$TiO_{2-\delta}:Co$ Magnetism Department, Faculty of Physics, MSU

Лекция 1

Понятие о магнетизме от древности до наших дней. Магнетизм и научно-технический прогресс. Современное представление о физике магнитных явлений.

А.Б. Грановский
кафедра магнетизма физического факультета МГУ им. М.В. Ломоносова

План

- Развитие представлений о магнетизме.
- Магнитные параметры.
- Единицы измерений.
- Основные понятия физики магнитных явлений.
- Магнитные материалы
- Проблемы сверхплотной магнитной записи
- Спинтроника
- Магнитофотоника
- Наномагнетизм
- Магнитобиология и биомагнетизм
- Заключение

"I swear to tell the truth, all the truth and nothing but the truth"

Магнетизм есть **универсальное свойство материи**, так как все вещества в природе состоят из электронов, протонов и нейтронов, которые обладают магнитным моментом. Все вещества магнитные

Глобальное проникновение физики магнетизма в науку и технику: генерация электроэнергии, радио и телефонная связь, магнитная память и вычислительная техника, магнитохимия, магнитобиология и биомагнетизм, геомагнетизм, магнетизм в космосе и т.д.

Начало: Откуда появилось название?

<u>Версия 1</u>. Древние греки, примерно 800 г до н.э. по провиниции Страны “Магнезия”
Лукреций (1 век до н.э.)
“Мне остается сказать по какому закону природы
Может железо в себе притягивать камень, который
Греки “магнитным” зовут по названию месторождения
Ибо находится оно в пределах отчизны магнетов….”

<u>Версия 2</u>. В книге Гильберта (1600) со ссылкой на Плиния
Пастух по имени Магнес- его посох вонзились в магнит.

Магнетит, магнитная железная руда, магнитный железняк

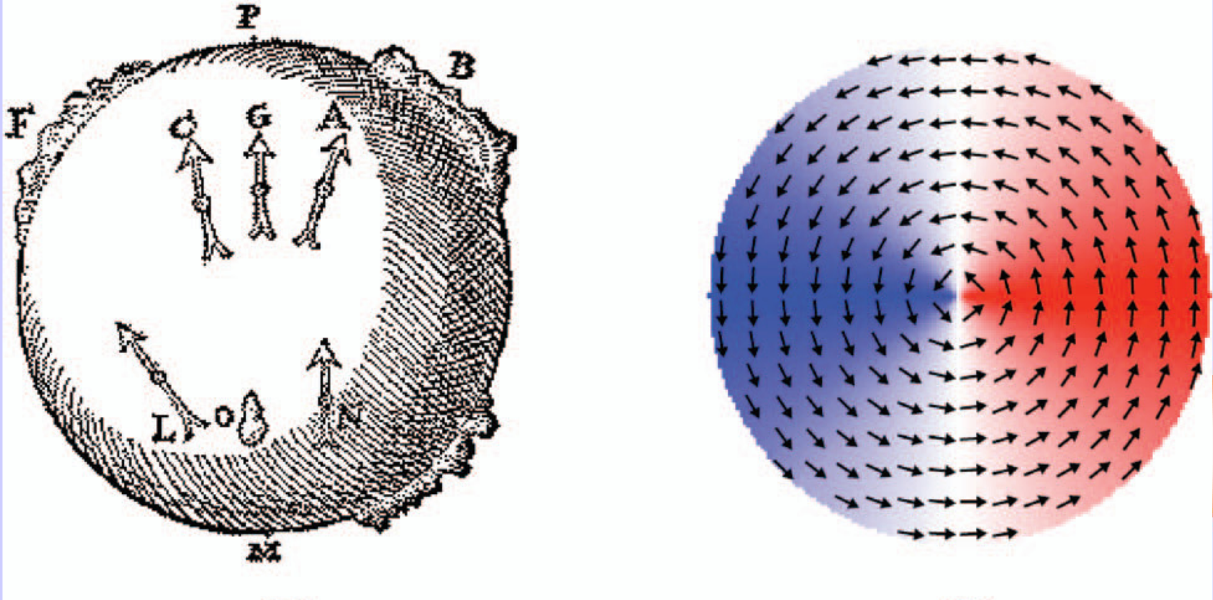
Анимисты- у магнитного железняка божественное начало. Магнит обладает душой.
Фалес, Анаксагор 460 г до н.э вплоть до XVII века

Механисты=атомисты- Диоген, Эмпидокл, Демокрит
В магните есть влага, которая питает сухость магнита, невидимая эманация.

Первое практическое применение – компас
Китай 2367 – 1100 лет до нашей эры
Либо итальянское, или арабское изобретение только в XIII веке, ввезенное в Китай.
В любом случае компас был известен в Европе с XII века

До Гильберта (до XVI века) единичные попытки экспериментального иследования

<u>Уильям Гильберт</u> родился в 1544 г (после Коперника и до Галилея),Умер от чумы в 1603 г. Был лейб-медиком королевы Елизаветы и президентом Королевского Медицинского Общества. Писал книгу De Magnete 17 лет, вышла в свет в 1600 г. Собрал все экспериментальные данные и первый установил, что Земля– магнит



(a) (b)

Ганс Христиан Эрстед опубликова 21 апреля 1820 г статью -Электрический ток влияет на подвешенную по близости иглу !

Био,Савар, Араго, Ампер, Пуанкаре, Лаплас, Френель, Фурье – Французская академия наук

Араго доложил 11 сентября 1820 г. Выбран в Академию в возрасте 23 лет. В 1806 г геодезическая съемка берегов Испании, Признан шпионом, пытался на лодке добраться в Марсель, захвачен, тюрьма и блуждания по Северной Африке, вернулся в Париж в 1809 г , сохранив все документы

Ампер через 7 дней после доклада Араго выступил с гипотезой-
Причина ферромагнетизма – внутренние молекулярные токи

М. Фарадей (1791-1867): диа- и парамагнетизм, магнитооптика, он ввел в декабре 1845 г термин “магнитное поле”

Дж. Максвелл (1831-1879) !! – волны, поля, источники.

Открытие электрона:
Дж. Стони предположил дискретность заряда в 1874 г и дал в 1891 г имя этой частице
Ж. Перен в 1895 г сказал, что в катодных лучах летят отрицательно заряженные частицы, Томсон определил e/m
В 1900 г на Международном физическом конгрессе в Париже было провозглашено существование электрона

Отречение от класической физики

Теорема Бора-Ван Левен: При любой конечной температуре и при любом конечном электрическом или магнитном поле истинная намагниченность системы электронов в тепловом равновесии равна нулю.

Бор – 1911, Ван Левен – 1919, Ван Флек – 1932 (поворотная веха)

Магнетон Бора – 1911 (назван в 1920)
Спин электрона – 1925 (Гаудсмит и Уленбек)
Обменные силы – 1927 (Дирак, Френкель, Гейзенберг)
Шестой Сольвеевский конгресс в 1930 г был посвящен целиком магнетизму в 1930 г. (Им всем не было и 30 лет)

Нобелевские премии по магнетизму: Неель,
Ван Флек-Андресон-Мотт, Клингелер, (Капица, Ландау),
Ферт-Грюнберг

Основные характеристики

	Си	СГСМ(Гауссова)	
$\vec{B}$- **магнитная индукция,**	Тесла (Тл),	Гаусс (Гс)	1 Тл=10^4 Гс
$\vec{H}$- **напряженность магнитного поля**	А/м	Эрстед(Э)	1 Э=80А/м
$\vec{\Phi}$- **магнитный поток**	Вб	Мкс	
$\vec{M}$- **намагниченность**	Тл	Гс	
μ- **магнитная проницаемость**	Гн/м	безразмерная	

$\mu_0 = 4\pi\, 10^{-7}$ **Гн/м** - магнитная проницаемость вакуума в СИ

$B = H + 4\pi M = \mu H$; (СГСМ) $B = \mu_0(H + M)$

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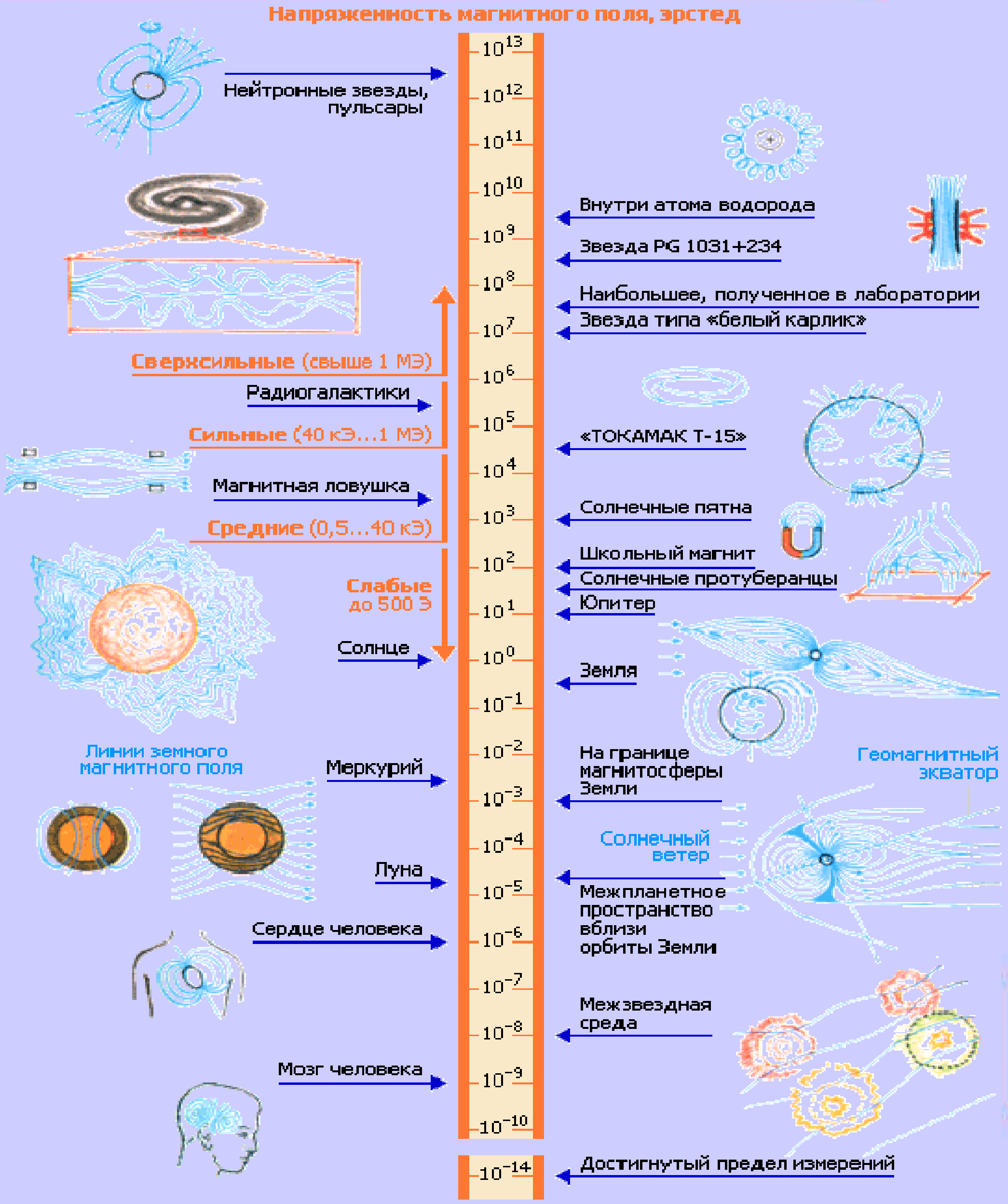


Магнетизм атомов порождается

1. Спиновым магнитным моментом электронов
2. Орбитальным движением= орбитальный магнитный момент
3. Магнитным моментом ядра , который создается спиновыми моментами протонов и нейтронов

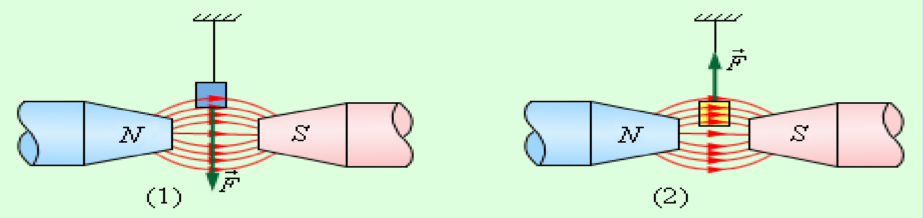
В зависимости как эти моменты взаимодействуют между собой и складываются или компенсируются в приложенном постоянном магнитном поле

μ>>1 ферромагнетики и другие сильно магнитные вещества

μ >1 парамагнетики

μ < 1 диамагнетики

μ =0 идеальные диамагнетики = поле не проникает



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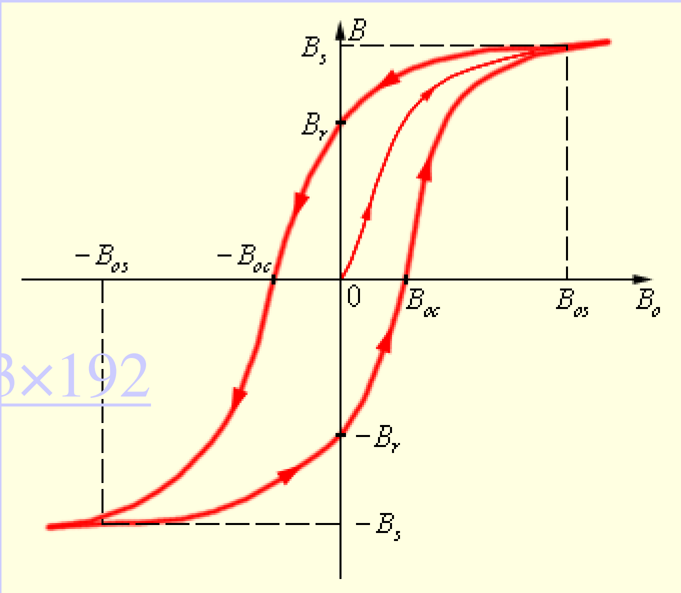
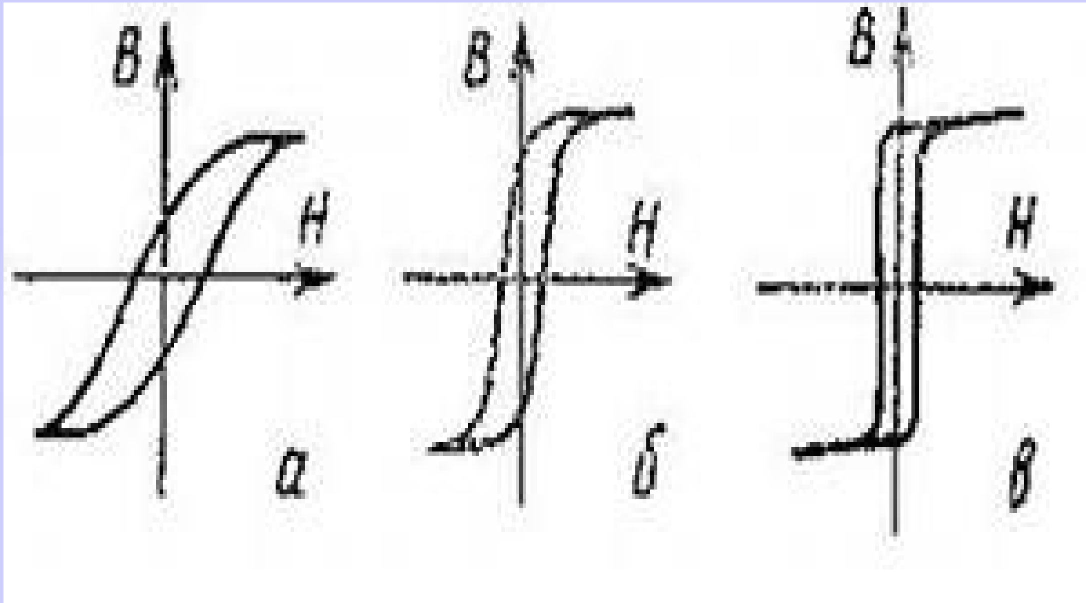




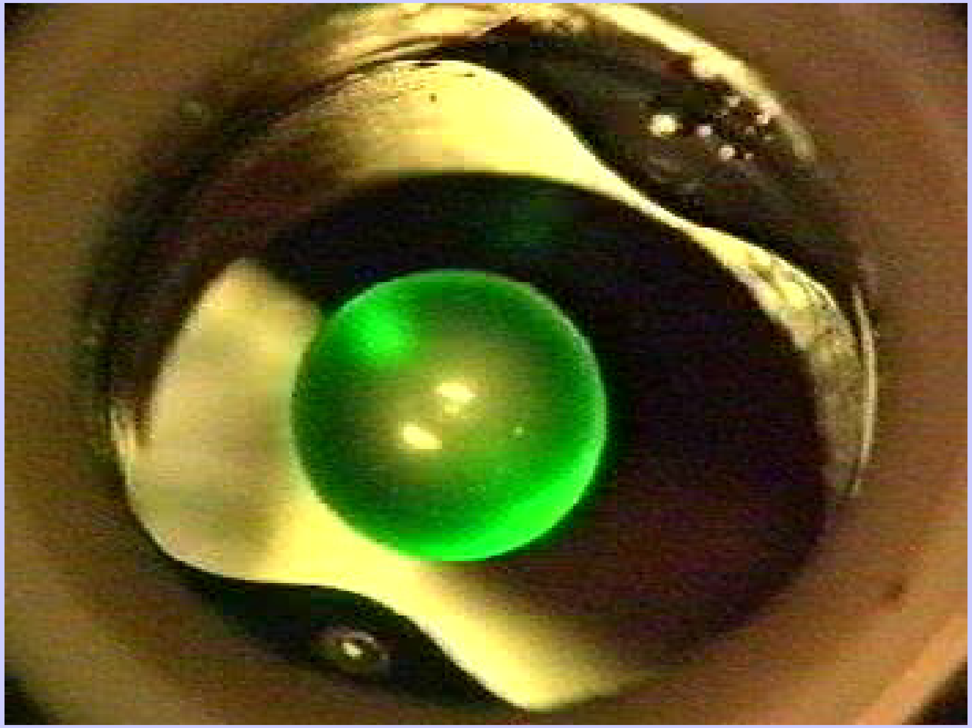
Motivation

- "The nation that controls magnetism will control the universe"
  - Dick Tracy - 1935

Dick Tracy by
Dick Locher and Michael Killian

All materials are magnetic!!!

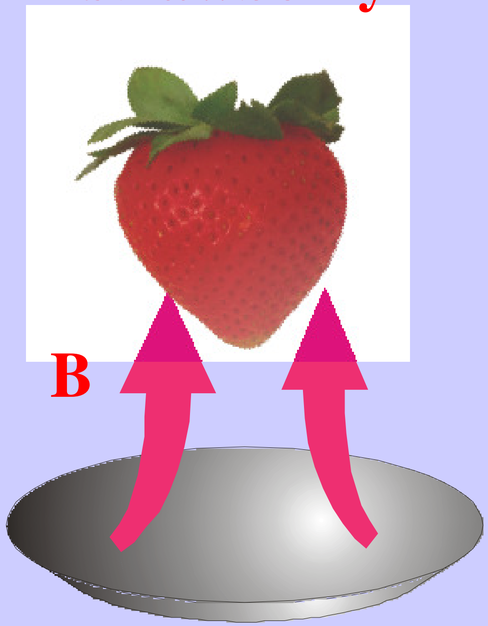
All materials are magnetic !!!!



drop of water (coloured in green)

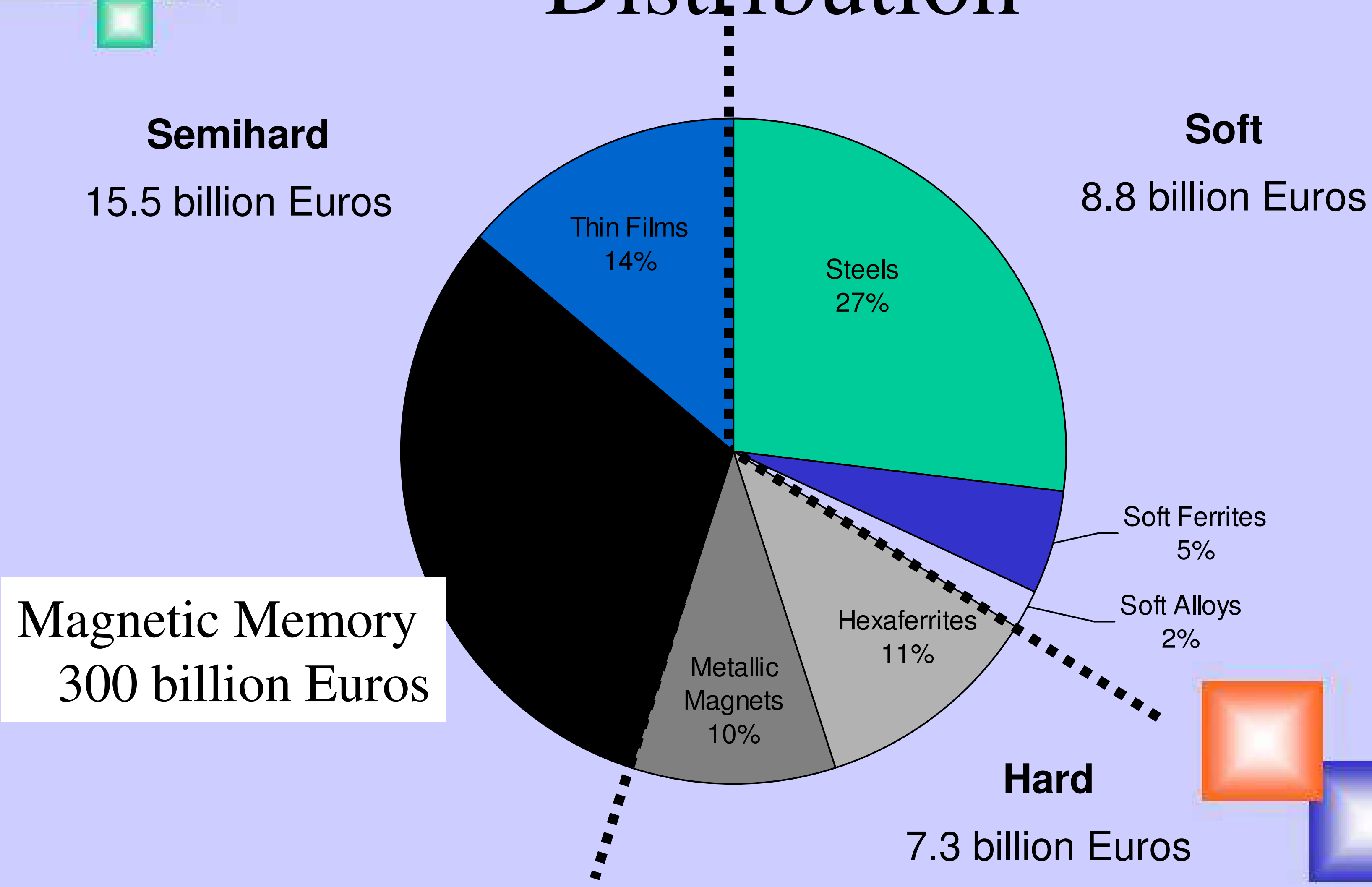
Nijmegen high magnetic field laboratory

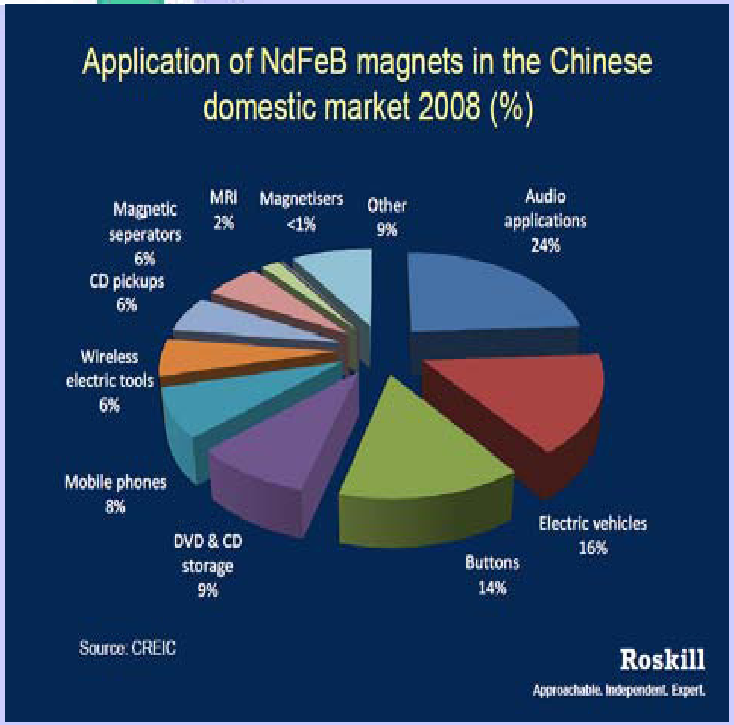
Levitating strawberry

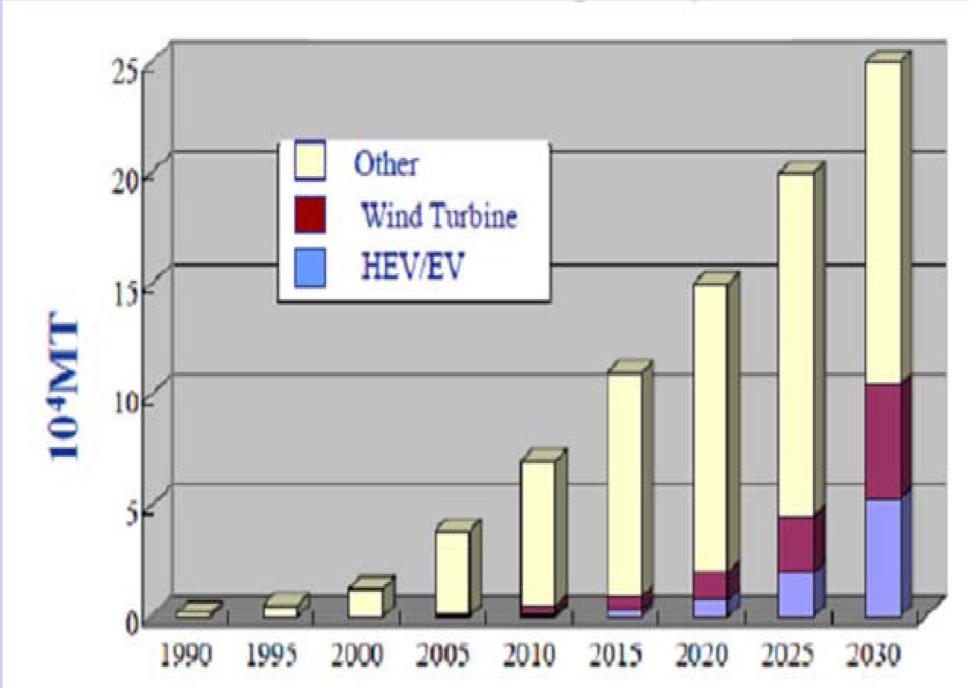


17 Tesla

Magnetic Materials: World Market Distribution







1 wind turbine- 250 kg NdFeB

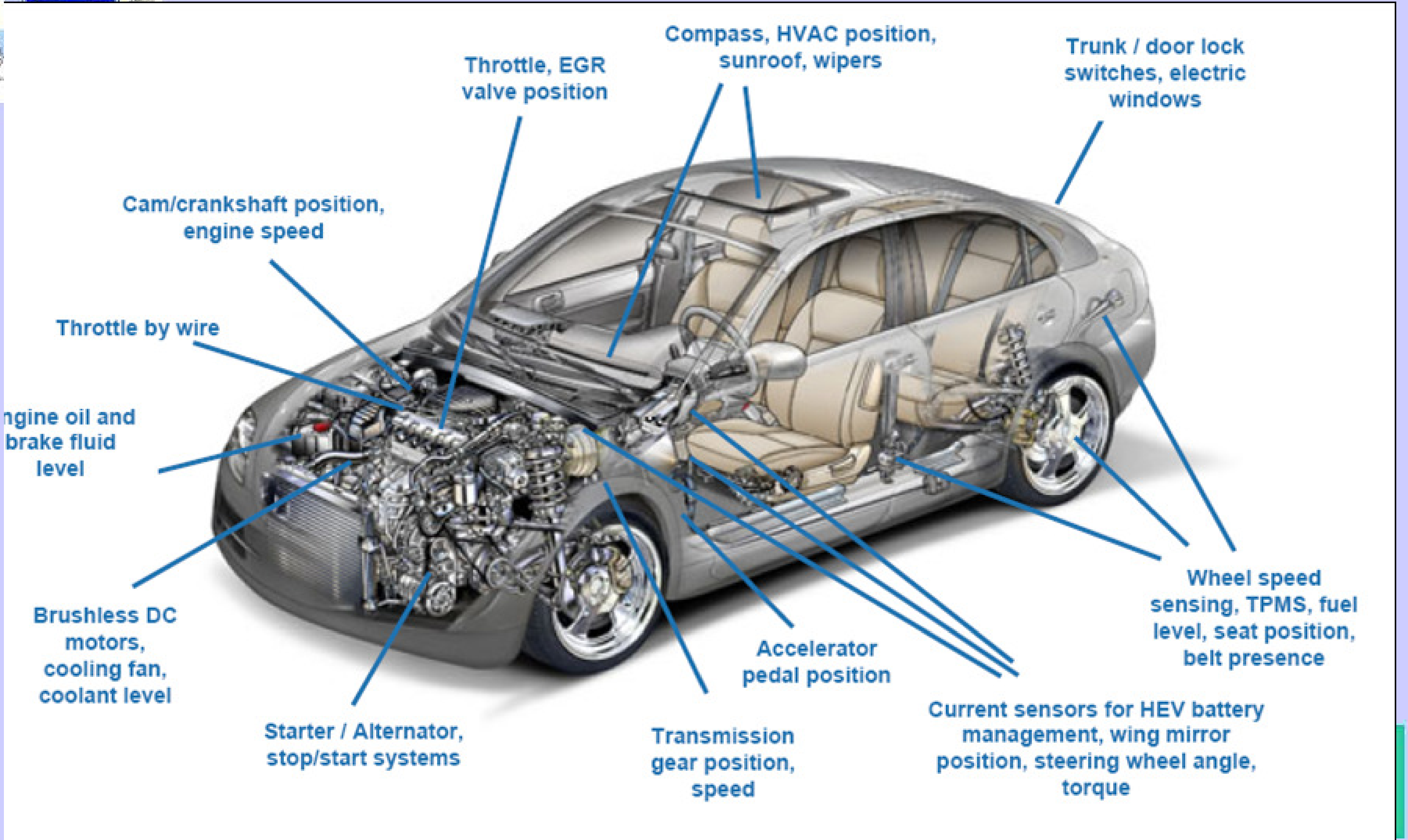
Magnetic sensors

1. Operating at room temperature
2. High sensitivity (10^{-8} Oe for medicine)
3. High spatial resolution (1-10 nm for magnetic heads)
4. Low dimensions
5. Low cost ($ 0.3 for autocar industry)

Magnetic Sensors are used for speed, rotational speed, linear position, linear angle and position measurement in automotive, industrial and consumer applications.

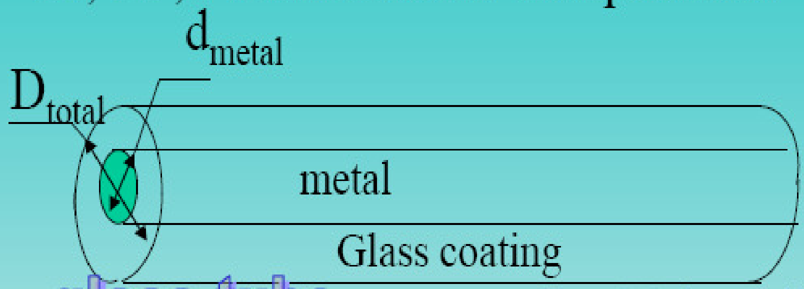
Toyota uses 86 types of magnetic sensors

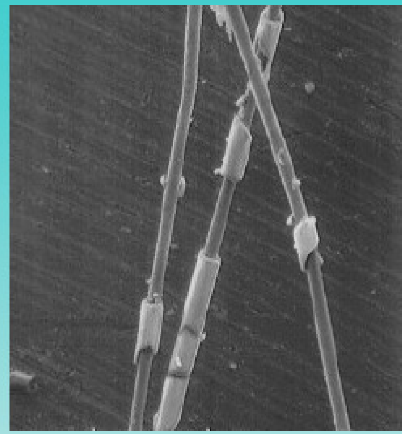
Flux-gate, Hall effect, magnetoresistance, GMI, NMR, magneto-optics, multiferroics etc


Throttle, EGR valve position
Compass, HVAC position, sunroof, wipers
Trunk / door lock switches, electric windows
Cam/crankshaft position, engine speed
Throttle by wire
ngine oil and brake fluid level
Brushless DC motors, cooling fan, coolant level
Starter / Alternator, stop/start systems
Transmission gear position, speed
Accelerator pedal position
Current sensors for HEV battery management, wing mirror position, steering wheel angle, torque
Wheel speed sensing, TPMS, fuel level, seat position, belt presence

Fabrication of Glass coated microwires

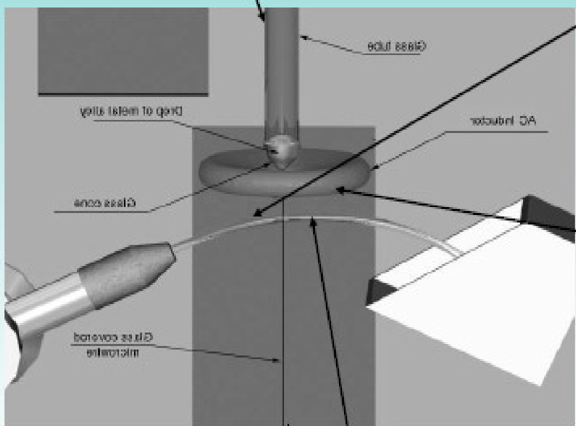
- Co, Ni , Fe and Cu rich compositions





glass tube

Molten alloy



HF Inductor

Typical dimensions:
Total diameter 3-40 microns
Metallic nucleus diameter 1-30 microns
Glass coating thickness 1-10 microns
Length - few km (up to 10 in 1 bobbin)

Fabrication – UPV/EHU, AmoTec (Moldova), TAMAG, Spain

Water jet

Receiving bobbins

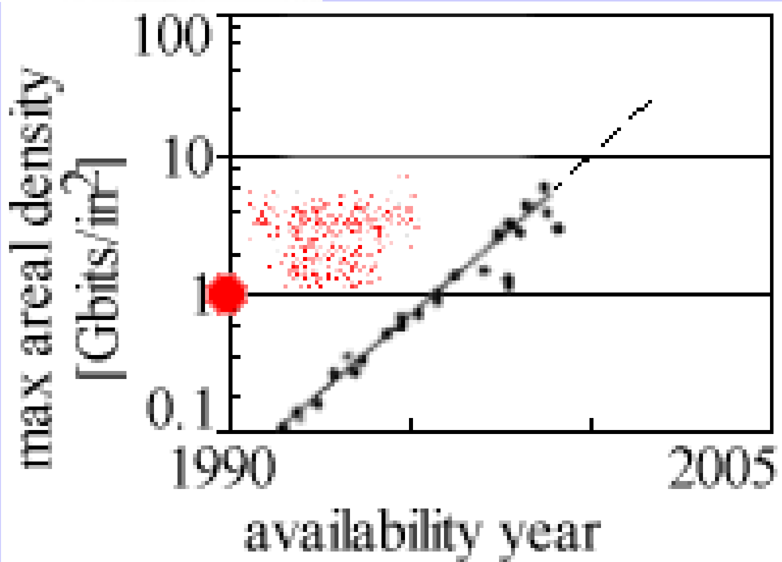
Novel, multifunctional and smart magnetic materials

Heusler alloys
Multiferroics
Magnetic fluids and composites
Magnetic polymers
Metamaterials
Superconductive materials
Diluted magnetic semiconductors and oxides

Magnetic Information Storage

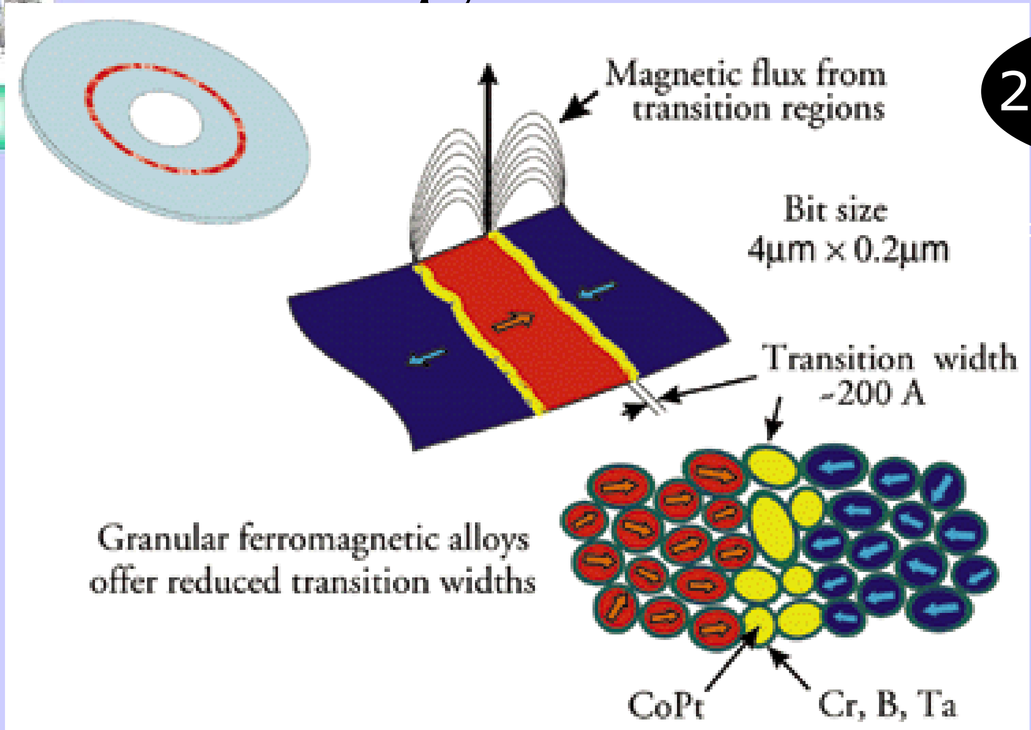
- Density: 2 kb/in^2
- Speed: 70 kb/s
- Size: f24″ x 50
- Capacity: 5 Mb

- Density: 20 Gb/in^2
- Speed: 200 Mb/s
- Size: f2.5″ x 2
- Capacity: 50 Gb



2010
100 Gb/in^2

Magnetic Recording

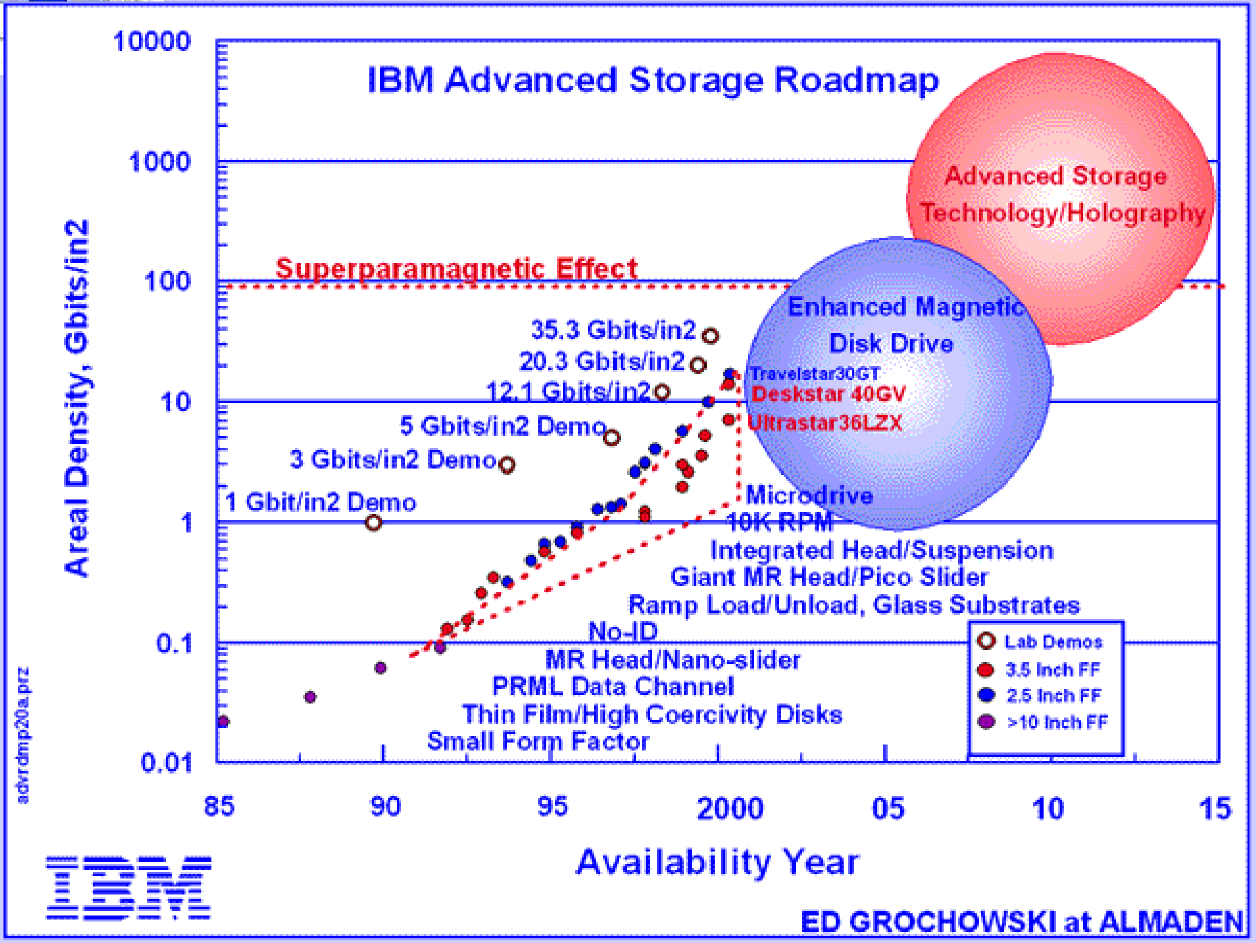


20 Gb/in²

Near the Superparamagnetic Limit !!

Computer disks consist of granular magnetic materials like CoPtCr with admixtures of boron or tantalum in order to minimize the transition width between the magnetic domains. In the disk material, the grains are believed to be coated by a non magnetic shell that reduces the magnetic coupling between the grains. A small transition width is required in order to achieve a high magnetic-flux density in the direction perpendicular to the disk surface, as shown. The flux from the spinning disk is sensed by the spin-valve magnetic read head. [Figure: J. Stöhr, IBM Research Center.]

Present and Future of Hard-Disks

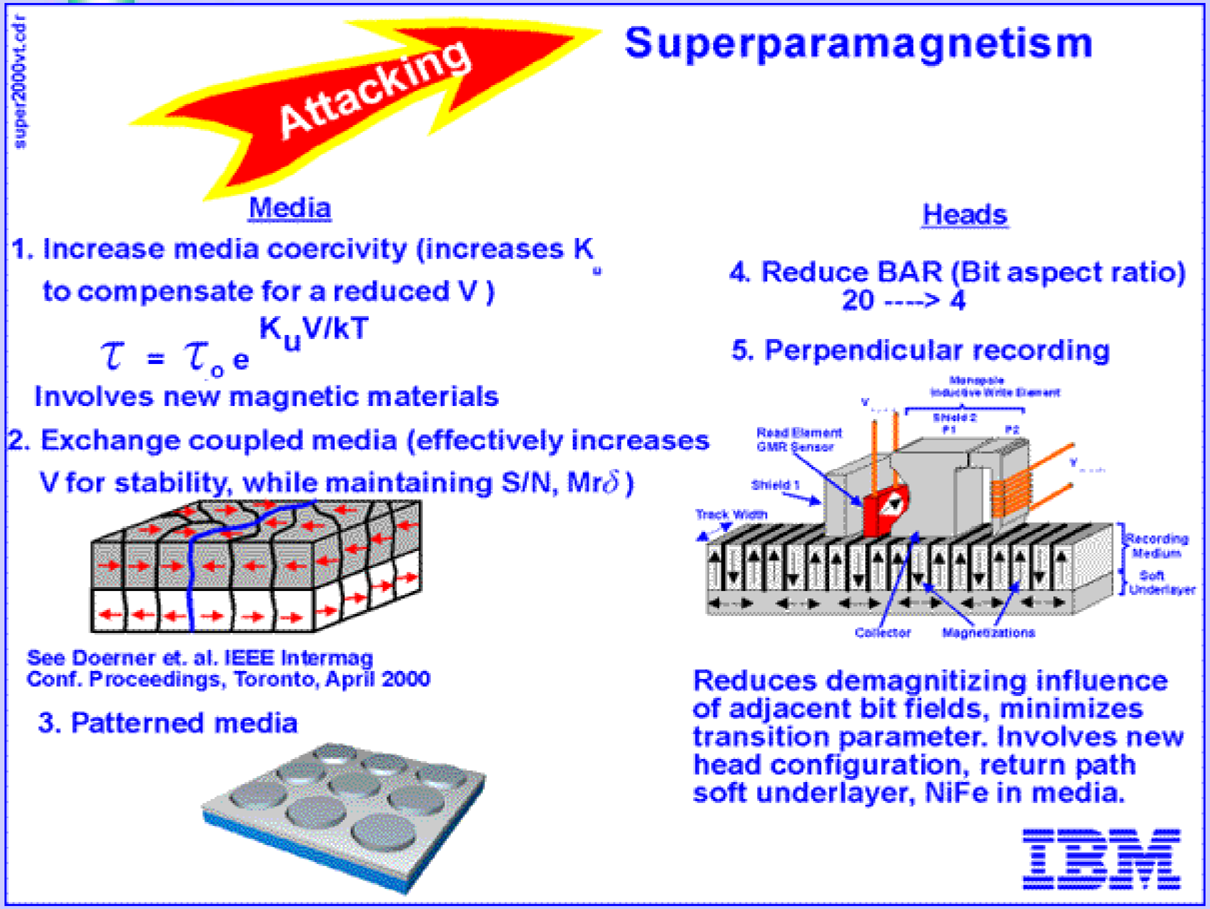


IBM has demonstrated a GMR head with an areal density capability greater than 35.3 billion bits per square inch, and labor... demonstr... beyond 5... have been reported, indicating that future disk drives could exhibit capacities at least two times higher than today.

Disk drives will continue to be enhanced through the use of MEMS micro-actuators, fluid bearing spindle motors and even split or multiple actuators. Also, new data storage techniques, as holographic storage are on horizon.

http://www.storage.ibm.com/technolo/grochows/g10.htm

Attacking Superparamagnetism



Modifying magnetic properties of the media is a front up approach to delaying superparamagnetism, and increasing Ku the energy barrier to magnetic reversal per grain volume is an effective means of accomplishing this. New magnetic materials and films are being investigated and applied to further delay the superparamagnetic phenomenon resulting in good media stability.

http://www.storage.ibm.com/technolo/grochows/g17.htm

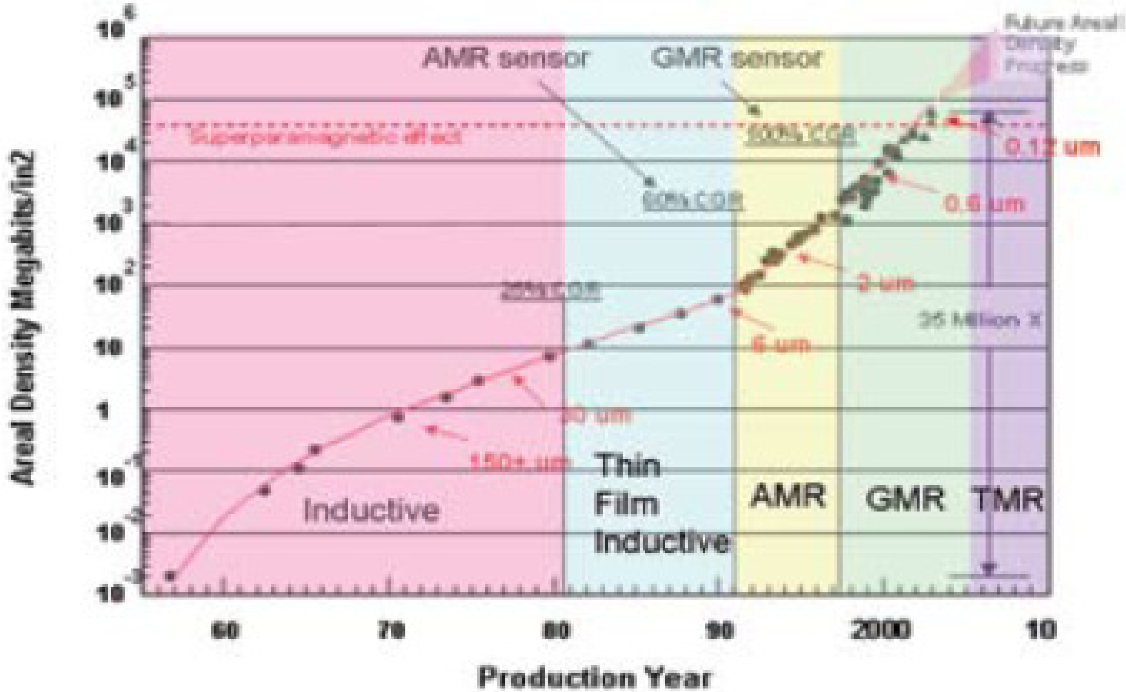
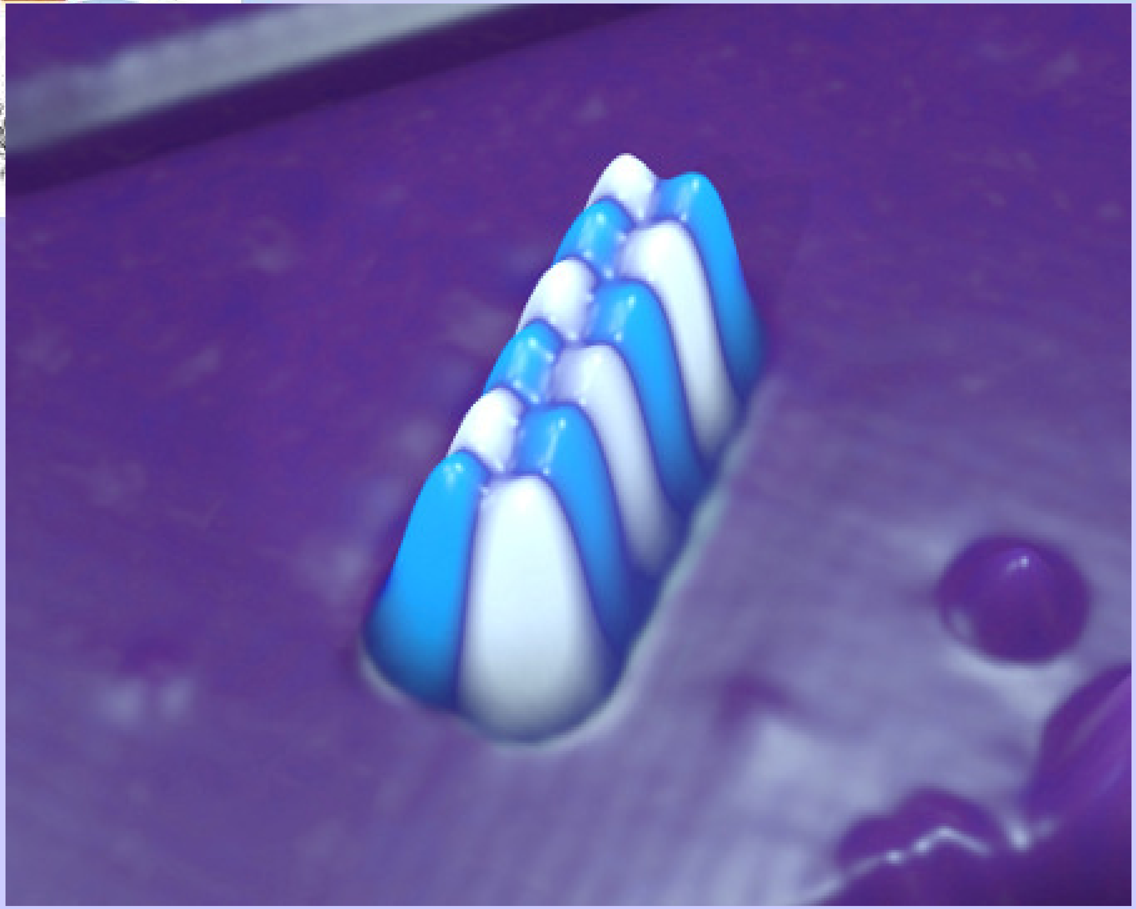
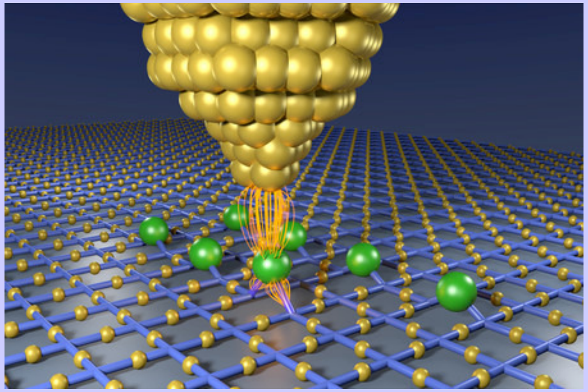


Fig. 7: Magnetic Recording Areal Density vs. year of product introduction, showing the evolution of sensor technologies. The introduction of the GMR spin valve in 1997 is the first commercially successful use of spintronics.





Tunnel microscope manipulation

1 byte =8 bit=96 atoms

Nowaday -10^8 atoms

12 atoms of Fe – artificial antiferomagnet

The smallest magnetic memory cell

↑ ↑ ↑ ↑ ↓ ↓ ↓ ↓

↑ ↓ ↑ ↓ ↓ ↑ ↓ ↑

Electronics, Micro- and Nanoelectronics → Charge of Electron

SPINTRONICS= SPIN+TRANSPORT+ELECTRONICS
(1992)

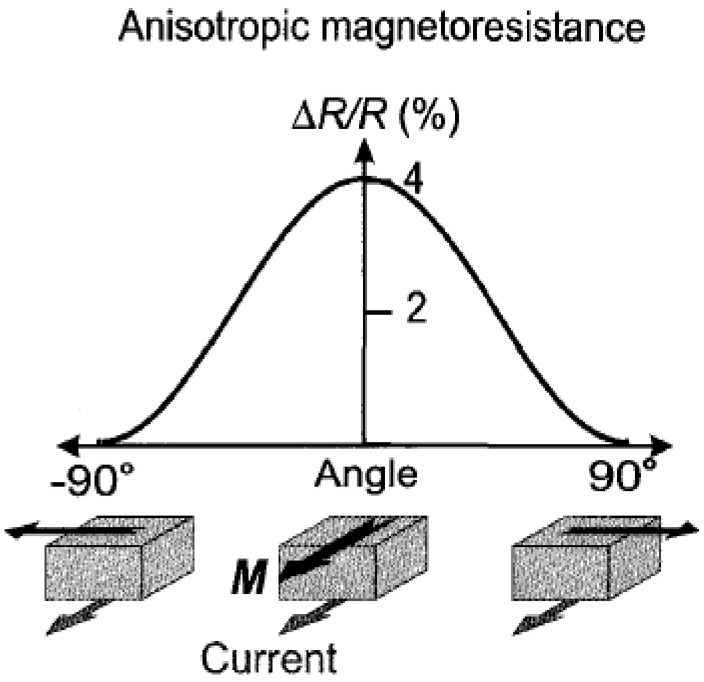
Spintronics → Charge + Spin of Electron

Spin control and manipulation

Spin current without dissipation!!!!?

Quantum Computers

1856
Thomson



$$\rho_{ij} = \begin{vmatrix} \rho_\perp(B) & -\rho_H(B) & 0 \\ \rho_H(B) & \rho_\perp(B) & 0 \\ 0 & 0 & \rho_\parallel(B) \end{vmatrix}$$

$$\frac{\Delta\rho}{\rho} = \frac{\rho_\parallel - \rho_\perp}{\frac{1}{3}\rho_\parallel + \frac{2}{3}\rho_\perp}.$$

$$\vec{E} = \rho_\perp(B)\vec{j} + [\rho_\parallel(B) - \rho_\perp(B)](\vec{\alpha}\cdot\vec{j})\cdot\vec{\alpha} + \rho_H(B)[\vec{\alpha}\times\vec{j}],$$

GMR – giant magnetoresistance

A.Fert and P. Gruinberg (1987)

$$\frac{\Delta R}{R} = \frac{R_{AP} - R_P}{R_P} =$$

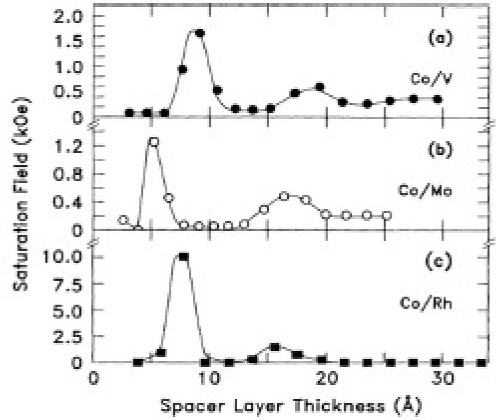
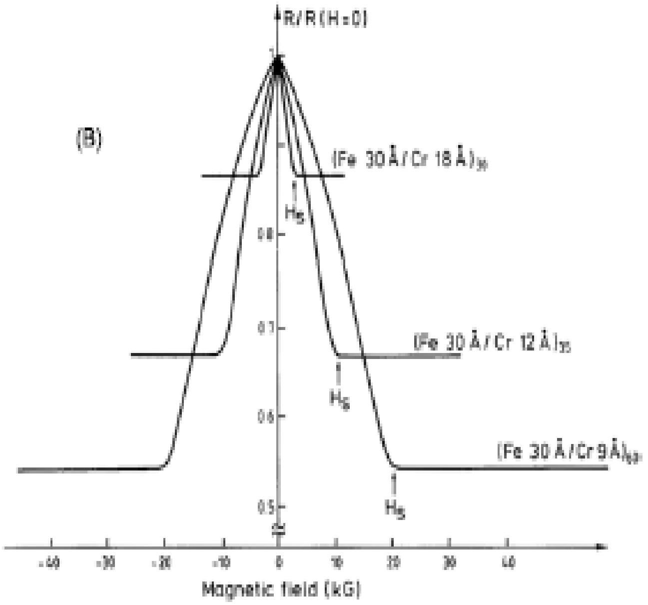
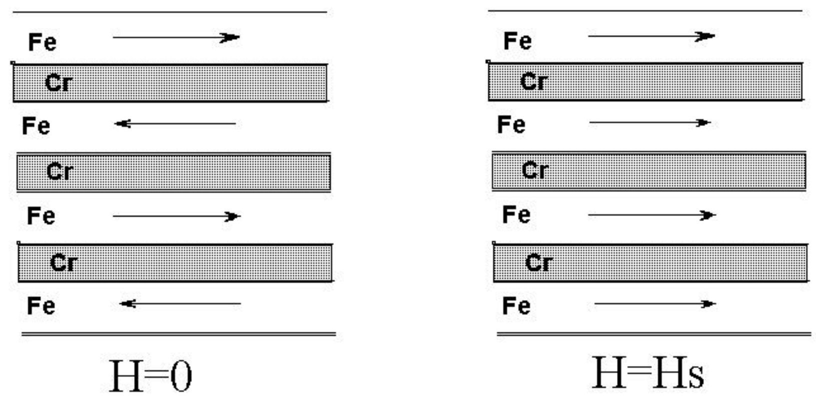
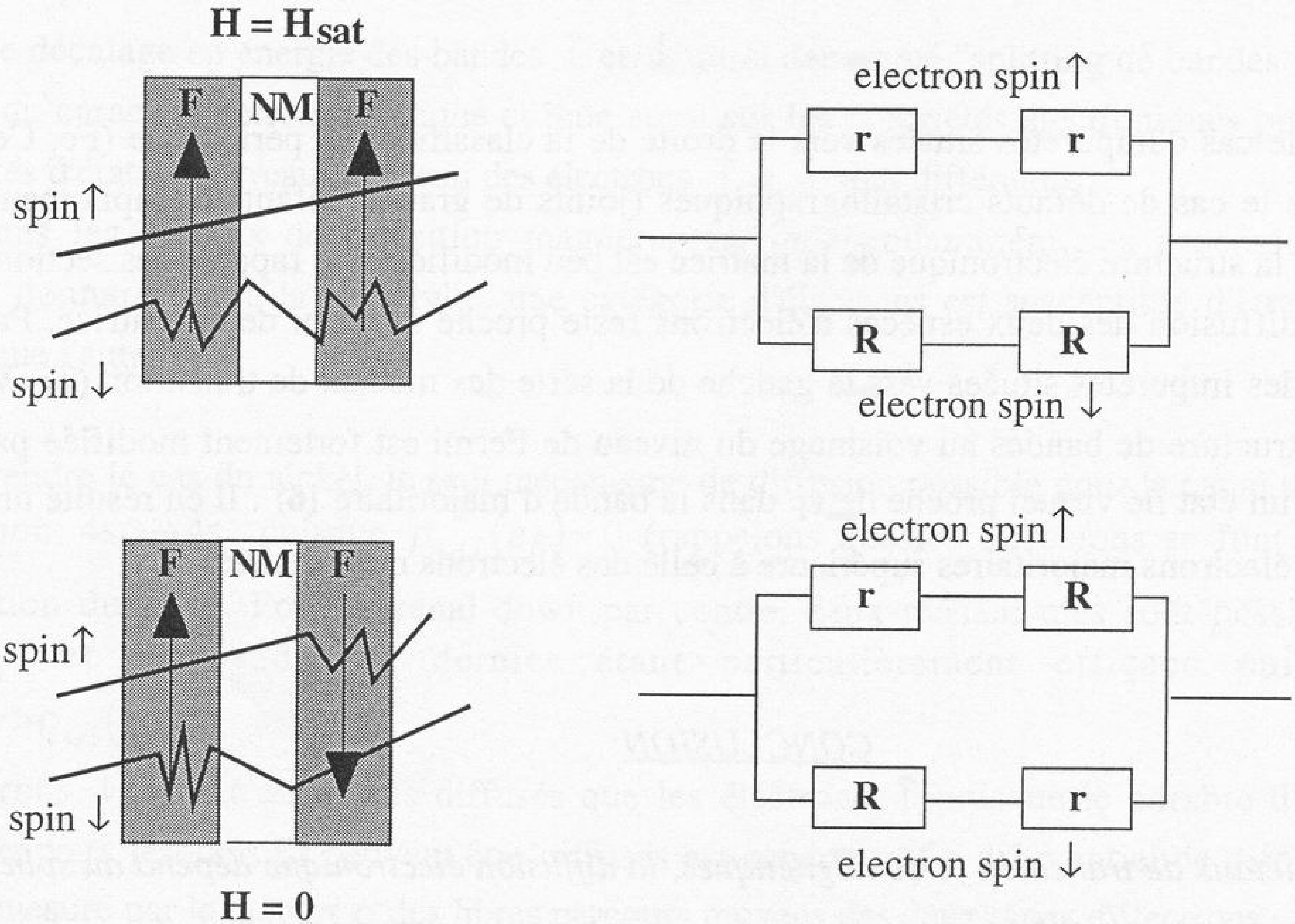


Figure 4. The oscillation of exchange coupling between Co layers across different spacer layers determined by the magnetic field required to reach 80% of the saturation magnetic moment. Note the period of oscillation of the coupling from ferromagnetic (low saturation field) to antiferromagnetic (high saturation field) is similar at about 1 nm for all the elements presented. This was part of an extensive study of many different ferromagnetic and spacer layers by Parkin [17]. (Reprinted with permission from figure 2 of [17]. Copyright 1991, American Physical Society.)






H = Hsat
F
NM
F
spin↑
spin↓
electron spin↑
r
r
R
R
electron spin ↓
F
NM
F
spin↑
spin ↓
H = 0
electron spin↑
r
R
R
r
electron spin ↓

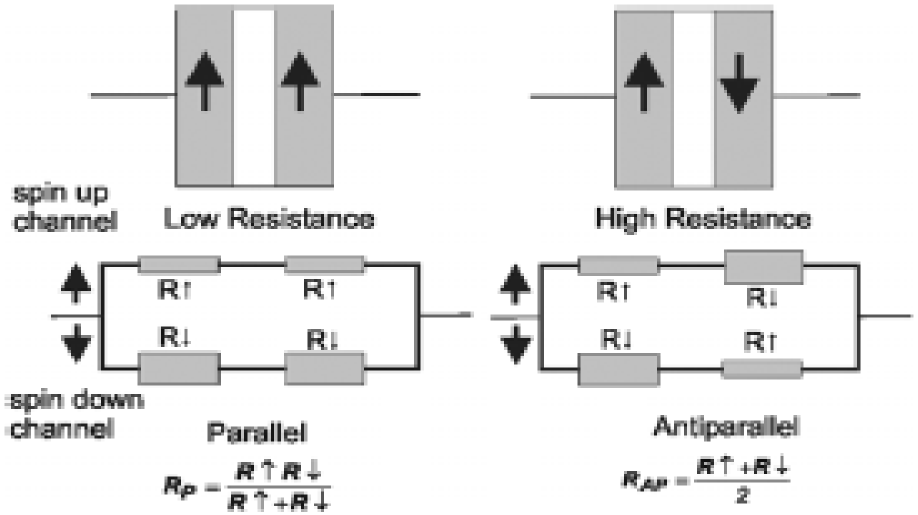
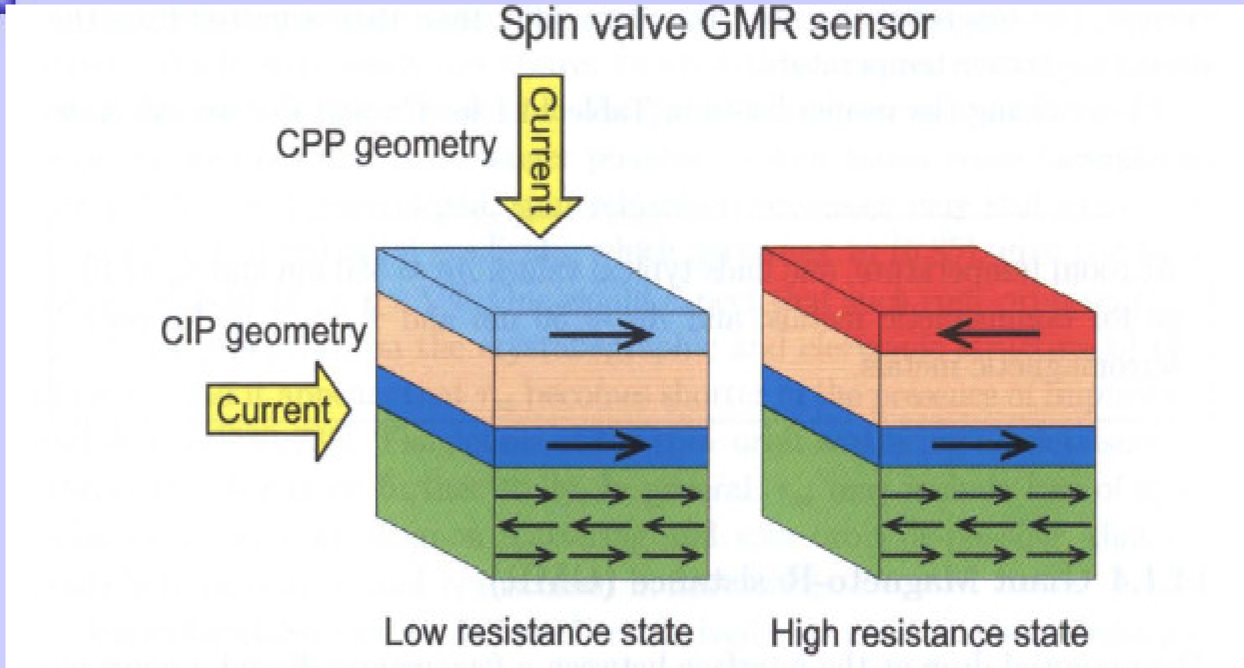


Figure 2. A schematic representation of GMR using a simple resistor network model. In the left picture, the spin-up channel is the majority spin channel in both the ferromagnetic layers, experiencing a low resistance ($R\uparrow$) throughout the structure. In the right-hand picture the spin-up channel is the majority spin channel ($R\uparrow$) in the first magnetic layer but the minority-spin channel ($R\downarrow$) in the second magnetic layer and vice versa for the spin-down channel. Neither spin channel is of low resistance throughout the structure and the overall resistance state of the structure is high. GMR occurs when the relative orientation of the magnetic layers is switched, usually by the application of a magnetic field.


Spin valve GMR sensor
CPP geometry
Current
CIP geometry
Current
Low resistance state
High resistance state

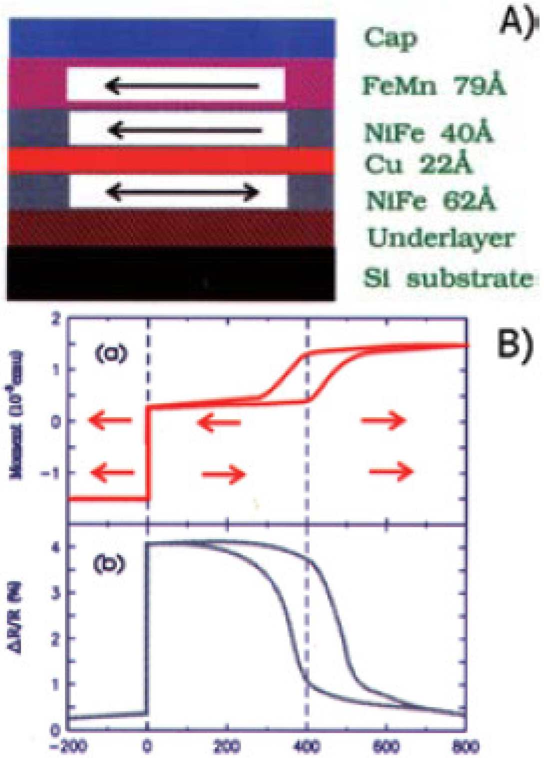
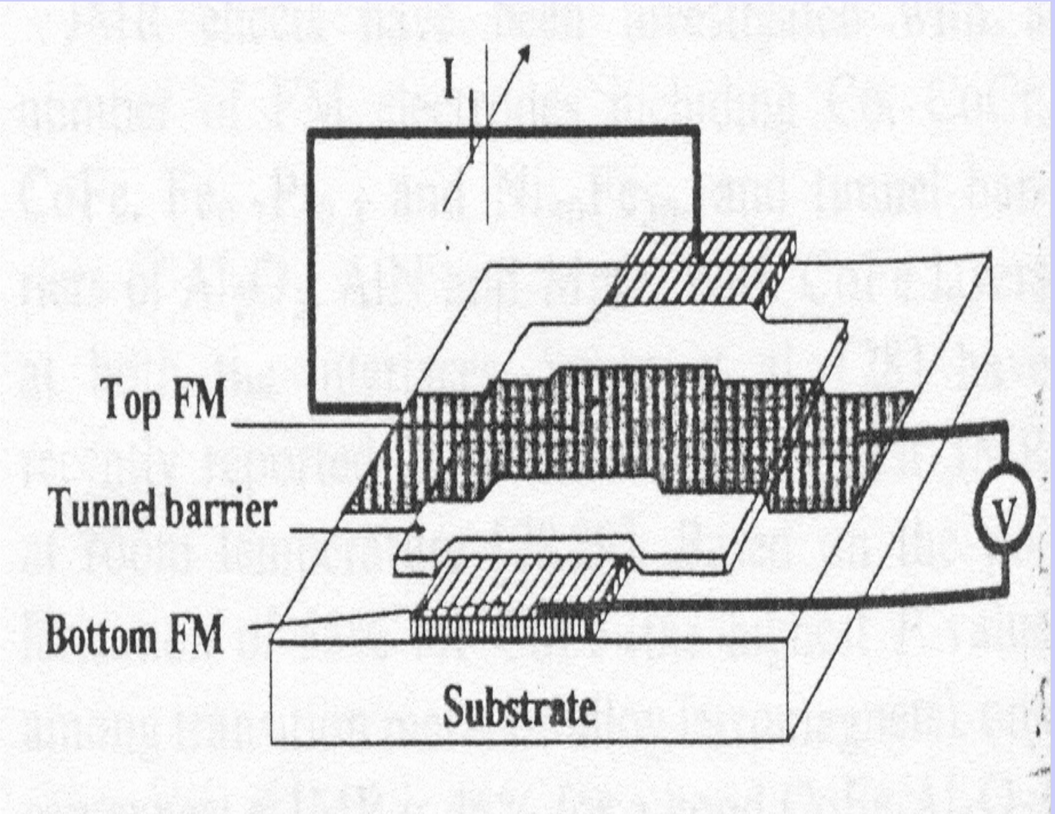


Fig. 3: A) The Spin Valve Structure consisting of a ferromagnetic layer whose magnetization is pinned through exchange anisotropy with an antiferromagnet, a second ferromagnetic layer with low anisotropy whose magnetization rotates in the presence of a magnetic field and a conducing spacer between them that permits carriers to flow easily between layers without significant scattering. B) The magnetization (a) and in-plane resistance (b) of an early spin valve structure vs. magnetic field.

TMR- Tunnel magnetoresistance

Jullier, Fe/GeO/Co 1975
Maekawa 1982, Parkin
1995 -2005



Al-O TMR up to 70% (2004)

MgO TMR up to 600% (2008)

Granular metal-insulator alloys

Co-Al-O TMR up to 20%

CoFeB/MgO/CoFeB

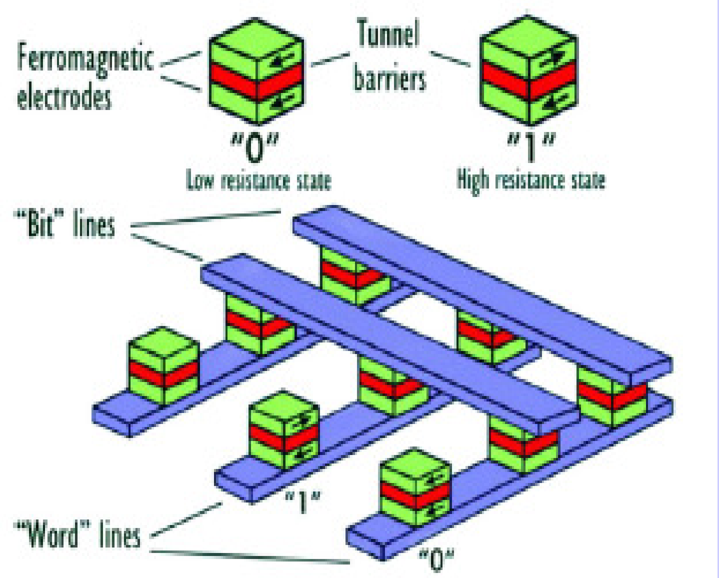
All metal-based Spin-valves related read-out heads were commercialized in 1997 – a low resistance (several Ohm) and a small GMR ratio

In-plane magnetized MTJs exhibit >500% at room temperature with a much larger resistance (kOhm) !!! (MRAM and more suitable for integration with CMOS industry)

Disadvantages: Low thermal stability and large critical current for current-induced magnetization switching

MTJs with perpendicular magnetic anisotropy(PMA)-pMTJ

1. GdFeCo and TbFeCo, 2. Co(Fe)-Pt, 3. Co/(Pd,Pt) multilayers
4. CoFeB-MgO (se review in Spin -March 2012)



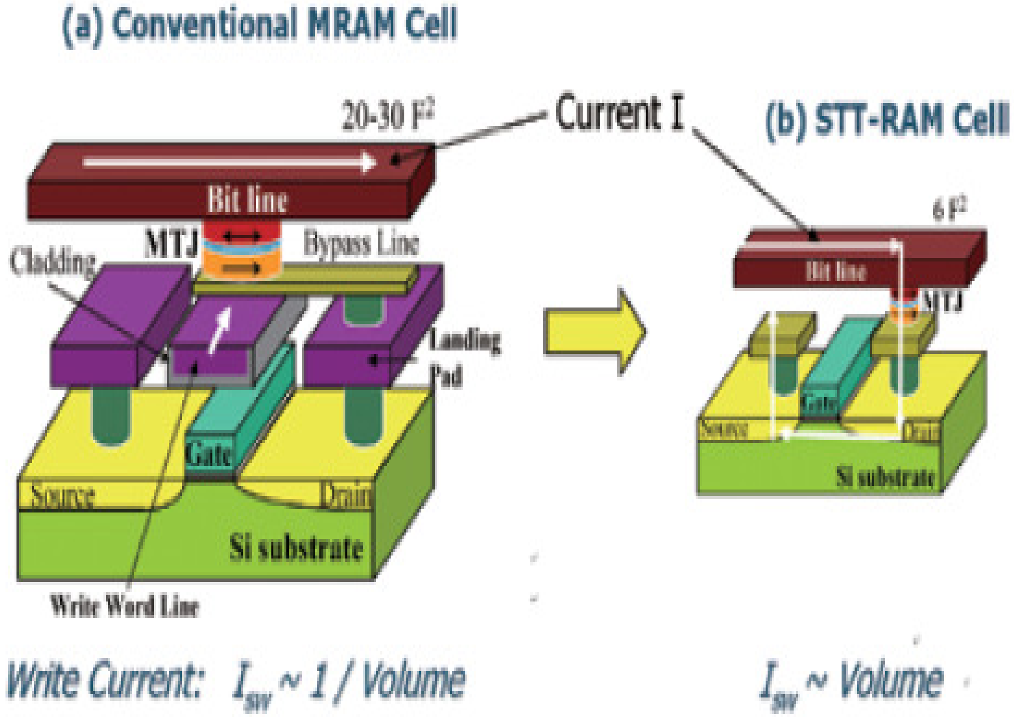


Fig. 1: Comparison of memory cell architecture between conventional field switching MRAM (a) and spin-transfer torque MRAM (STT-MRAM) (b).

Future: From charge current to pure spin current

$$J_e = J_\uparrow + J_\downarrow \quad (1)$$

$$J_s = J_\uparrow - J_\downarrow \quad (2)$$

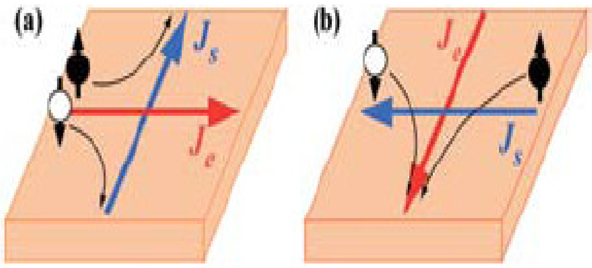


Fig. 6: Schematic illustration of (a) direct and (b) inverse spin-Hall effects in a nonmagnetic material. J_e and J_s are the charge and spin currents, respectively.

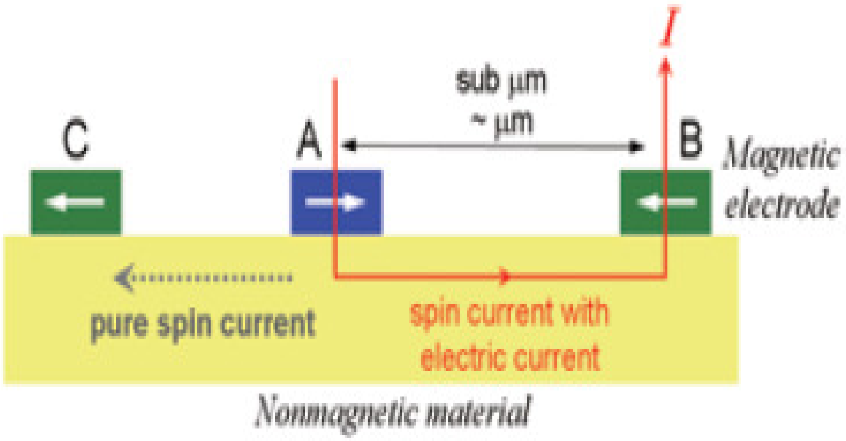


Fig. 1: A basic device structure for the study of spin current.

Spin Hall Effect

Introduction

Furdyna
Zavadskii
Nagaev
Ohno
Dietl
Matsumoto
Coey
Dubroca
Kaminski&
Sarma

DMS

Low Temperature

Room Temperature

$Cd_{1-x}Mn_xSe$, $Hg_{1-x}Mn_xTe$

$A^{II}B^{VI}$:Mn before1987

GaAs:Mn (Tc=173 K)

Si:Mn (>400K) 2004

DMO

$TiO_{2-\delta}$:Co (600-800 K) 2001

ZnO:TM, SnO_2:TM, CeO_2:TM etc, TM=Mn, Co, Fe

d^0 magnetism=quasiferromagnetism

Si , HfO_2 2004

TiO_2, ZnO, In_2O_3,

FM in nanostructures

Nanoparticles CeO_2, Al_2O_3, ZnO, In_2O_3, and SnO_2. 2006

There is an ongoing quest for ferromagnetic semiconductors with a Curie temperature well above room temperature, which could be used for a second generation of spin electronics, as well as a search for transparent ferromagnets which can add an optoelectronic dimension.

Intrinsic Ferromagnetism
High Curie Temperature
High spin-polarization
Semiconducting properties
Transparent for light
Homogeneity

Questions:

1. Intrinsic or Extrinsic? (parasitic phases and ferromagnetic clusters)
2. Which ions bear magnetic moment?
3. Type of exchange? (carrier-mediated, superexchange, percolation etc)
4. Does a TM doping play key role?

Si:Mn and $TiO_{2-\delta}$:Co

I. Newton

1643

1727

Introduction

1845

1845

Michael Faraday
(1791-1867)

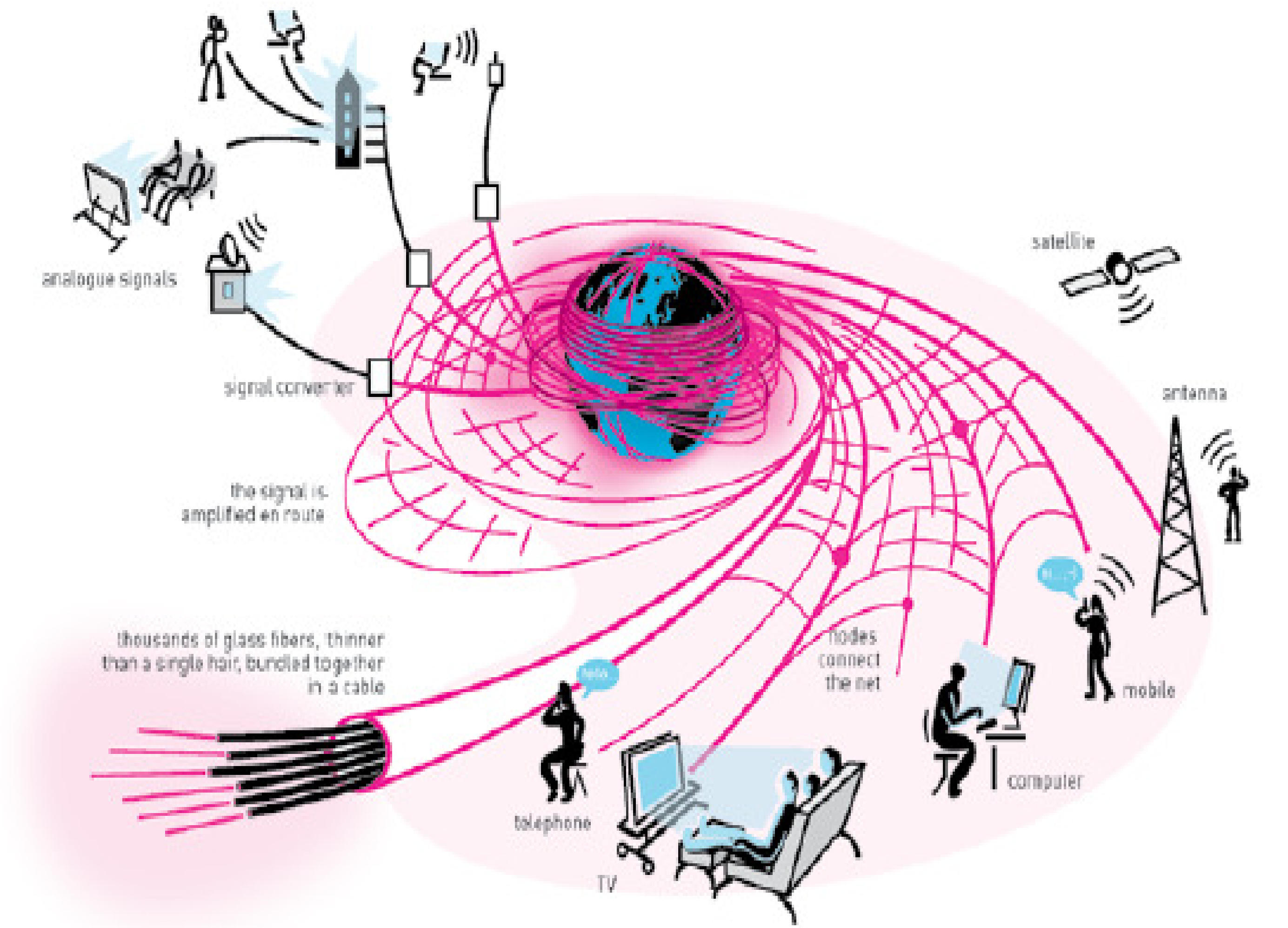


Fig. 1: Optic fibers made of glass make up the circulatory system of our communication society. There is enough fiber to encircle the globe more than 25,000 times. (Illustration Airi Iliste & RSAS.)

Electronics, Micro- and Nanoelectronics → Charge of Electron

Spintronics → Charge + Spin of Electron

Magnetophotonics = Spintronics at microwave, infrared and optical frequencies → Charge+Spin of Electron+ Photon

- Manipulating light with a magnetic field
- Manipulating charge and magnetization with a light

Photons do not couple directly to magnetic field or magnetization, but its interaction with magnetic materials depends on

- Charge of electrons
- Spin of electrons
- Photon frequency
- Interaction between charge and spin

MAGNETOOPTICAL EFFECTS ARE EXTREMELY WEAK !!!

Linear Magneto-optics

- Surface sensitive (10-30 nm for metals)
- MO micromagnetometer (0.5 mkm spatial resolution, 4-400K)
- Vector-MOKE
- Domain Observation and Magnetization Reversal
- MO spectroscopy – (composition, structure, electronic band structure)
- Determination of spin polarization
- Ultrafast Spin Dynamics and Domain Wall Motion (1 femtosec)
- Cheap

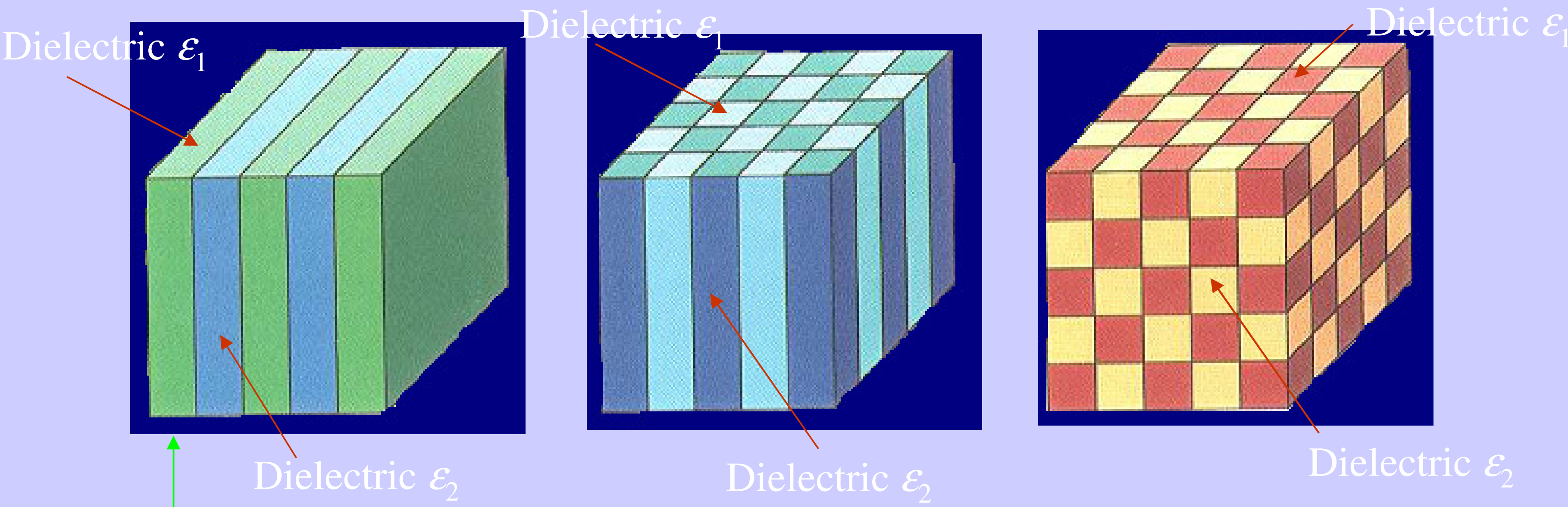
Nonlinear Magneto-optics

- One-layer sensitive
- Interfaces and Structural Transformation
- Expensive

Photonic Crystals

Artificial optical material with optical-wavelength scale structures

One-dimensional **Two-dimensional** **Three-dimensional**

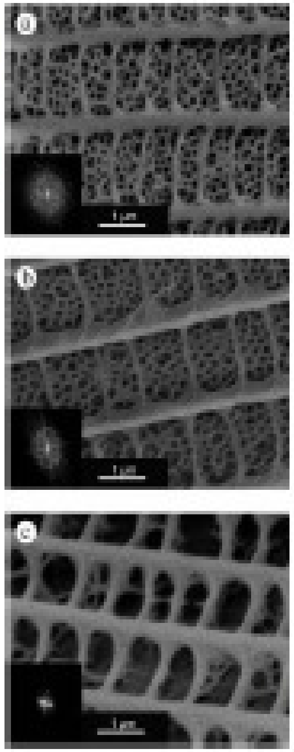


Traditional multilayer film

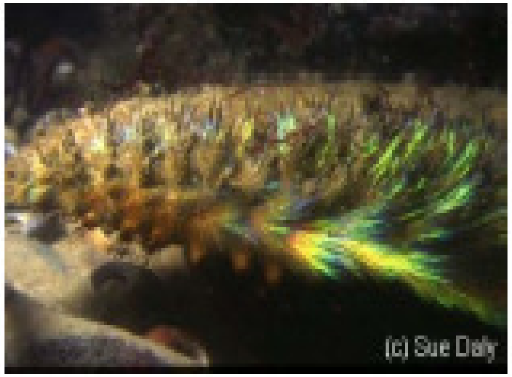
Prepared by a film formation technique such as sputtering method

Catching up with Mother Nature…

Just a 4 billion year head start…



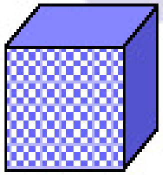
Biro et al, Phys. Rev. E, (2003)



Sea Mouse

Parker et al, Nature (2001)

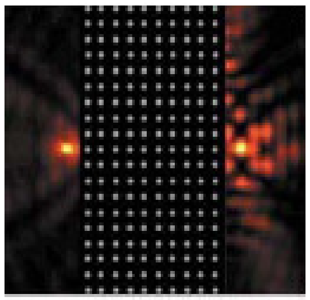
What can you do with a photonic crystal?



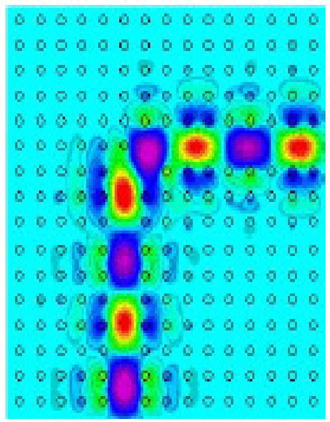
Trap Light
A single defect in a photonic crystals acts like a resonant cavity with a defect level in the band gap.

Right turns with photons
Photonic crystals prevent photons in the band gap from propagating in the material. If we create a line defect in the structure, it will act like a waveguide.

Negative index of refraction – Flat lens



Parimi *et al., 2003, Nature* ***426*** *404*



http://ab-initio.mit.edu/photons/bends.html

and much more…


Grand Challenges in Nanomagnetism
Ultra Strong Permanent Magnets
Ultra High Density Media
Spin Transistor With Gain
~100% Spin Polarized Materials
R.T. Magnetic Semiconductors
Instant Boot-Up Computer
Magnetic Logic
Spin-Based Qubits
Hierarchically Assembled Media
Computer From Test Tube
Nano-Bio Mag Sensors

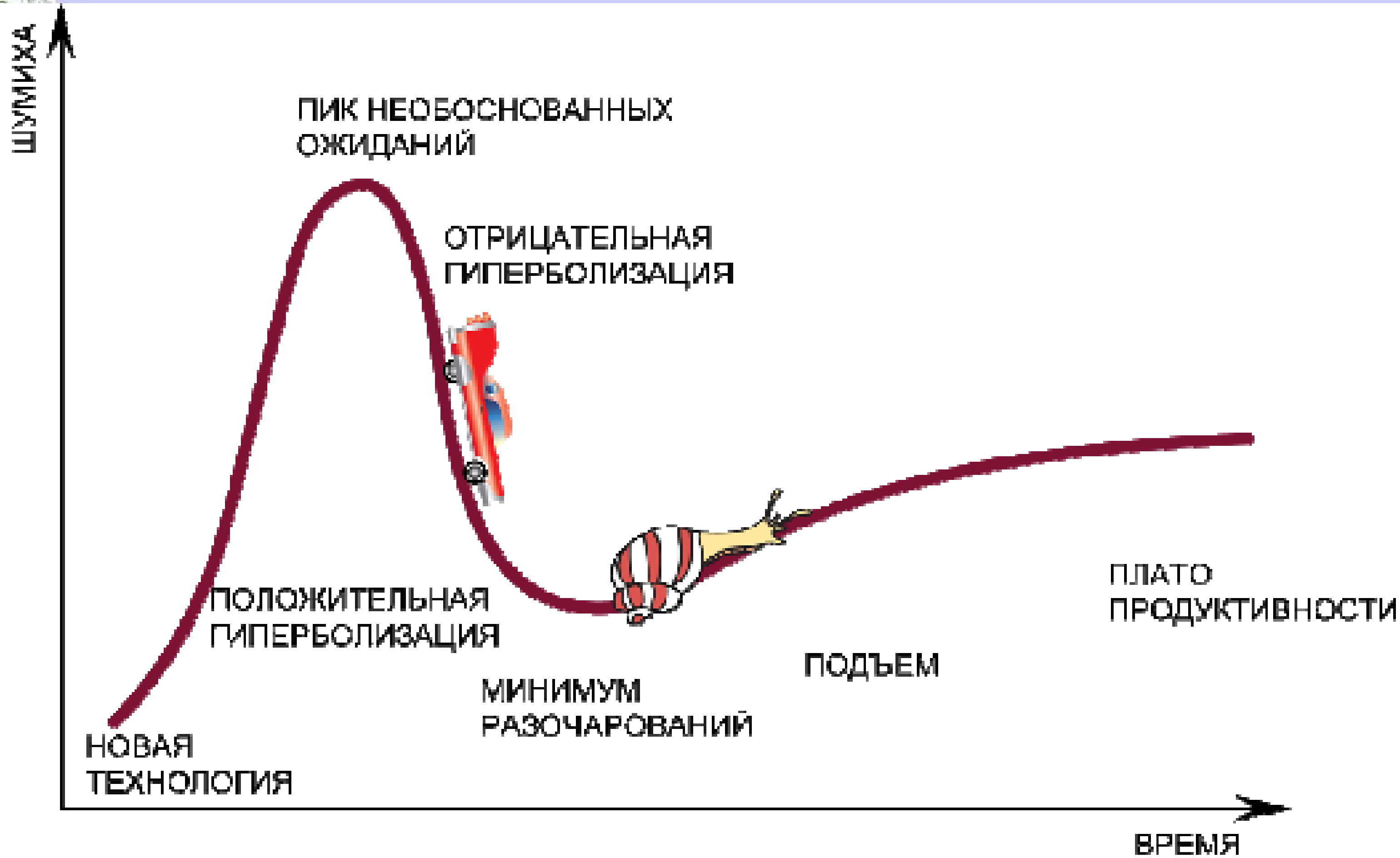
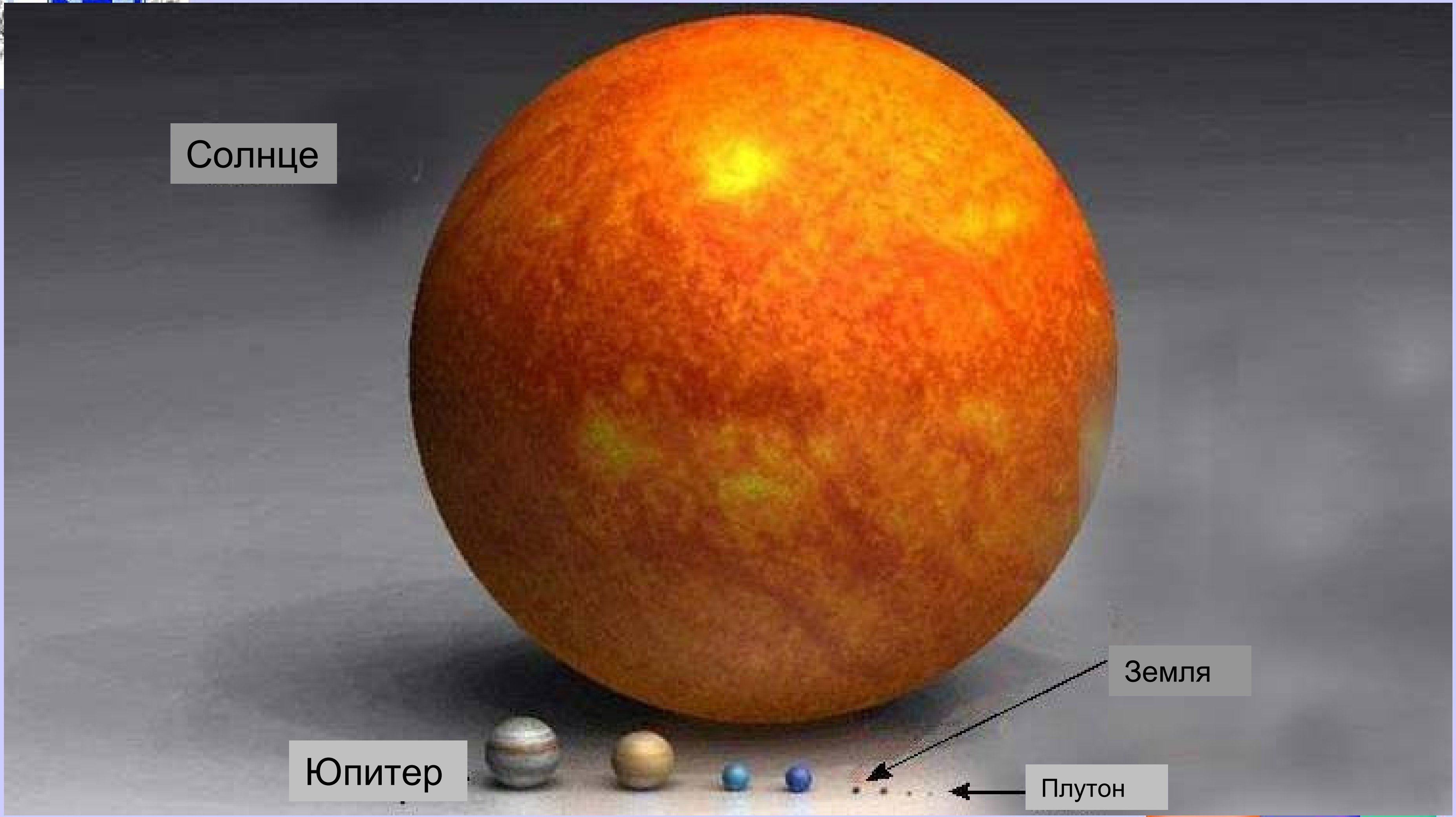
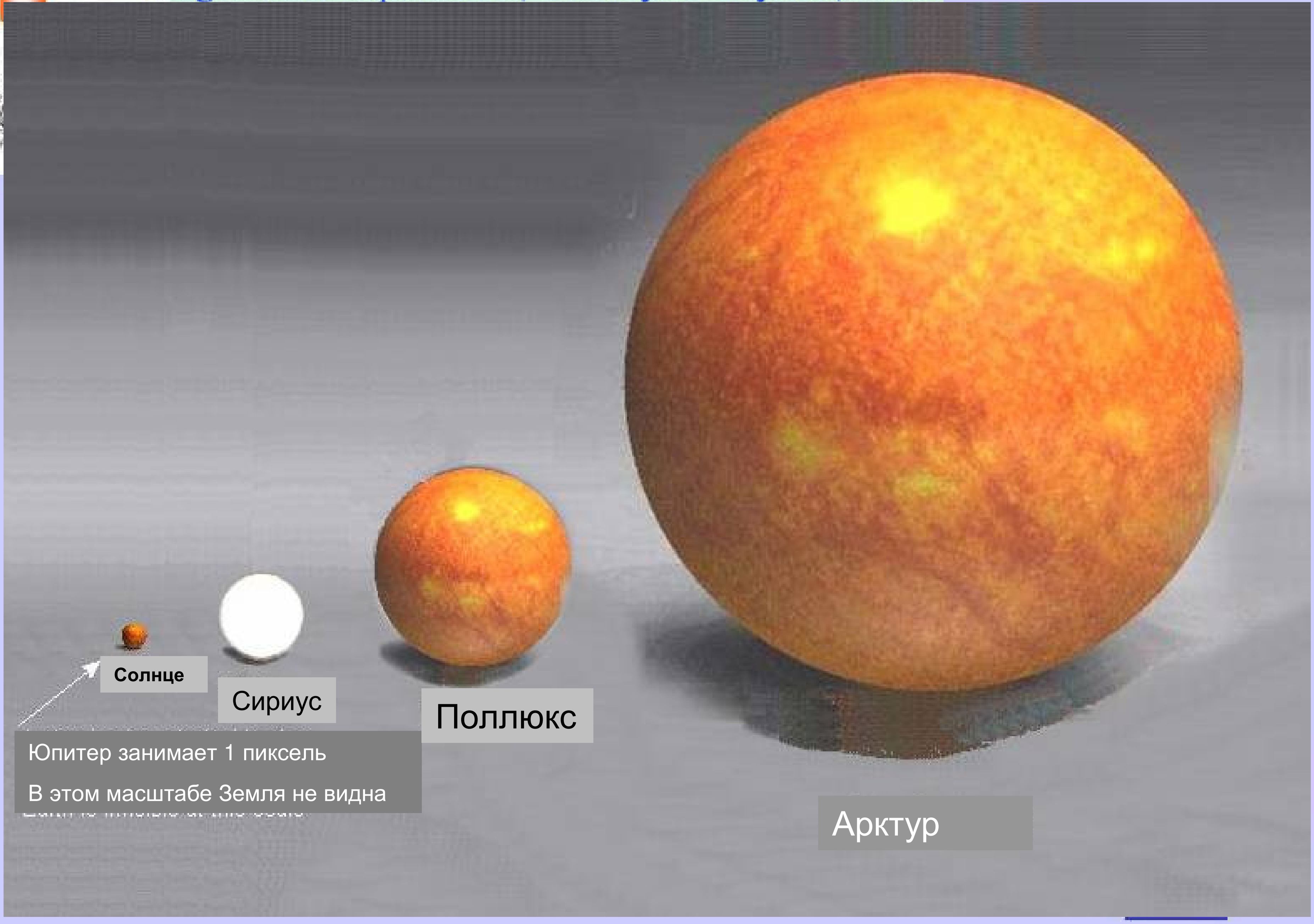
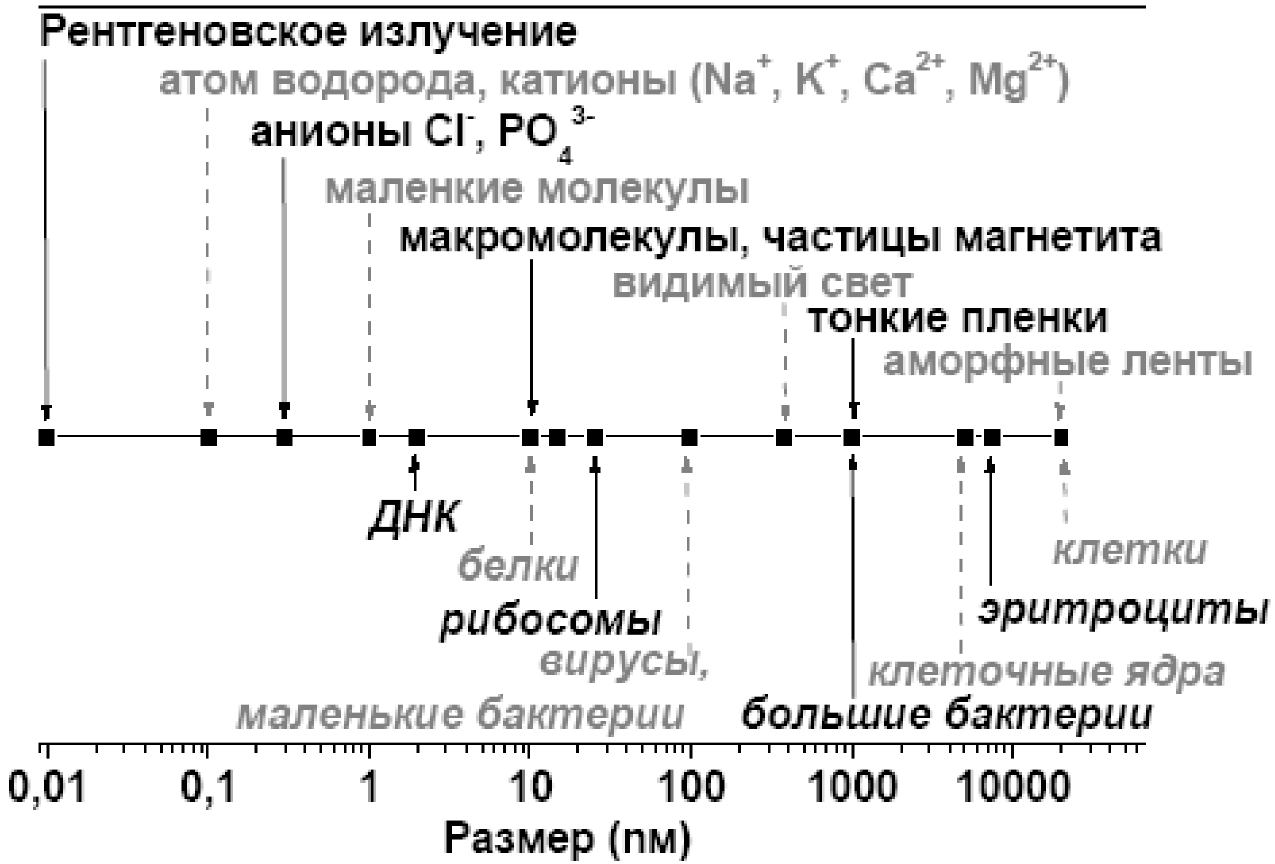


Рис.1. *Типичный график отношению общества к новым технологиям (адаптировано И.В.Колесник, ФНМ МГУ)*


Мир потерянных величин
10 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14} 10^{-15} м
МАКРО
МИКРО
НАНО
ПИКО
ФЕМТО
Человек
Клетка
Вирус
Атом
Протон
Световой
Электронный
Атомно-силовой
Глаз
Микроскопы


Солнце
Земля
Юпитер
Плутон


Солнце
Сириус
Поллюкс
Юпитер занимает 1 пиксель
В этом масштабе Земля не видна
Арктур


Рентгеновское излучение
атом водорода, катионы (Na+, K+, Ca2+, Mg2+)
анионы Cl-, PO4 3-
маленкие молекулы
макромолекулы, частицы магнетита
видимый свет
тонкие пленки
аморфные ленты
ДНК
белки
рибосомы
вирусы,
маленькие бактерии
большие бактерии
клеточные ядра
эритроциты
клетки
0,01
0,1
1
10
100
1000
10000
Размер (нм)

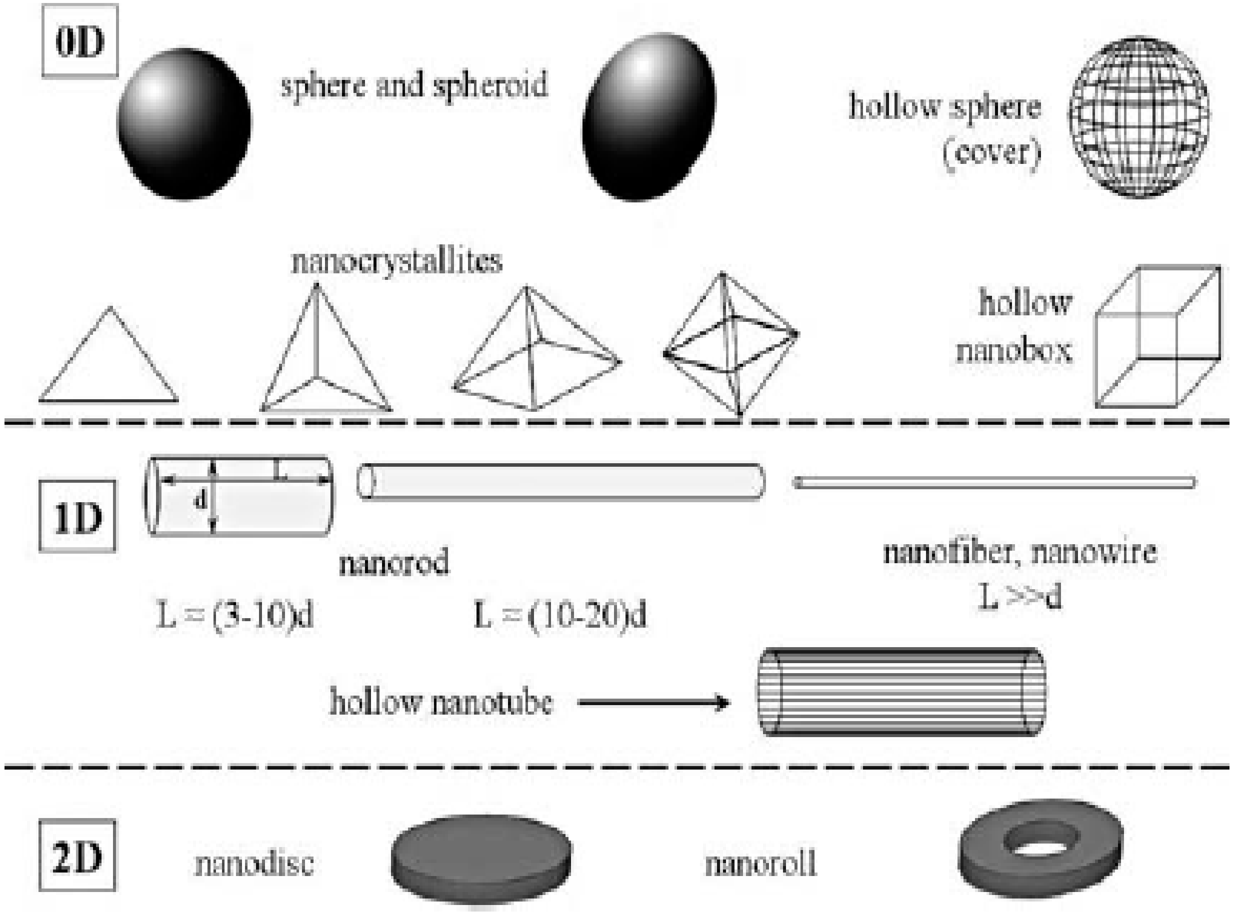
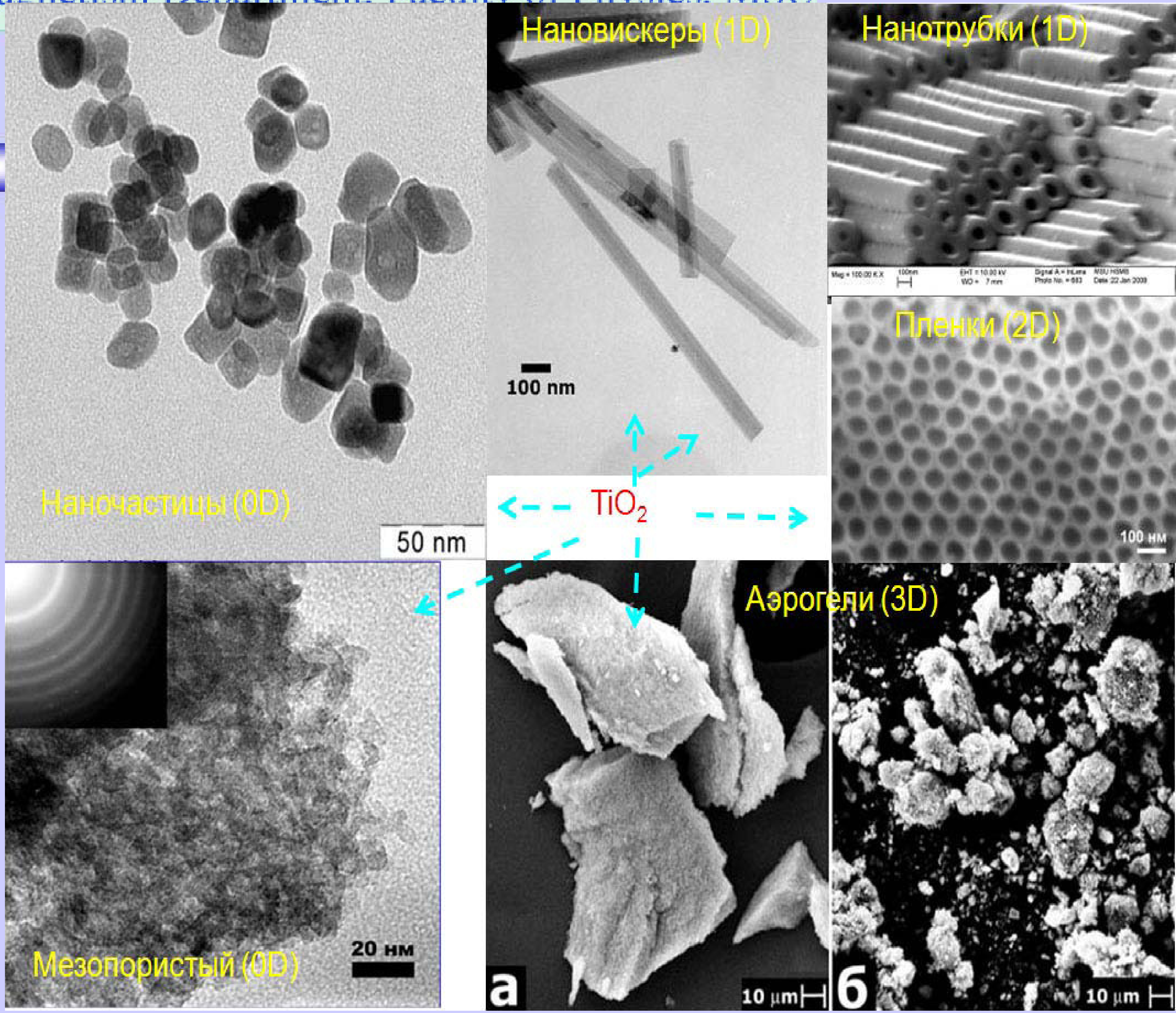
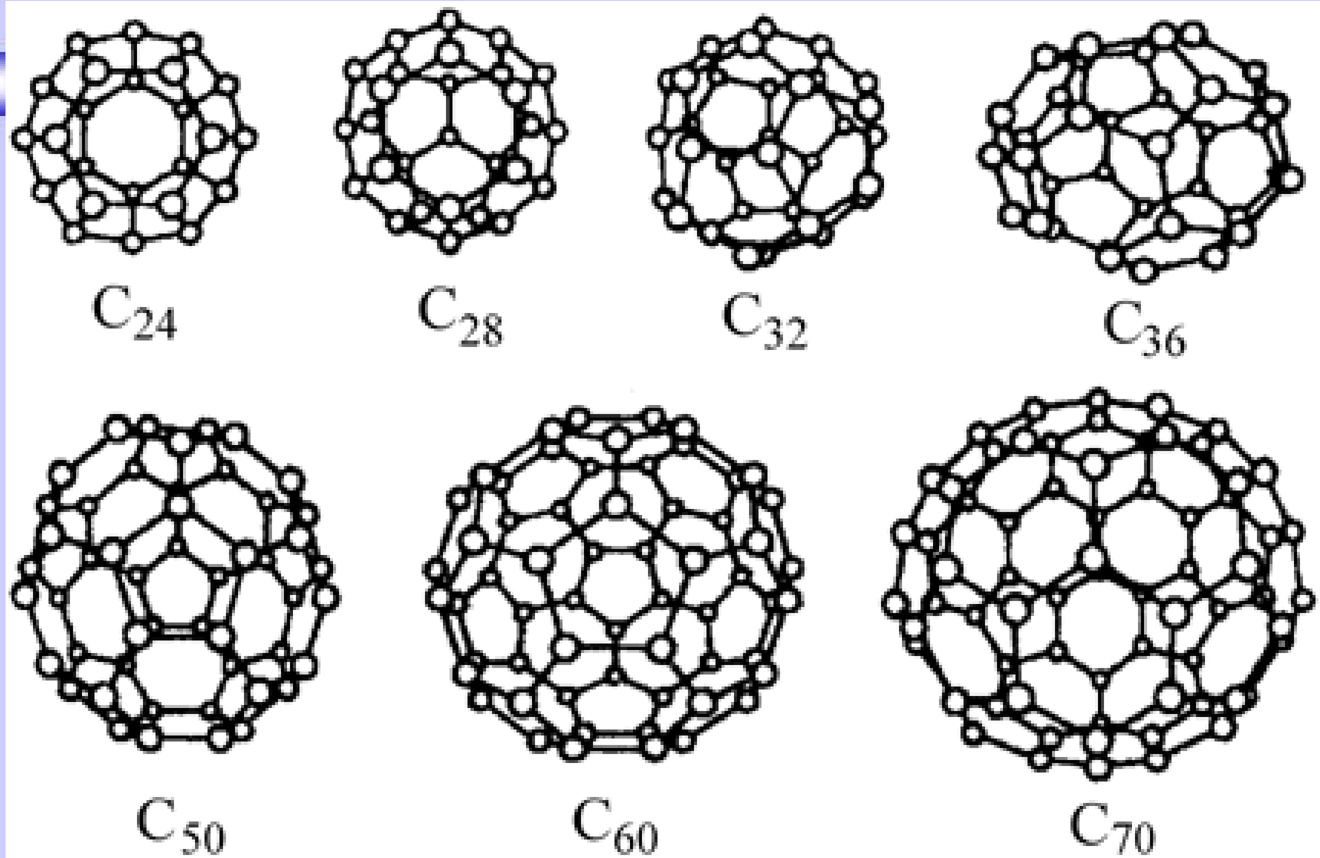


Figure 1.1 The classification of metal containing nanoparticles by the shape.

Magnetism Department, Faculty of Physics, MSU





Диаметр C_{60} – 2.1 нм

Боровский радиус =0.053 нм, диаметр атомов 0.1-0.6 нм

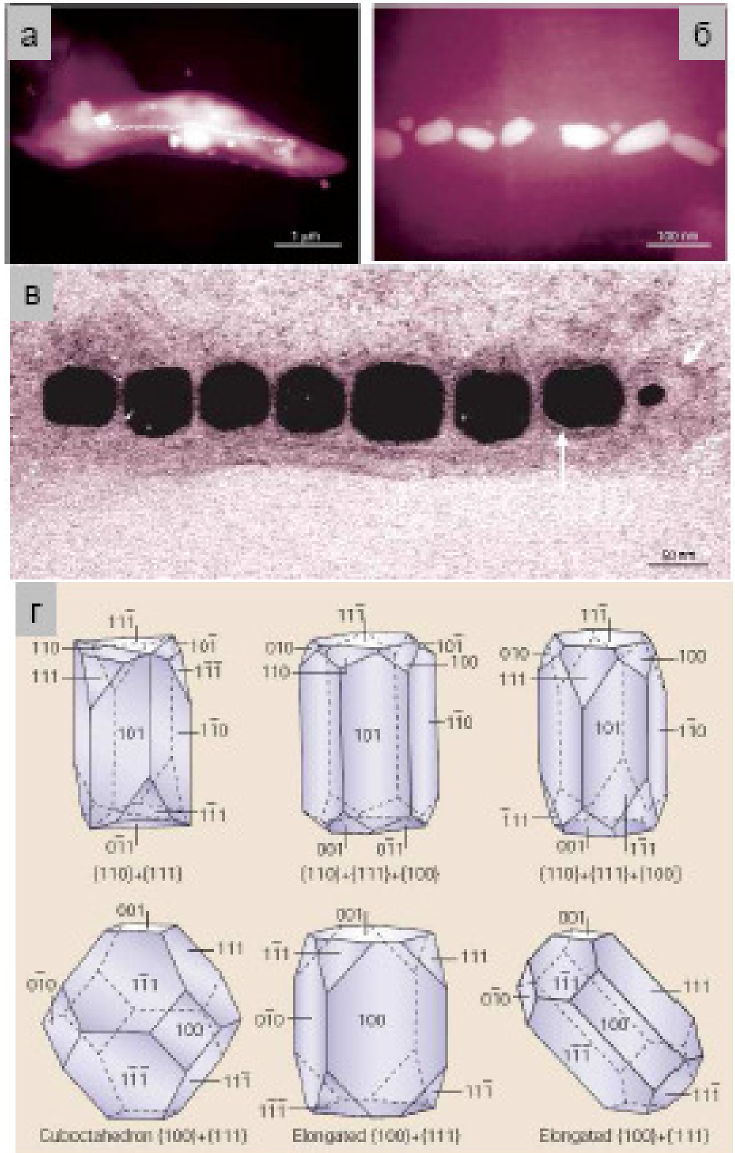


Рис 7. Кристаллы магнетита типа «зубы акулы» внутри бактерии «Spirilum de Pettaquamscutt Estuary» при двух разных увеличениях (а-б). Кристаллы магнетита внутри бактерии «Spirilum MV-4» (в). Набор кристаллографических форм наночастиц магнетита, обнаруженных в бактерии «Spirilum MV-4» (г). D.A. Bazylinski, R.B. Frankel, NATURE REVIEWS, Microbiology, Vol. 2, March 2004, 229.

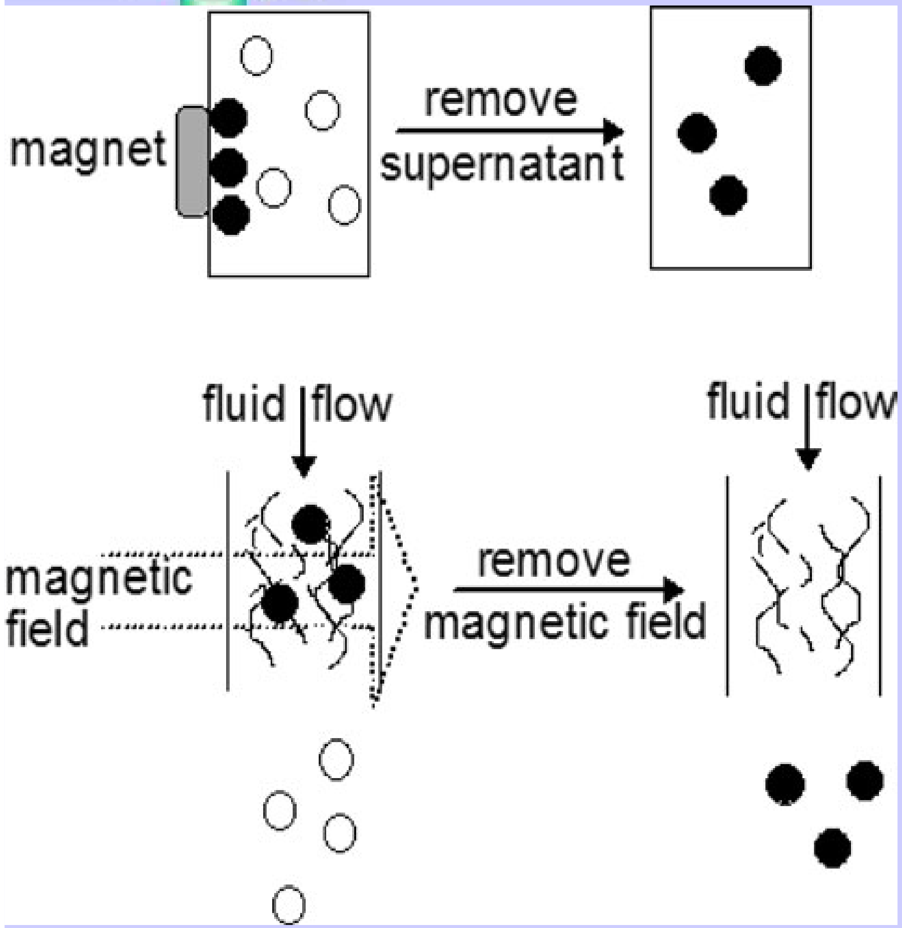
Magnetic therapy for healing has been around for centuries. Many ancient civilizations, such as the Greeks, Hebrews, Indians, Chinese and Egyptians, used magnets for medical purposes. It's only been recently that using magnets has come back into medical use. No one exactly knows how the magnets promote healing, but it's theorized that magnets attract metal elements in the body, such as iron in blood, to increase blood circulation and therefore instigate healing.

Knowledge in this field is comparatively poor, even in the case of physicists.

Although hemoglobin, the blood protein that carries oxygen, is weakly diamagnetic and is repulsed by magnetic fields, the magnets used in magnetic therapy are many orders of magnitude too weak to have any measurable effect on blood flow.

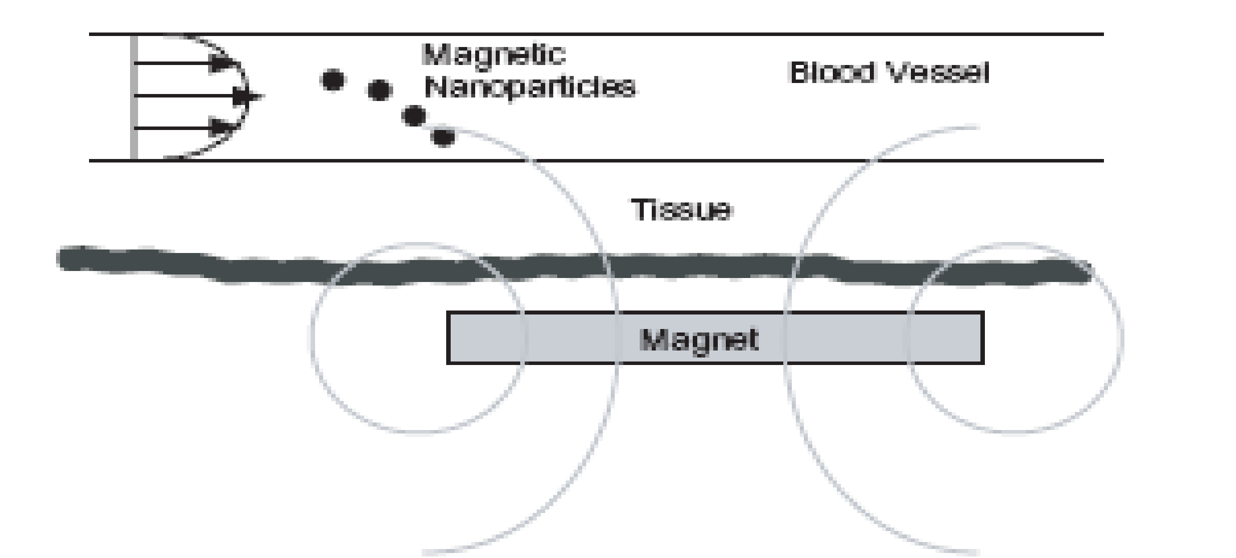
The magnetic therapy business is so large that over 120 million people all around the world are using some type of magnetic therapy product. Magnets can be worn in many different styles. The most popular styles are forms of jewelry, like bracelets, watches, necklaces, anklets, and rings.

Magnetic separation, drug delivery, hyperthermia treatments and magnetic resonance imaging (MRI) contrast enhancement.



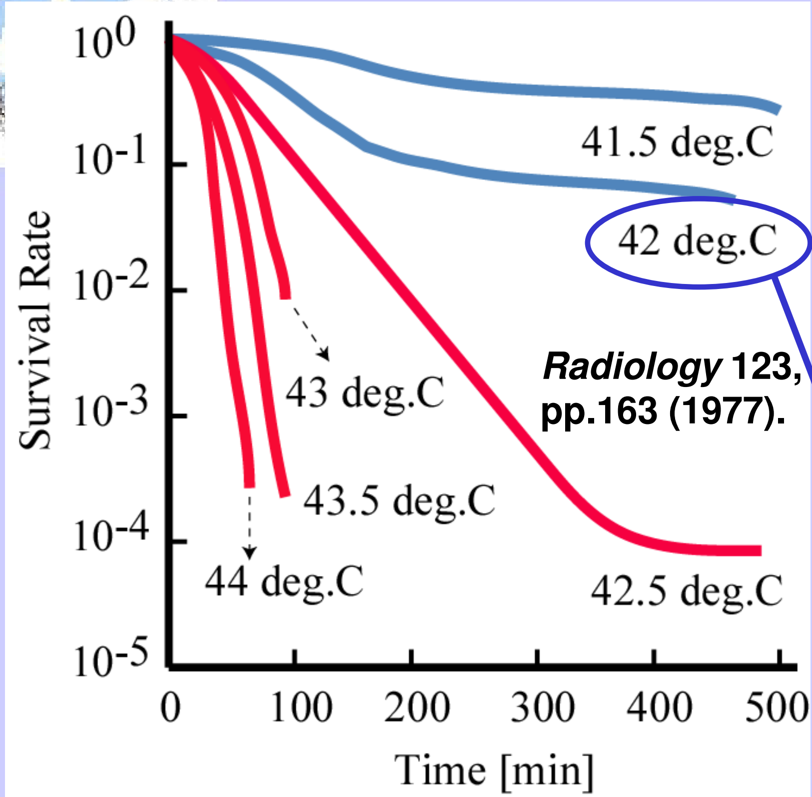
Tagging is made possible through chemical modification of the surface of the magnetic nanoparticles, usually by coating with biocompatible molecules such as dextran, polyvinylalcohol (PVA) and phosopholipids—all of which have been used on iron oxide nanoparticles

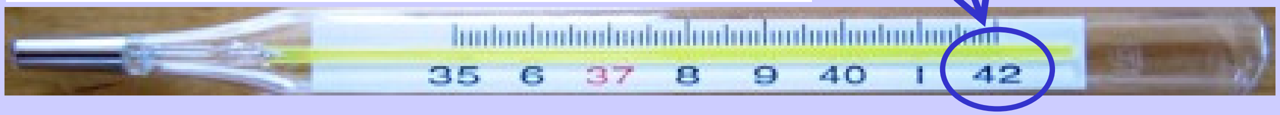
Drug Delivery



The objectives are two-fold: (i) to reduce the amount of systemic distribution of the cytotoxic drug, thus reducing the associated side-effects; and (ii) to reduce the dosage required by more efficient, localized targeting of the drug. In magnetically targeted therapy, a cytotoxic drug is attached to a biocompatible magnetic nanoparticle carrier. These drug/carrier complexes—usually in the form of a biocompatible ferrofluid—are injected into the patient via the circulatory system. When the particles have entered the bloodstream, external, high-gradient magnetic fields are used to concentrate the complex at a specific target site within the body

Hyperthermia: Thermal Therapy for Cancer





Established cancer treatment

Surgical operation, Chemotherapy etc.

- Risk of scar
- Harmful side-effect

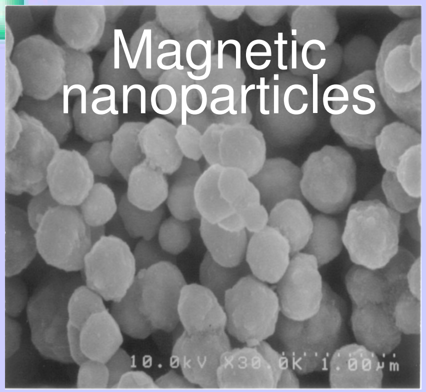
Advantages:

- Less side-effect
- Less invasive
- Combined treatment

Father of Medicine: Hippocrates (460 - 377 BC)

Those diseases which medicines do not cure, iron cures;
those which iron cannot cure, ***fire*** *cures;*
and those which ***fire*** *cannot cure, are to be reckoned wholly incurable.*

Magnetic nanoparticles for biomedical applications



MFe_2O_4 (M : Fe, Ni, Co etc.)

- Induce to tumor through blood vessel
- Magnetic guidance & isolation
- Self-heating in ac magnetic field

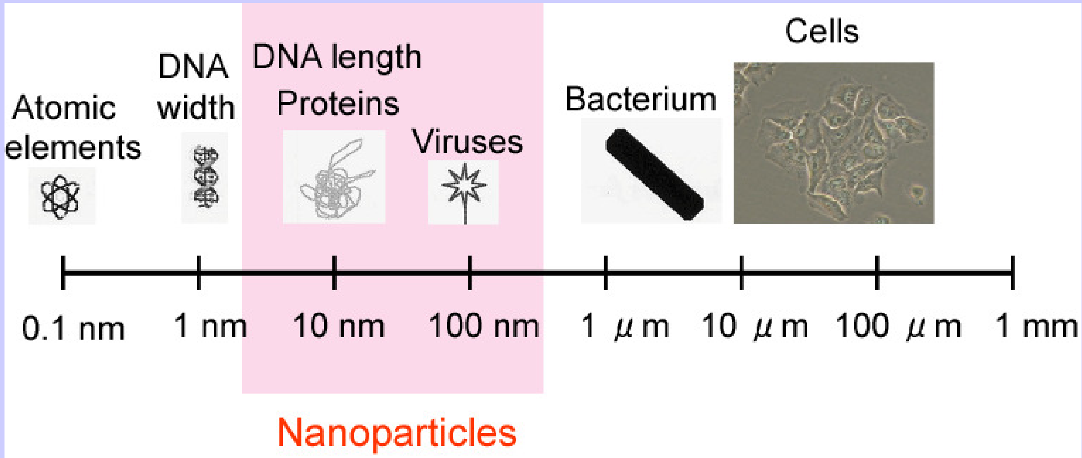
Medical application

MRI contrast agents

Bio-screening

Drug delivery system

Hyperthermia



MRI contrast agent: Resovist®

Schering AG, Germany

Superparamagnetic γ-Fe_2O_3 (10 nm) ~ secondly 57 nm

Carboxydextran-coated superparamagnetic iron oxide (SPIO).

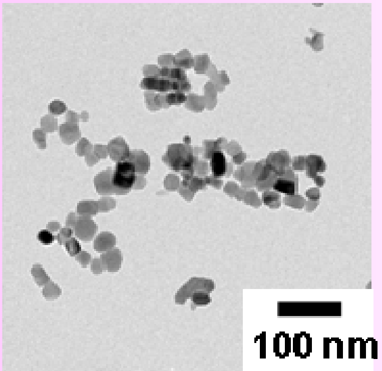
The only magnetic nanoparticle approved for use ***in vivo***.

Uptake by Kupffer cells in the liver shortens both T1 and T2 relaxation times.

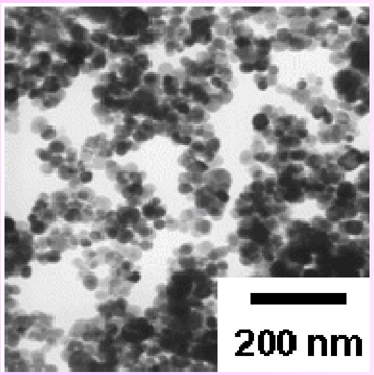
MRI images agar dispersed with magnetic nanoparticles

Pharmaceuticals　　Medical Devices

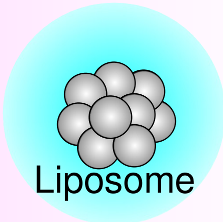
for hyperthermia in pharmacy law



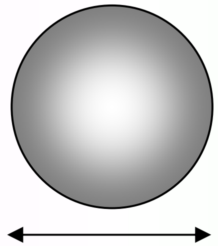
Magnetic Nanoparticles



Coated Magnetic Nanoparticles

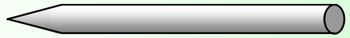


Chubu U
Nagoya U



100 μm = 0.1 mm

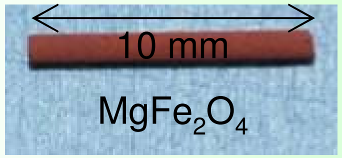
Magnetic Micro-particles



Fe-Pt — Nagoya U

Ni-Cu-Zn Ferrite　Au Plating

Tohoku U



Ehime U

LaSrMnCuO — Osaka U

Resonant Circuit — Yokohama NU

“IN THE THEORY THERE IS NO DIFFERENCE BETWEEN PRACTICE AND THEORY. BUT IN PRACTICE THERE IS.”

Conference on Symbolic Logic

THANK YOU!!!