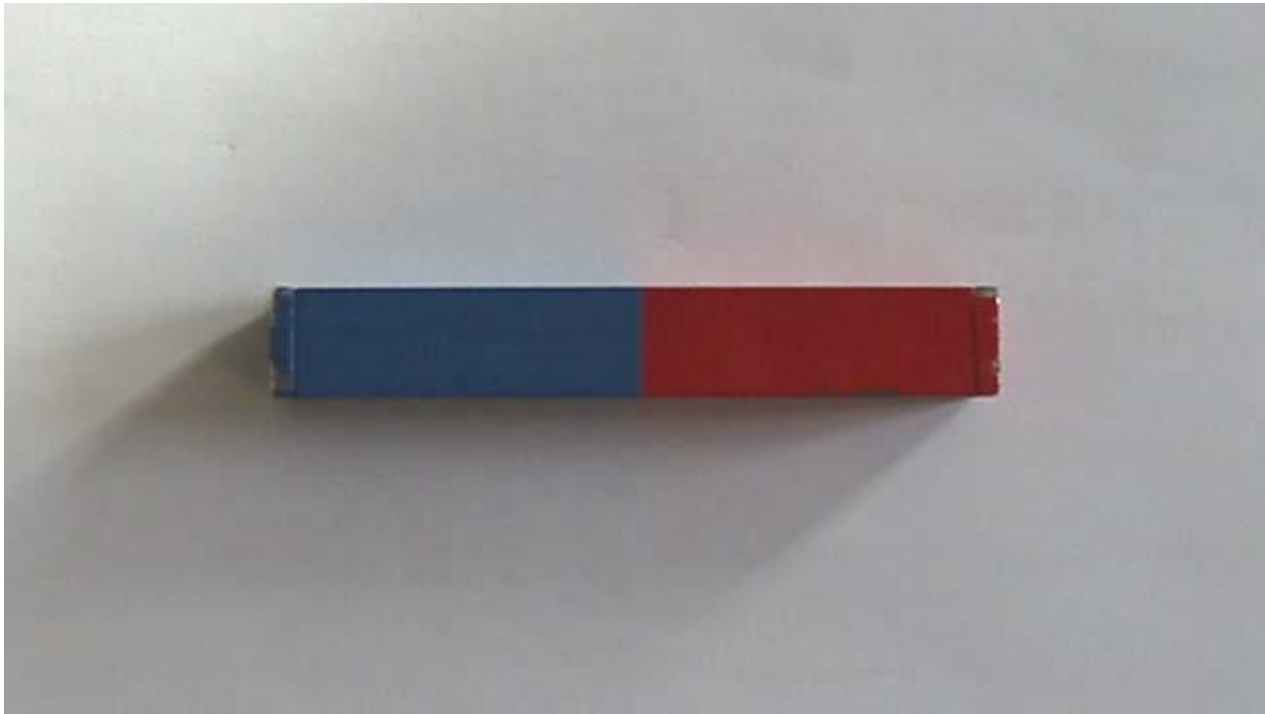
https://commons.wikimedia.org/wiki/File:The_energy_product_of_major_class_of_Permanent_Magnets.svg

<http://www.tcd.ie/Physics/Schools/what/materials/magnetism/seven.html>

A lodestone magnet from the 1750's and typical ferrite and rare earth used in modern appliances. Each of these produce about 1J of energy.

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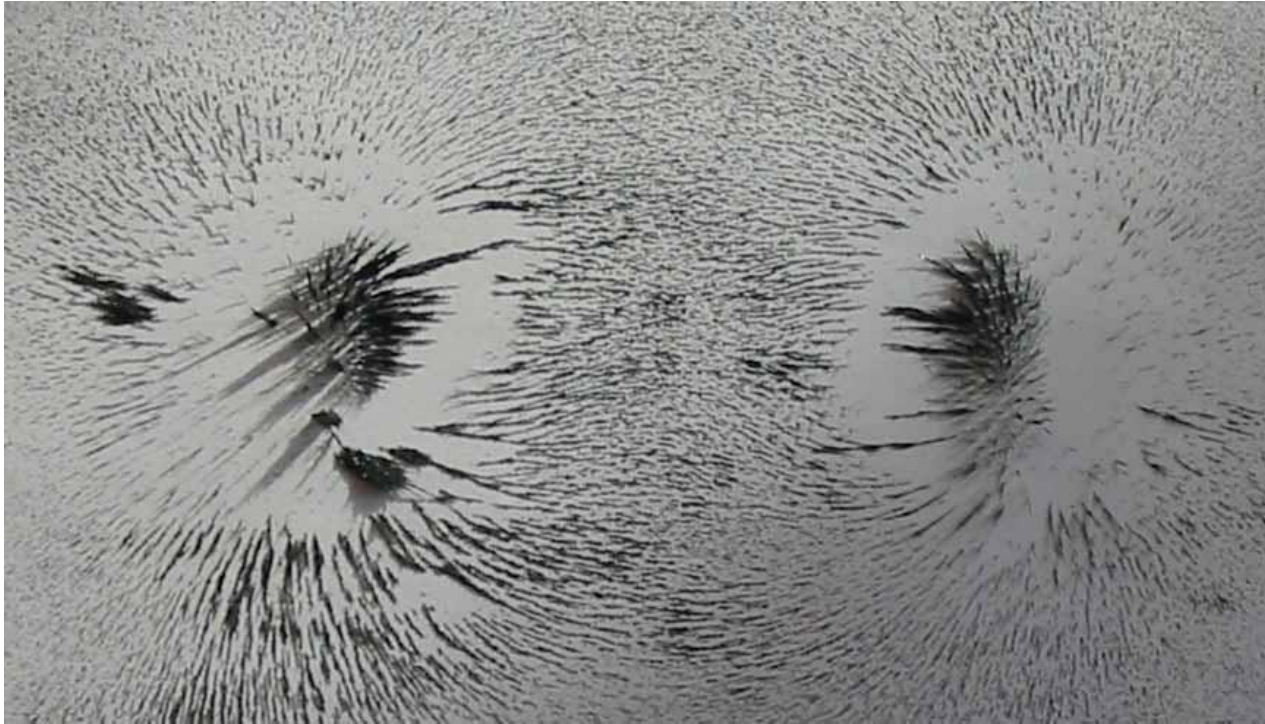
Skąd się biorą magnesy?



http://lucy.troja.mff.cuni.cz/~tichy/elektross/magn_pole/stac_mp.html

Co to jest spin?

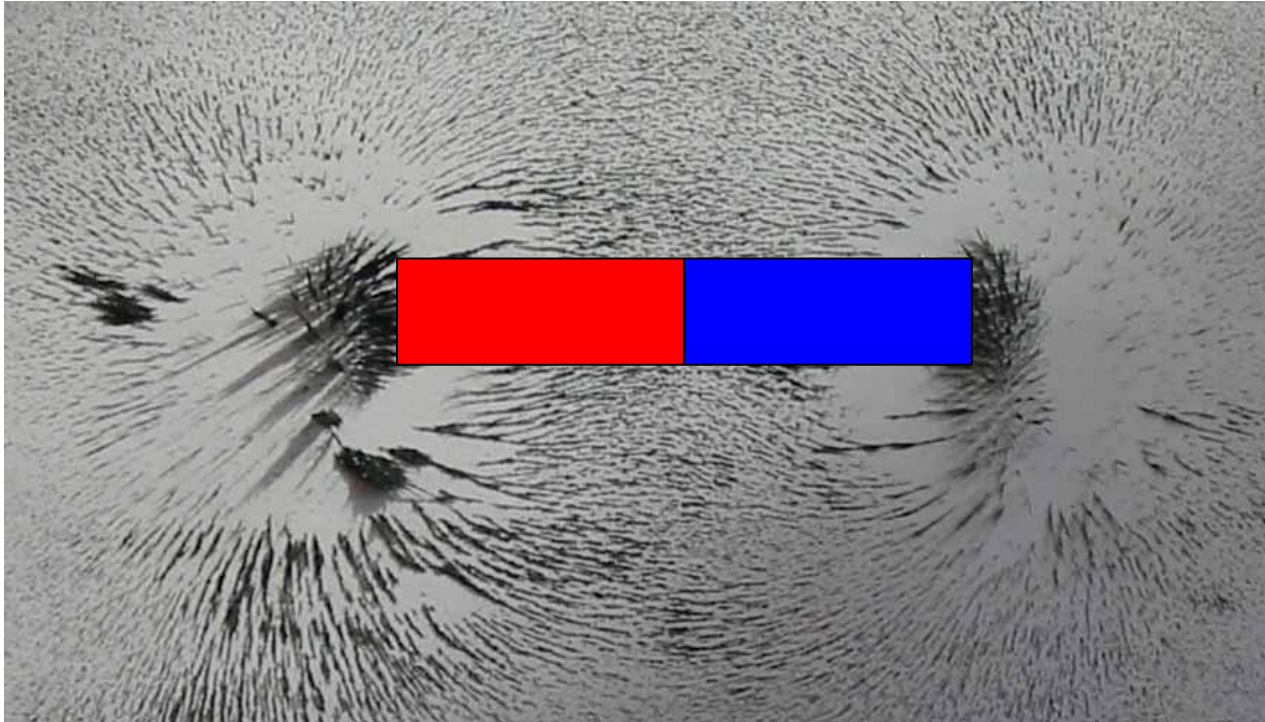
Skąd się biorą magnesy?



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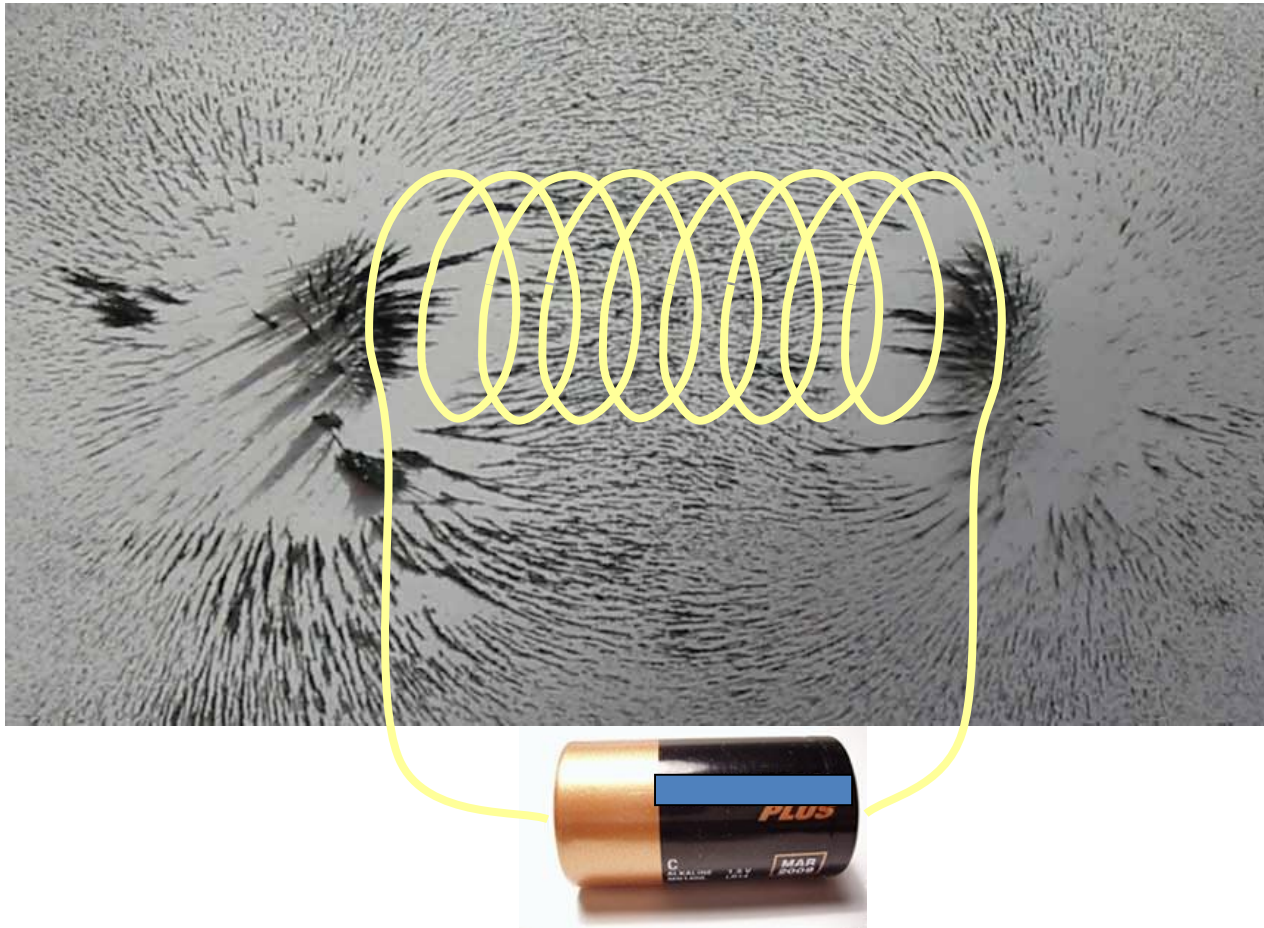
Co to jest spin?

Skąd się biorą magnesy?



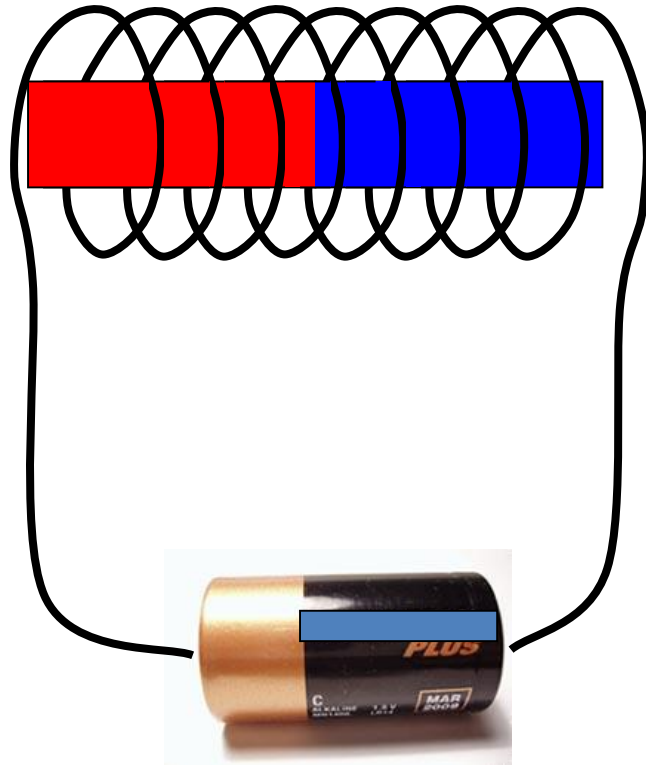
Co to jest spin?

Skąd się biorą magnesy?



Co to jest spin?

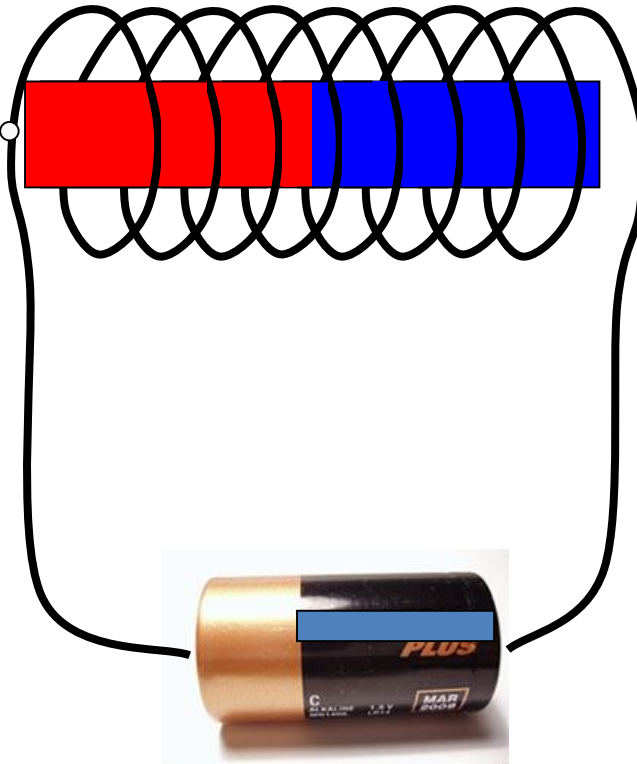
Skąd się biorą magnesy?



Co to jest spin?

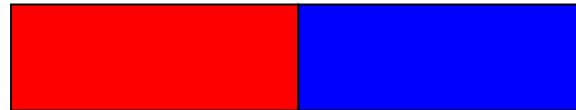
Skąd się biorą magnesy?

Poruszające się ładunki
wywołują pole
magnetyczne...



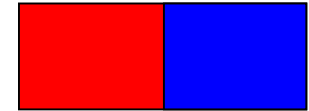
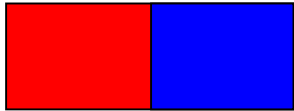
Co to jest spin?

Skąd się biorą magnesy?



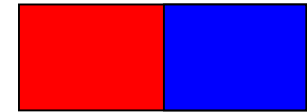
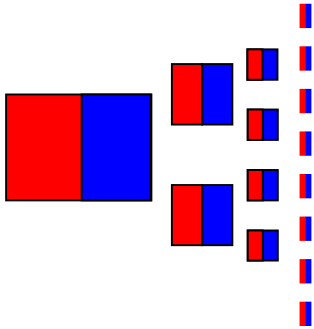
Co to jest spin?

Skąd się biorą magnesy?



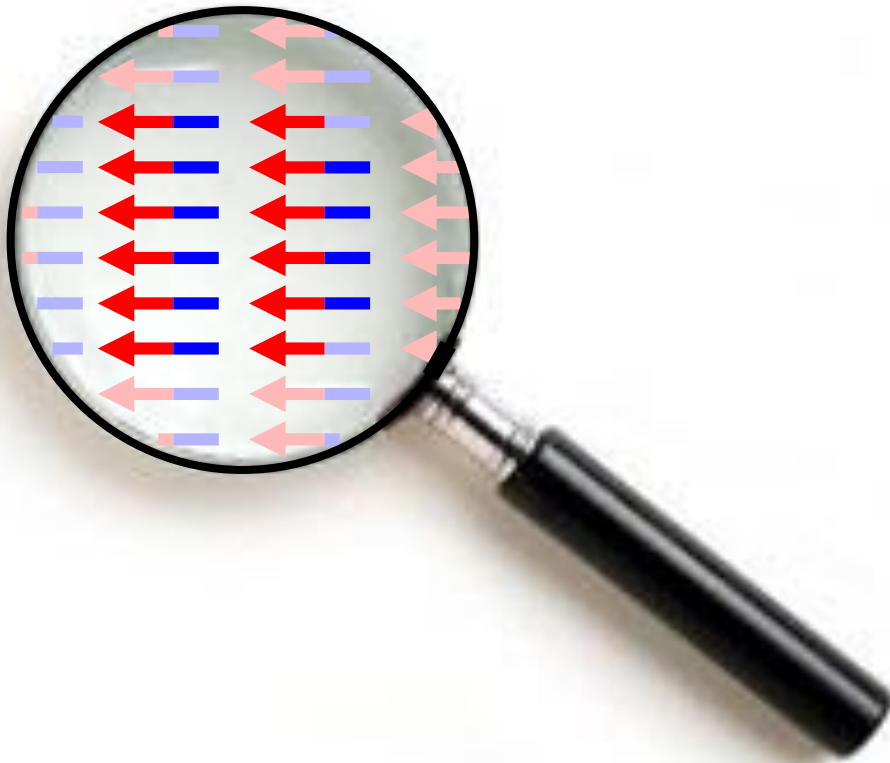
Co to jest spin?

Skąd się biorą magnesy?



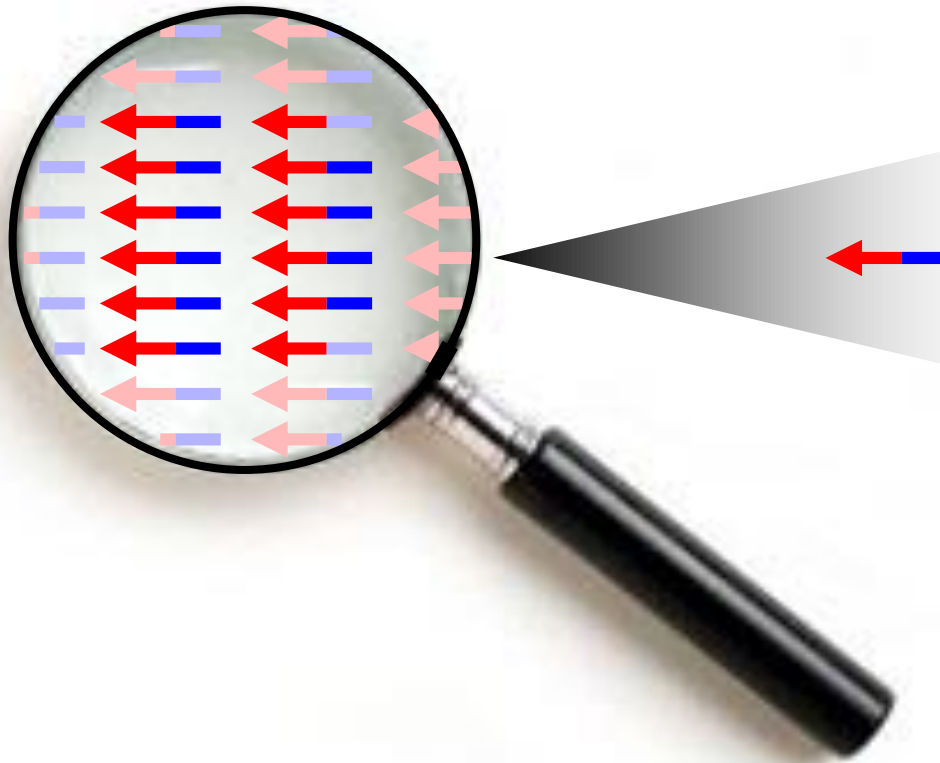
Co to jest spin?

Skąd się biorą magnesy?



Co to jest spin?

Skąd się biorą magnesy?



Te małe magnesiki to elektrony

Co to jest spin?

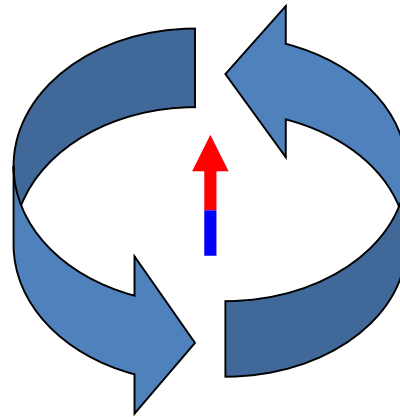
Skąd się biorą magnesy?



Te małe magnesiki to elektrony

Co to jest spin?

Skąd się biorą magnesy?



A więc płynie jakiś prąd?

Co to jest spin?

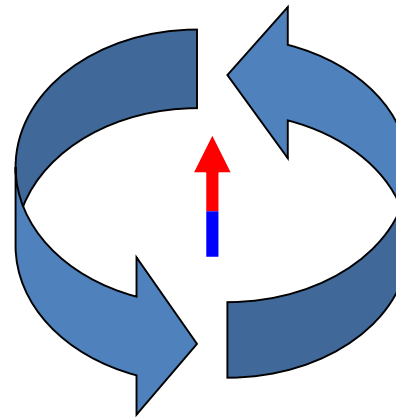
Skąd się biorą magnesy?

Ruch elektronów
wokół jąder
atomowych?

Ruch elektronów
wokół osi?

A więc płynie jakiś prąd?

Wewnętrzna własność
elektronów?

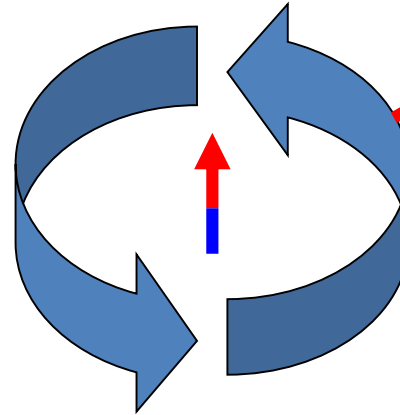


Co to jest spin?

Skąd się biorą magnesy?

~~Ruch elektronów
wokół jąder
atomowych?~~

~~Ruch elektronów
wokół osi?~~



Wewnętrzna własność
elektronów?

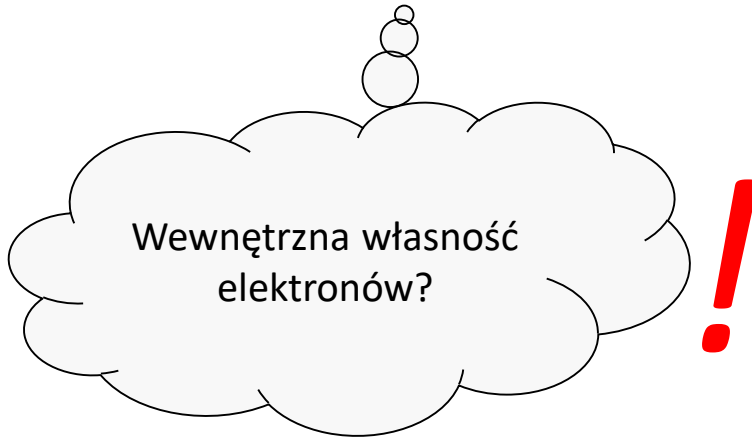
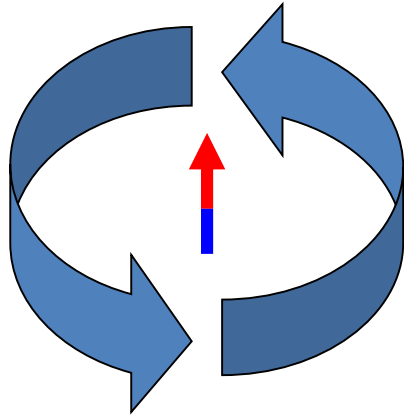
tzw: **Wewnętrzny moment pędu**
czyli **SPIN**

tak samo jak **masa** albo **ładunek**



Co to jest spin?

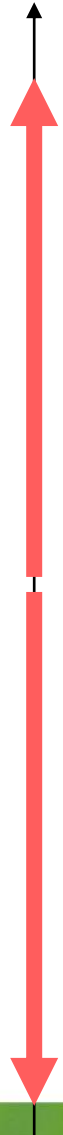
Kwantowy moment pędu



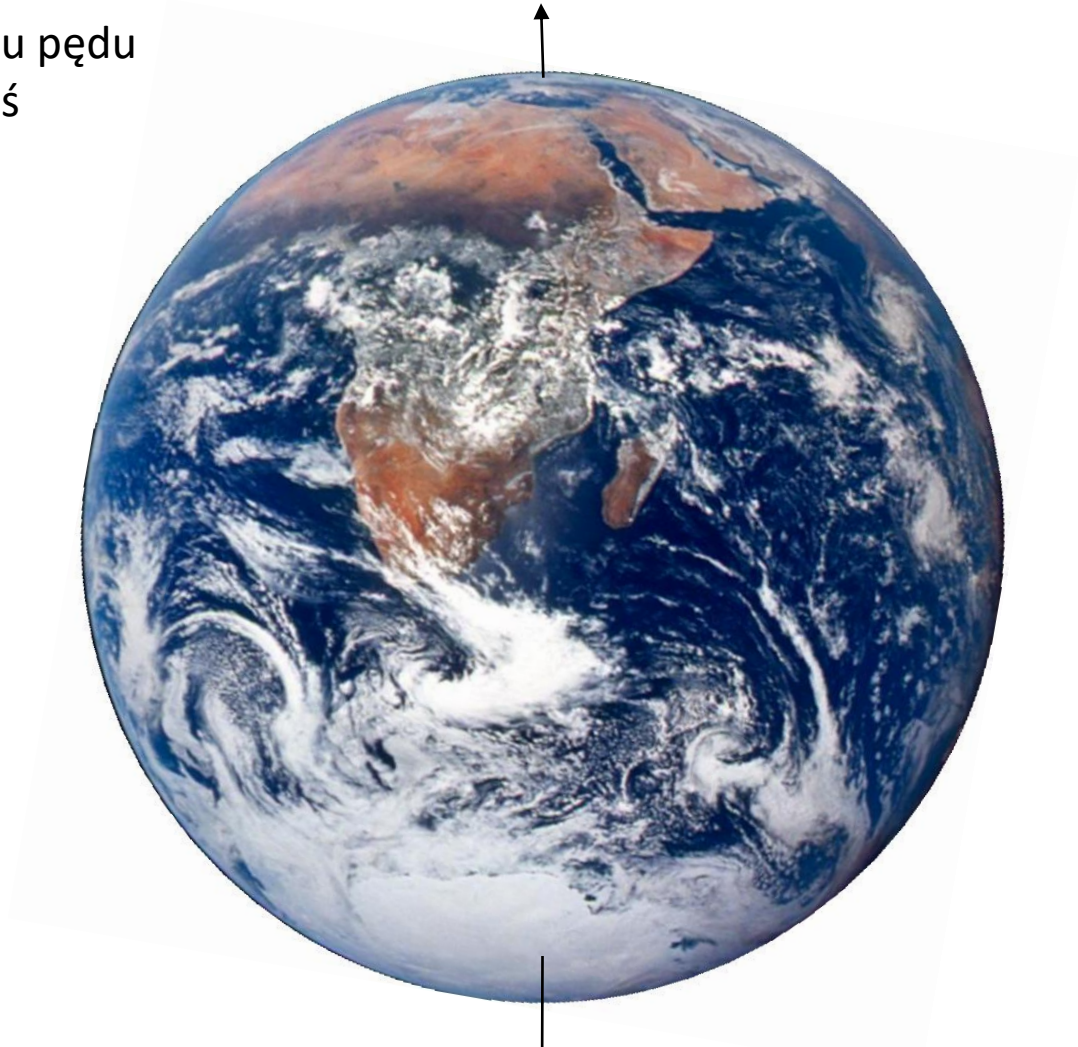
Albert **Einstein** - Johannes Wander **de Haas**,
Berlin 1914,



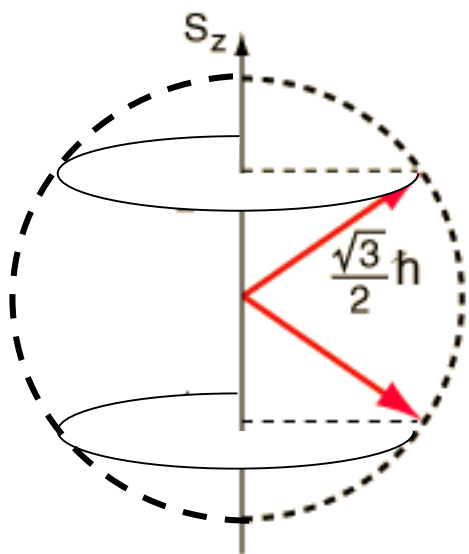
Co to jest spin?



Rzut momentu pędu
na wybraną oś



Co to jest spin?

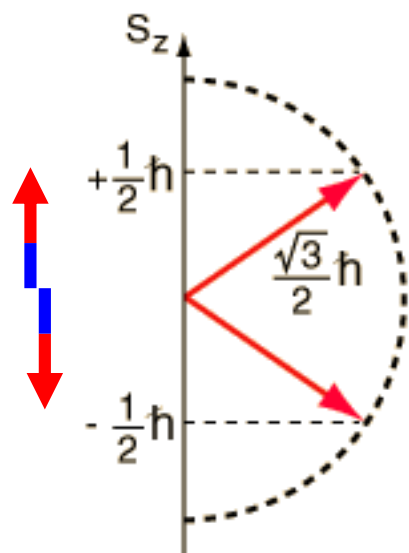


Rzut momentu pędu elektronu na **dowolną** oś ma tylko dwie możliwe wartości:

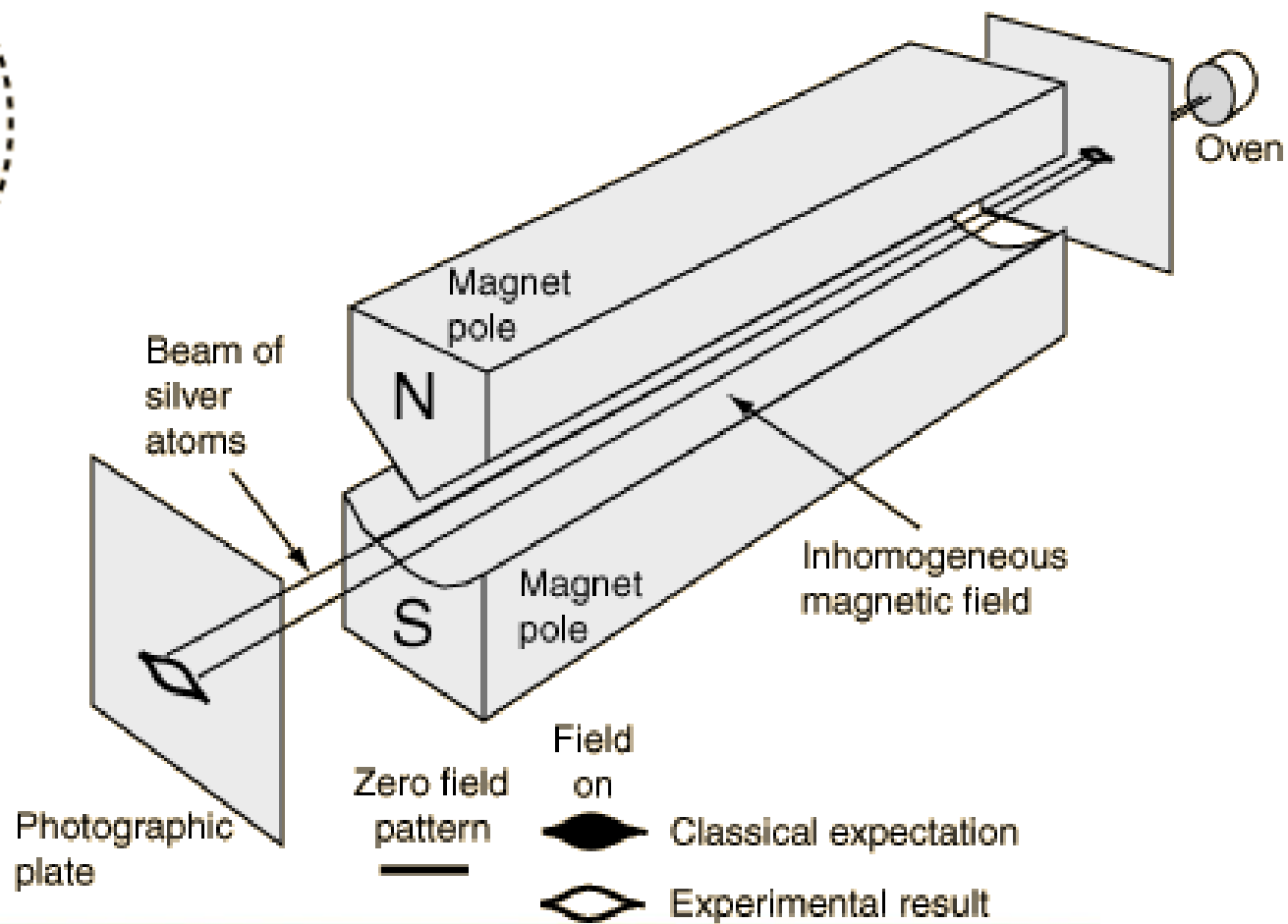
$$+\frac{1}{2}\hbar \uparrow \quad -\frac{1}{2}\hbar \downarrow$$



Co to jest spin?



Eksperyment Sterna-Gerlacha (1922 r.)



No dobra, ale...

- **Co to jest spin?**

Co to jest spin?

- Co to jest masa?

$$\vec{F} = m \vec{a}$$

$$F = G \frac{m_1 m_2}{r^2}$$



Mariusz Pudzianowski <http://www.pudzian.pl/>

Co to jest spin?

- Co to jest ładunek?

$$F = k \frac{q_1 q_2}{r^2}$$



Co to jest spin?

- Co to jest pęd?

$$\vec{p} = m \vec{v}$$



Co to jest spin?

- Co to jest moment pędu?

$$\vec{L} = \vec{r} \times \vec{p}$$



Co to jest spin?

- Spin?



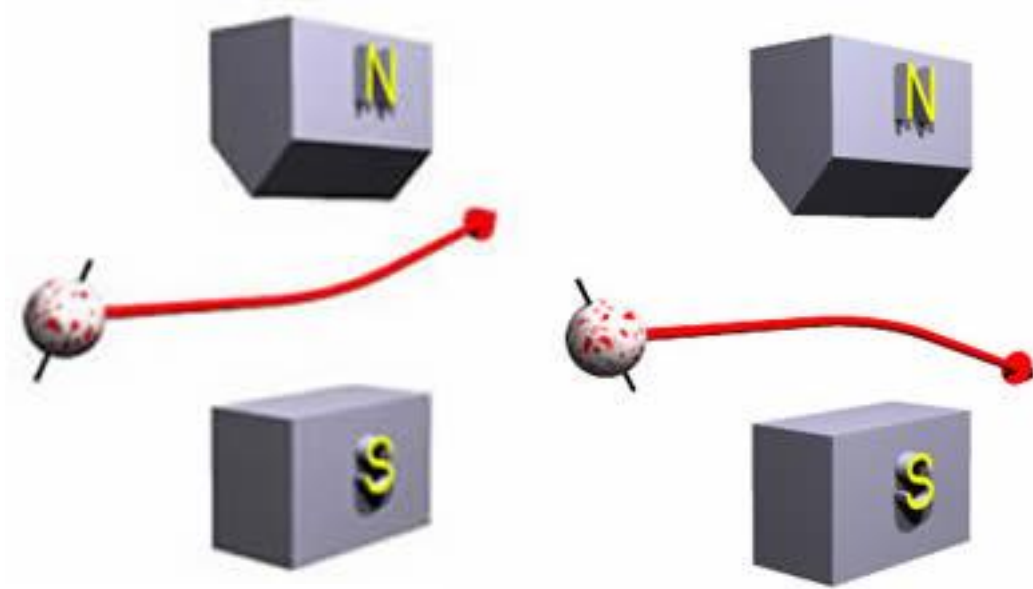
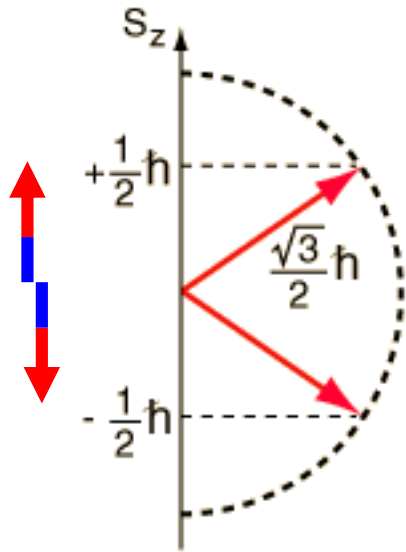
Sebastian Münster, *Cosmographia* in 1544



Disney

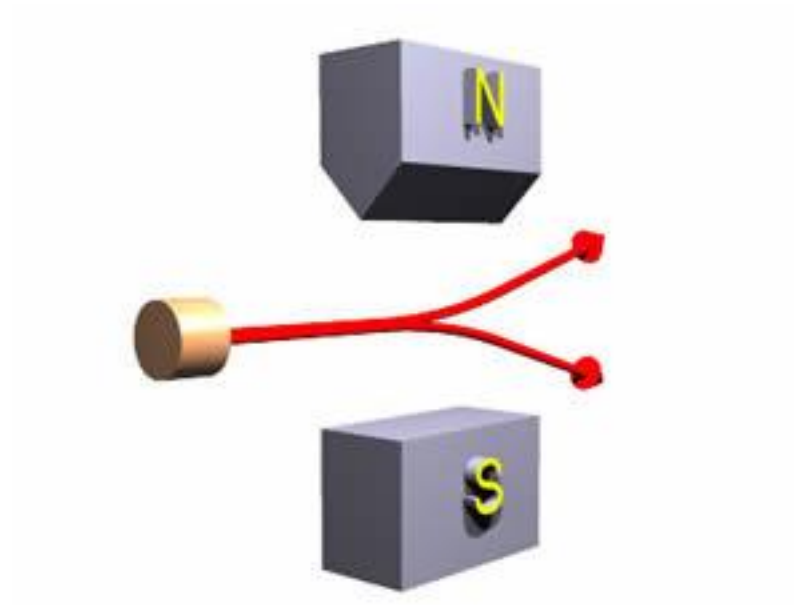
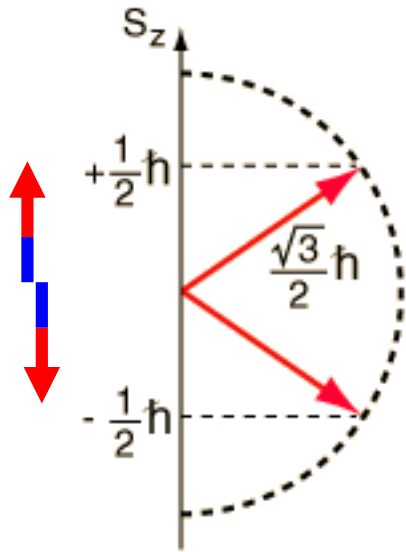
<http://www.floridahistory.com/us@1570.html>

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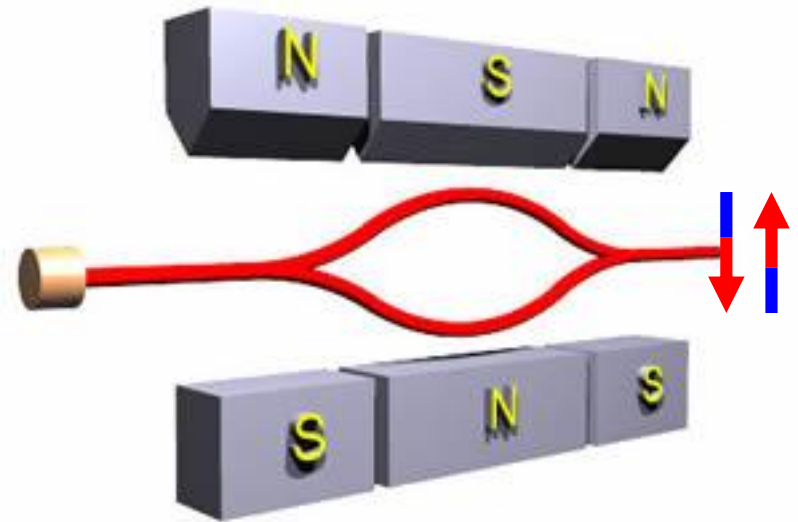
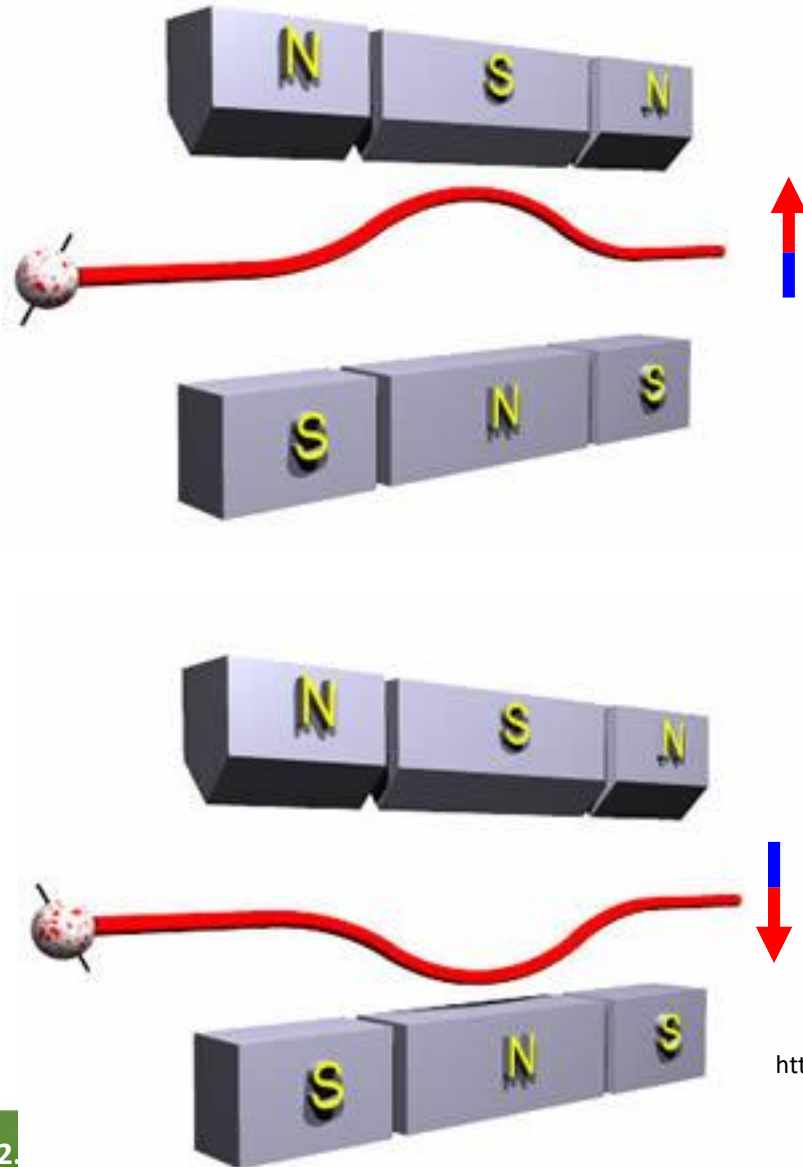
<http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SternGerlach/SternGerlach.html>

Co to jest spin?



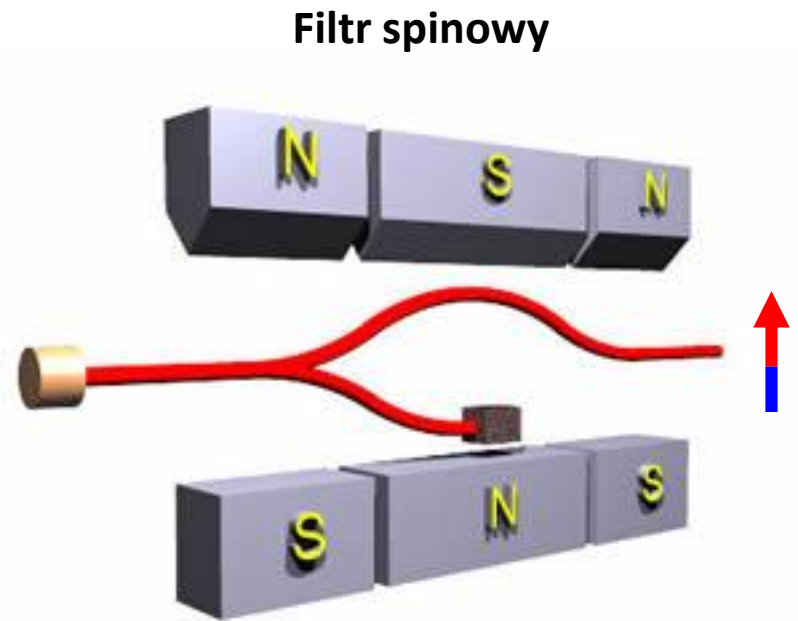
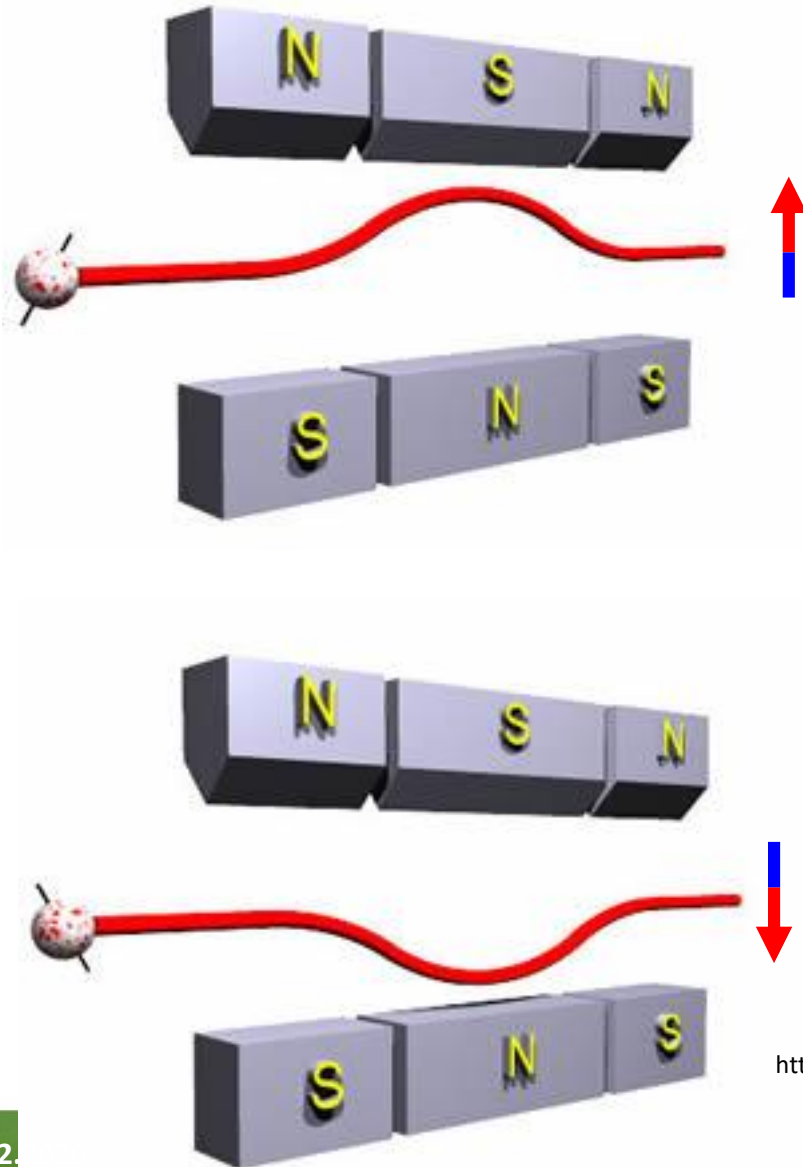
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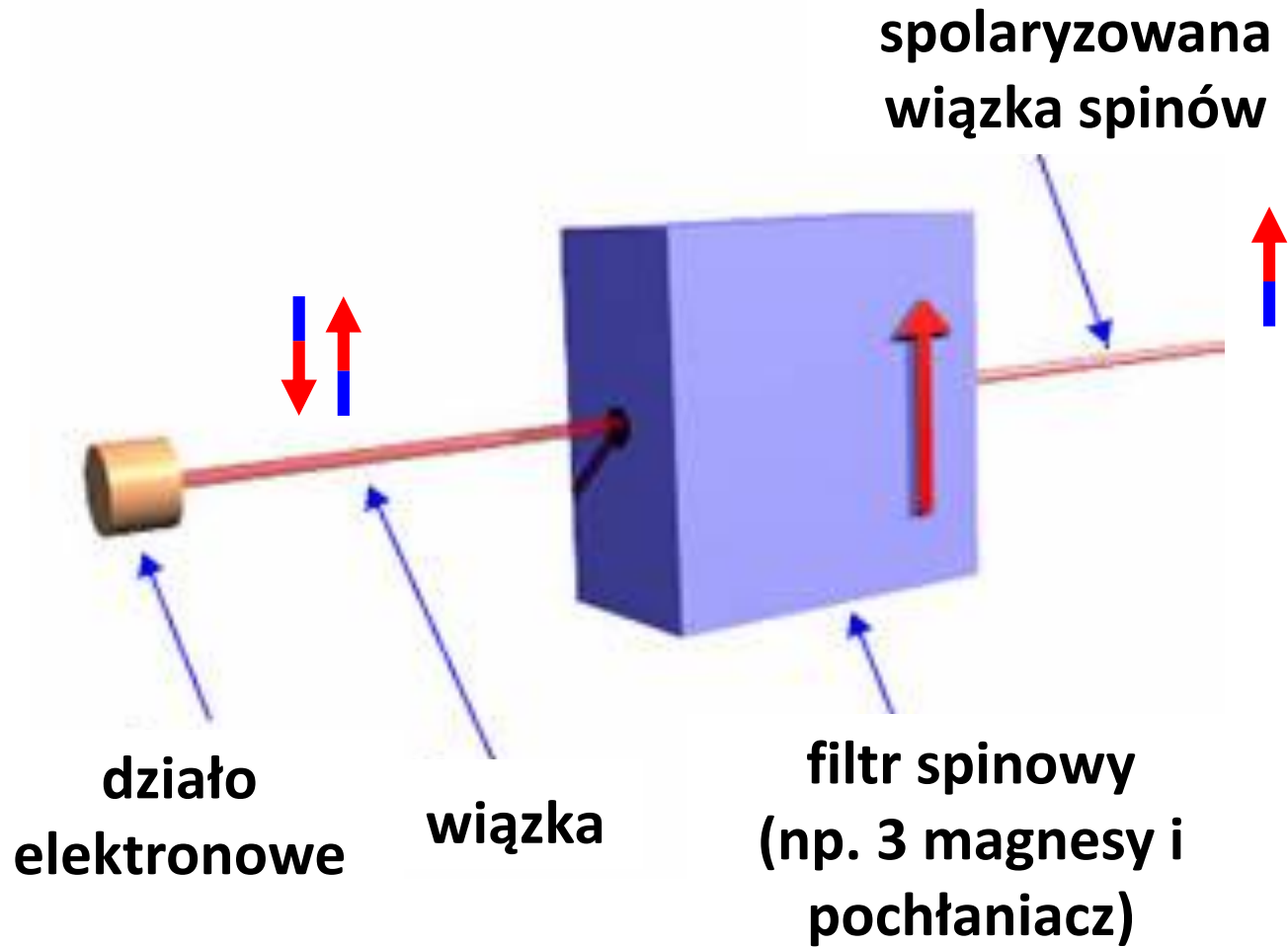
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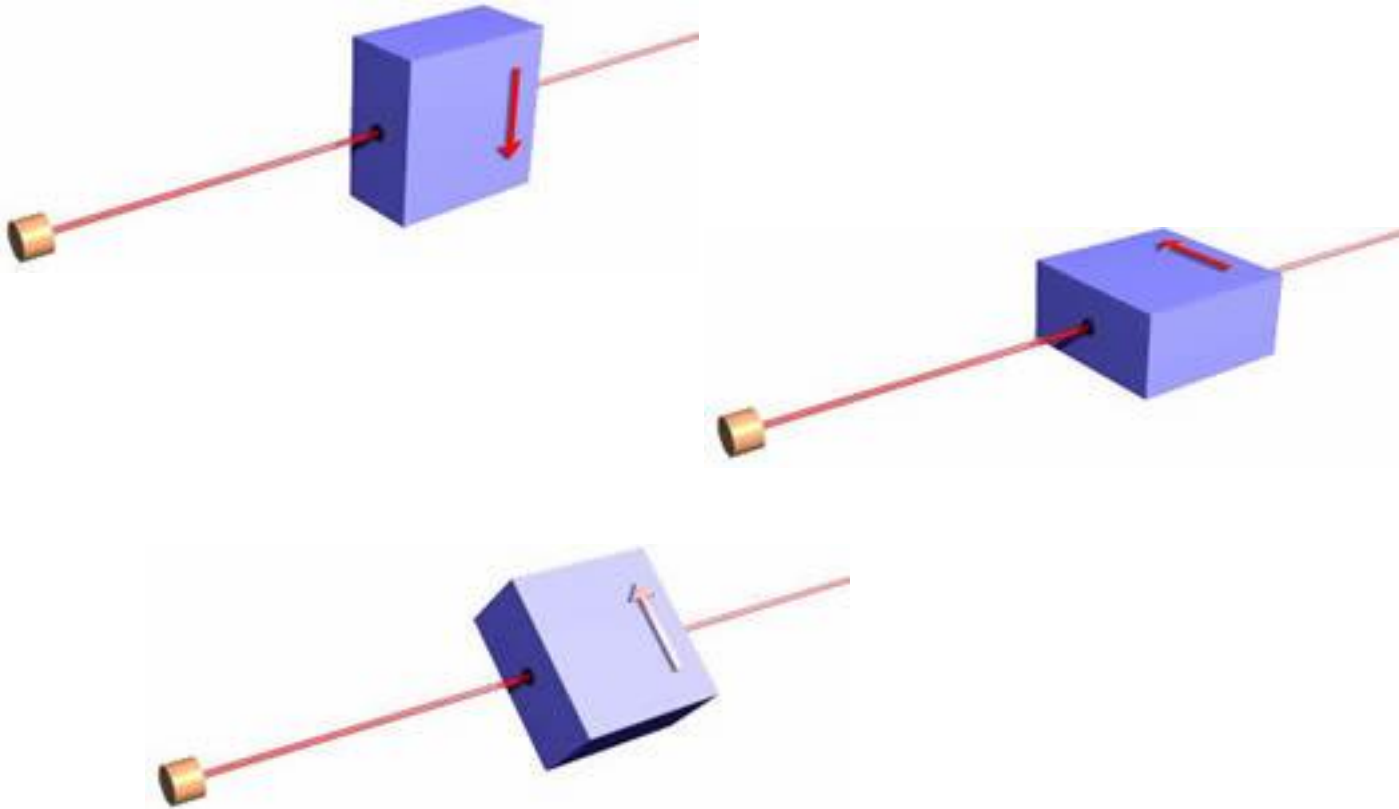
<http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SternGerlach/SternGerlach.html>

Filtr spinowy



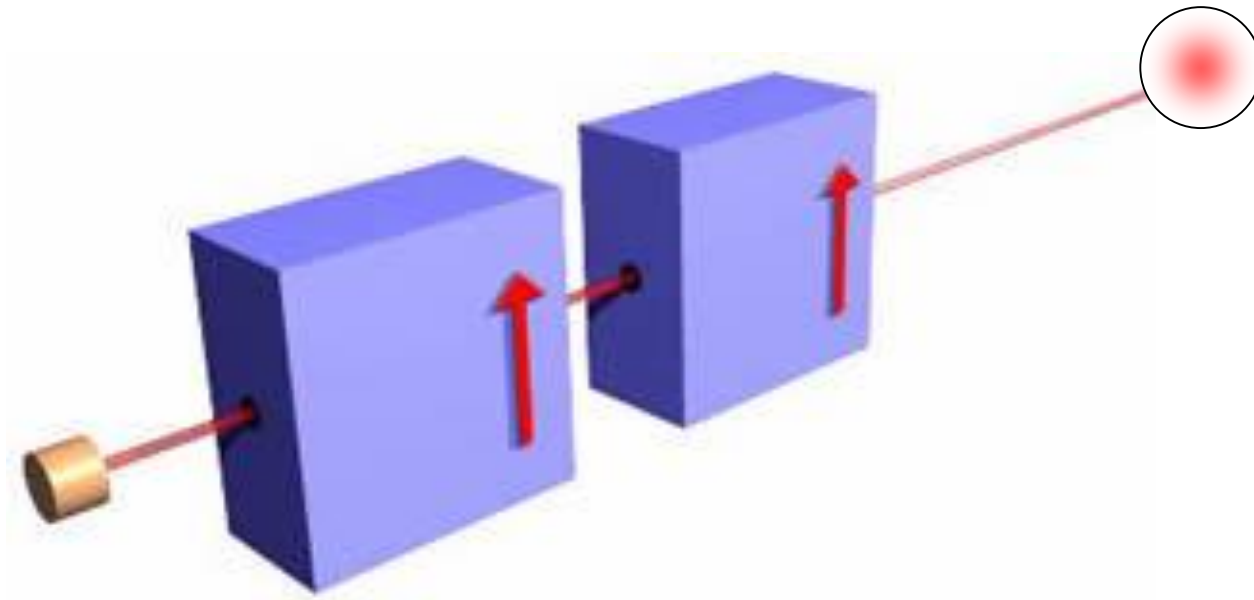
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Filtr spinowy



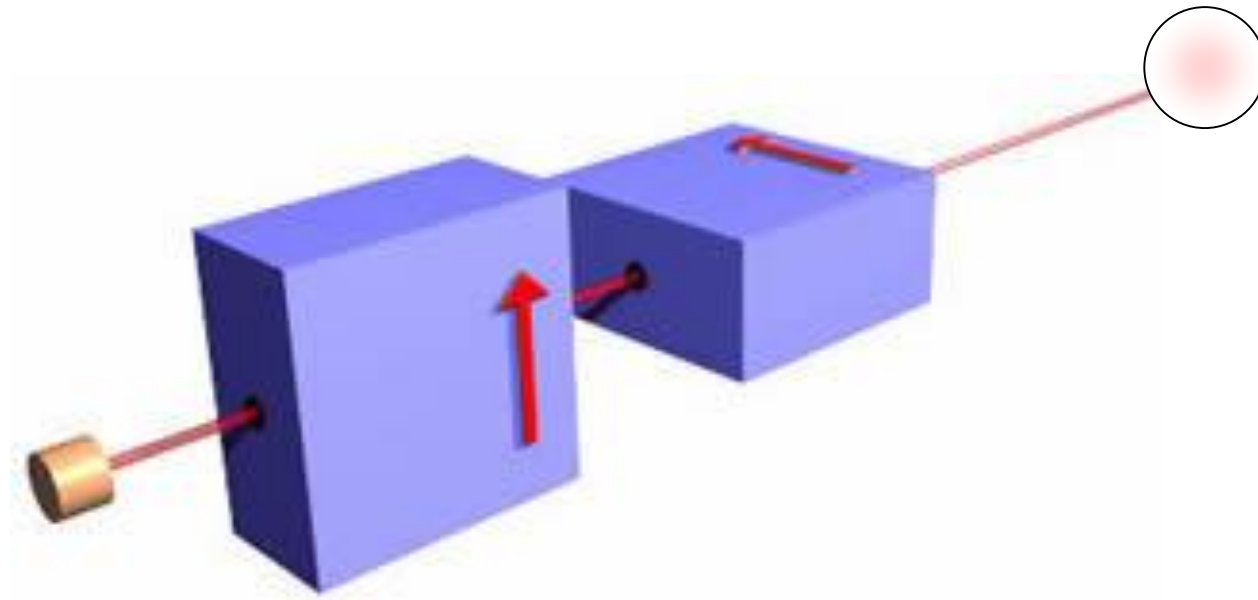
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Filtr spinowy



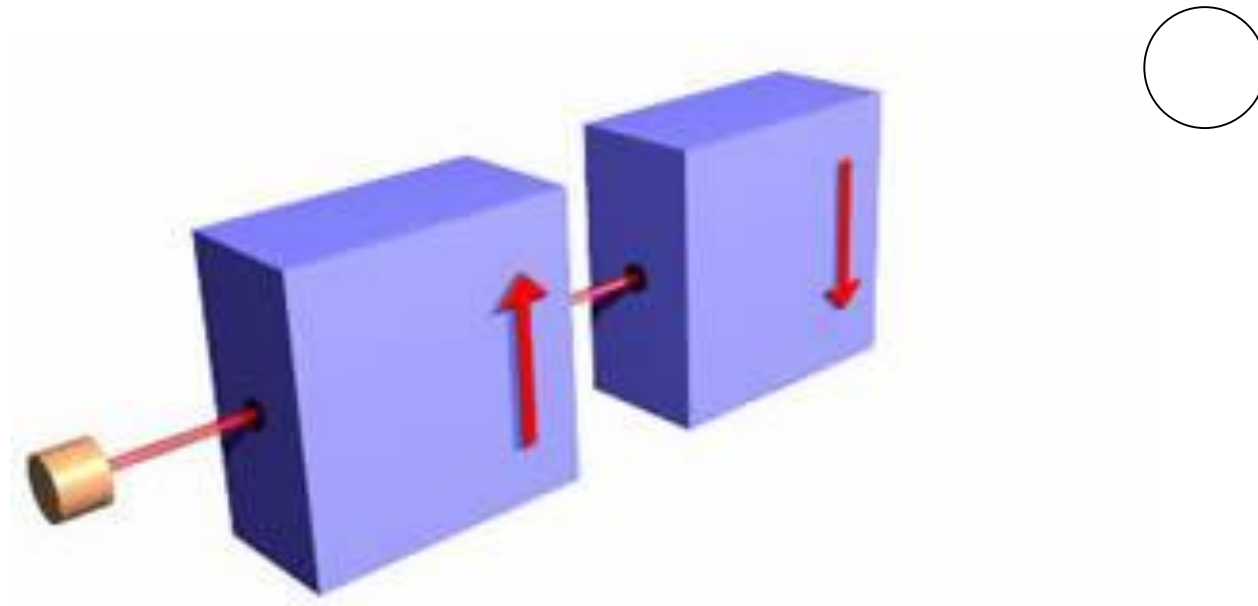
<http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SternGerlach/SternGerlach.html>

Filtr spinowy



<http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SternGerlach/SternGerlach.html>

Filtr spinowy



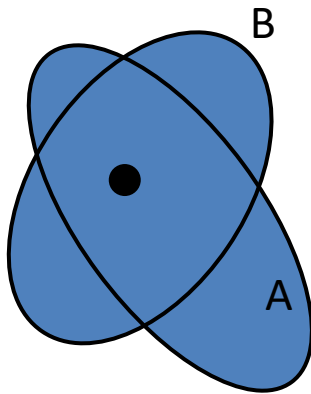
<http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SternGerlach/SternGerlach.html>

Rodzaje oddziaływań wymiennych

Oddziaływanie wymienne = Oddziaływanie kulombowskie + Zasada Pauliego

$$\Psi = \Psi_{\text{orbitalna}} \times \Psi_{\text{spinowa}} \quad \underline{\text{Antysymetryczna!}}$$

Przykład:



Dwa elektrony zlokalizowane na jednym centrum

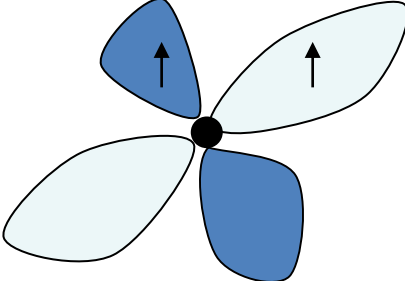
$$\mathcal{H}(1, 2) = H_0(1) + H_0(2) + \frac{e^2}{r_{12}}$$

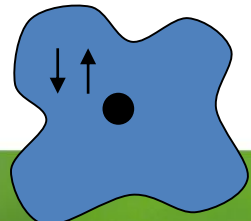
Rodzaje oddziaływań wymiennych

Oddziaływanie wymienne = Oddziaływanie kulombowskie + Zasada Pauliego

$$\Psi = \Psi_{\text{orbitalna}} \times \Psi_{\text{spinowa}} \quad \underline{\text{Antysymetryczna!}}$$

Reguły Hunda, $E_T < E_S$

$$\frac{1}{\sqrt{2}} [\varphi_A(1)\varphi_B(2) - \varphi_A(2)\varphi_B(1)] \times \left[\begin{array}{c} \chi_{\uparrow}(1)\chi_{\uparrow}(2) \\ \frac{1}{\sqrt{2}} [\chi_{\uparrow}(1)\chi_{\downarrow}(2) + \chi_{\downarrow}(1)\chi_{\uparrow}(2)] \\ \chi_{\downarrow}(1)\chi_{\downarrow}(2) \end{array} \right]$$


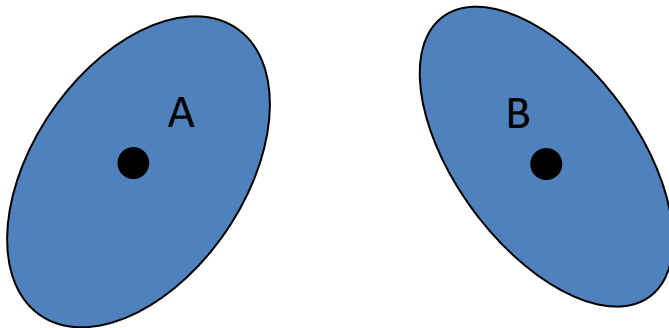
$$\frac{1}{\sqrt{2}} [\varphi_A(1)\varphi_B(2) + \varphi_A(2)\varphi_B(1)] \frac{1}{\sqrt{2}} [\chi_{\uparrow}(1)\chi_{\downarrow}(2) - \chi_{\downarrow}(1)\chi_{\uparrow}(2)]$$


Rodzaje oddziaływań wymiennych

Oddziaływanie wymienne = Oddziaływanie kulombowskie + Zasada Pauliego

$$\Psi = \Psi_{\text{orbitalna}} \times \Psi_{\text{spinowa}} \quad \underline{\text{Antysymetryczna!}}$$

Przykład:



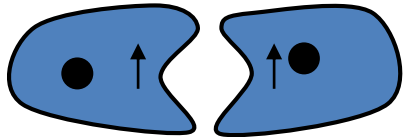
Dwa elektrony na dwóch różnych centrach

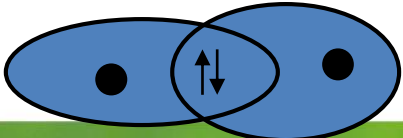
$$\mathcal{H}(1, 2) = H_0^A(1) + H_0^B(2) + \frac{e^2}{r_{12}}$$

Rodzaje oddziaływań wymiennych

Oddziaływanie wymienne = Oddziaływanie kulombowskie + Zasada Pauliego

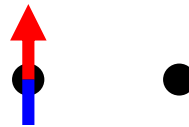
$$\Psi = \Psi_{\text{orbitalna}} \times \Psi_{\text{spinowa}} \quad \underline{\text{Antysymetryczna!}}$$

$$\frac{1}{\sqrt{2}} [\varphi_A(1)\varphi_B(2) - \varphi_A(2)\varphi_B(1)] \times \left[\begin{array}{c} \chi_{\uparrow}(1)\chi_{\uparrow}(2) \\ \frac{1}{\sqrt{2}} [\chi_{\uparrow}(1)\chi_{\downarrow}(2) + \chi_{\downarrow}(1)\chi_{\uparrow}(2)] \\ \chi_{\downarrow}(1)\chi_{\downarrow}(2) \end{array} \right]$$


$$\frac{1}{\sqrt{2}} [\varphi_A(1)\varphi_B(2) + \varphi_A(2)\varphi_B(1)] \frac{1}{\sqrt{2}} [\chi_{\uparrow}(1)\chi_{\downarrow}(2) - \chi_{\downarrow}(1)\chi_{\uparrow}(2)]$$


Wiązania chemiczne, $E_S < E_T$

Magnes

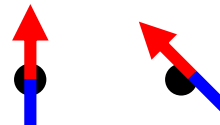


Oto kryształ:

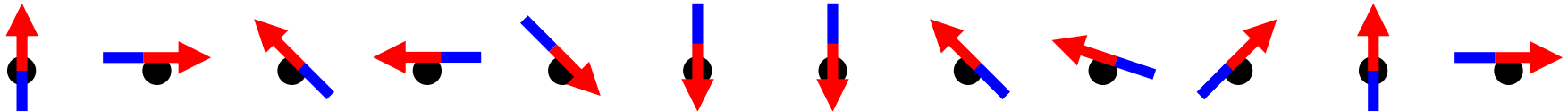


Magnes

PARA

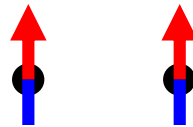


Namagnesowanie M przy braku pola $M = 0$



Magnes

FERRO

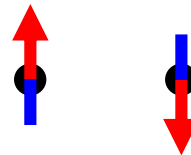


Namagnesowanie M przy braku pola $M > 0$

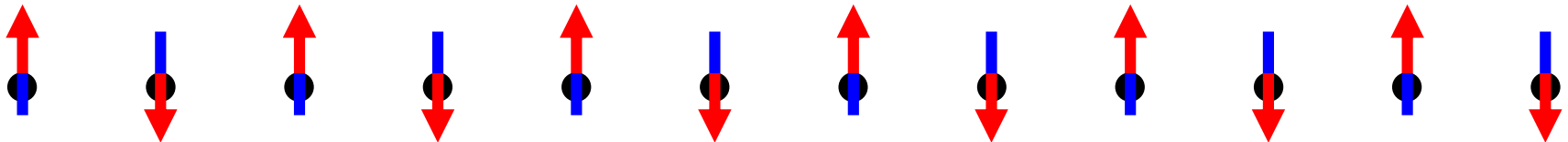


Magnes

ANTYFERRO

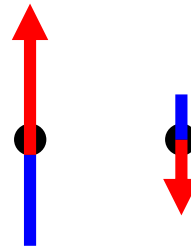


Namagnesowanie M przy braku pola $M = 0$

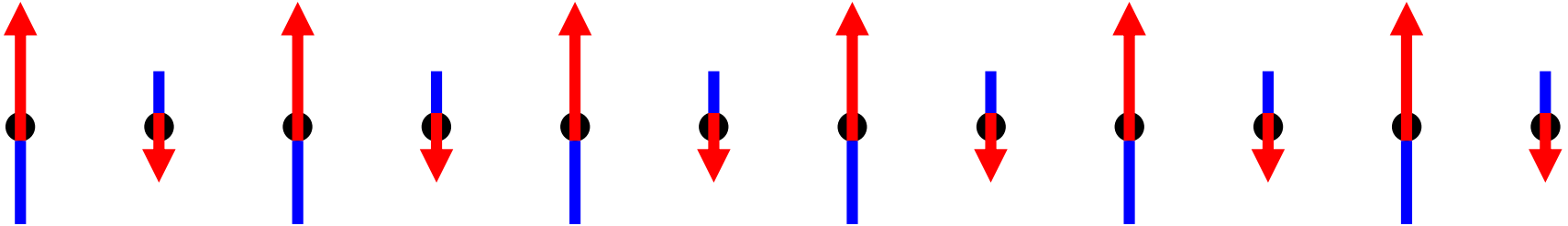


Magnes

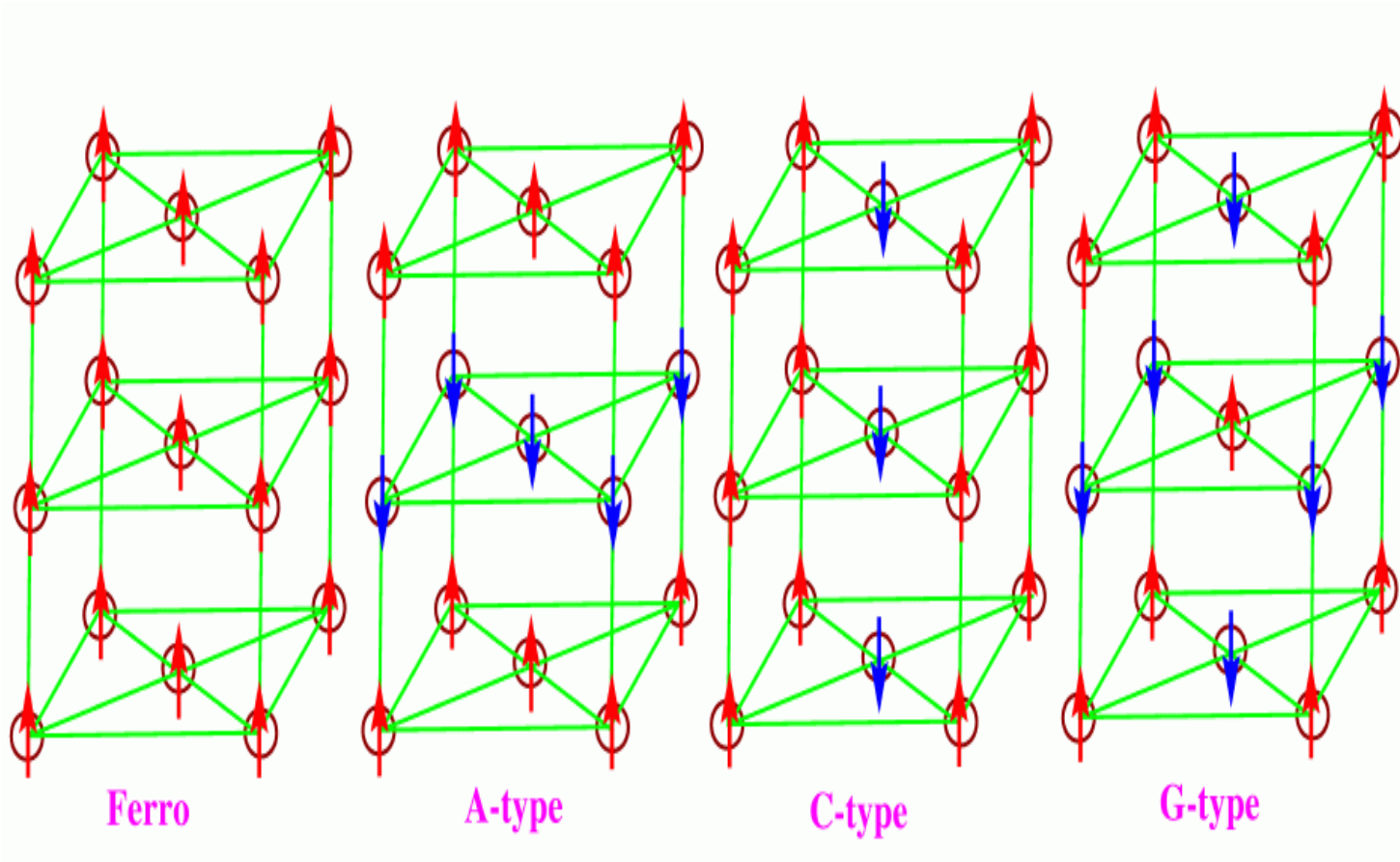
FERRI



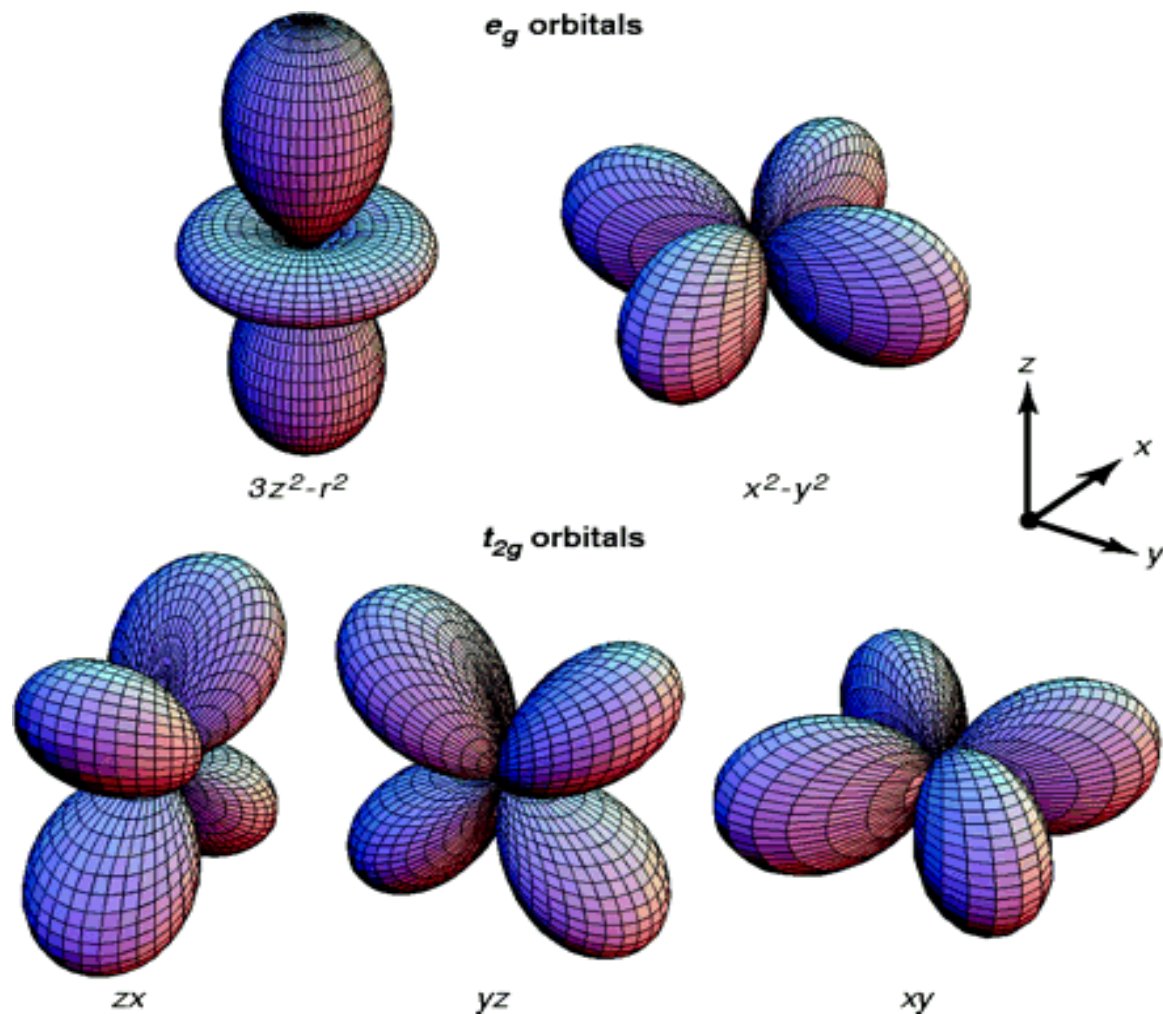
Namagnesowanie M przy braku pola $M > 0$



Magnes



Magnes

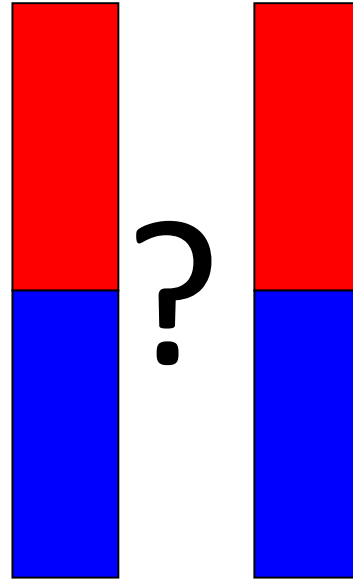


Magnes



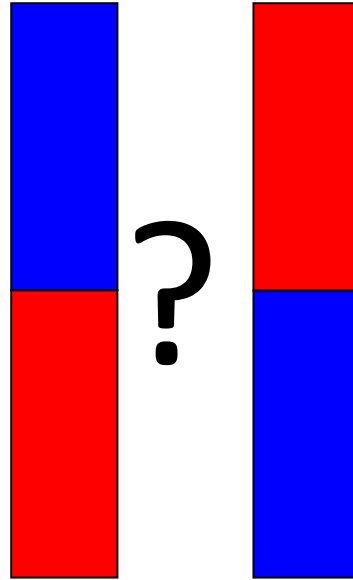
Magnes

FERRO?

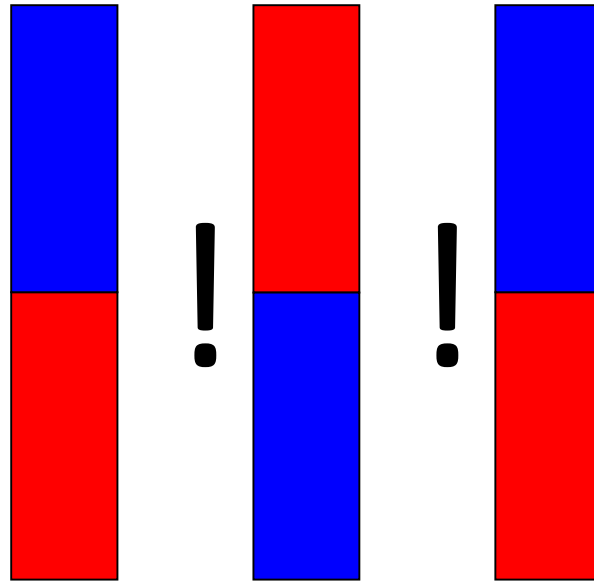


Magnes

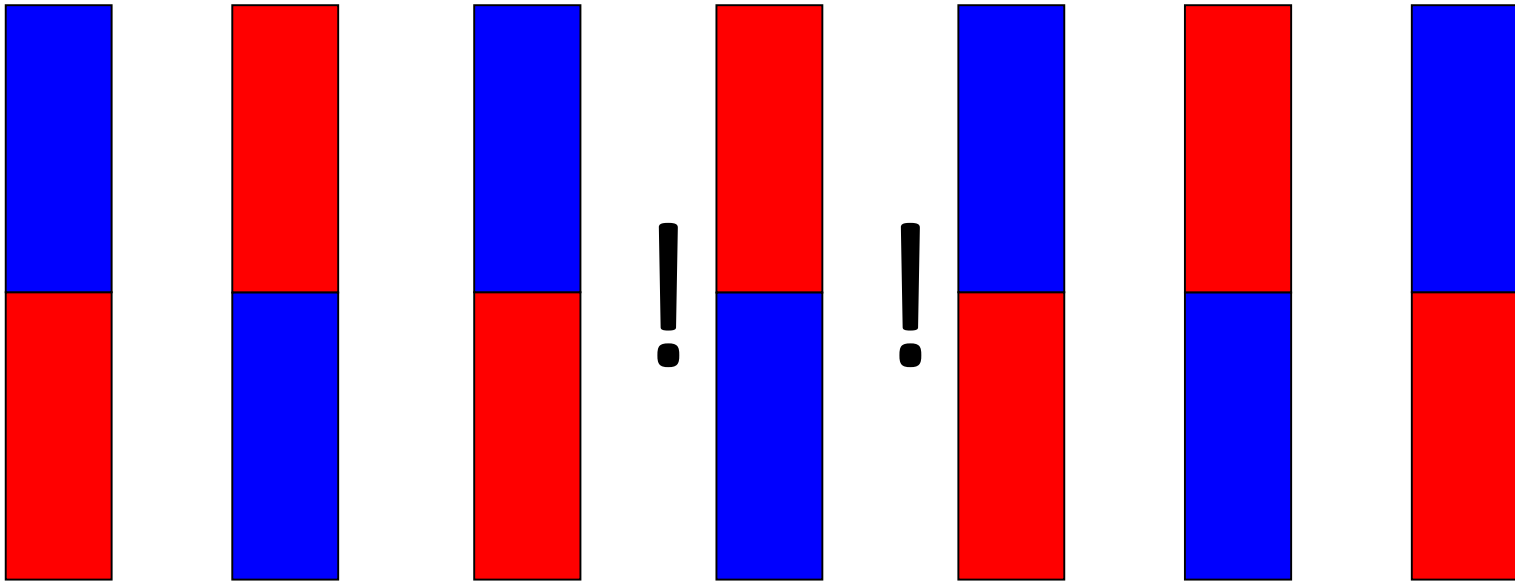
ANTY - FERRO?



Magnes

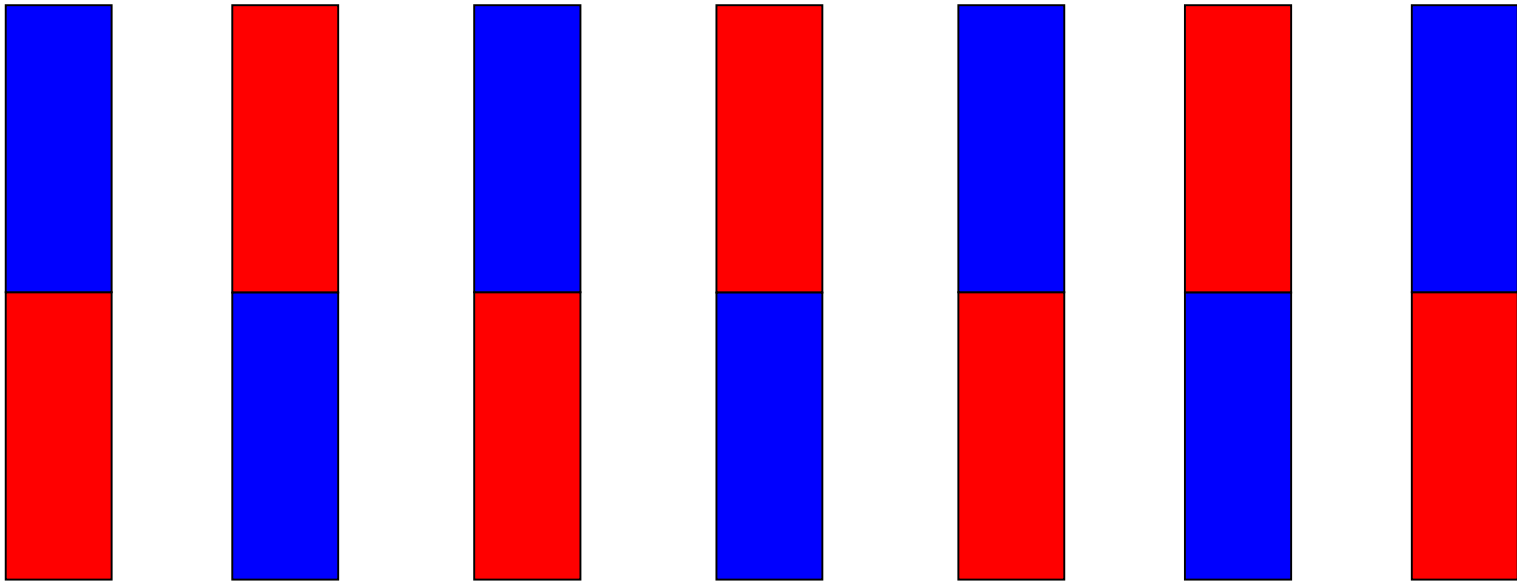


Magnes



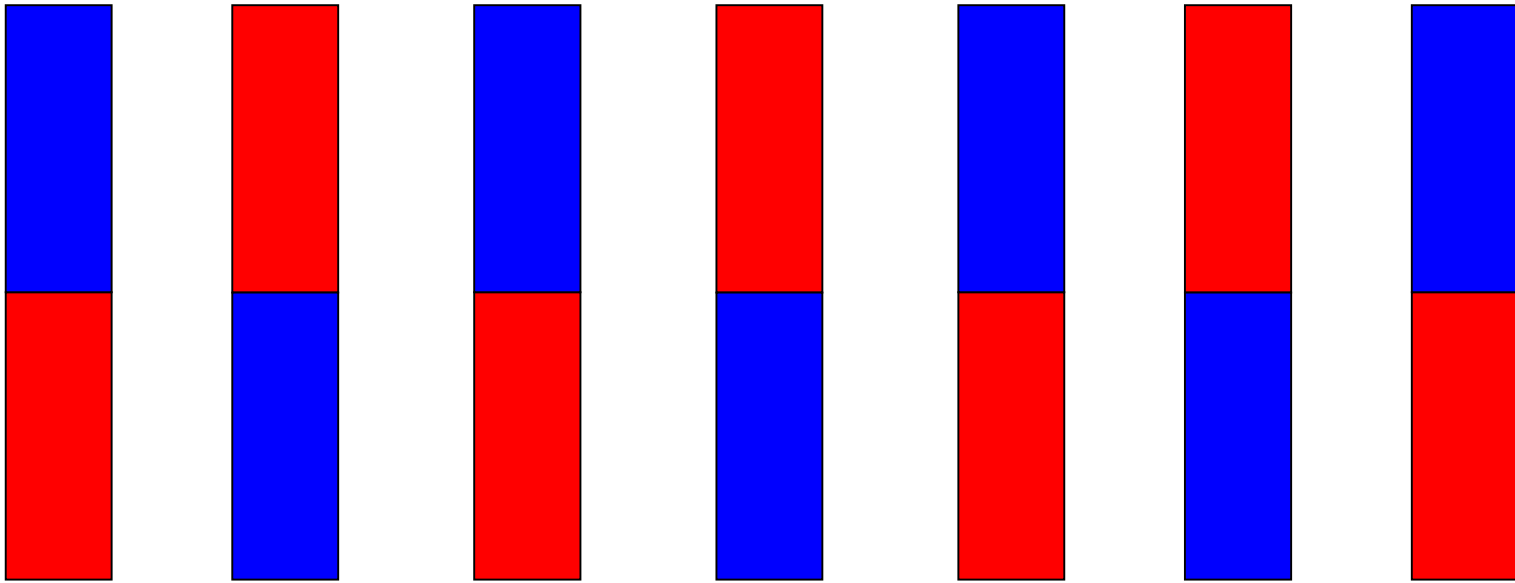
Korzystniejsze jest ustawienie antyferromagnetyczne

Magnes



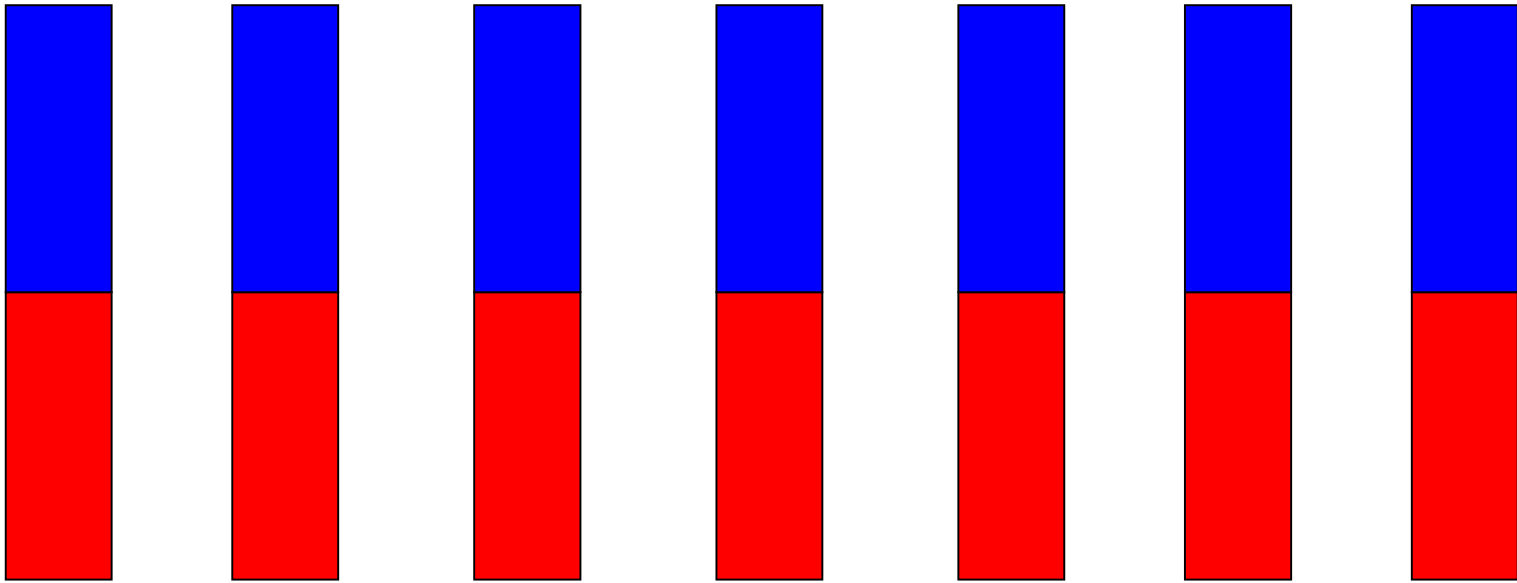
To skąd się biorą magnezysy???

Magnes



To skąd się biorą magnez???

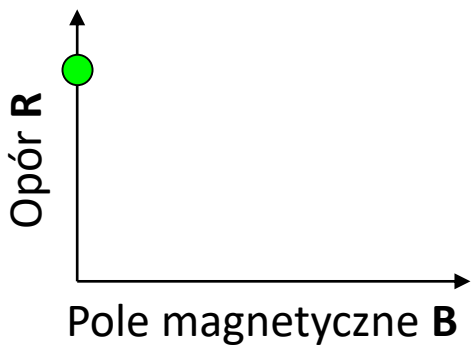
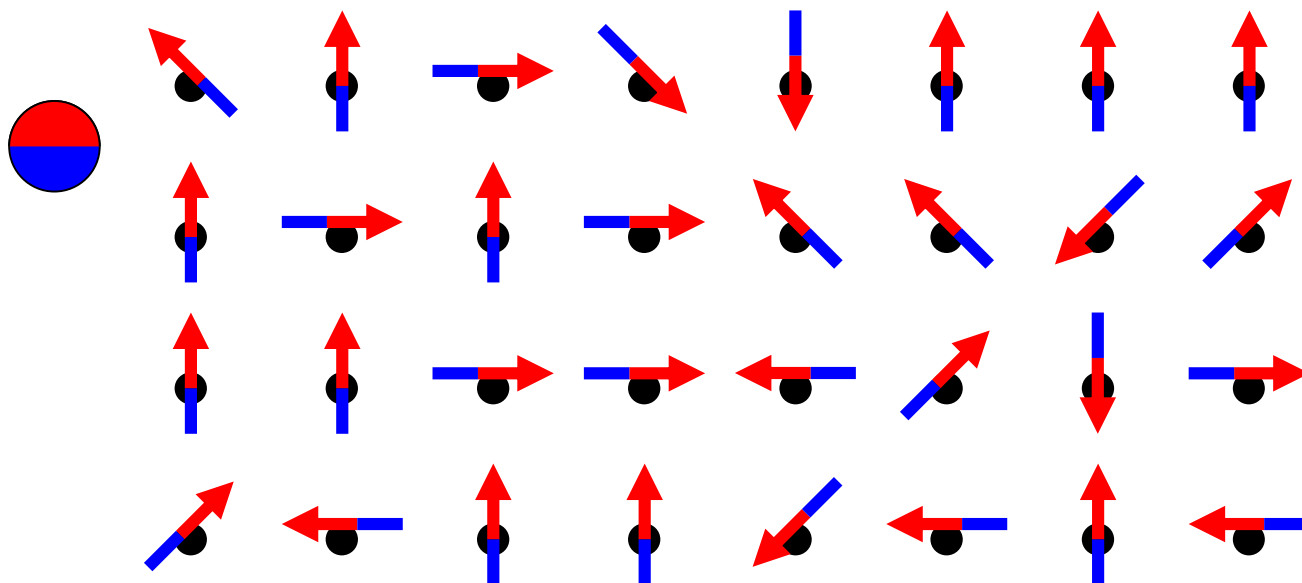
Magnes



To skąd się biorą magnesy???

Magnetoopór

Zewnętrzne pole magnetyczne $B = 0$ T



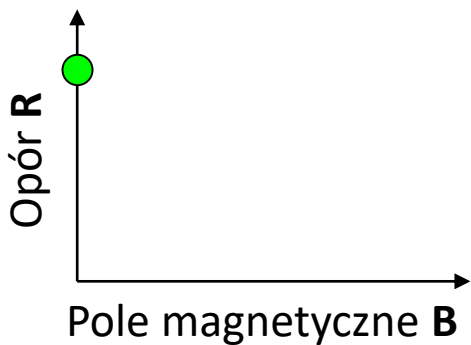
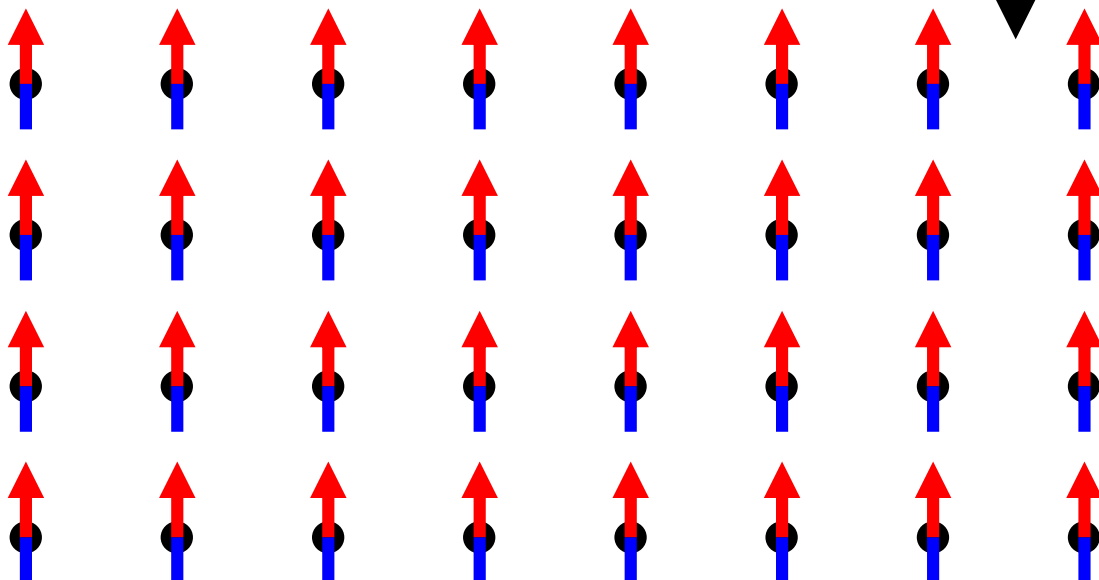
Energia sieci



Energia nośników

Magnetoopór

Zewnętrzne pole magnetyczne $B > 0$ T

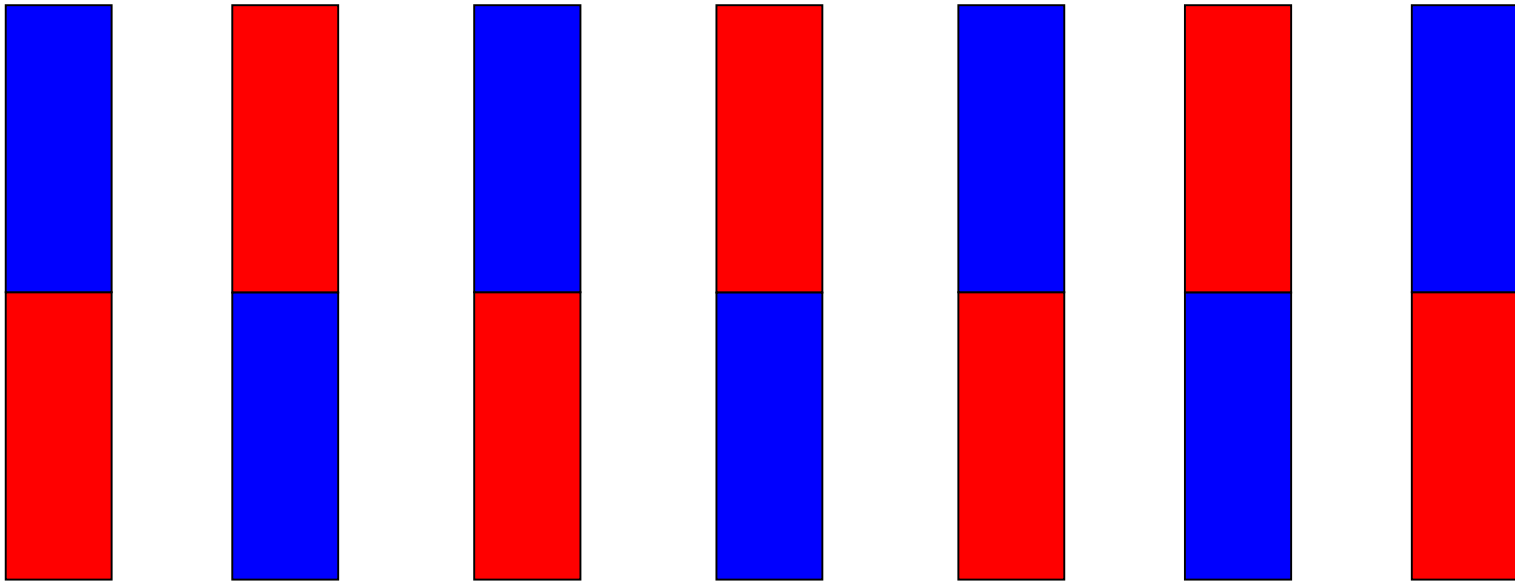


Energia sieci



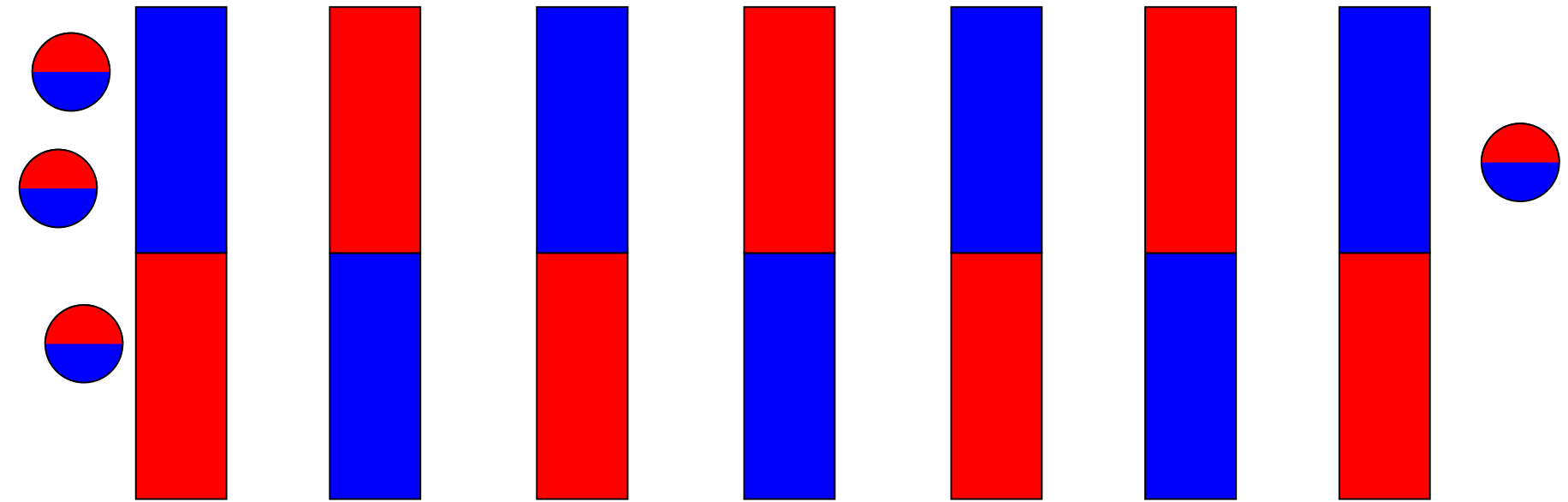
Energia nośników

Magnes



To skąd się biorą magnezysy???

Magnes



Nośniki!!!



Nagroda FNP 2006 w obszarze nauk ścisłych:

prof. dr hab. Tomasz Dietl z Instytutu Fizyki PAN oraz Instytutu Fizyki Teoretycznej Uniwersytetu Warszawskiego za opracowanie potwierdzonej w ostatnich latach teorii rozcieńczonych półprzewodników ferromagnetycznych oraz zademonstrowanie nowych metod sterowania namagnesowaniem;

Alexander von Humboldt Research Award in Germany (2003),
Agilent Technologies Europhysics Prize (2005)

Spintronika

Magnetoopór $\Delta R/R \sim$ kilka %

Spintronika

Magnetoopór $\Delta R/R \sim$ kilka %

Gigantyczny magnetoopór
(Giant Magnetoresistance – GMR) 1988
 $\Delta R/R \sim 20 \%$

Spintronika

Magnetoopór $\Delta R/R \sim$ kilka %

Gigantyczny magnetoopór

(Giant Magnetoresistance – GMR) 1988

$\Delta R/R \sim 20$ %

Kolosalny magnetoopór

(Colossal Magnetoresistance – CMR)

1993 $\Delta R/R \sim$ kilka rzędów

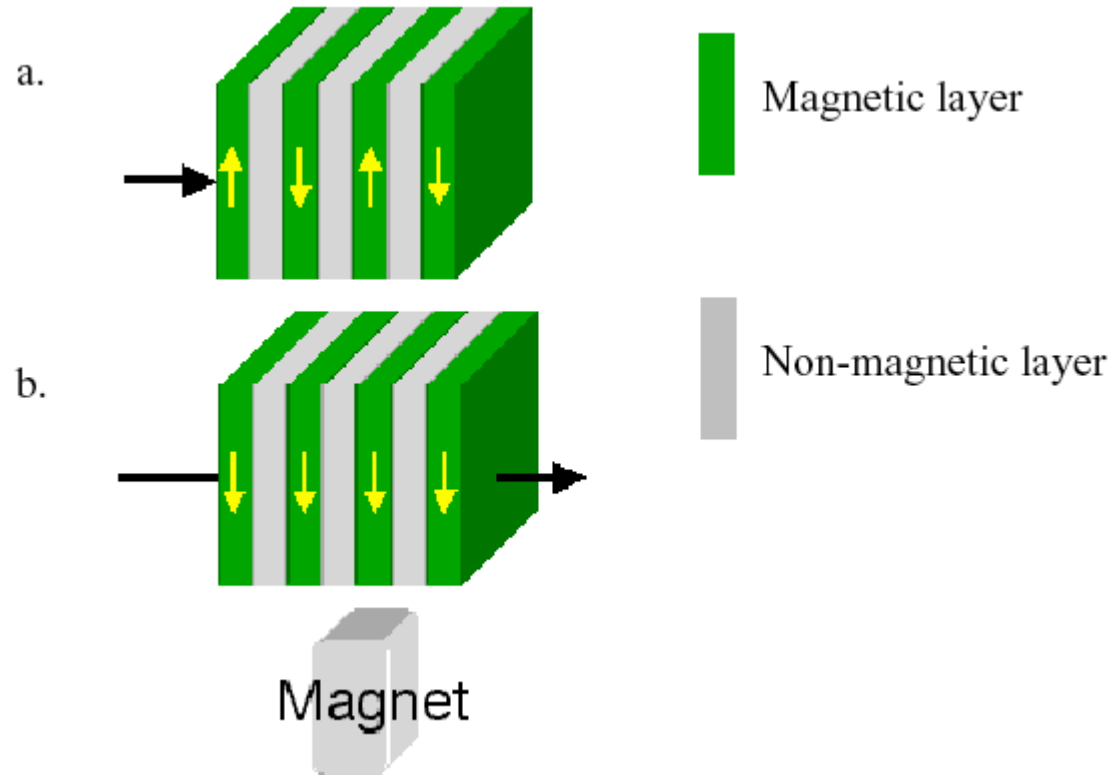
wielkości!

Spintronika

Magnetoopór $\Delta R/R \sim$ kilka %

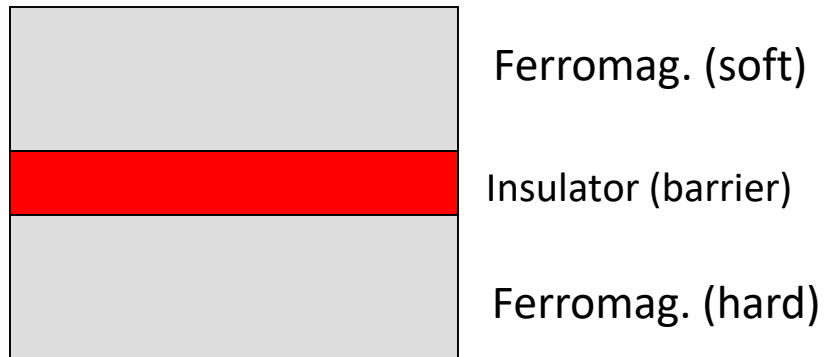
Gigantyczny magnetoopór (Giant Magnetoresistance – GMR) 1988

$\Delta R/R \sim 20\%$



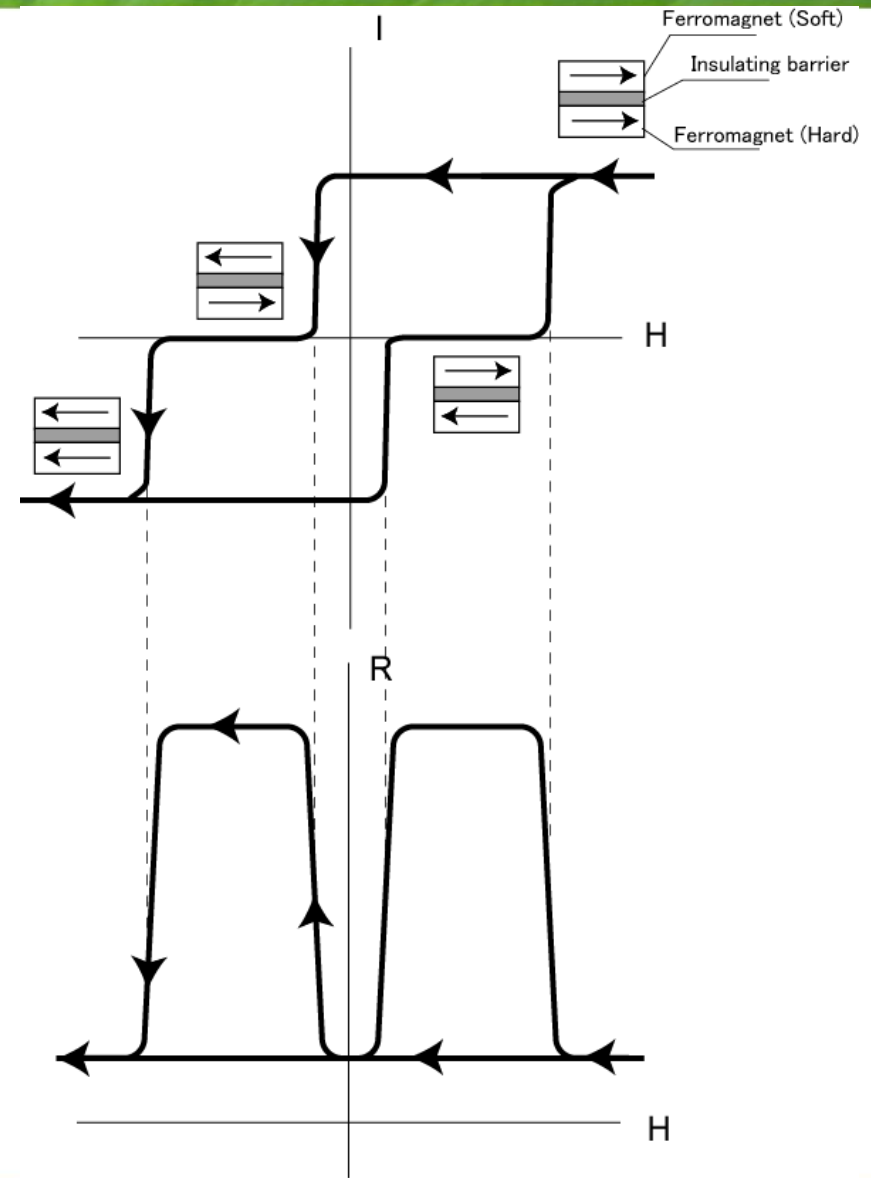
Spintronika

Magnetic tunnel junction (MTJ)



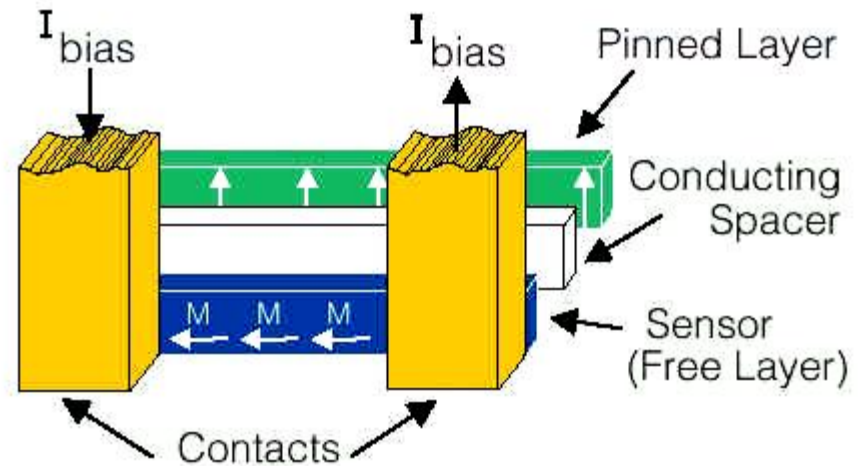
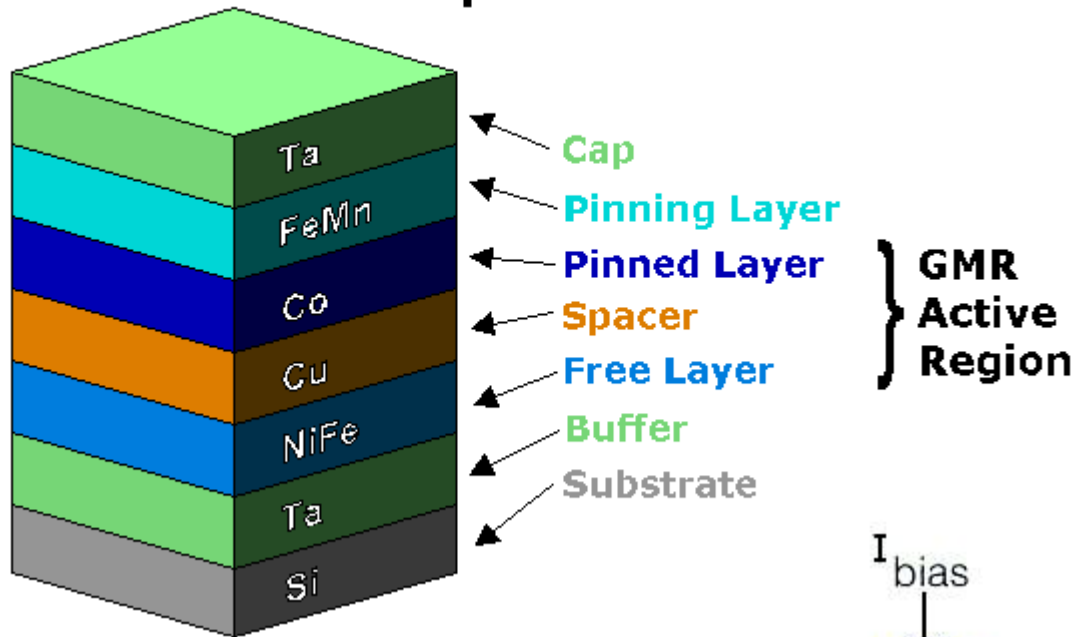
Ferromag.
Co, Py, FeCo, etc.
Barrier
Al₂O₃, MgO, etc.

$$\text{TMR}(\%) = (R_{AP} - R_P) / R_P * 100$$








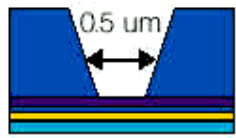
Spintronika

Spin Valve Structure

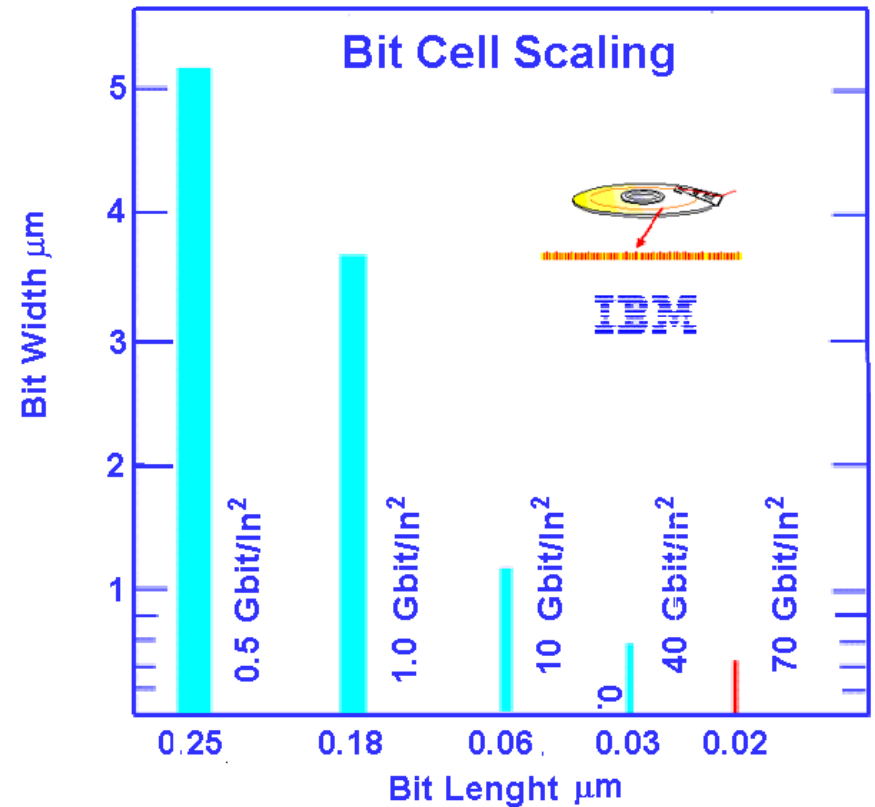


http://www.ing.unitn.it/~colombo/hard_disks/Magnetic_Heads_003.html

Spintronika

Year	Areal Density Gbits/in ²	MR Element
1991	0.132	
1992	0.260	
1993	0.354	
1994	0.578	
1995	0.829 0.923	
1996	1.32	
1997	1.45 2.64	
1998	3.0-5.0	 
2000	10.0	

- Leads
- Exchange
- Hard Bias
- Adv Bias
- NiFe
- Spacer
- Soft Film
- GMR
- Pinned Film



http://www.ing.unitn.it/~colombo/hard_disks/Magnetic_Heads_003.html



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The Nobel Prize in Physics 2007



Photo: U. Montan

Albert Fert

Prize share: 1/2



Photo: U. Montan

Peter Grünberg

Prize share: 1/2

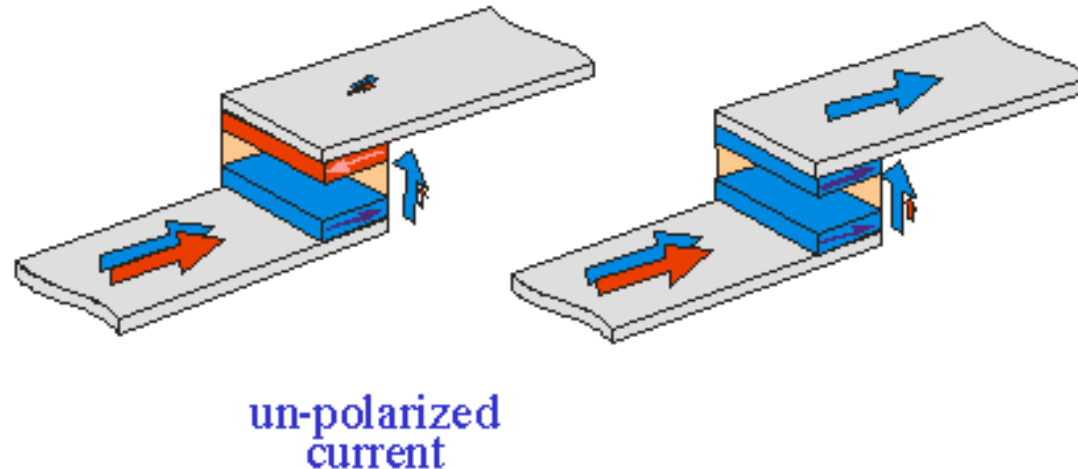
The Nobel Prize in Physics 2007 was awarded jointly to Albert Fert and Peter Grünberg *"for the discovery of Giant Magnetoresistance"*

Spintronika

MTJ

*insulating space layer
current perpendicular to
plane*

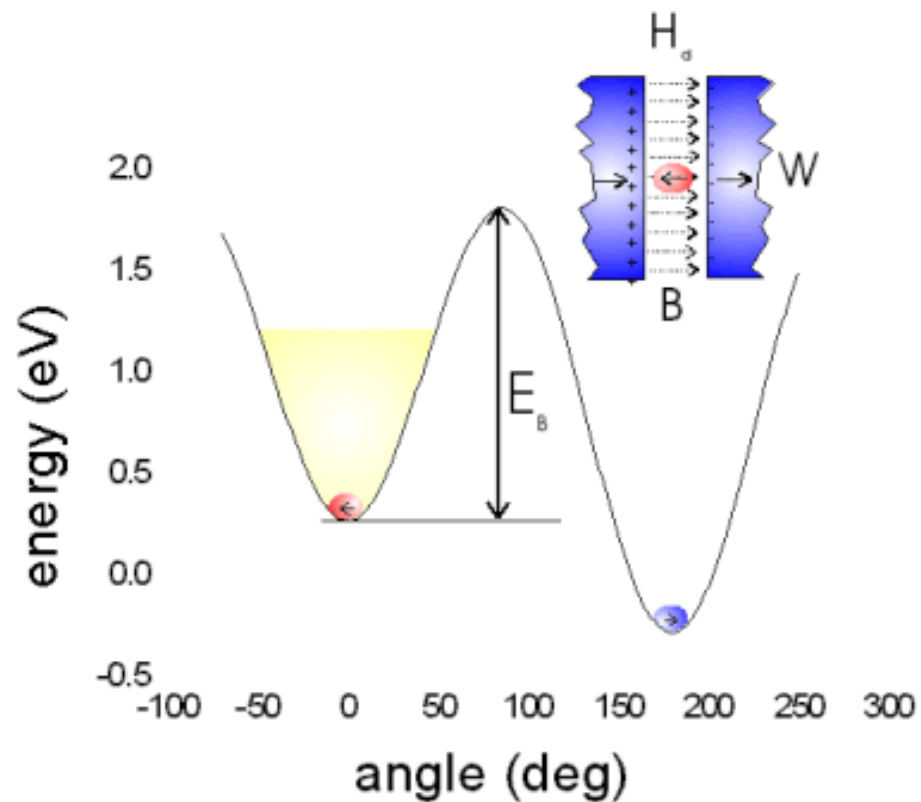
**Ferromagnetic
electrode 1**
**Tunneling
barrier**
**Ferromagnetic
electrode 2**



first ferromagnetic electrode acts as spin filter
second FM layer acts as spin detector

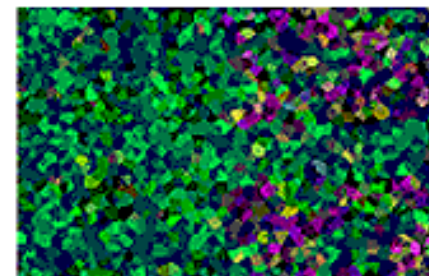
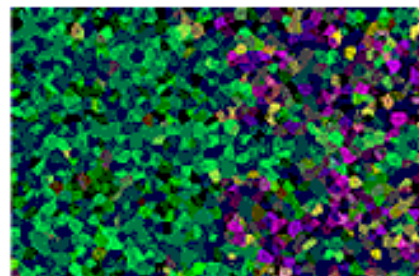
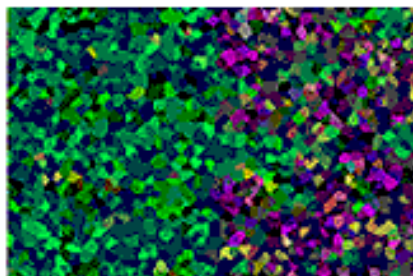
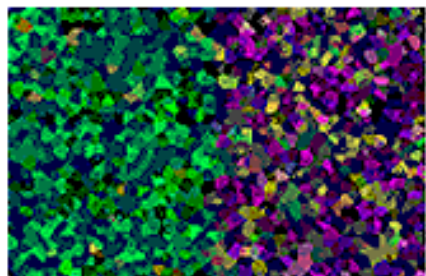
http://www.research.ibm.com/resources/news/20001207_mramimages.shtml

Spintronika



Limit Superparamagnetyczny

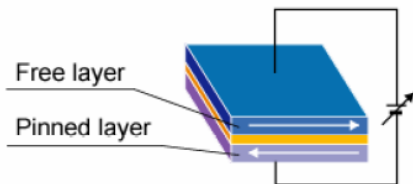
$$E_k = K_u V \sin^2(\vartheta)$$



http://www.ing.unitn.it/~colombo/hard_disks/Magnetic_Heads_003.html

Spintronika

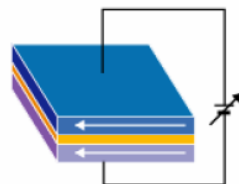
MRAM architecture



Resistance Large

Information "0"

Magnetization Configuration Anti -parallel



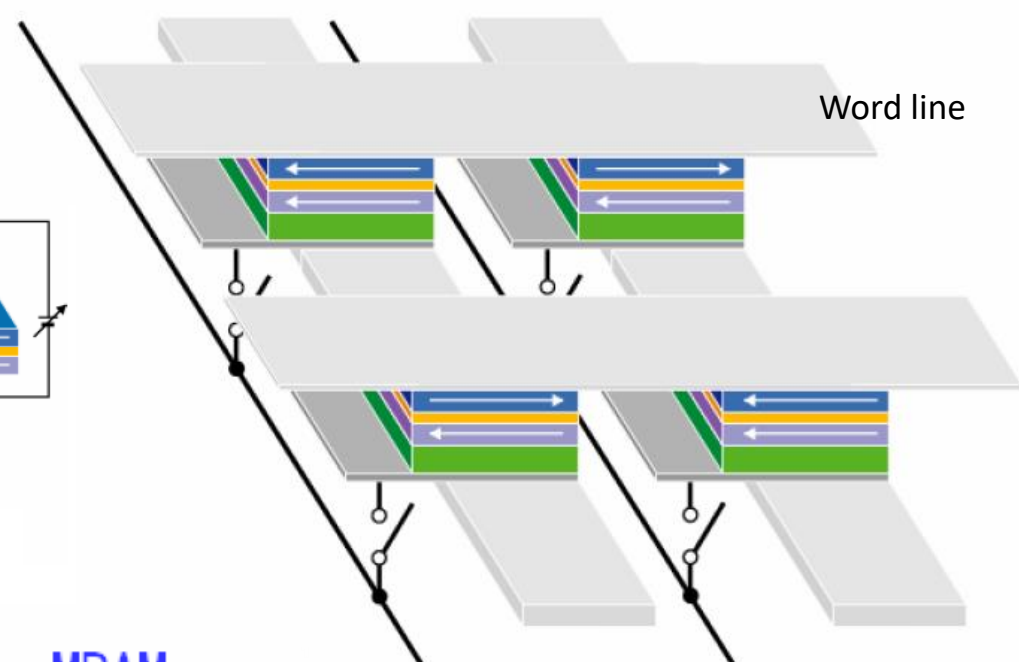
Resistance Small

Information "1"

Magnetization Configuration parallel

Bit line

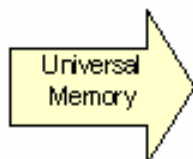
Word line



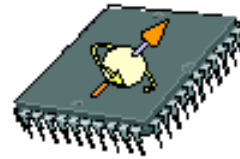
ROM  Non-volatile

DRAM  High Density

SRAM  High Speed



MRAM

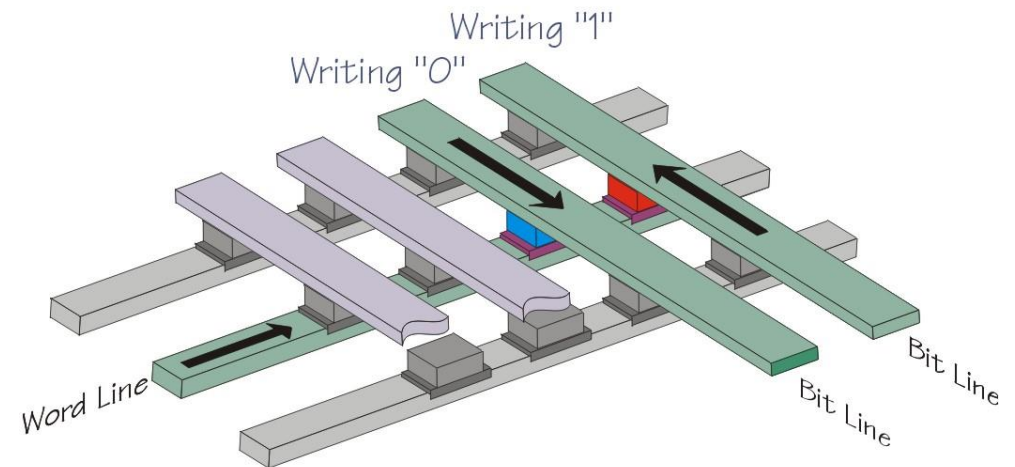
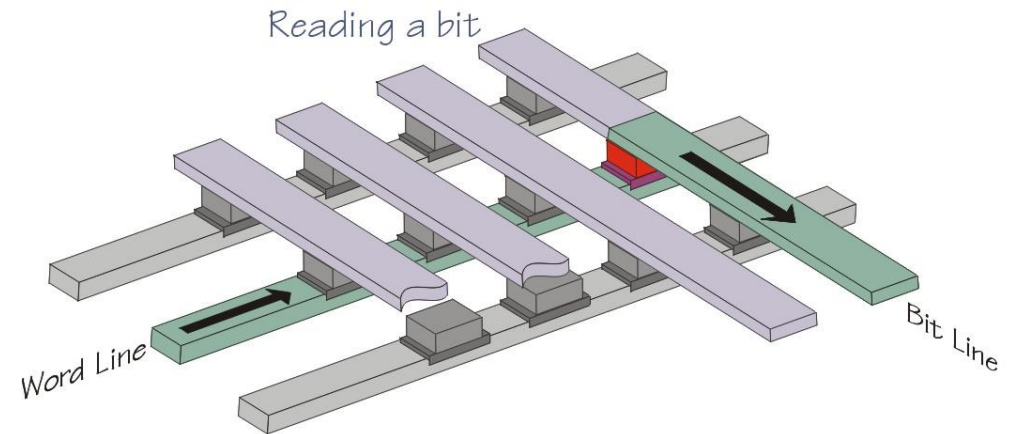


Non-volatile High Speed
High Density

Spintronika



MagRAM Architecture



MTJ MagRAM promises

- density of DRAM
- speed of SRAM
- non-volatility

http://www.research.ibm.com/resources/news/20001207_mramimages.shtml

Spintronika

Zalety MRAM

	DRAM	MRAM	Flash EEPROM	FeRAM
Trwałość zapisu	Nie	TAK	TAK	TAK
Czas zapisu	50ns	10 to 50ns	1us or longer	30 to 200ns
Czas odczytu	50ns	10ns to 1us	20 to 120ns	30 to 200ns
Metoda odczytu	Destructive	Non-Destructive	Destructive	Non-Destructive
Rewrite cycle	10^{15}	10^{15}	10^5	10^{12} to 10^{15}
Pobór prądu	100mA	10mA	10 to 100mA	10mA
Prąd uśpienia	100uA	1uA or lower	1uA or lower	1uA or lower

DRAM: Dynamic Random Access Memory

Flash EEPROM: Electrically Erasable Programmable Read-Only Memory

FeRAM: Ferroelectric RAM

MRAM pokonuje DRAM !!

Takahiro Moriyama <http://www.ece.udel.edu/~appelbau/spintronics/>

Spintronika

Magnetoopór $\Delta R/R \sim$ kilka %

Gigantyczny magnetoopór

(Giant Magnetoresistance – GMR) 1988

$\Delta R/R \sim 20\%$

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(Colossal Magnetoresistance – CMR)

1993 $\Delta R/R \sim$ kilka rzędów

wielkości!

Kolosalny magnetoopór (CMR)

VOLUME 71, NUMBER 14

PHYSICAL REVIEW LETTERS

4 OCTOBER 1993

Giant Negative Magnetoresistance in Perovskitelike $\text{La}_{2/3}\text{Ba}_{1/3}\text{MnO}_x$ Ferromagnetic Films

R. von Helmlolt,^{1,2} J. Wecker,¹ B. Holzapfel,¹ L. Schultz,¹ and K. Samwer²

¹Siemens AG, Research Laboratories, D-8520 Erlangen, Germany

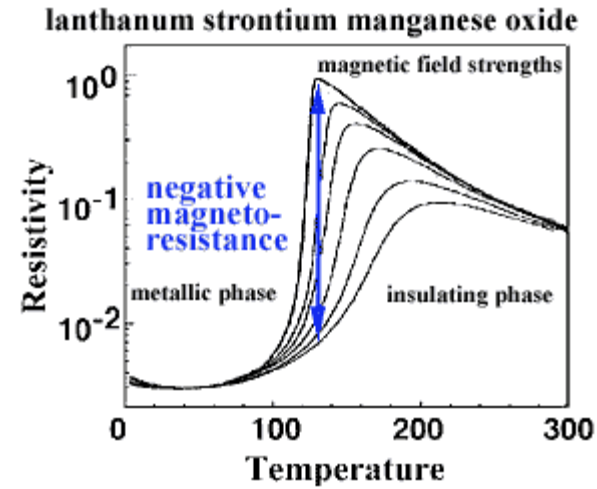
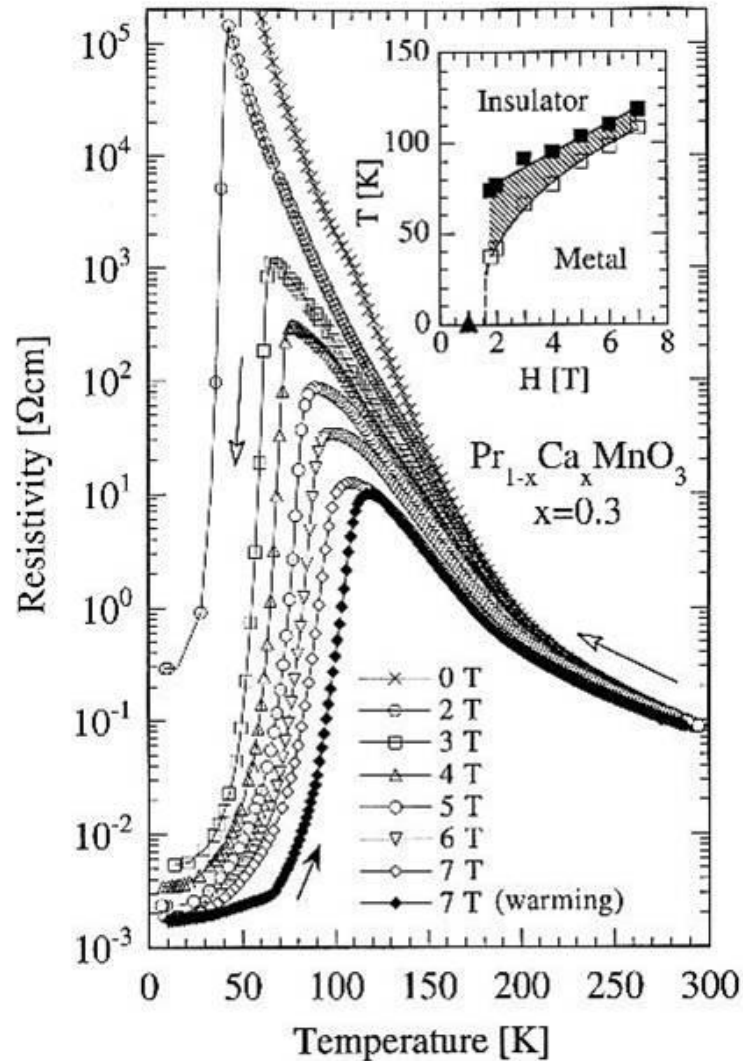
²Institute of Physics, University of Augsburg, D-8900 Augsburg, Germany

(Received 14 May 1993)

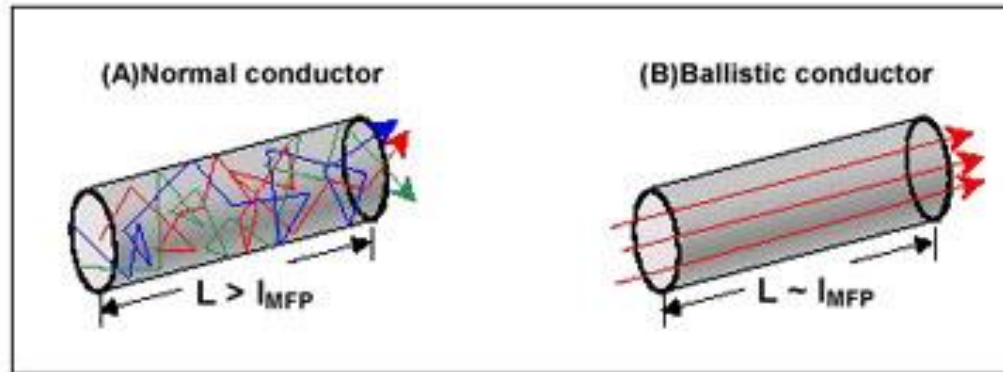
At room temperature a large magnetoresistance, $\Delta R/R(H=0)$, of 60% has been observed in thin magnetic films of perovskitelike La-Ba-Mn-O. The films were grown epitaxially on SrTiO_3 substrates by off-axis laser deposition. In the as-deposited state, the Curie temperature and the saturation magnetization were considerably lower compared to bulk samples, but were increased by a subsequent heat treatment. The samples show a drop in the resistivity at the magnetic transition, and the existence of magnetic polarons seems to dominate the electric transport in this region.

JIN S, TIEFEL TH, MCCORMACK M, FASTNACHT RA, RAMESH R, CHEN LH *et al.*
Thousandfold change in resistivity in magnetoresistive La-Ca-Mn-O films. *Science*
264, 413–415 (1994)

Kolosalny magnetoopór (CMR)



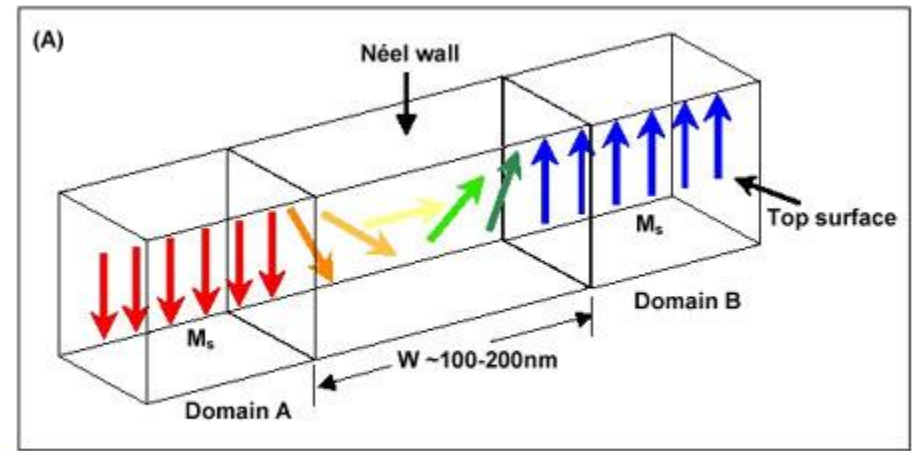
Nano-spintronika



In normal conductors, the conductor length is larger than the electron mean free path and motion is zigzag, figure (A) above.

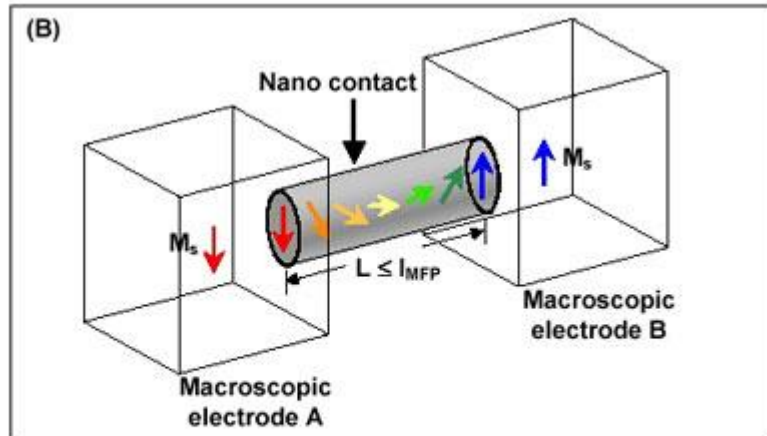
For electrons passing through a nanocontact, the nanocontact length is comparable to or less than electron mean free path and motion is ballistic, figure (B) above.

Ballistic Magnetoresistance



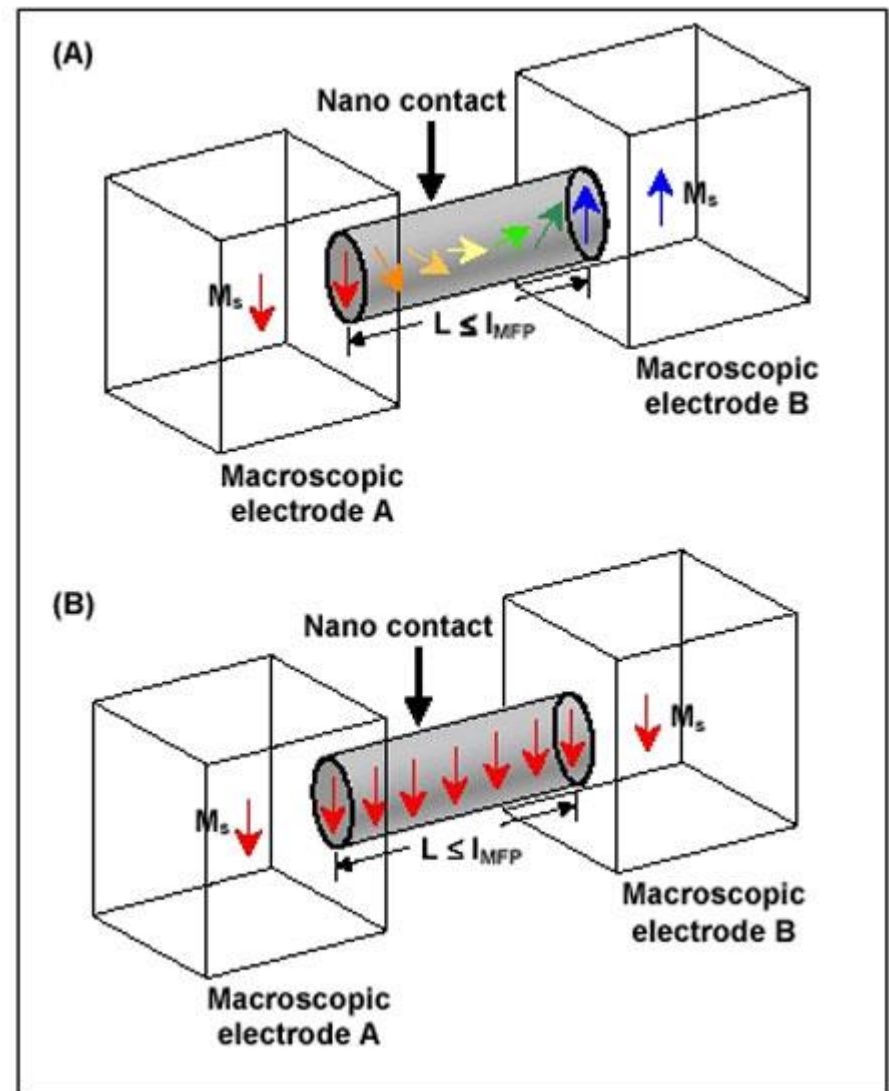
Néel wall in a thin film separates two domains of opposite magnetization. Wall width "W" is several hundred nanometers and BMR effect is negligible.

Nano-spintronika



Wall width within a nanocontact separating two macroscopic electrodes of opposite magnetization. Wall width is in the nanometer range and electrons passing through the nanocontact experiences a huge scattering moment.

(A) Magnetization across nanocontact opposite in direction, giving rise to high resistance state.
 (B) Magnetization across nanocontact parallel in direction, giving rise to low resistance state.
 Transition from state A to state B by applied magnetic field - BMR effect.



Magnetic domain-wall logic

Magnetic Domain-Wall Logic

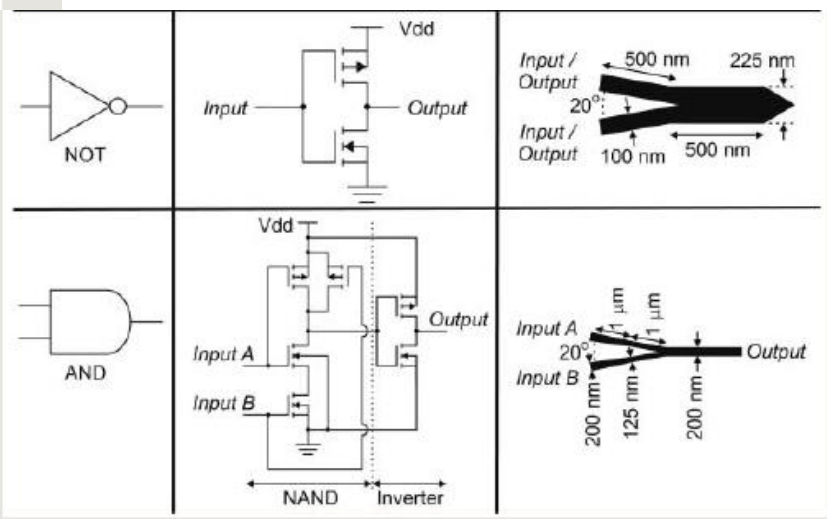
D. A. Allwood,¹ G. Xiong,² C. C. Faulkner,³ D. Atkinson,² D. Petit,³ R. P. Cowburn^{3,4*}

9 SEPTEMBER 2005 VOL 309 SCIENCE www.sciencemag.org

Table 1. Symbols for electronic logic, together with the appropriate CMOS circuit element and a schematic drawing of the optimized domain-wall logic element (dimensions shown refer to the design rule used here of 200-nm-wire width connecting logic elements and 1- μm turning radius of corners). The fan-out, cross-over, and logical AND junctions all contain tapered regions to connect to the 200-nm-wide wire links. Vdd is the supply voltage.

Symbol	CMOS Circuit	Domain Wall Logic Circuit
Vdd (+5 V)	Charge	
0 V	No charge	
Fan-out		
Cross-over	Vias	

« kasyczna » logika



Permalloy ($\text{Ni}_{80}\text{Fe}_{20}$)

Magnetic domain-wall logic

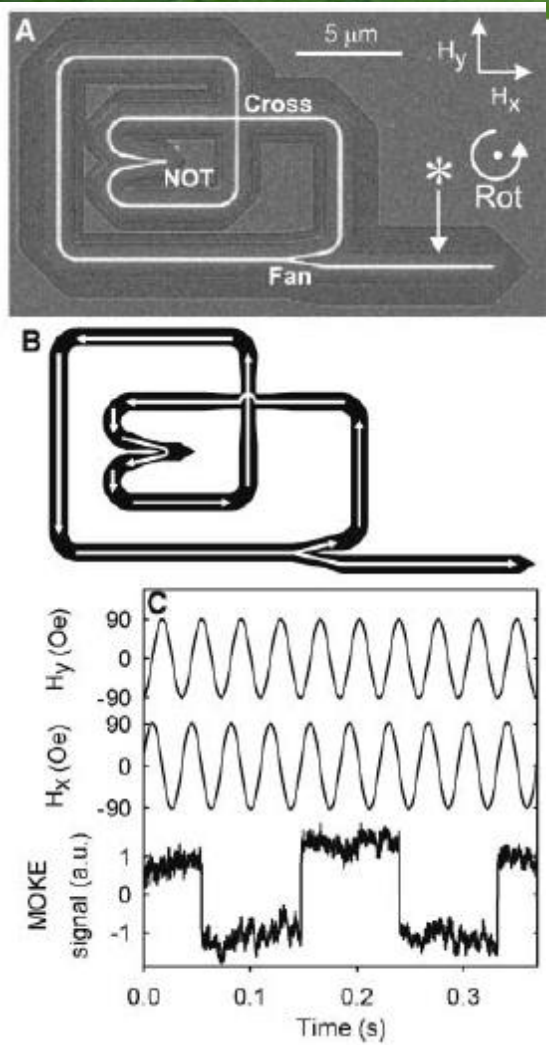


Fig. 1. (A) Focused ion beam (FIB) image of a magnetic nanowire loop containing a NOT gate, fan-out junction, and cross-over junction. Only the bright lines indicate the presence of magnetic material; all other features are artifacts of the fabrication process. The directions of rotating

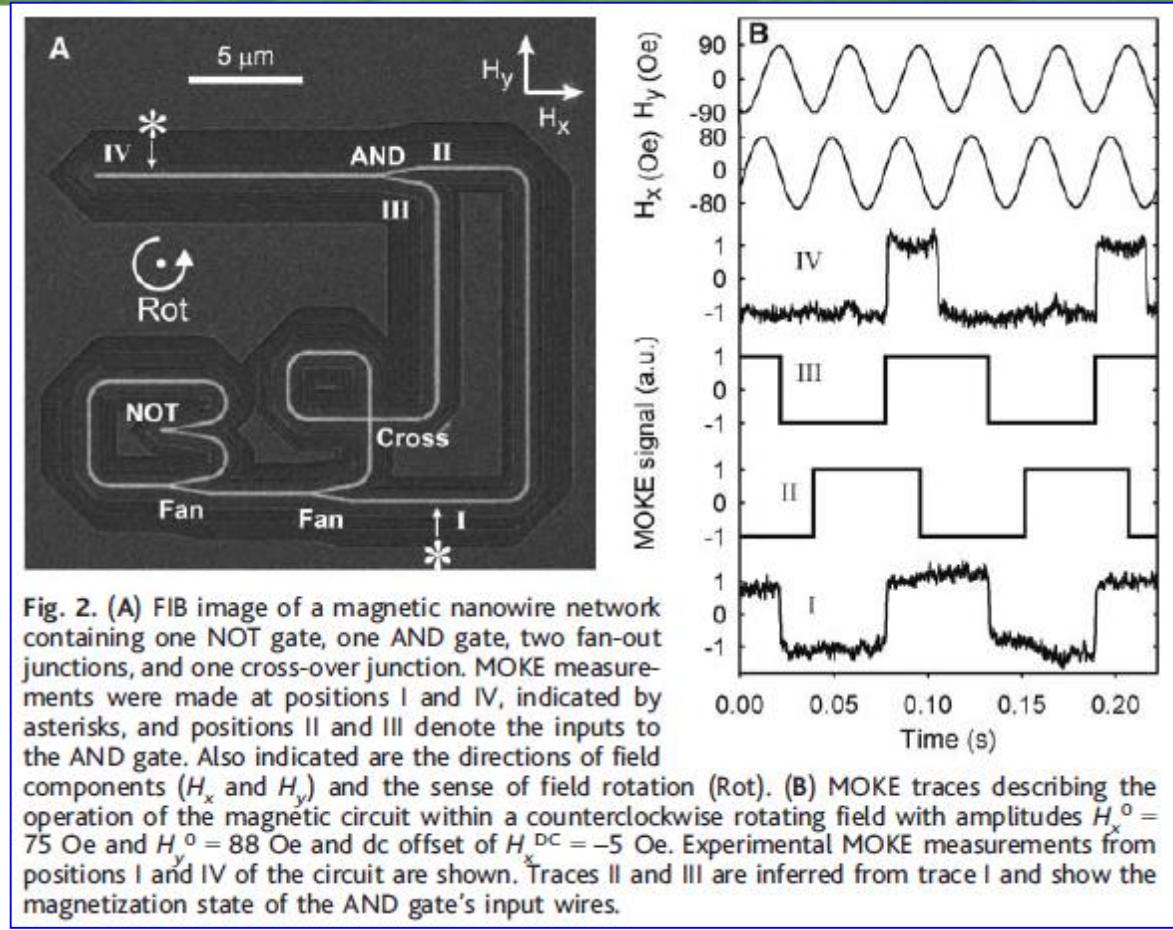


Fig. 2. (A) FIB image of a magnetic nanowire network containing one NOT gate, one AND gate, two fan-out junctions, and one cross-over junction. MOKE measurements were made at positions I and IV, indicated by asterisks, and positions II and III denote the inputs to the AND gate. Also indicated are the directions of field components (H_x and H_y) and the sense of field rotation (Rot). (B) MOKE traces describing the operation of the magnetic circuit within a counterclockwise rotating field with amplitudes $H_x^0 = 75$ Oe and $H_y^0 = 88$ Oe and dc offset of $H_x^{DC} = -5$ Oe. Experimental MOKE measurements from positions I and IV of the circuit are shown. Traces II and III are inferred from trace I and show the magnetization state of the AND gate's input wires.

field components (H_x and H_y), and the sense of field rotation (Rot) are indicated, and the asterisk denotes the position of MOKE measurement. (B) Schematic diagram with arrows illustrating the route of a domain wall propagating through the magnetic structure within a counterclockwise

rotating field. (C) MOKE trace obtained from the position marked with an asterisk of the nanowire structure within an applied counterclockwise rotating field with amplitudes $H_x^0 = 75$ Oe and $H_y^0 = 91$ Oe.

Magnetic domain-wall logic

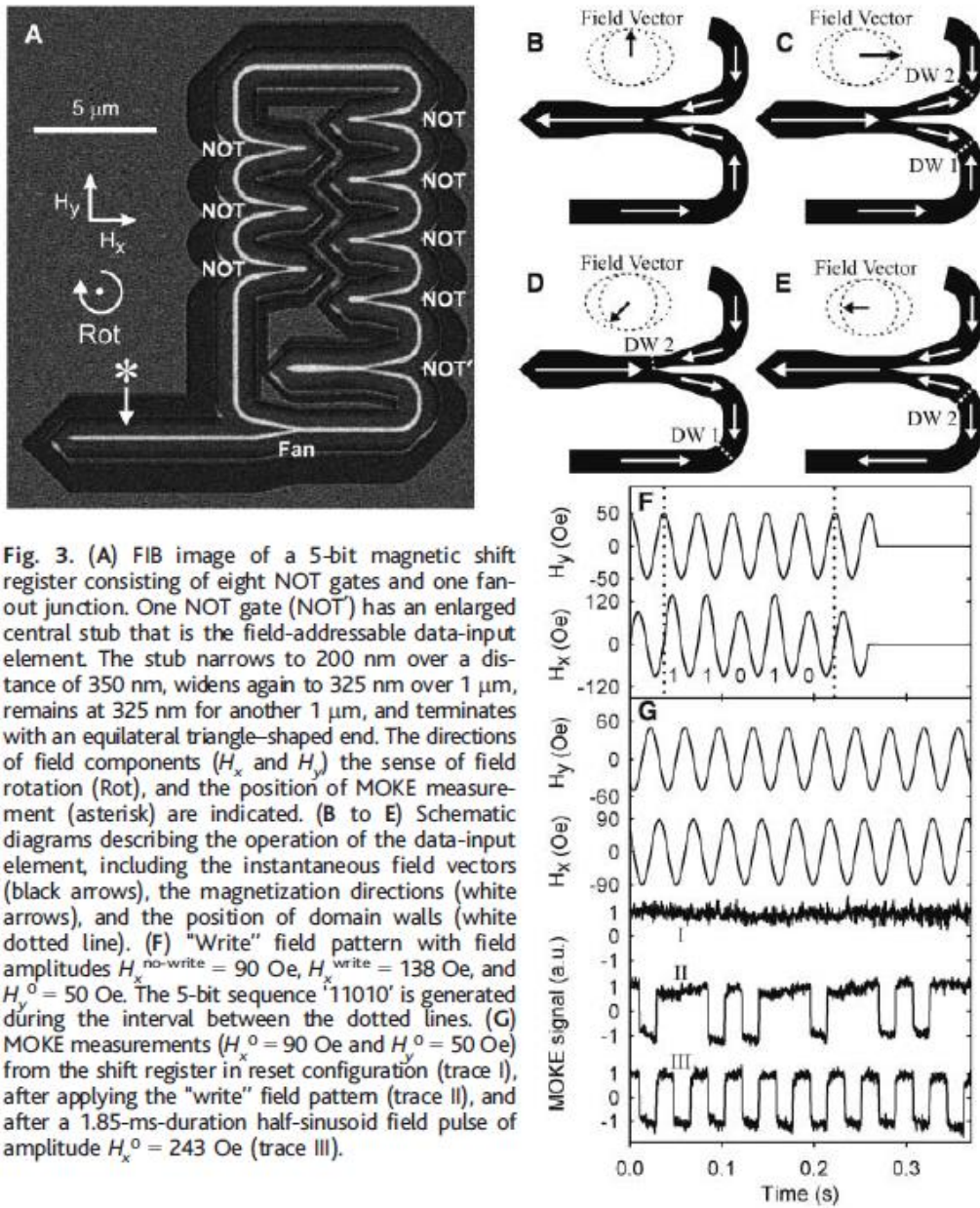


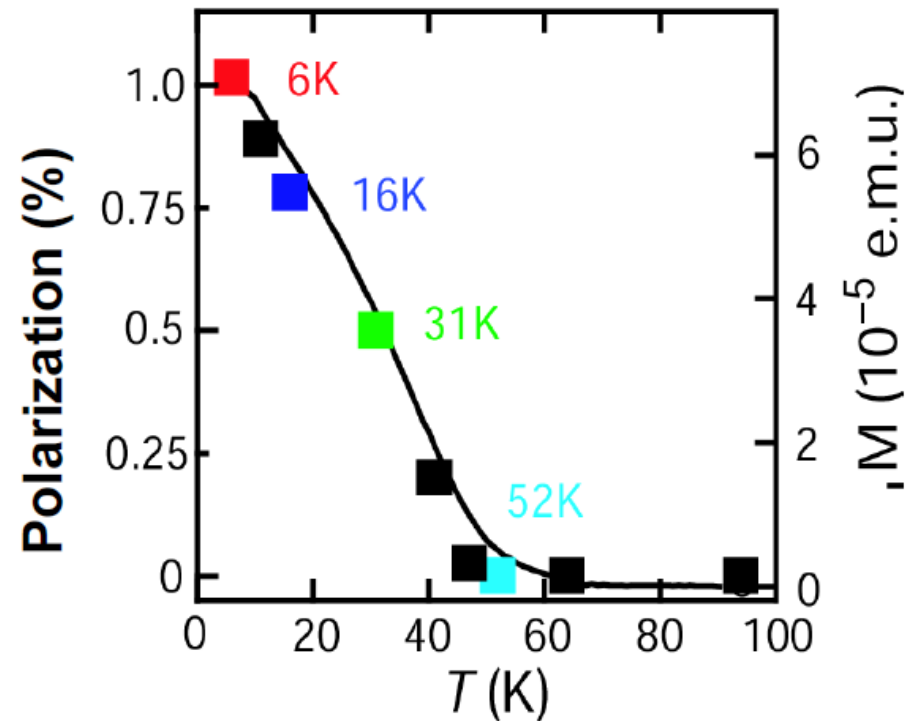
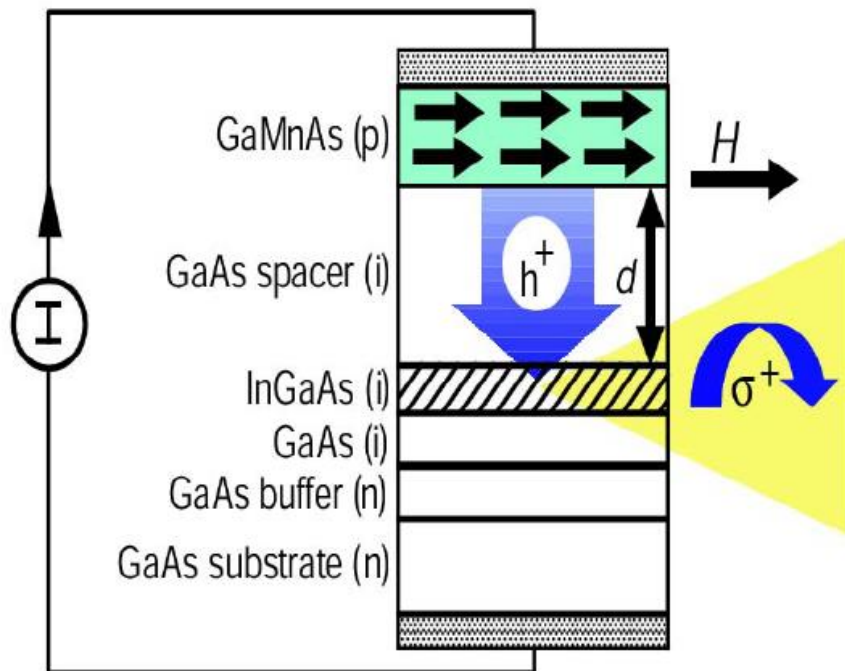
Fig. 3. (A) FIB image of a 5-bit magnetic shift register consisting of eight NOT gates and one fan-out junction. One NOT gate (NOT) has an enlarged central stub that is the field-addressable data-input element. The stub narrows to 200 nm over a distance of 350 nm, widens again to 325 nm over 1 μm , remains at 325 nm for another 1 μm , and terminates with an equilateral triangle-shaped end. The directions of field components (H_x and H_y), the sense of field rotation (Rot), and the position of MOKE measurement (asterisk) are indicated. (B to E) Schematic diagrams describing the operation of the data-input element, including the instantaneous field vectors (black arrows), the magnetization directions (white arrows), and the position of domain walls (white dotted line). (F) "Write" field pattern with field amplitudes $H_x^{\text{no-write}} = 90$ Oe, $H_x^{\text{write}} = 138$ Oe, and $H_y^0 = 50$ Oe. The 5-bit sequence '11010' is generated during the interval between the dotted lines. (G) MOKE measurements ($H_x^0 = 90$ Oe and $H_y^0 = 50$ Oe) from the shift register in reset configuration (trace I), after applying the "write" field pattern (trace II), and after a 1.85-ms-duration half-sinusoid field pulse of amplitude $H_x^0 = 243$ Oe (trace III).

Magnetic Semiconductors

NATURE | VOL 402 | 16 DECEMBER 1999 | www.nature.com

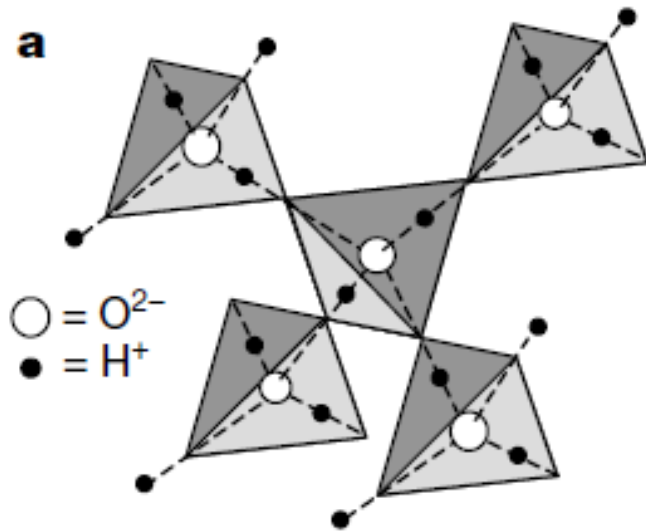
Electrical spin injection in a ferromagnetic semiconductor heterostructure

Y. Ohno^{*}, D. K. Young[†], B. Beschoten[†], F. Matsukura^{*}, H. Ohno^{*}
& D. D. Awschalom[†]



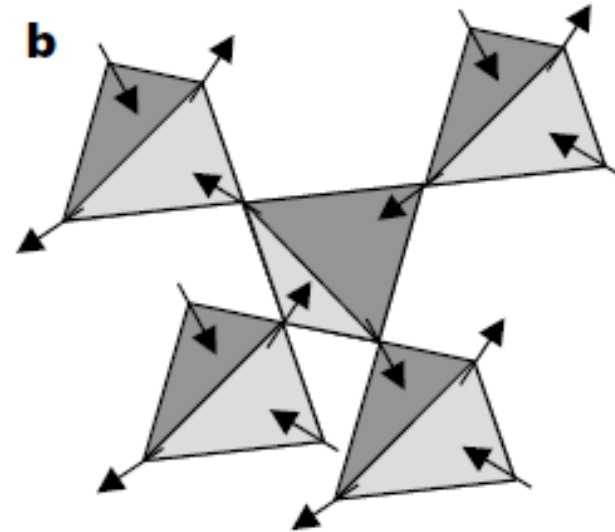
Magnetic monopoles in spin ice

six-fold degeneracy of protonic states



Water ice

six-fold degeneracy of spins



Spin ice

“two spins in, two spins out”

Schematic representation of frustration in water ice and spin ice. a, In water ice, each hydrogen ion is close to one or the other of its two oxygen neighbours, and each oxygen must have two hydrogen ions closer to it than to its neighbouring oxygen ions. b, In spin ice, the spins point either directly toward or away from the centres of the tetrahedra, and each tetrahedron is constrained to have two spins pointing in and two pointing out.

J. Snyder et al. Nature 413 (2001)

Magnetic monopoles in spin ice

Spin-ice systems, such as $\text{Dy}_2\text{Ti}_2\text{O}_7$ and $\text{Ho}_2\text{Ti}_2\text{O}_7$, can be described by a corner-sharing network of tetrahedra forming a pyrochlore lattice of localized magnetic moments.

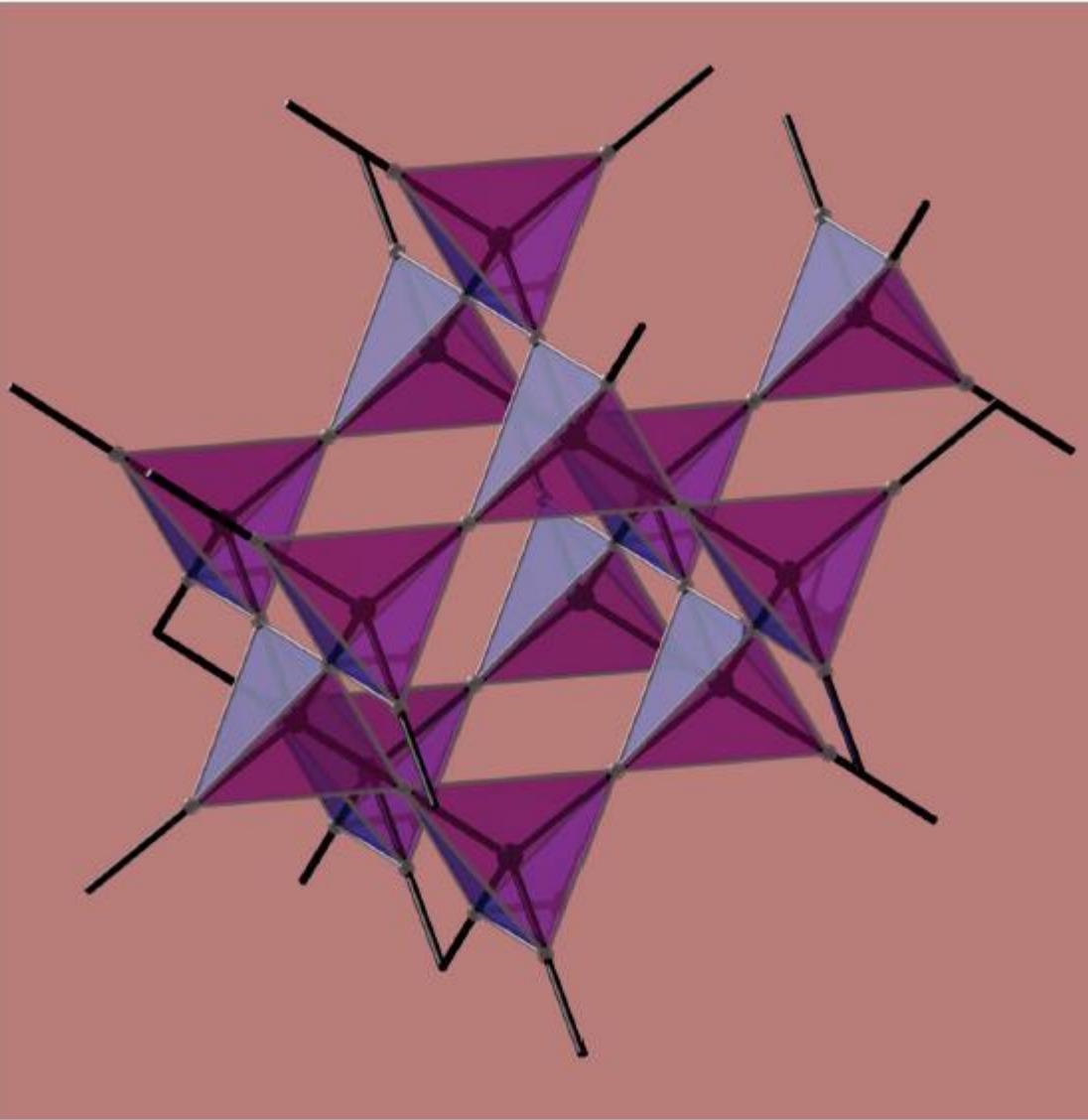
$$H = J m^2 \sum_{\langle i,j \rangle} \vec{S}_i \cdot \vec{S}_j + D m^2 \sum_{\langle i,j \rangle} \left[\frac{\vec{S}_i \cdot \vec{S}_j}{|\vec{r}_{ij}|^3} - \frac{3(\vec{S}_i \cdot \vec{r}_{ij})(\vec{S}_j \cdot \vec{r}_{ij})}{|\vec{r}_{ij}|^5} \right]$$

Exchange

Dipole

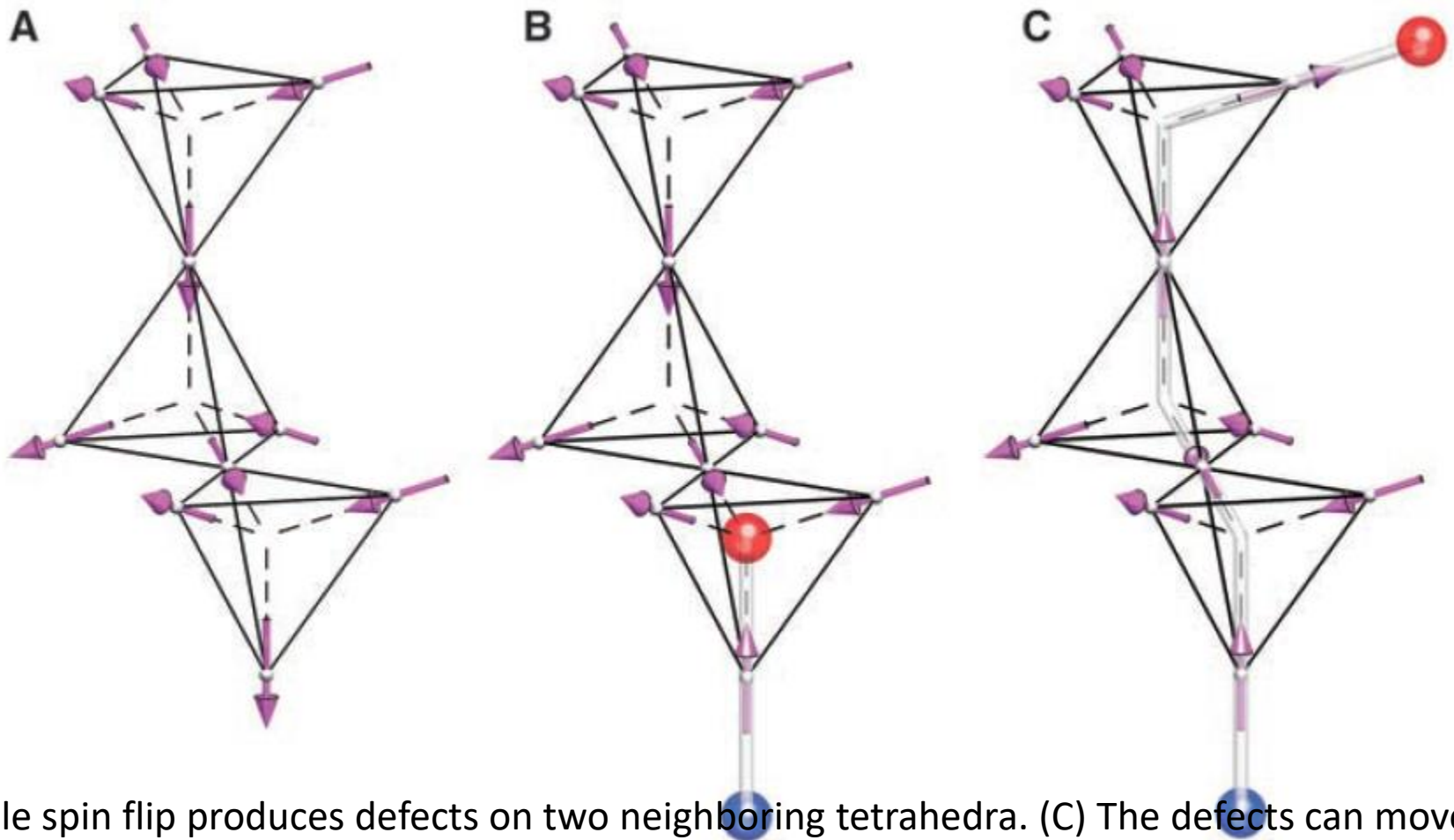
$m = 10\mu_B$ (rare-earth ions), \vec{r}_{ij} is the distance between spins i and j and \vec{S}_i is a spin of unit length. The coupling constants are on the 1 K energy scale. These energy scales are 100 times smaller than the crystal field terms that confine the spins along the axis joining the centres of two adjoining tetrahedra. As a result, on the 1 K energy scale, the moments behave as Ising spins along this axis.

Magnetic monopoles in spin ice



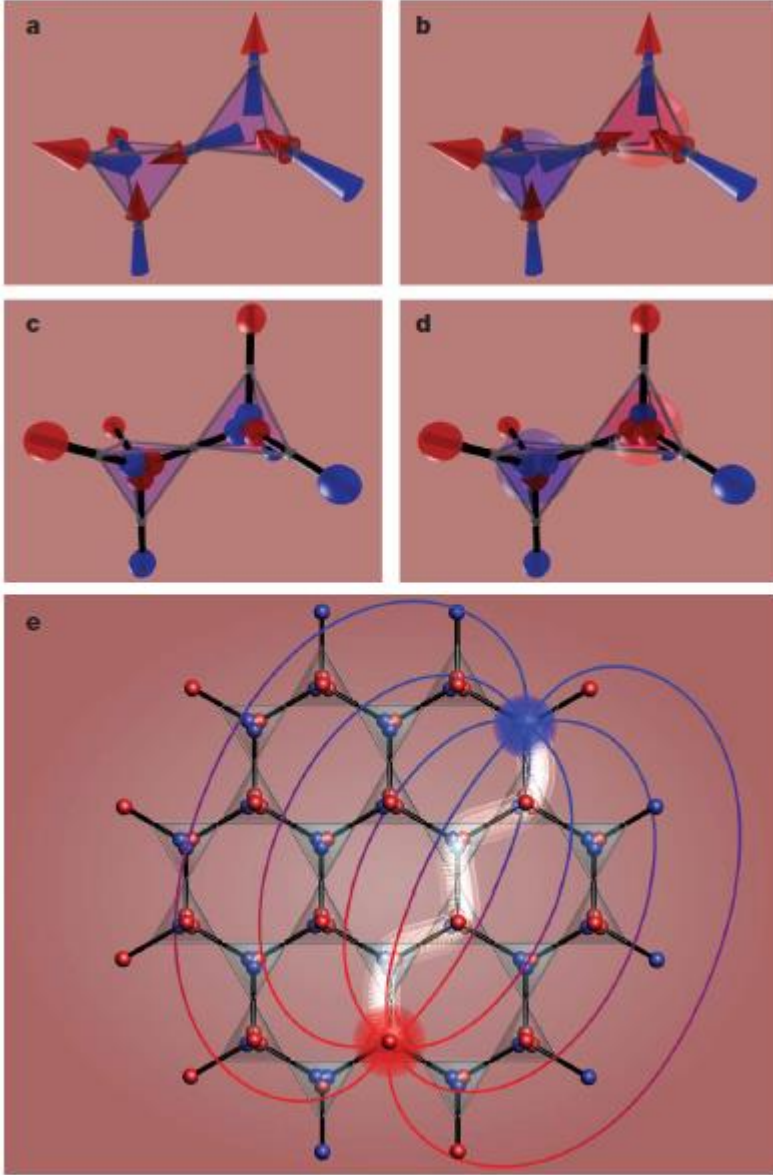
The pyrochlore and diamond lattices. The magnetic moments in spin ice reside on the sites of the pyrochlore lattice, which consists of cornersharing tetrahedra. These are at the same time the midpoints of the bonds of the diamond lattice (black) formed by the centres of the tetrahedra. The ratio of the lattice constant of the diamond and pyrochlore lattices is $a_d/a = \sqrt{3/2}$. The Ising axes are the local [111] directions, which point along the respective diamond lattice bonds.

Magnetic monopoles in spin ice

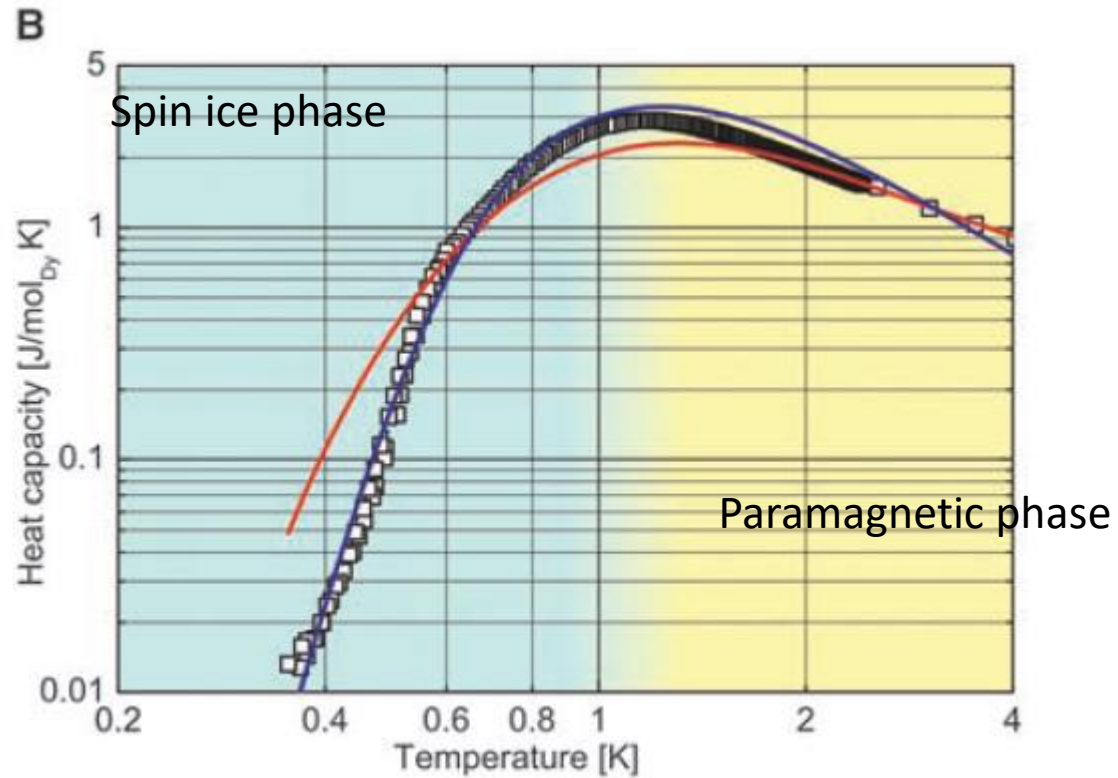
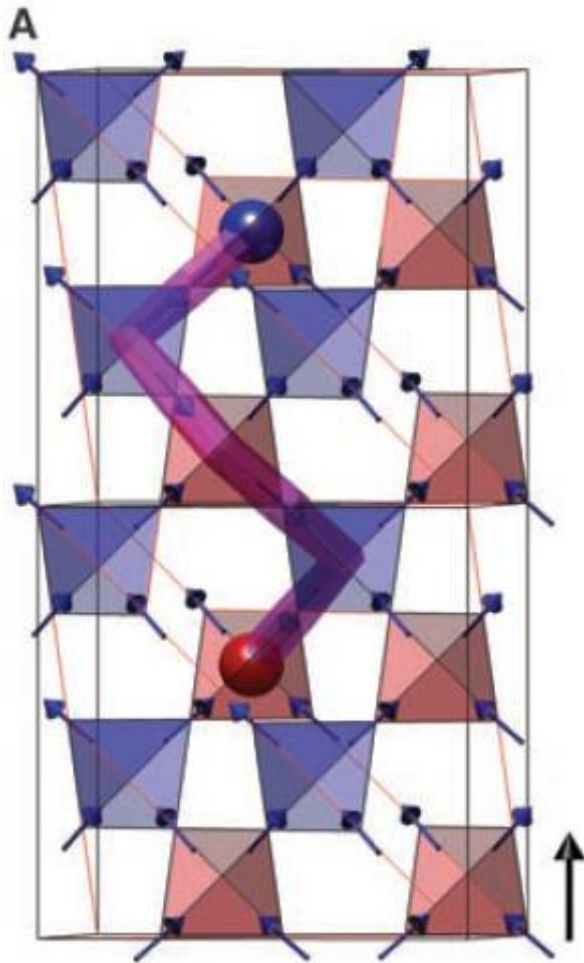


A single spin flip produces defects on two neighboring tetrahedra. (C) The defects can move apart. They interact like oppositely charged magnetic monopoles connected by a trail of flipped spins (a Dirac string). The pink arrows indicate spins, the blue spheres indicate monopoles, and the red spheres indicate antimonopoles.

Magnetic monopoles in spin ice



Magnetic monopoles in spin ice

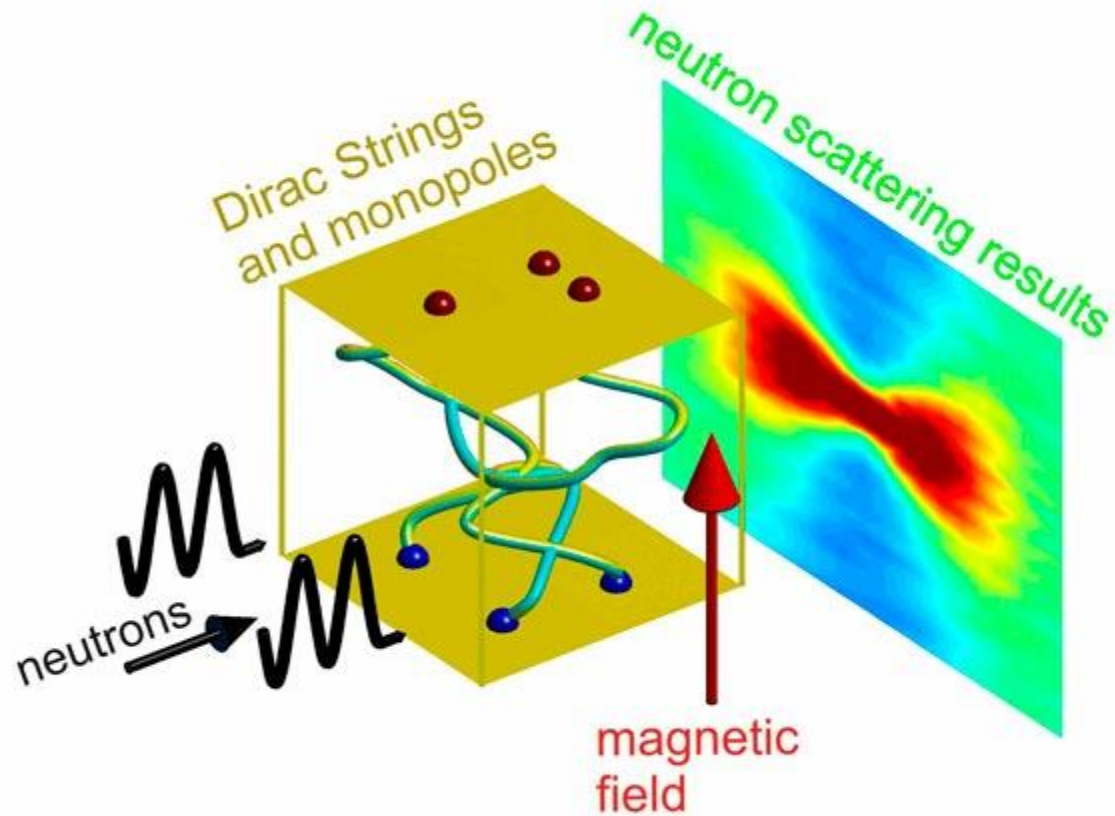


The measured heat capacity per mole of $\text{Dy}_2\text{Ti}_2\text{O}_7$ at zero field (open squares) is compared with a Debye-Hückel theory for the monopoles (blue line) and the best fit to a single-tetrahedron (Bethe lattice) approximation (red line).

D. J. P. Morris et al. SCIENCE VOL 326, 411 (2009)

Magnetic monopoles in spin ice

Dirac string



<http://physicsworld.com/cws/article/news/2009/sep/03/magnetic-monopoles-spotted-in-spin-ices>

Magnetic monopoles in spin ice

AIP | Conference Proceedings

Dirac's Dream—the Search for the Magnetic Monopole

James L. Pinfold

Citation: *AIP Conf. Proc.* 1304, 234 (2010); doi: 10.1063/1.3527206

Dirac string

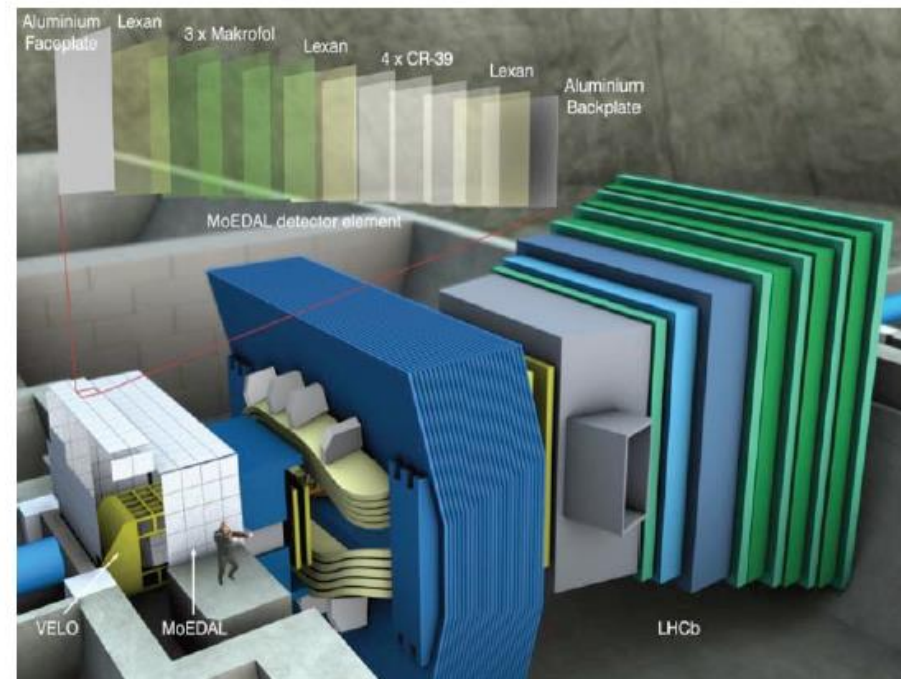
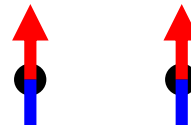


FIGURE 1. A visualization of the MoEDAL detector adjacent to the LHCb detector at intersection point 8 on the LHC ring

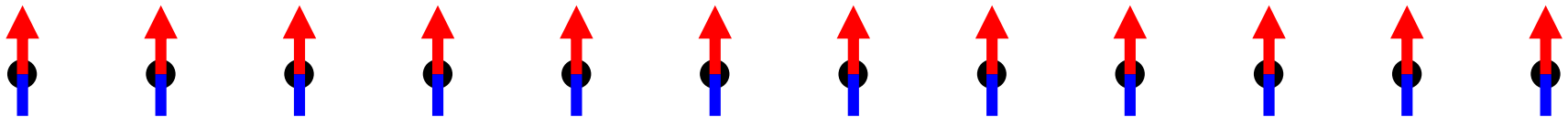
Skyrmions

$$\hat{H} = g\mu_B \vec{B} \cdot \vec{S} + \sum_{\langle ij \rangle} J_{ij} \vec{S}_i \cdot \vec{S}_j$$

FERRO



The magnetization M in the absence of B $M = 0$

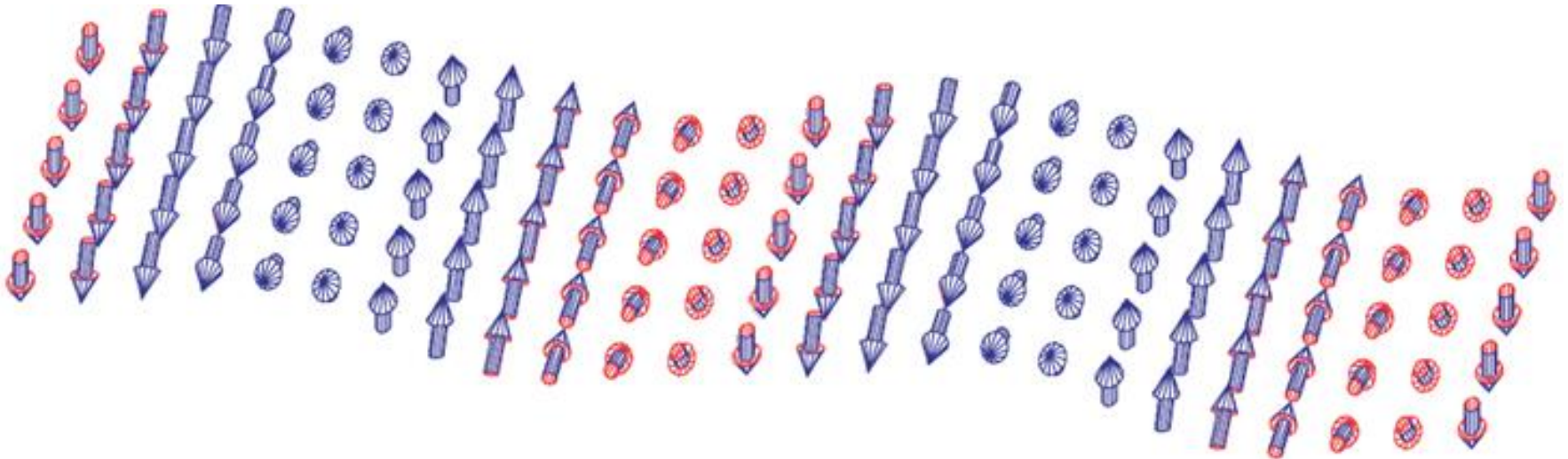
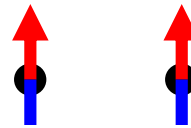


Skyrmions

Dzyaloshinsky-Moriya term

$$\hat{H} = g\mu_B \vec{B} \cdot \vec{S} + \sum_{\langle ij \rangle} J_{ij} \vec{S}_i \cdot \vec{S}_j + \sum_{\langle ij \rangle} D_{ij} \vec{S}_i \times \vec{S}_j$$

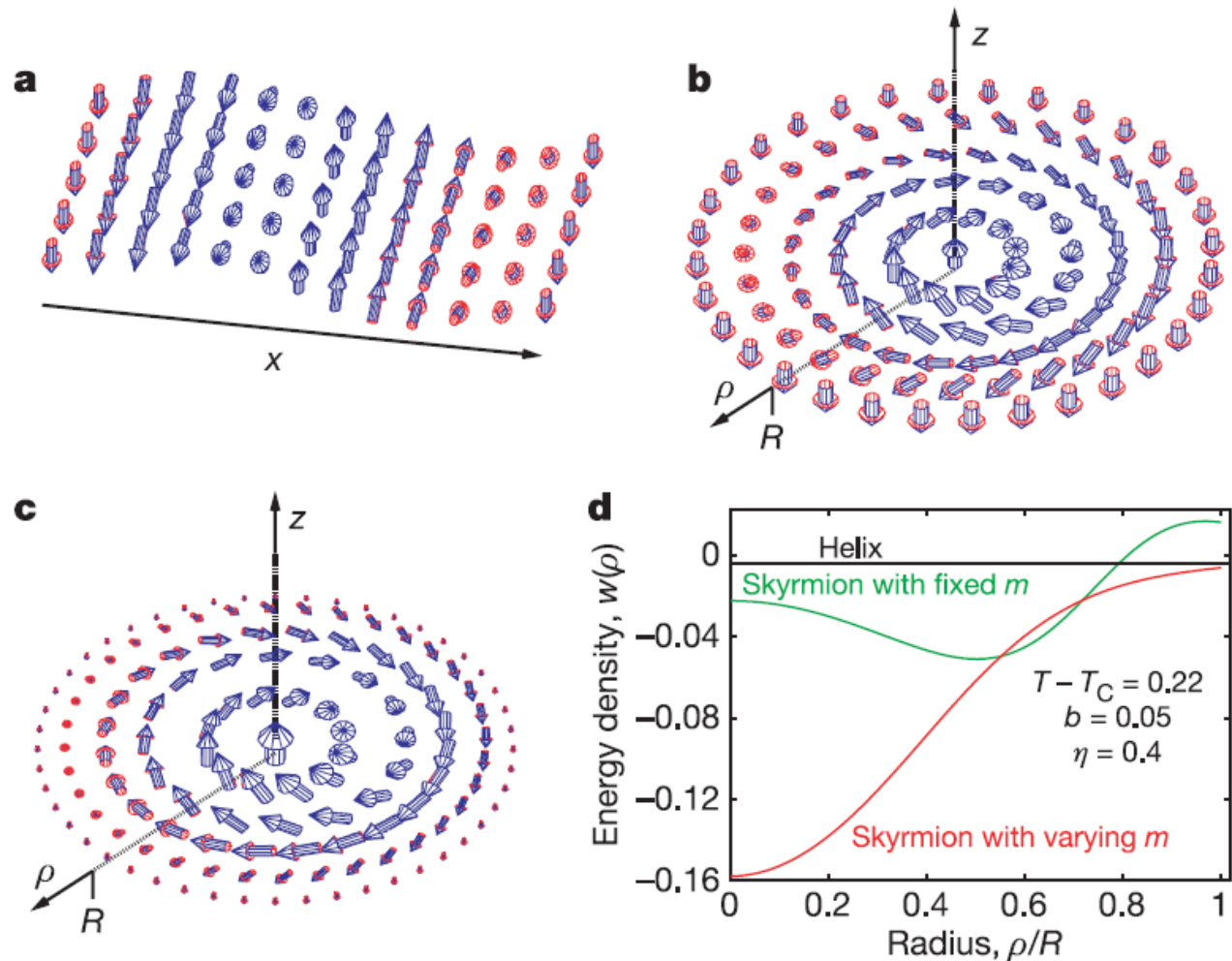
CHIRAL MAGNETS



Skyrmions

Spontaneous skyrmion ground states in magnetic metals

U. K. Rößler¹, A. N. Bogdanov^{1,2} & C. Pflüger

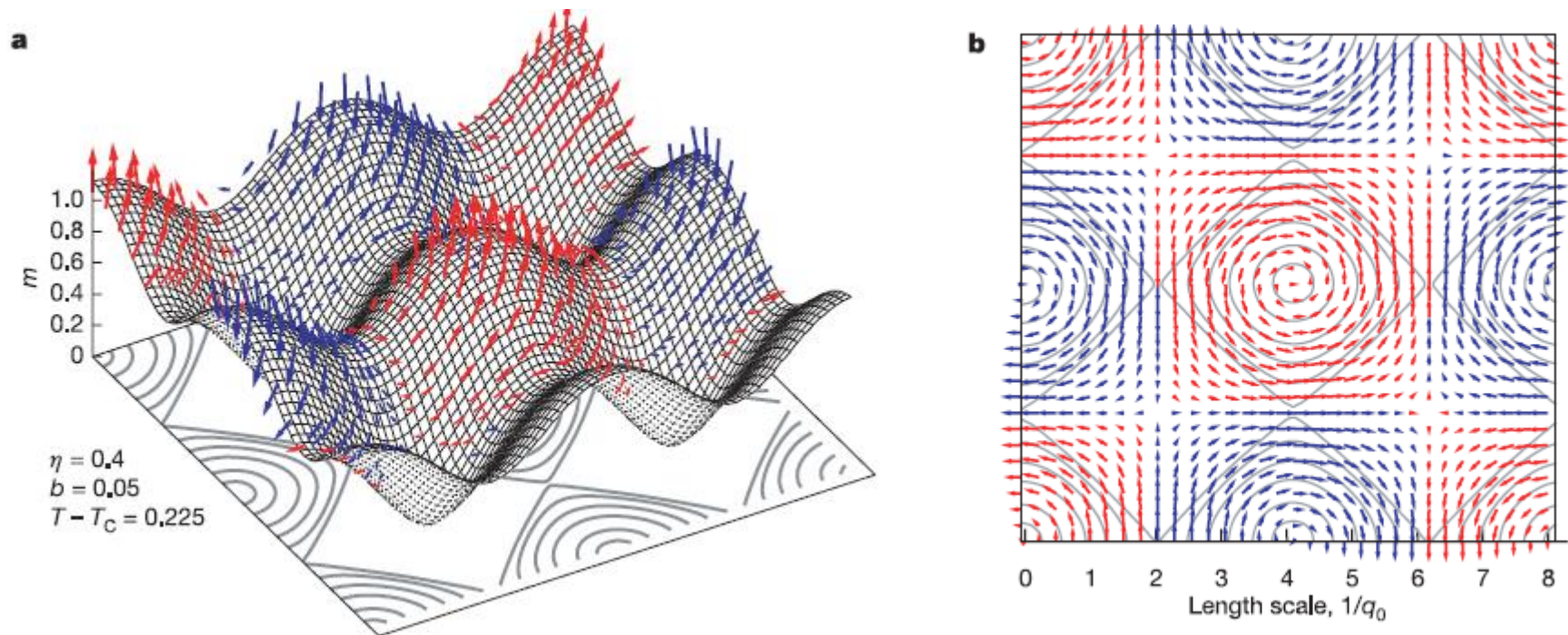


Nature **442**, 797 (2006)

Skyrmions

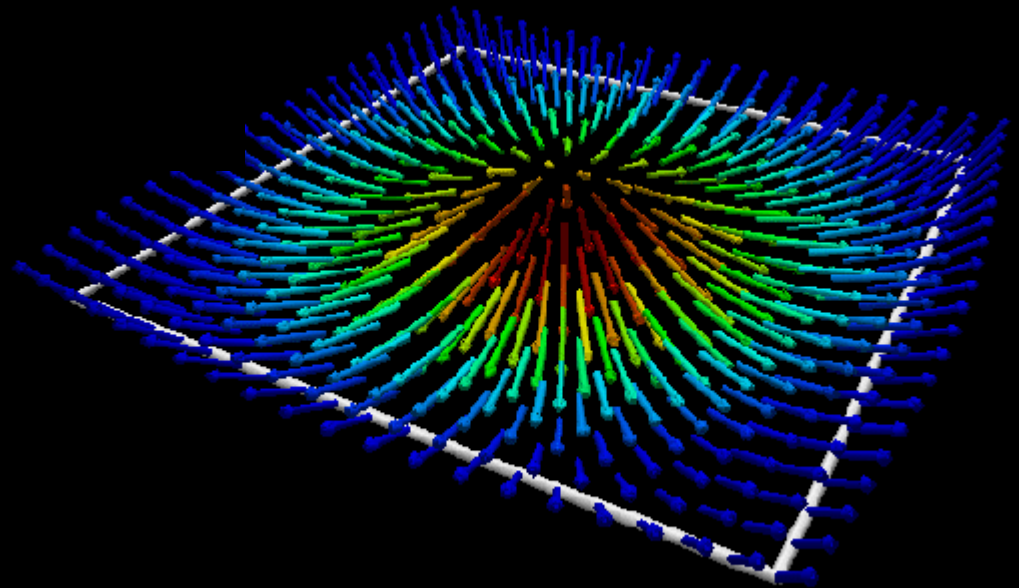
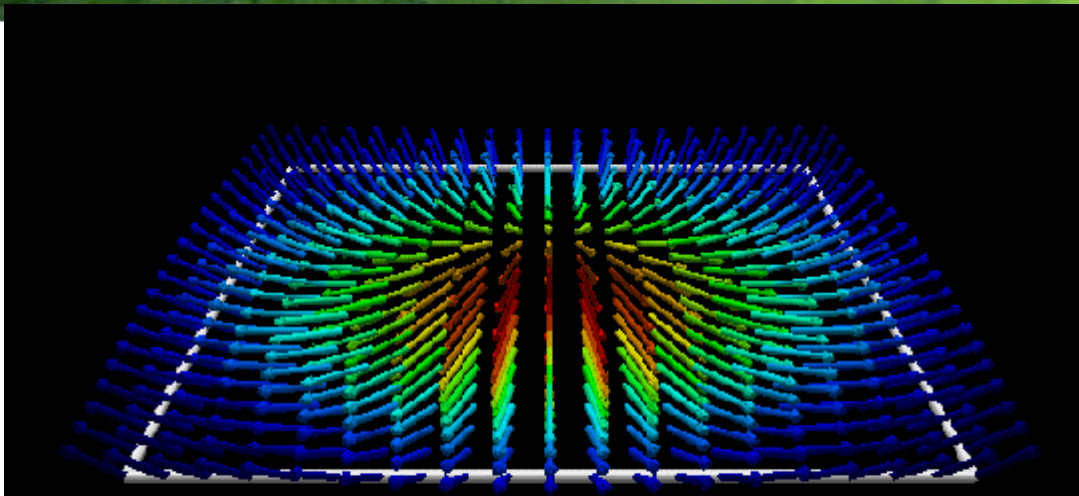
Spontaneous skyrmion ground states in magnetic metals

U. K. Rößler¹, A. N. Bogdanov^{1,2} & C. Pfleiderer^{2,3,4}



Nature **442**, 797 (2006)

Skyrmion lattices and helimagnetism

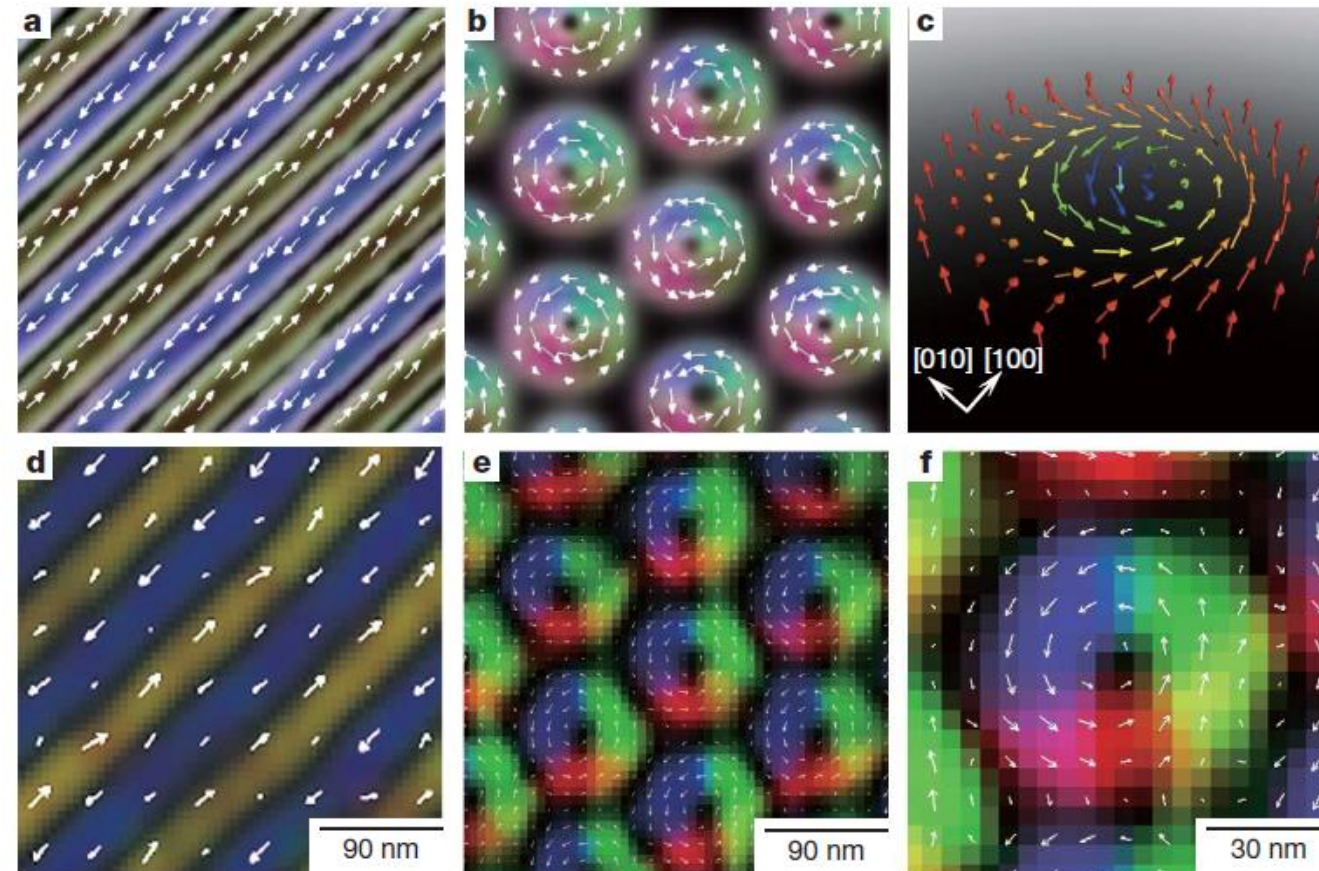


<http://www.tcm.phy.cam.ac.uk/~nrc25/projects/skyrmions.htm>

Skyrmions

Real-space observation of a two-dimensional skyrmion crystal

X. Z. Yu^{1,2}, Y. Onose^{2,3}, N. Kanazawa³, J. H. Park⁴, J. H. Han⁴, Y. Matsui¹, N. Nagaosa^{3,5} & Y. Tokura^{2,3,5}



Topological spin textures in the helical magnet $\text{Fe}_{0.5}\text{Co}_{0.5}\text{Si}$. **a, b**, Helical (**a**) and skyrmion (**b**) structures predicted by Monte Carlo simulation. **c**, Schematic of the spin configuration in a skyrmion. **d–f**, The experimentally observed real-space images of the spin texture, represented by the lateral magnetization distribution as obtained by transport-of-intensity equation (TIE) analysis of the Lorentz TEM data: helical structure at zero magnetic field (**d**), the skyrmion crystal (SkX) structure for a weak magnetic field (50 mT) applied normal to the thin plate (**e**) and a magnified view of **e** (**f**).

Nature **465**, 901 (2010)

Skyrmions



Spin Transfer Torques in MnSi at Ultralow Current Densities

F. Jonietz *et al.*

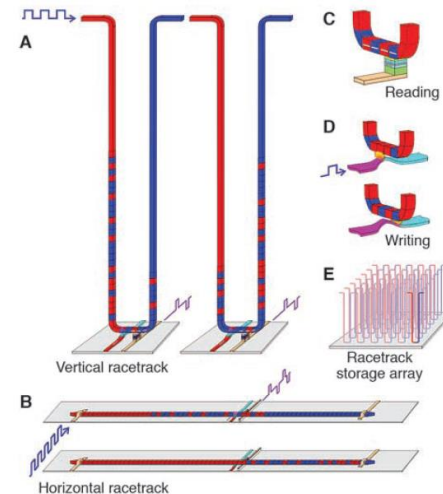
Science 330, 1648 (2010);

DOI: 10.1126/science.1195709

Spin Transfer Torques in MnSi at Ultralow Current Densities

F. Jonietz,¹ S. Mühlbauer,^{1,2} C. Pfleiderer,^{1*} A. Neubauer,¹ W. Münzer,¹ A. Bauer,¹ T. Adams,¹ R. Georgii,^{1,2} P. Böni,¹ R. A. Duine,³ K. Everschor,⁴ M. Garst,⁴ A. Rosch⁴

Spin manipulation using electric currents is one of the most promising directions in the field of spintronics. We used neutron scattering to observe the influence of an electric current on the magnetic structure in a bulk material. In the skyrmion lattice of manganese silicon, where the spins form a lattice of magnetic vortices similar to the vortex lattice in type II superconductors, we observe the rotation of the diffraction pattern in response to currents that are over five orders of magnitude smaller than those typically applied in experimental studies on current-driven magnetization dynamics in nanostructures. We attribute our observations to an extremely efficient coupling of inhomogeneous spin currents to topologically stable knots in spin structures.



Skyrmions

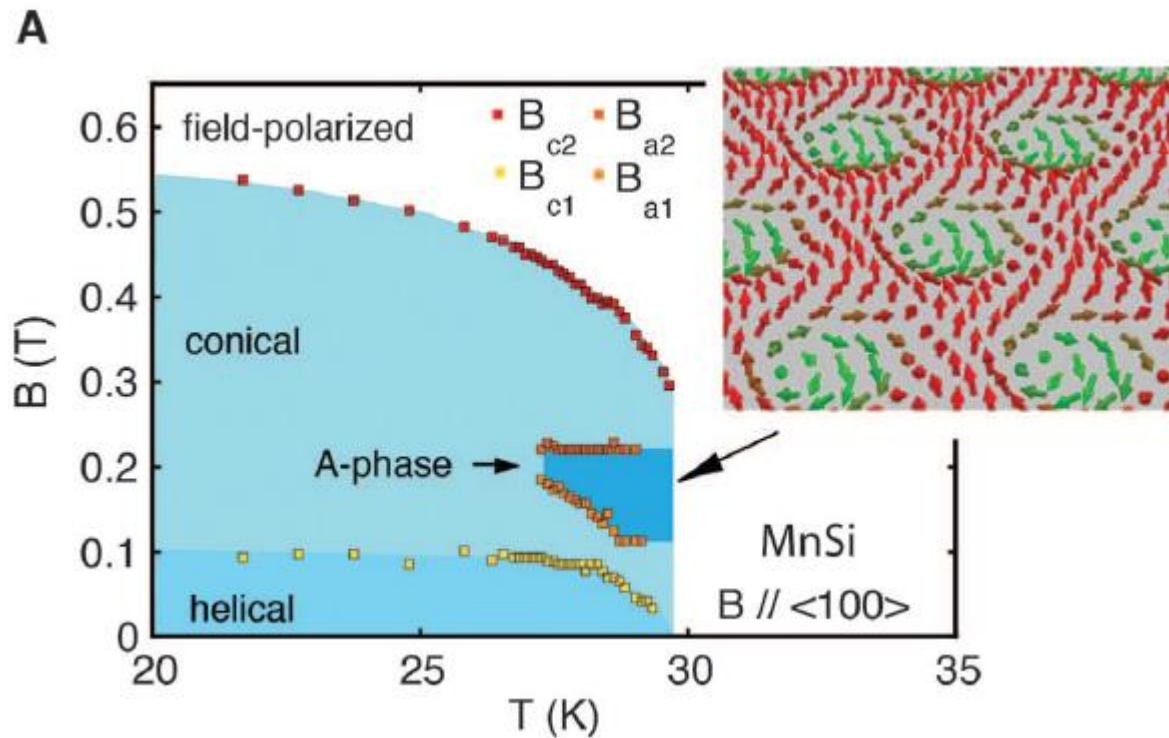


Spin Transfer Torques in MnSi at Ultralow Current Densities

F. Jonietz *et al.*

Science 330, 1648 (2010);

DOI: 10.1126/science.1195709



Skymions

Science

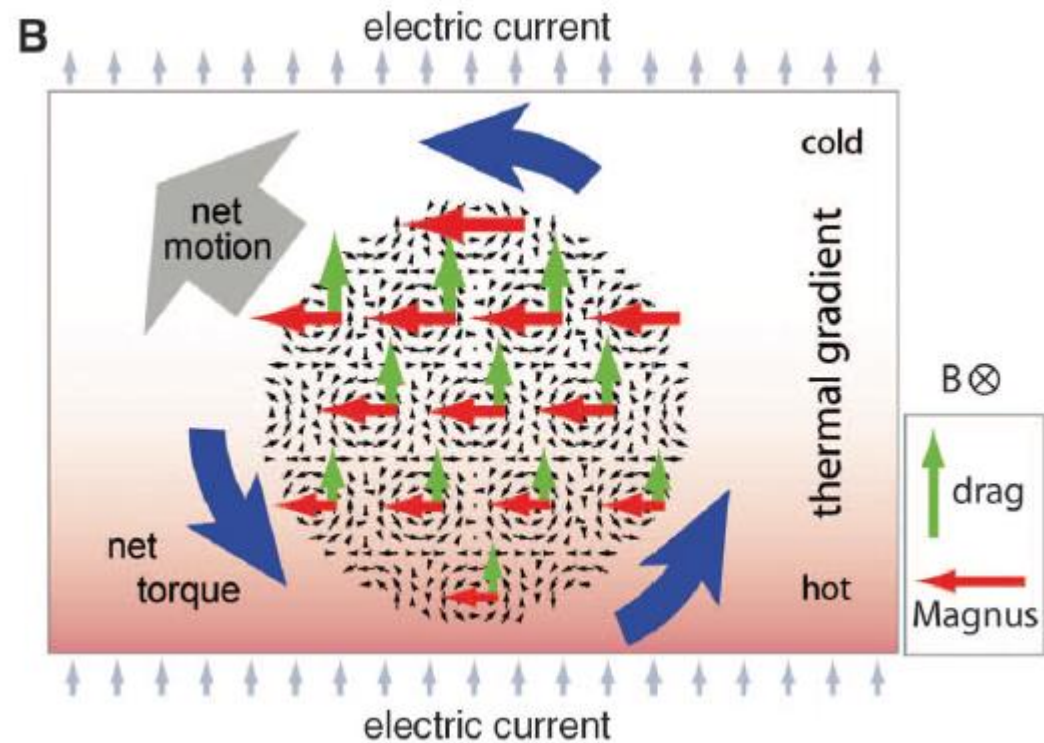
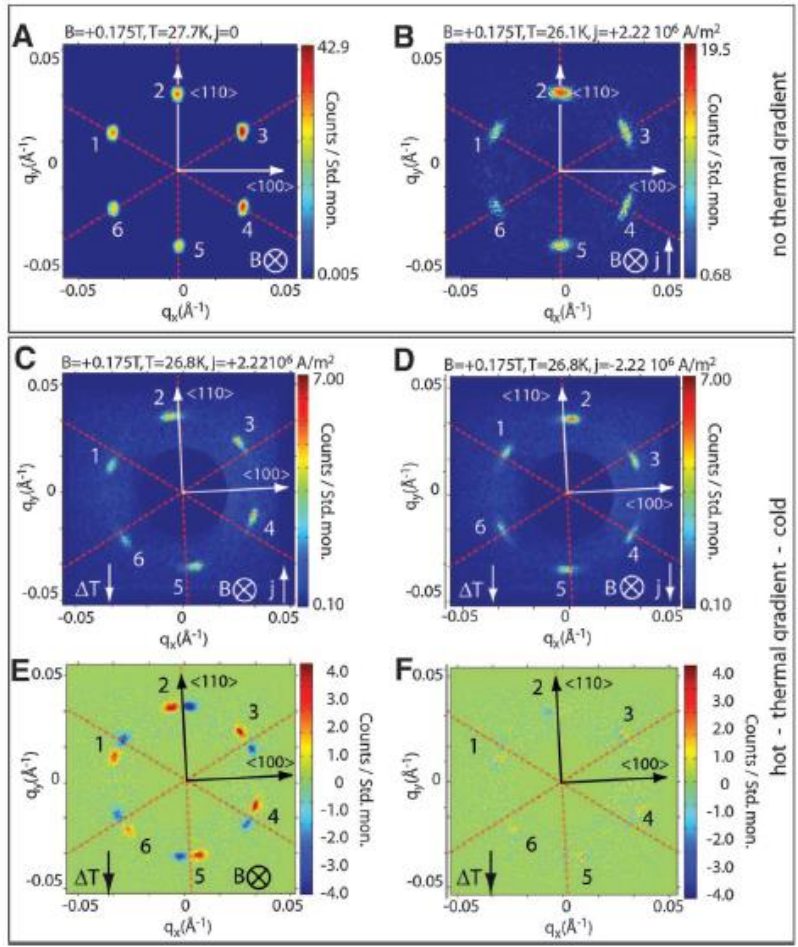
AAAS

Spin Transfer Torques in MnSi at Ultralow Current Densities

F. Jonietz *et al.*

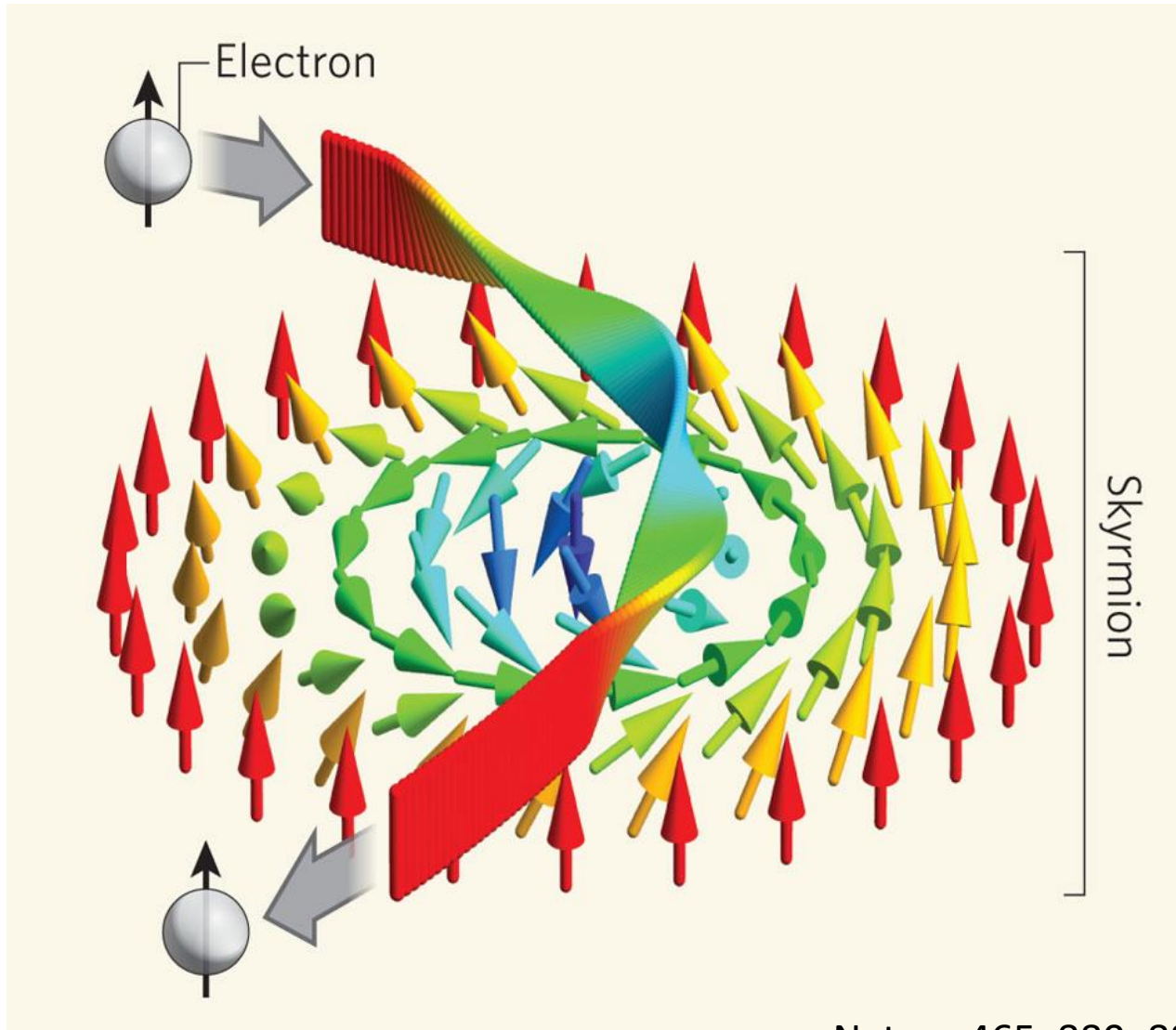
Science 330, 1648 (2010);

DOI: 10.1126/science.1195709



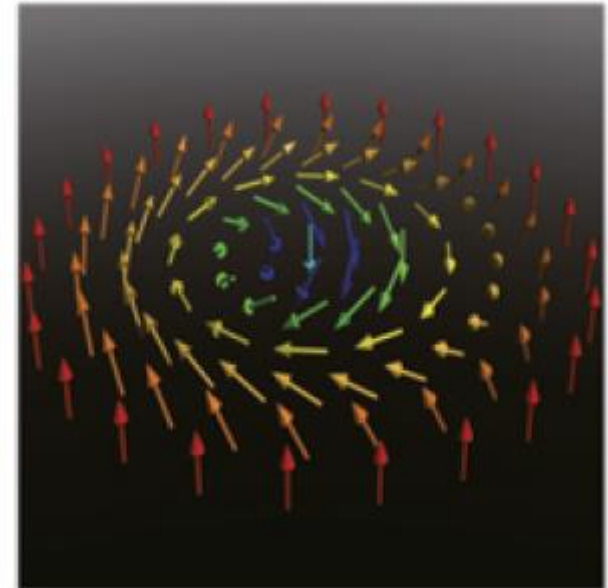
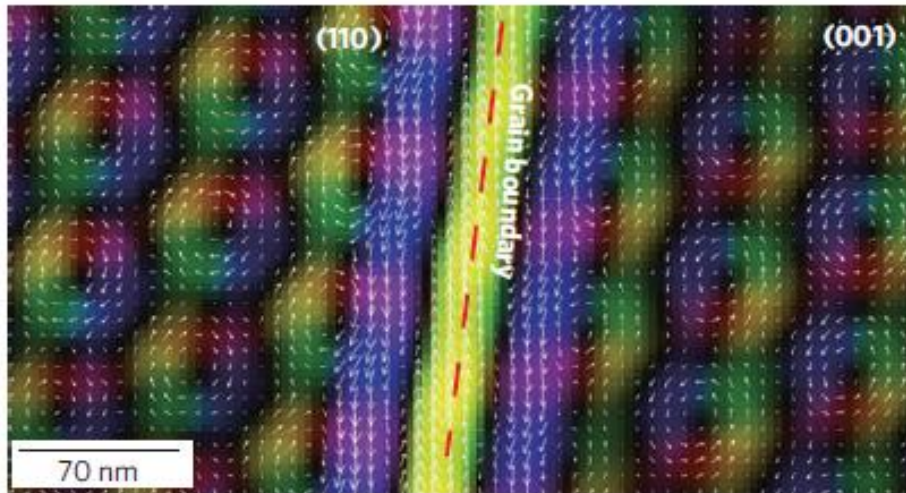
neutron-scattering measurements for a neutron beam parallel to the applied magnetic field

Skyrmion lattices and helimagnetism



Near room-temperature formation of a skyrmion crystal in thin-films of the helimagnet FeGe

X. Z. Yu^{1*}, N. Kanazawa², Y. Onose^{1,2}, K. Kimoto³, W. Z. Zhang³, S. Ishiwata², Y. Matsui³
and Y. Tokura^{1,2,4*}



high-resolution Lorentz TEM

Skyrmions

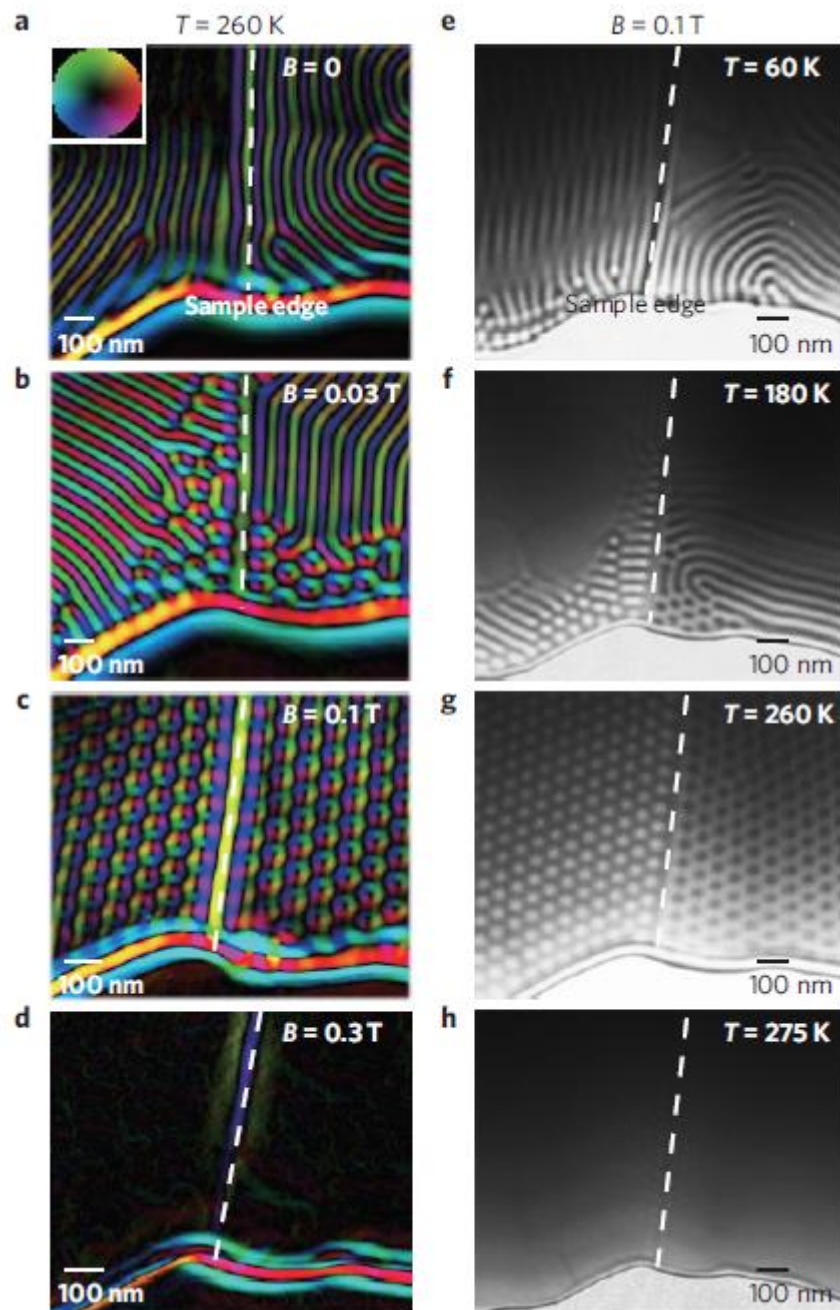
LETTERS

PUBLISHED ONLINE: 5 DECEMBER 2010 | DOI: 10.1038/NMAT2916

Near room-temperature formation of skyrmion crystal in thin-films of the heli

X. Z. Yu^{1*}, N. Kanazawa², Y. Onose^{1,2}, K. Kimoto³, W. Z. Zhan and Y. Tokura^{1,2,4*}

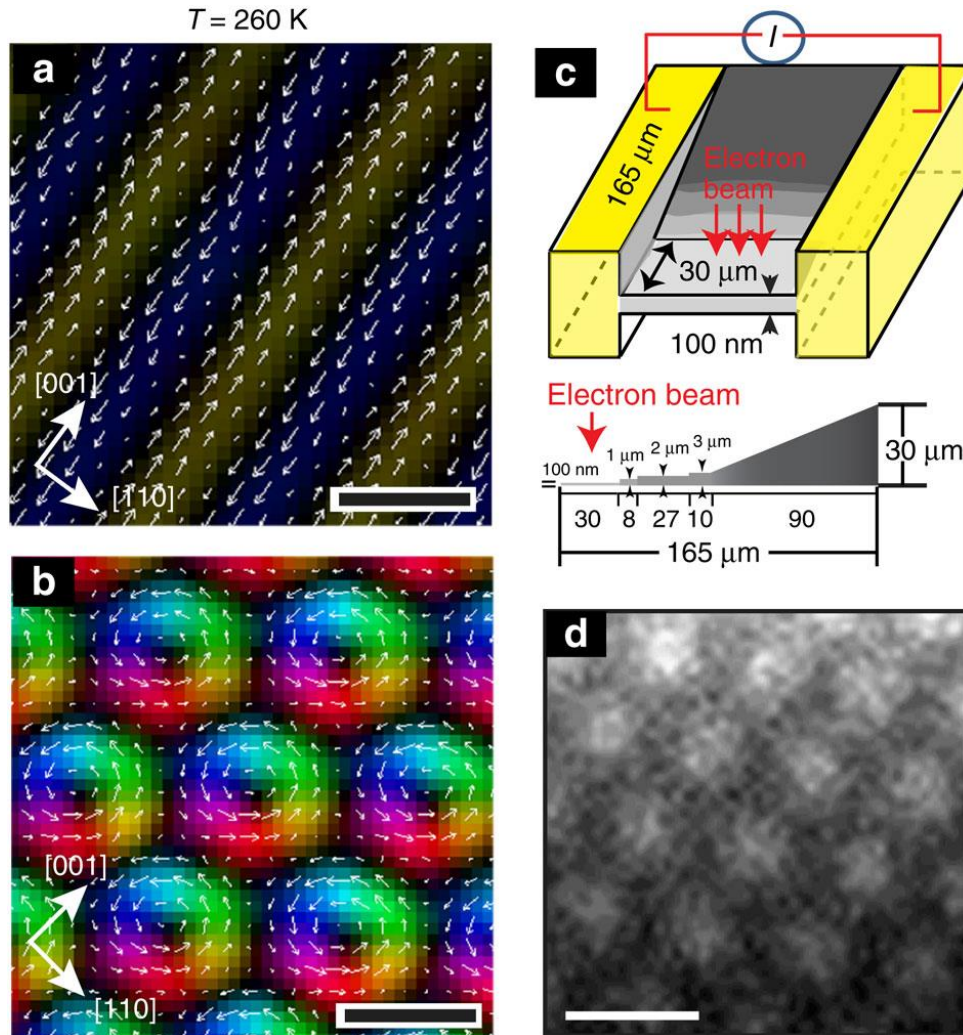
260 K!



Skyrmion lattices and helimagnetism

Skyrmion flow near room temperature in an ultralow current density

X.Z. Yu, N. Kanazawa, et al., Nature Communications **3**, 988 (2012)



(a,b) The in-plane magnetization textures of the helical structure ($B=0$) and of the skyrmion crystal ($B=150 \text{ mT}$), as deduced from the transport-of-intensity equation analysis of the under-focus and over-focus Lorentz TEM images on a 30-nm -thick FeGe plate. Scale bar, 70 nm . Colours and white arrows are signs of the magnitude and orientation of in-plane magnetizations, whereas the dark colour depicts the upward (downward) spins in the periphery (core) of the skyrmions. **(c)** Schematic diagram and cross-sectional view of a microdevice with a trapezoidal FeGe plate that is composed of a 100 nm -thick thinner terrace for electron-beam transmission and another trapezoidal thicker part for supporting the thinner part. **(d)** The under-focus Lorentz TEM image for the skyrmion crystal taken at 250 K and 150 mT for the present device. Scale bar **(d)**, 100 nm .

Skyrmions

Science

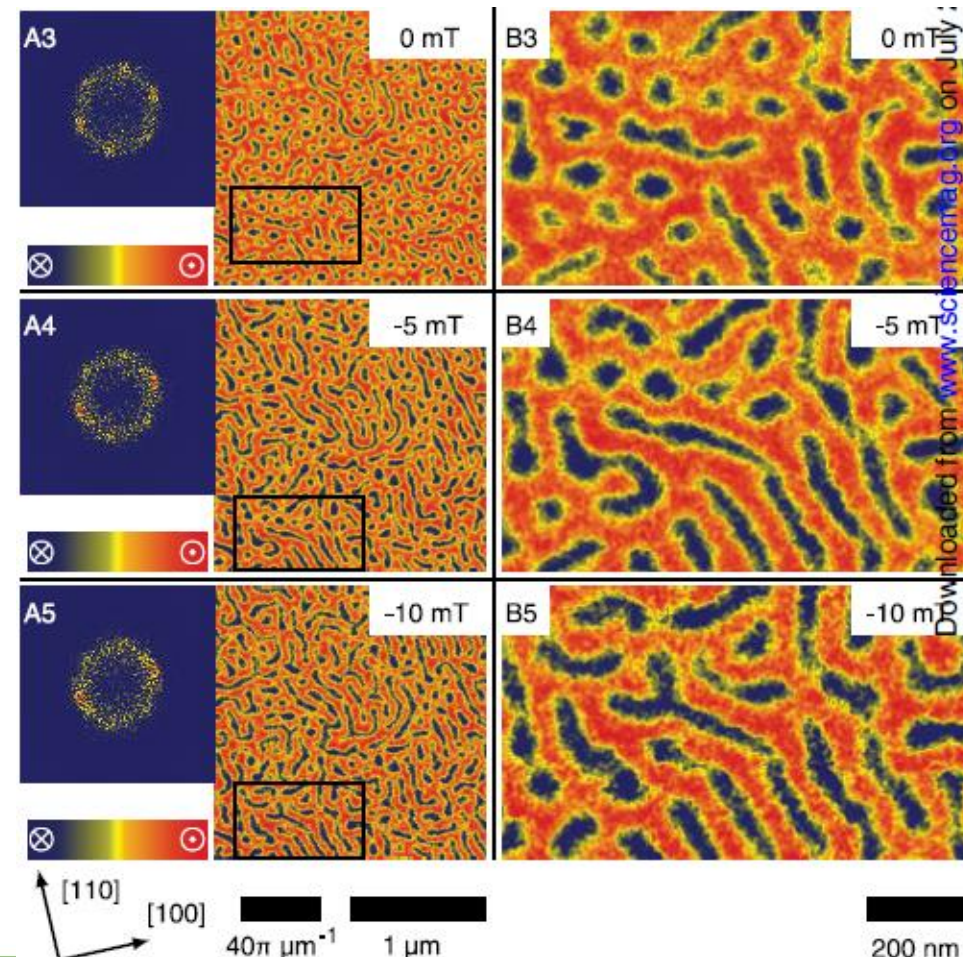
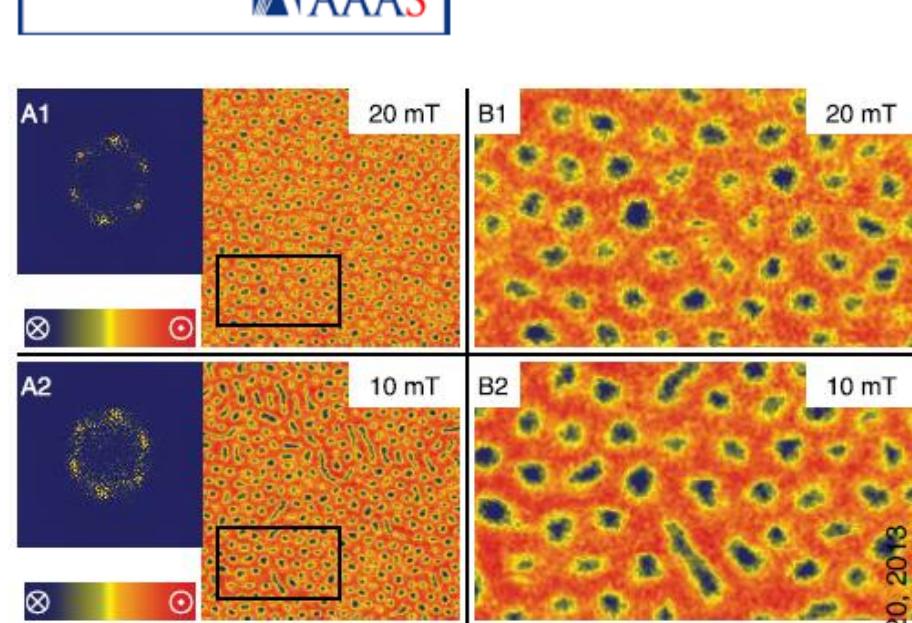
AAAS

Unwinding of a Skyrmion Lattice by Magnetic Monopoles

P. Milde *et al.*

Science **340**, 1076 (2013);

DOI: 10.1126/science.1234657



Typical magnetic force microscopy data at the surface of $\text{Fe}_{1-x}\text{Co}_x\text{Si}$ ($x = 0.5$)

Skyrmions

Science

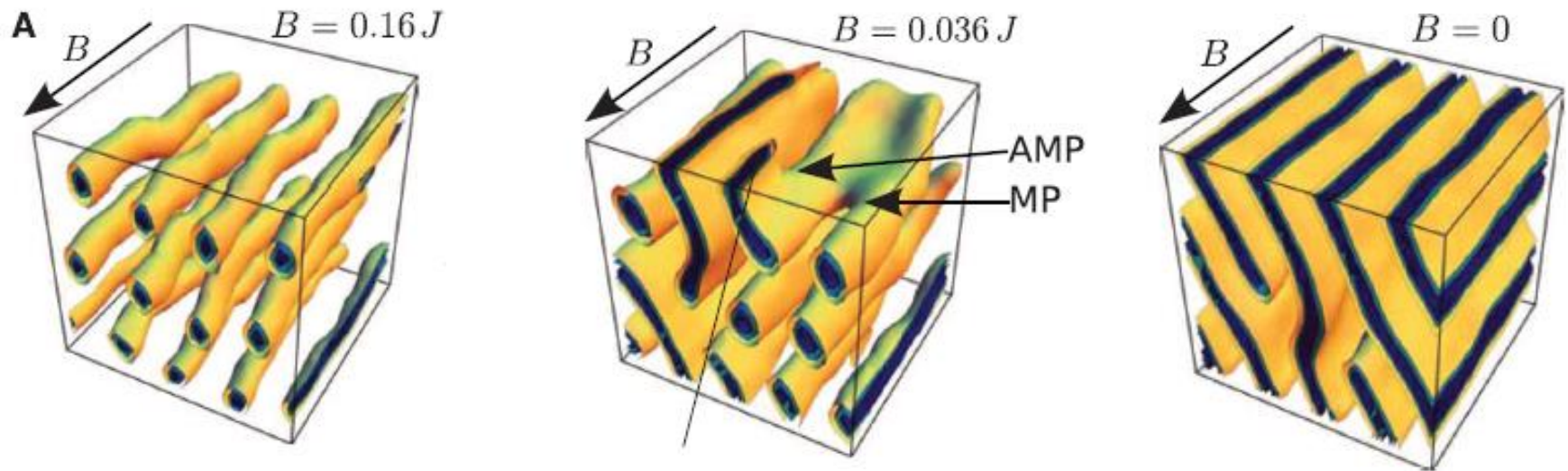
AAAS

Unwinding of a Skyrmion Lattice by Magnetic Monopoles

P. Milde *et al.*

Science **340**, 1076 (2013);

DOI: 10.1126/science.1234657



Monte Carlo simulation for a system first field cooled at $B=0.16J$ ($B \parallel [110]$) down to $T = 0.6 J$.

Skyrmions

Science

AAAS

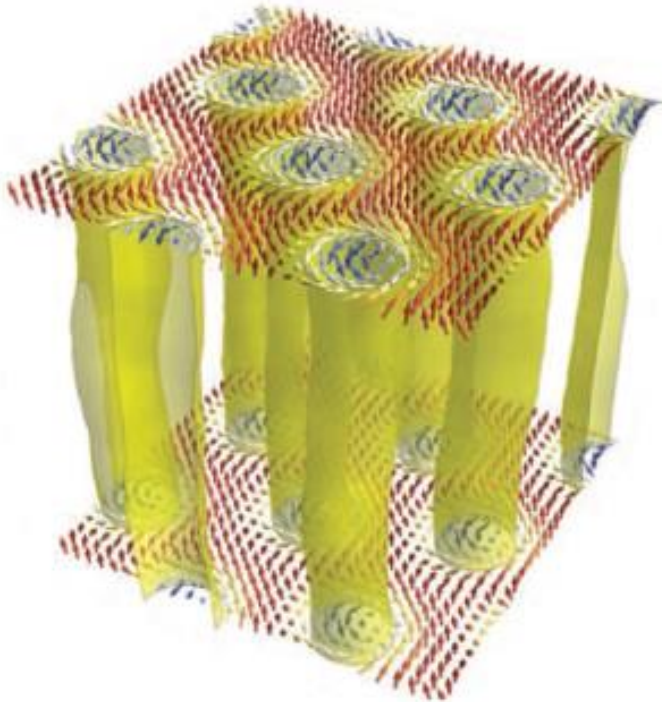
Unwinding of a Skyrmion Lattice by Magnetic Monopoles

P. Milde *et al.*

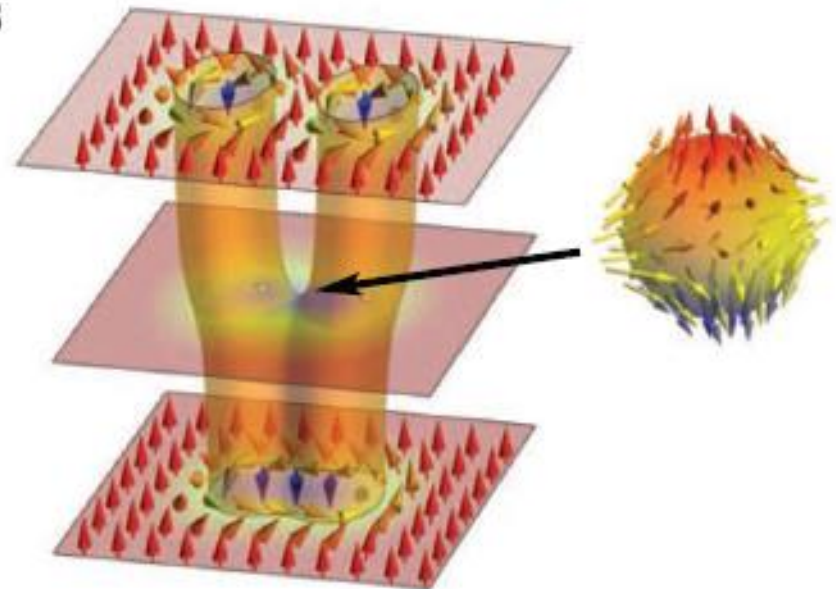
Science **340**, 1076 (2013);

DOI: 10.1126/science.1234657

A



B



Magnetism in All-Carbon Nanostructures with Negative Gaussian Curvature

Noejung Park,^{1,2} Mina Yoon,³ Savas Berber,³ Jisoon Ihm,^{4,2} Eiji Osawa,⁵ and David Tománek^{3,*}

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²Center for Nanotube and Nanostructured Composites, Sungkyunkwan University, Suwon, 440-746, Korea

³Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824-2320, USA

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⁵NanoCarbon Research Institute Limited, Chosei-mura, Chosei-gun, Chiba 2994395, Japan

(Received 8 July 2003; published 5 December 2003)

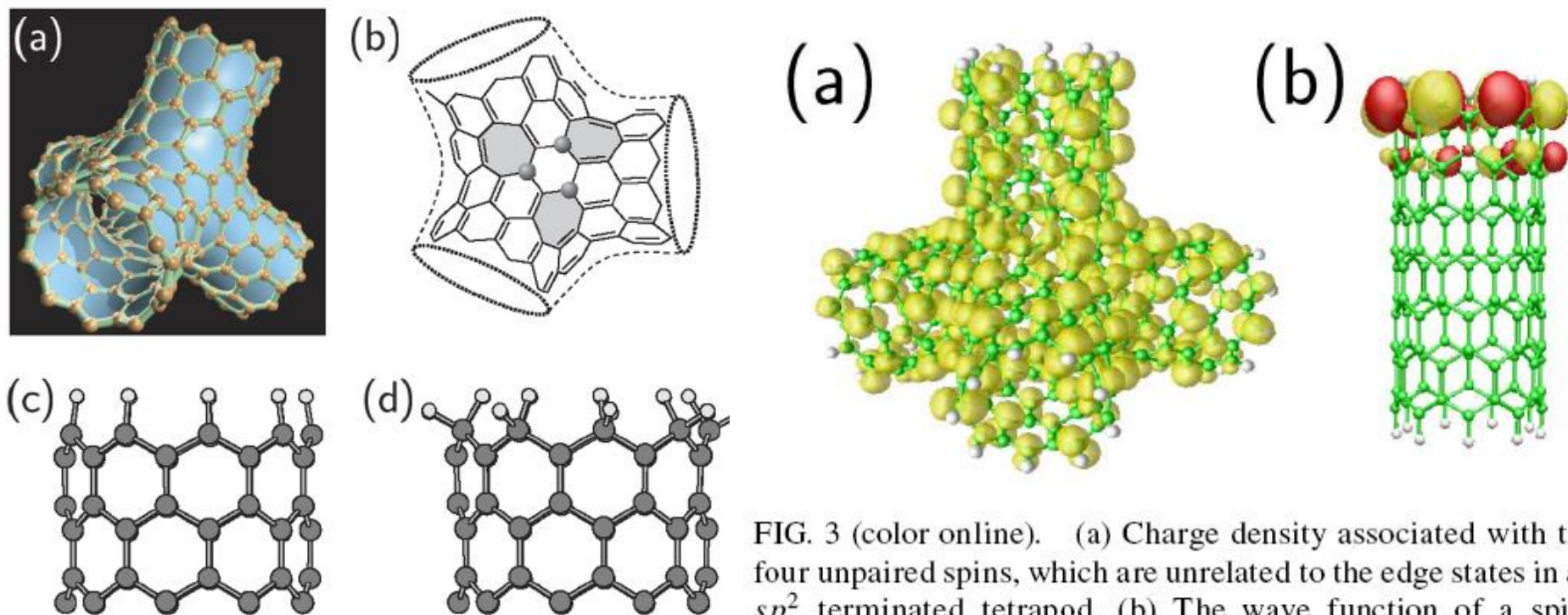


FIG. 3 (color online). (a) Charge density associated with the four unpaired spins, which are unrelated to the edge states in an sp^2 terminated tetrapod. (b) The wave function of a spin-polarized edge state in an sp^2 terminated (9,0) nanotube. We use color shading to represent the phase of the wave function.

Negatively Curved Graphitic Sheet Model of Amorphous Carbon

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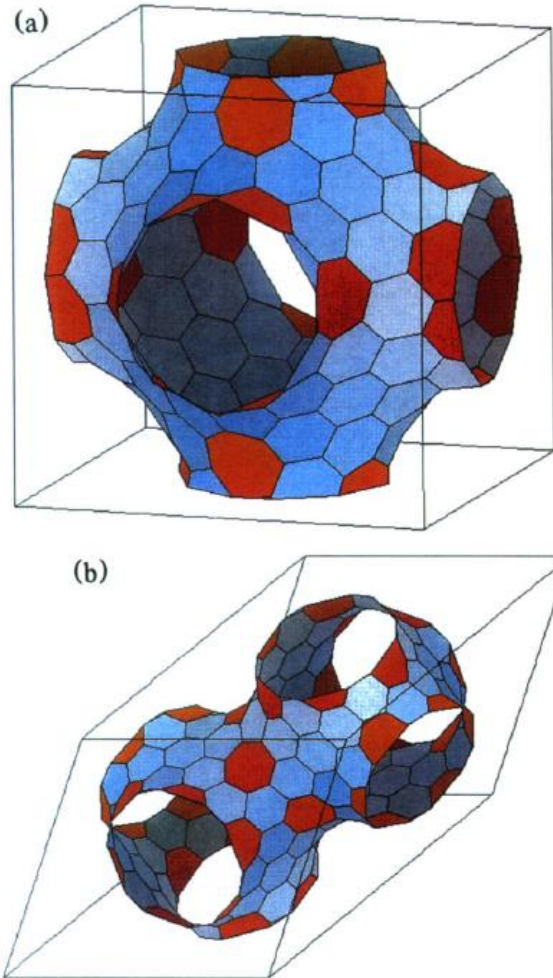


FIG. 1. Views of two new crystalline schwarzites. Each has 216 carbon atoms per primitive unit cell with 80 six-membered rings (blue) and 24 seven-membered rings (orange). The structure in (a) lies on a *P* minimal surface in a cubic cell 15.7 Å on a side. The structure in (b) lies on a *D* minimal surface in an fcc cell whose cubic lattice constant is 24.6 Å.

„plumber’s nightmare”

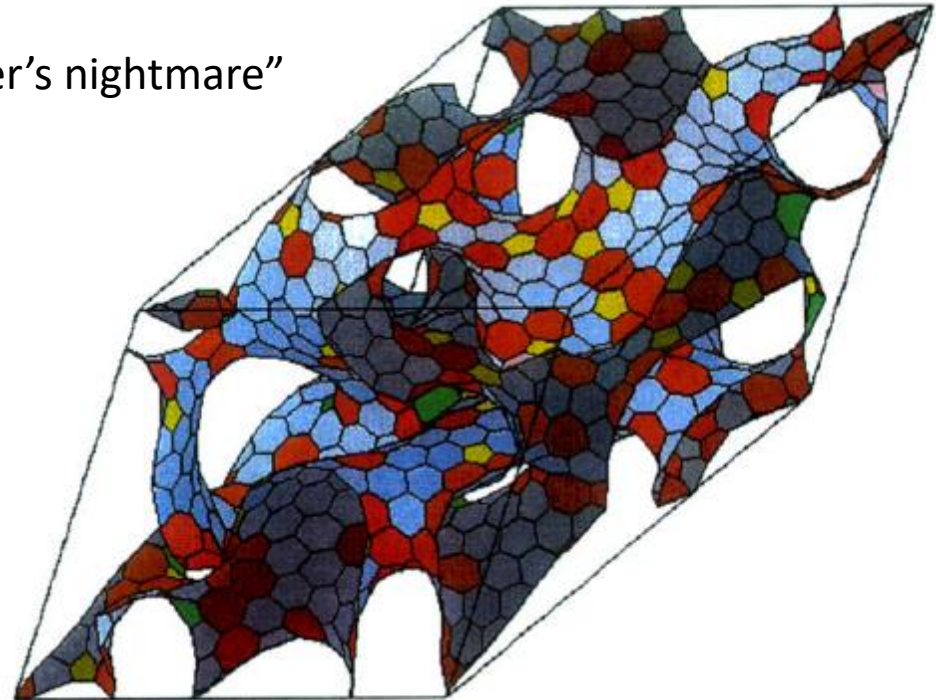
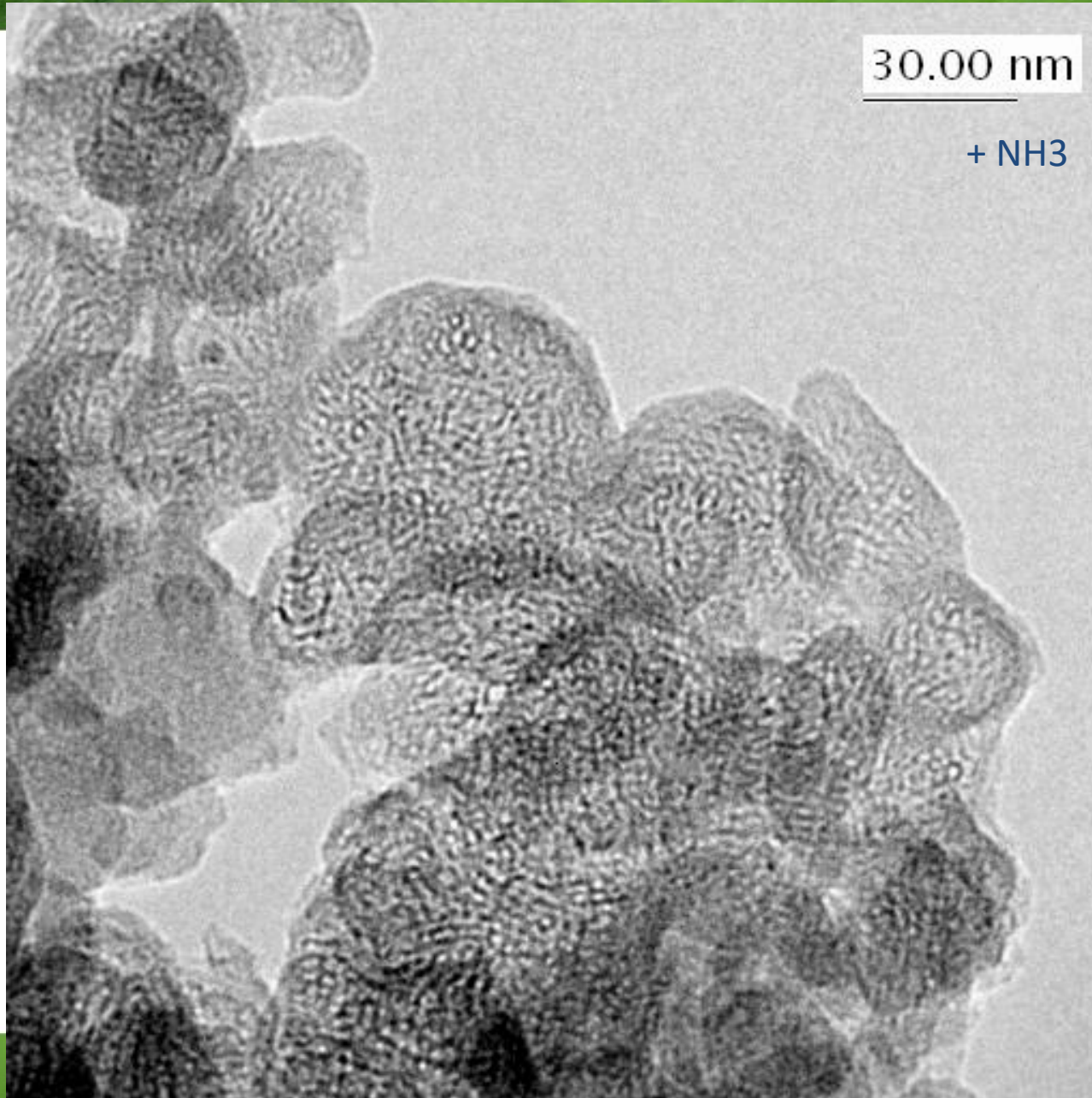


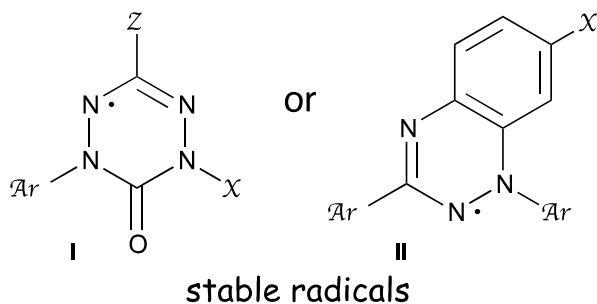
FIG. 2. View of a random schwarzite model on a surface of genus 12 per fcc supercell. The structure has 1248 carbons arranged into 38 five-membered rings (yellow), 394 six-membered rings (blue), 155 seven-membered rings (orange), 12 eight-membered rings (green), and 1 nine-sided ring (pink). Slower annealing produces a structure with many fewer five-membered rings. The cubic unit cell (4 times the volume of the fcc cell shown) is 42.9 Å on a side.

Schwarzites

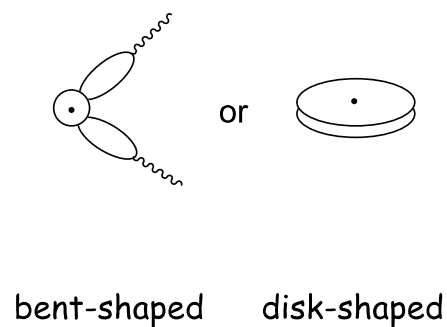


Organic magnetic liquid crystals

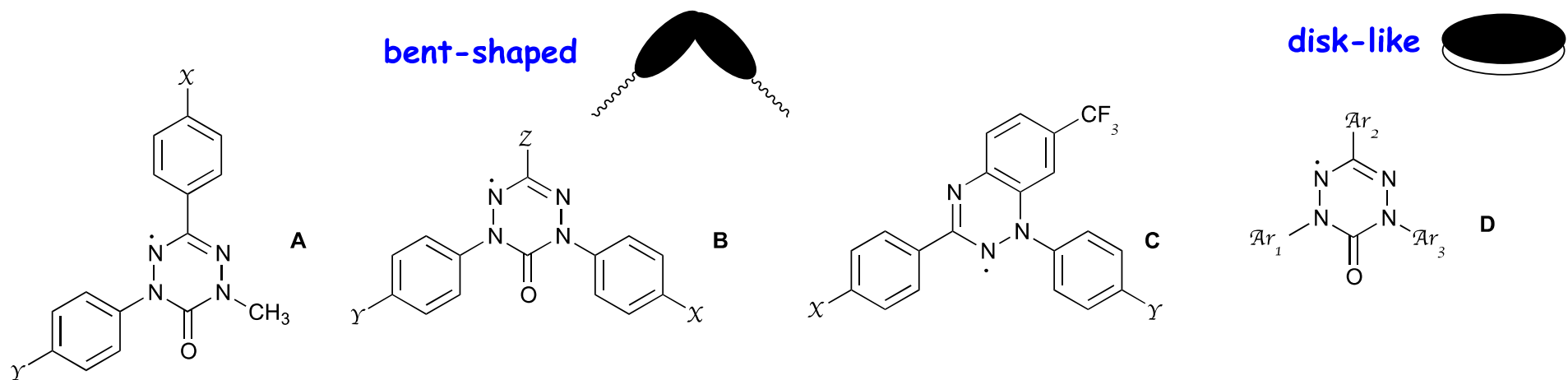
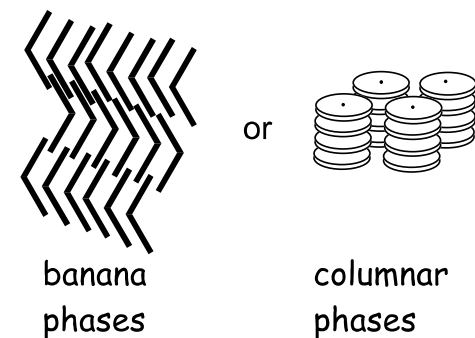
active element



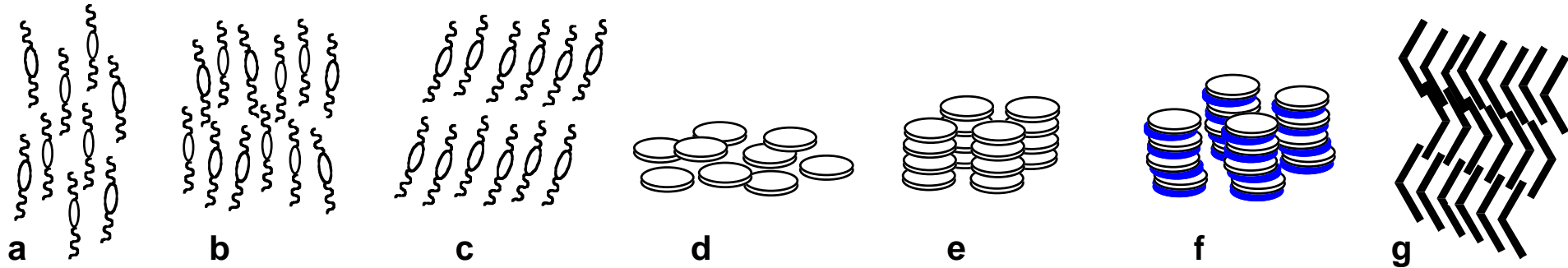
molecular design



supramolecular architecture



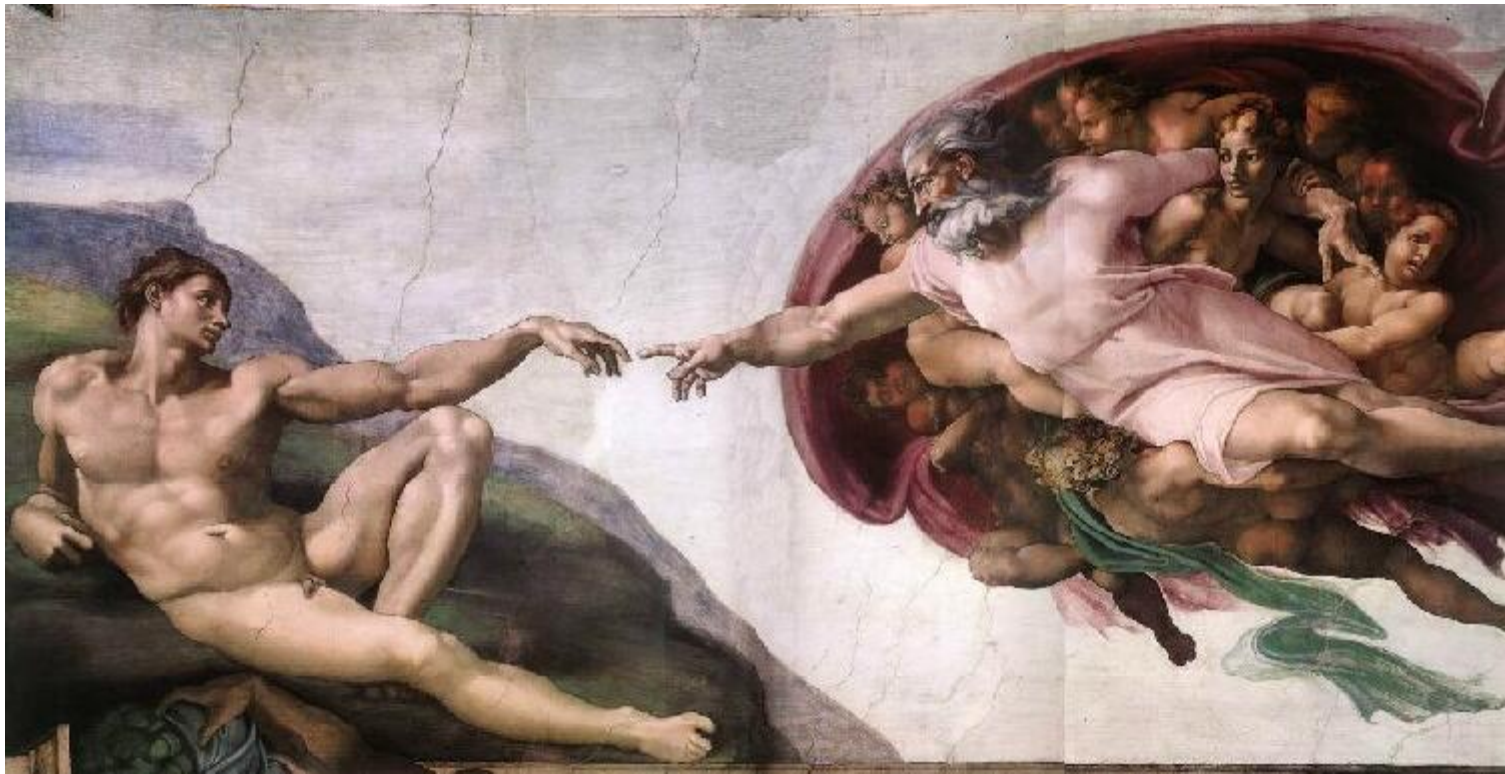
Organic magnetic liquid crystals



Molecular arrangements in selected liquid crystalline phases: a) nematic b) smectic A, c) smectic C, d) nematic discotic, e) columnar discotic, f) alternating stacks of columnar phase of a binary system, g) banana phase. The ovals represent the rigid cores and the lines are the flexible tails. Discs are comprised of a rigid core and radially distributed flexible tails.

Instead of conclusions:

Create your own quasi-particle!





Nowy Firefox. Szybki, już na dobre.

Dzisiaj mamy przyjemność zaprezentować Wam naszą nową przeglądarkę – Firefox Quantum.

Pierwsza rzecz, którą od razu zauważycie to to, jak szybko działa nowy Firefox. Będziecie cieszyć się dwa razy szybszą przeglądarką niż rok temu. Jest także mocniejsza w działaniu. Przebudowaliśmy Firefoksa od podstaw, skupiając się na tym, jak nasi użytkownicy używają sieci do oglądania, słuchania, tworzenia i grania bez limitów. Dostarczamy Wam przeglądarkę, która jest nowoczesna, szybka i efektywna. Mamy nadzieję, że się zgodzicie: to miły krok, jeśli chodzi o korzystanie z Internetu.

Korzystając z Firefoksa przyczyniasz się również do tego, aby Internet pozostawał globalnym zasobem publicznym, otwartym i dostępnym dla wszystkich. Jako niezależna organizacja non-profit od 2003 roku jesteśmy zaangażowani w tworzenie produktów, które pomagają Ci kontrolować Twoją obecność online, a także w rozwijanie otwartej technologii oraz zasad i praw, które promują otwarty Internet. To użytkownik jest w centrum wszystkich naszych działań.

W imieniu globalnej społeczności Mozilli mamy zaszczyt zaprezentować Wam [nowego Firefoksa](#). Szybkiego, już na dobre.

Chris Beard

Firefox Quantum.