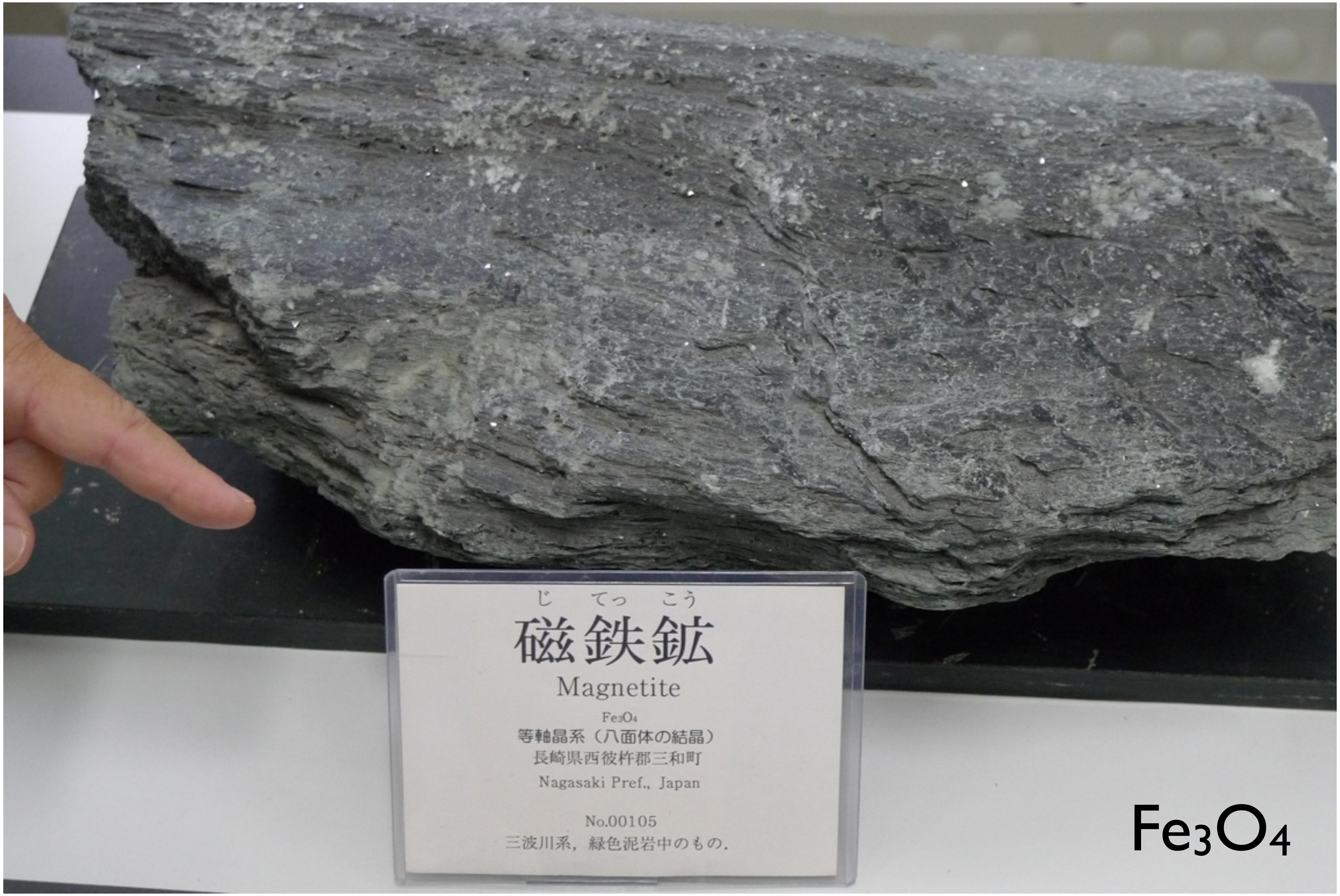
Magnetic Materials



From Akita, Japan

We will learn how to predict the *paramagnetic properties* of a molecule from MO theory, based on whether it possesses unpaired electrons:

For a molecule, there are two possibilities:

Diamagnetic: All electrons are paired.

Paramagnetic: Unpaired electrons are present.

We will learn how to predict the *paramagnetic properties* of a molecule from MO theory, based on whether it possesses unpaired electrons:

For a molecule, there are two possibilities:

Diamagnetic: All electrons are paired.

Paramagnetic: Unpaired electrons are present.

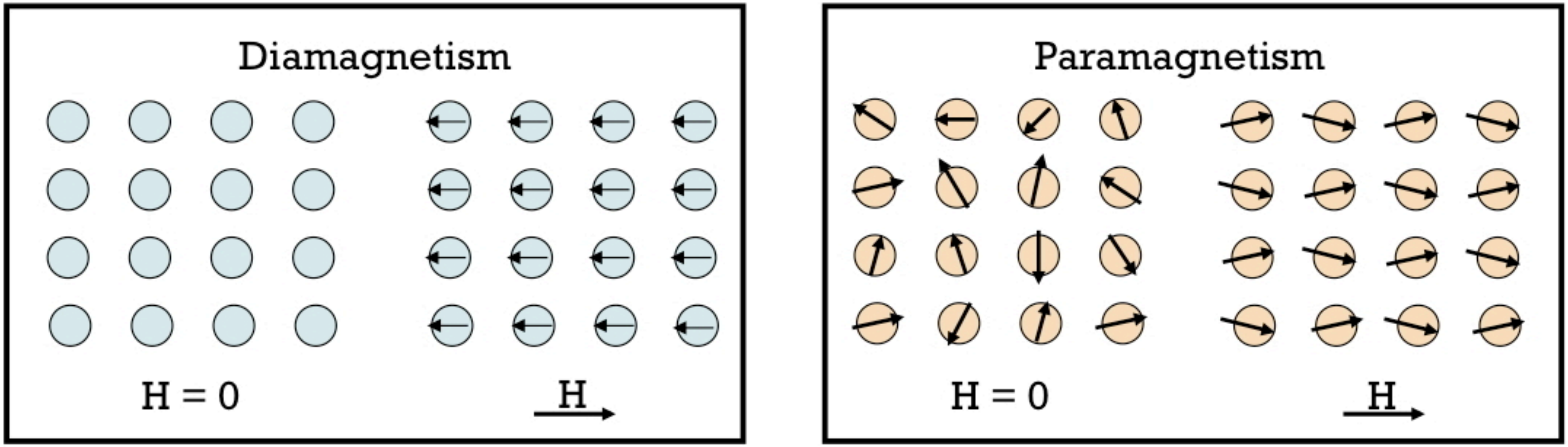
$$\mu = \chi H$$

μ is the induced magnetic dipole.
χ is the magnetic susceptibility.
H is the applied magnetic field.

$\chi < 0$: Diamagnetic

$\chi > 0$: Paramagnetic

Diamagnetic and Paramagnetic Materials



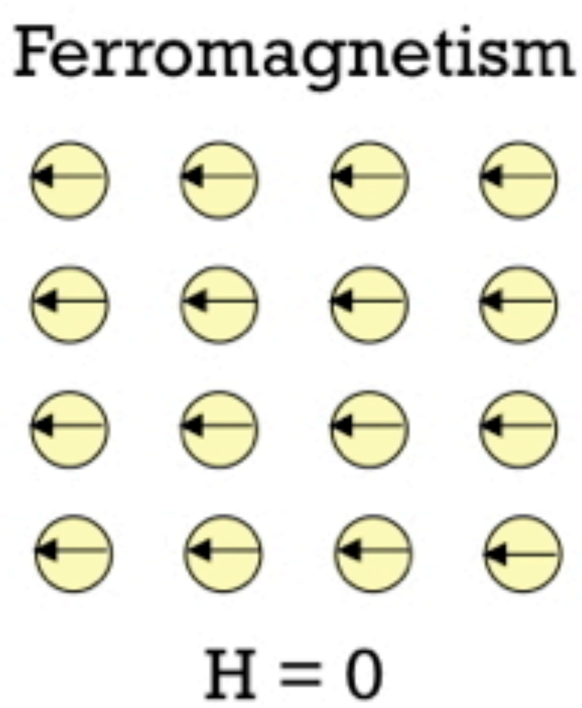
$\mu = \chi H$

$\chi < 0$: Diamagnetic

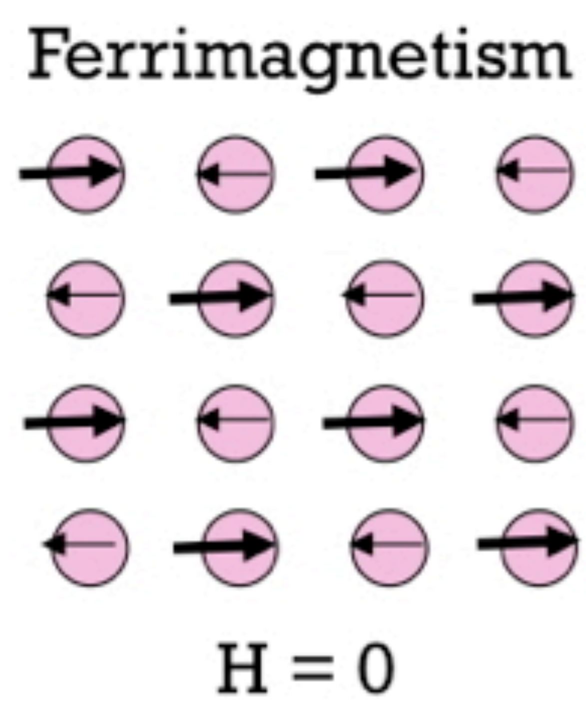
$\chi > 0$: Paramagnetic

Paramagnetic molecules are attracted by a magnetic field.

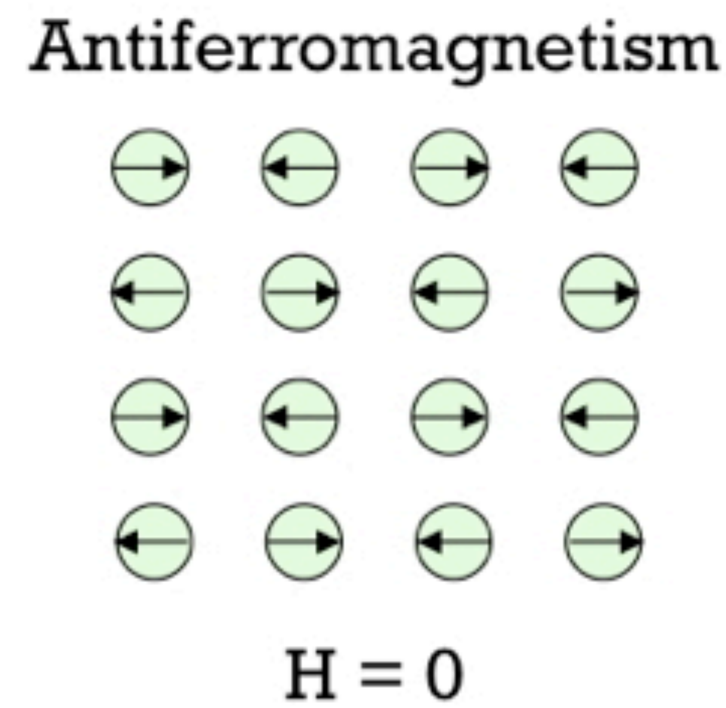
Additionally, there are ferromagnetic, ferrimagnetic and antiferromagnetic materials. The magnetic structure of these materials is complicated and involves the interaction of many spins.



Fe
Iron



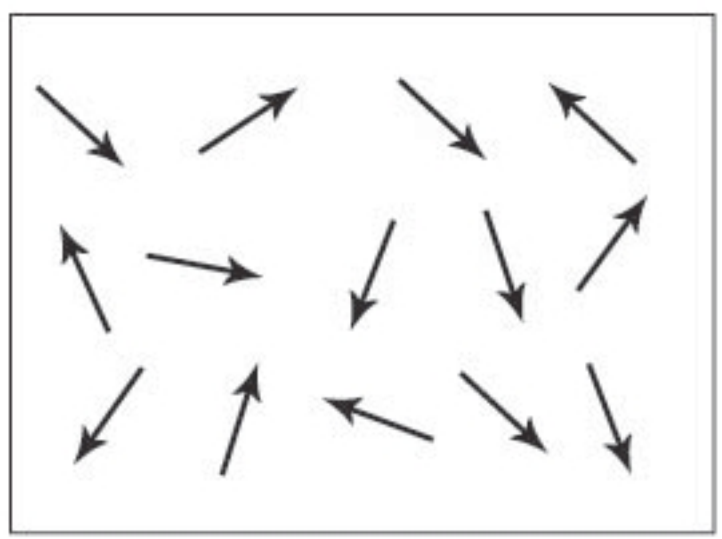
Fe_3O_4
Magnetite



Fe_2O_3
Hematite

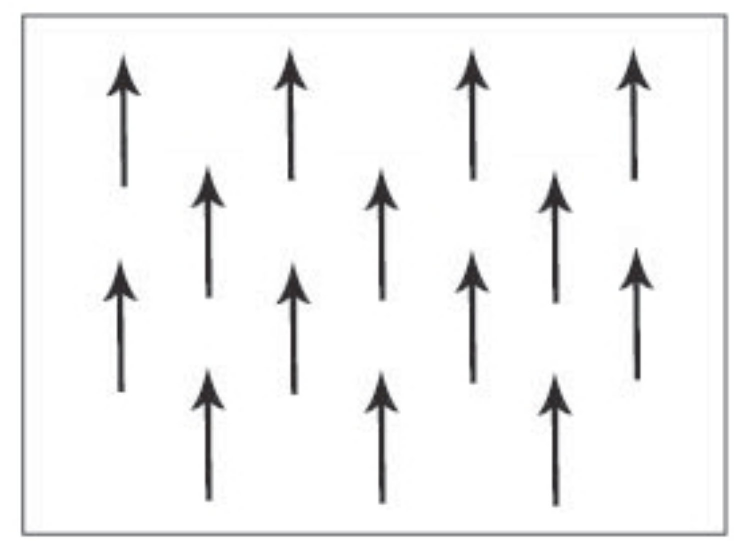
Magnetic Materials

Paramagnetism is actually quite weak. Ferromagnetism is much stronger.



Paramagnetism

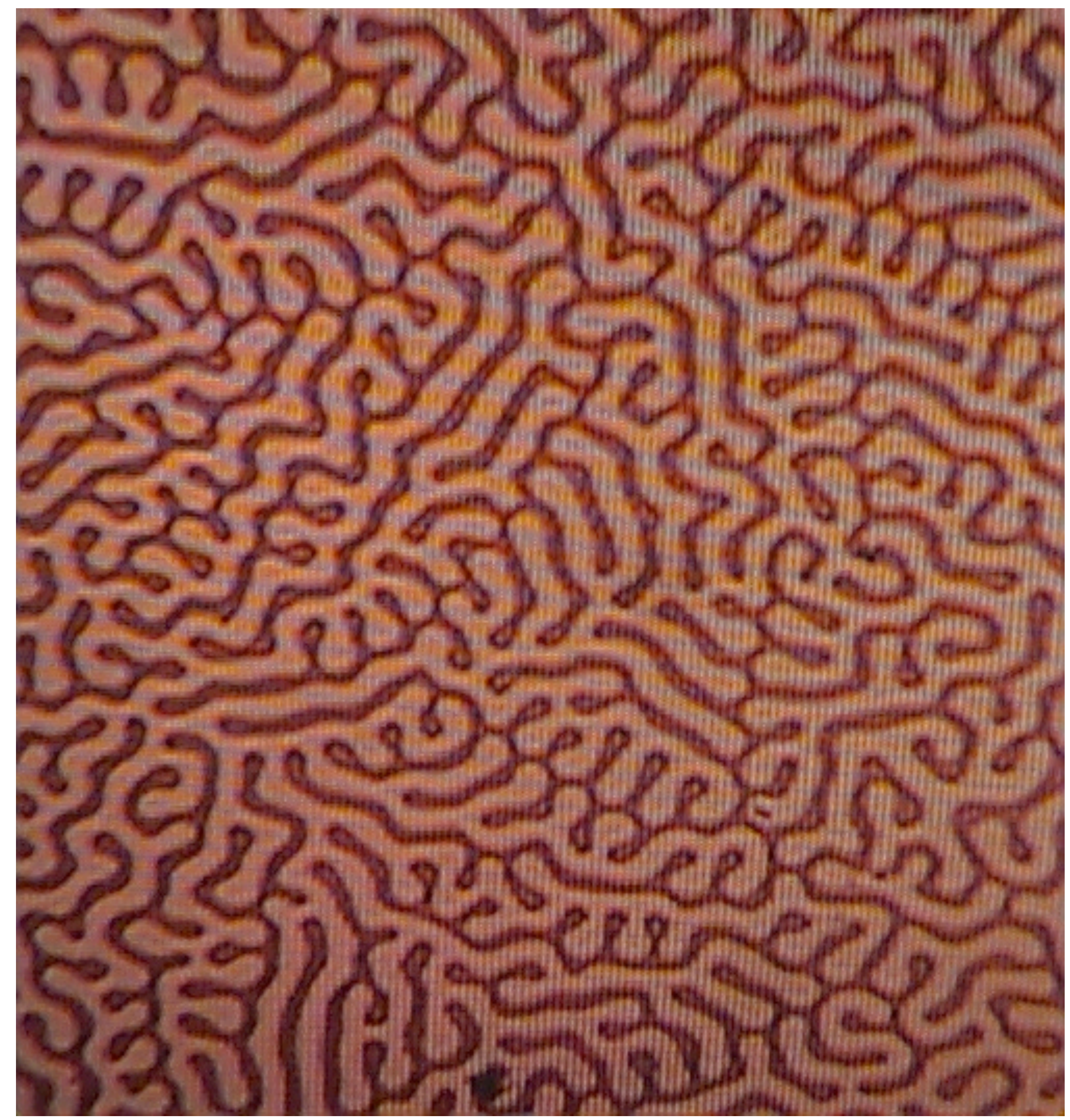
O_2



Ferromagnetism

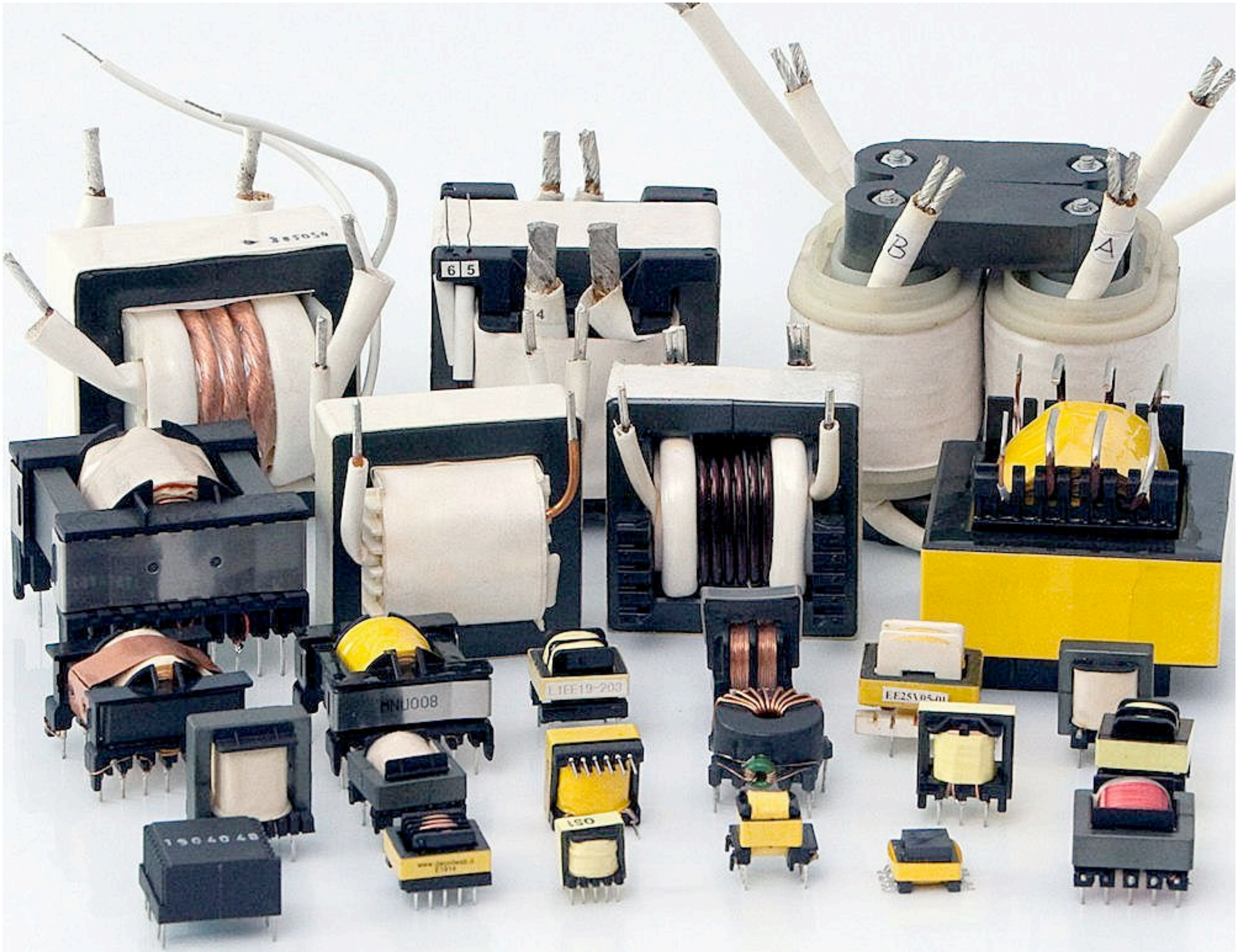
Fe, Co, Ni

Ferromagnetic materials have domains that can be permanently oriented with an external B field.



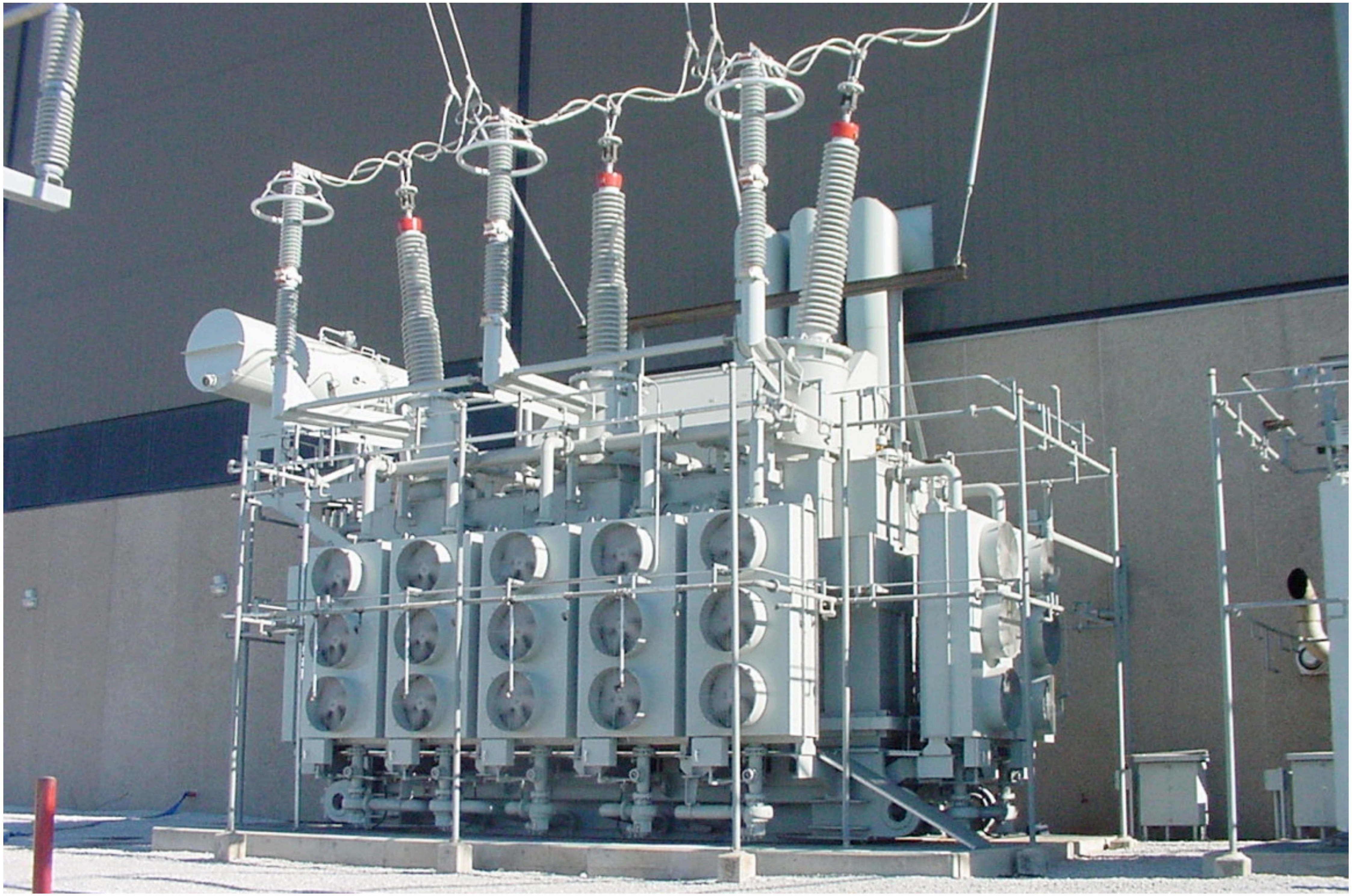
Magnetic domains

Permanent magnets are used for many things:



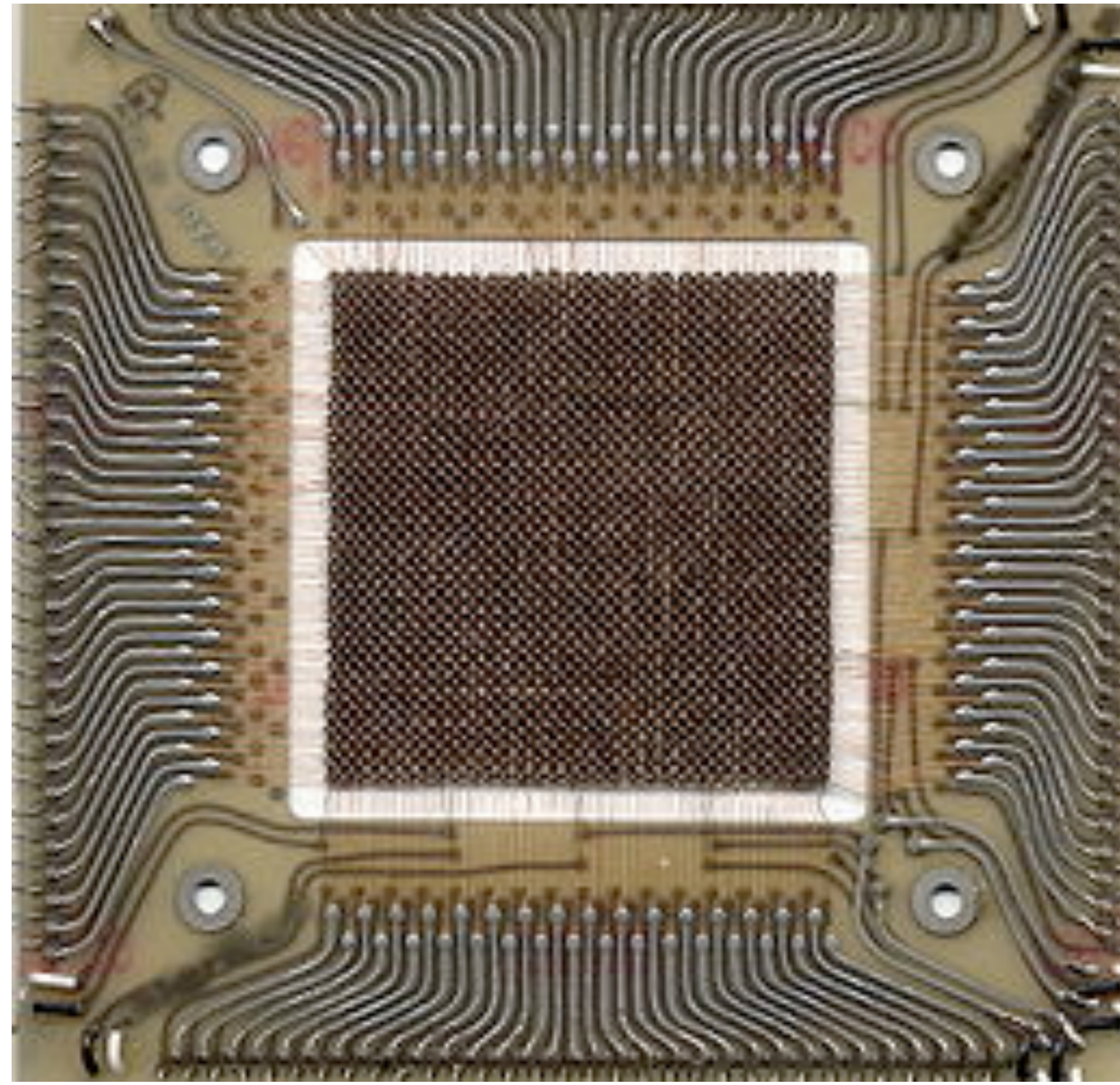
Electrical Transformers

Permanent magnets are used for many things:



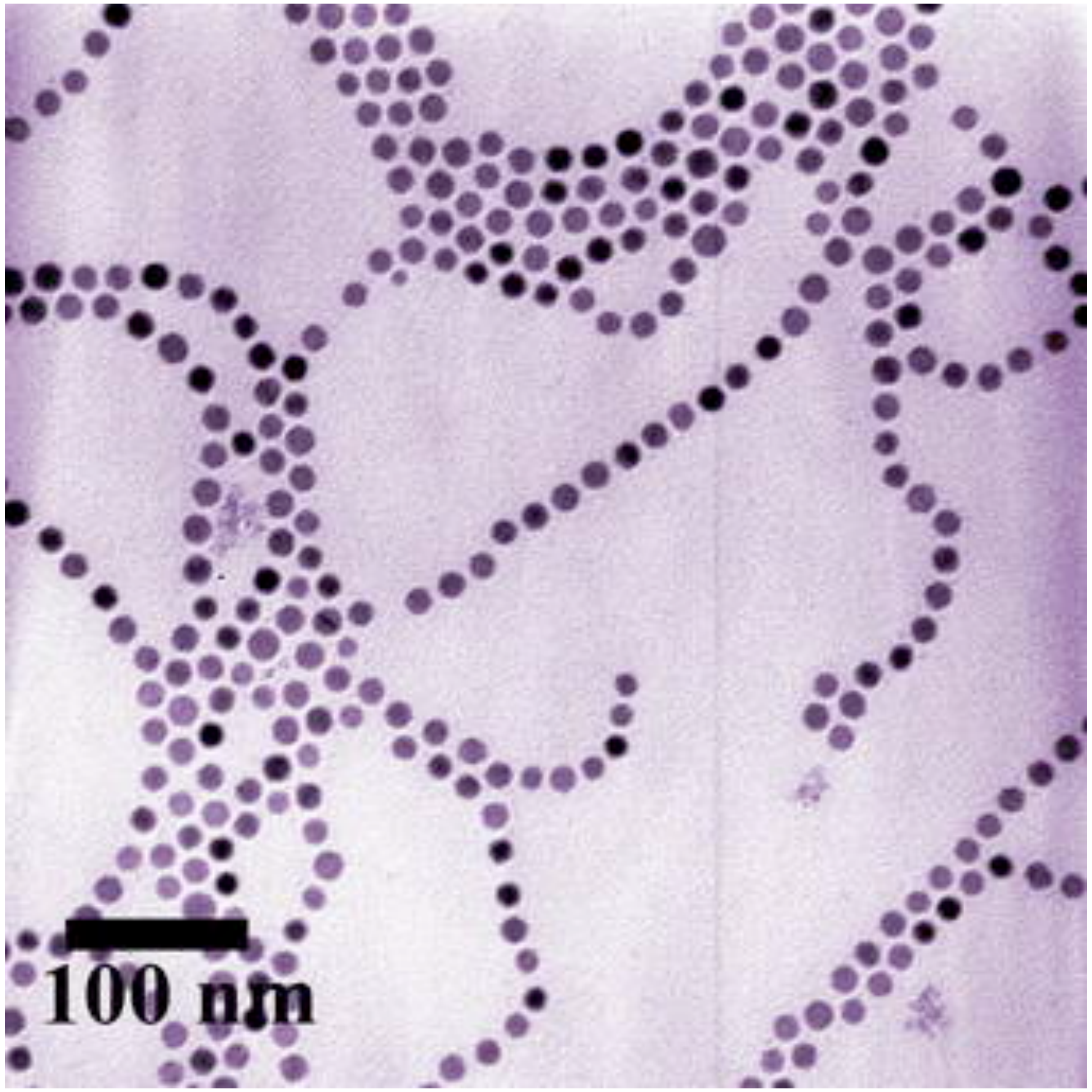
BIG Electrical Transformers

Permanent magnets are used for many things:

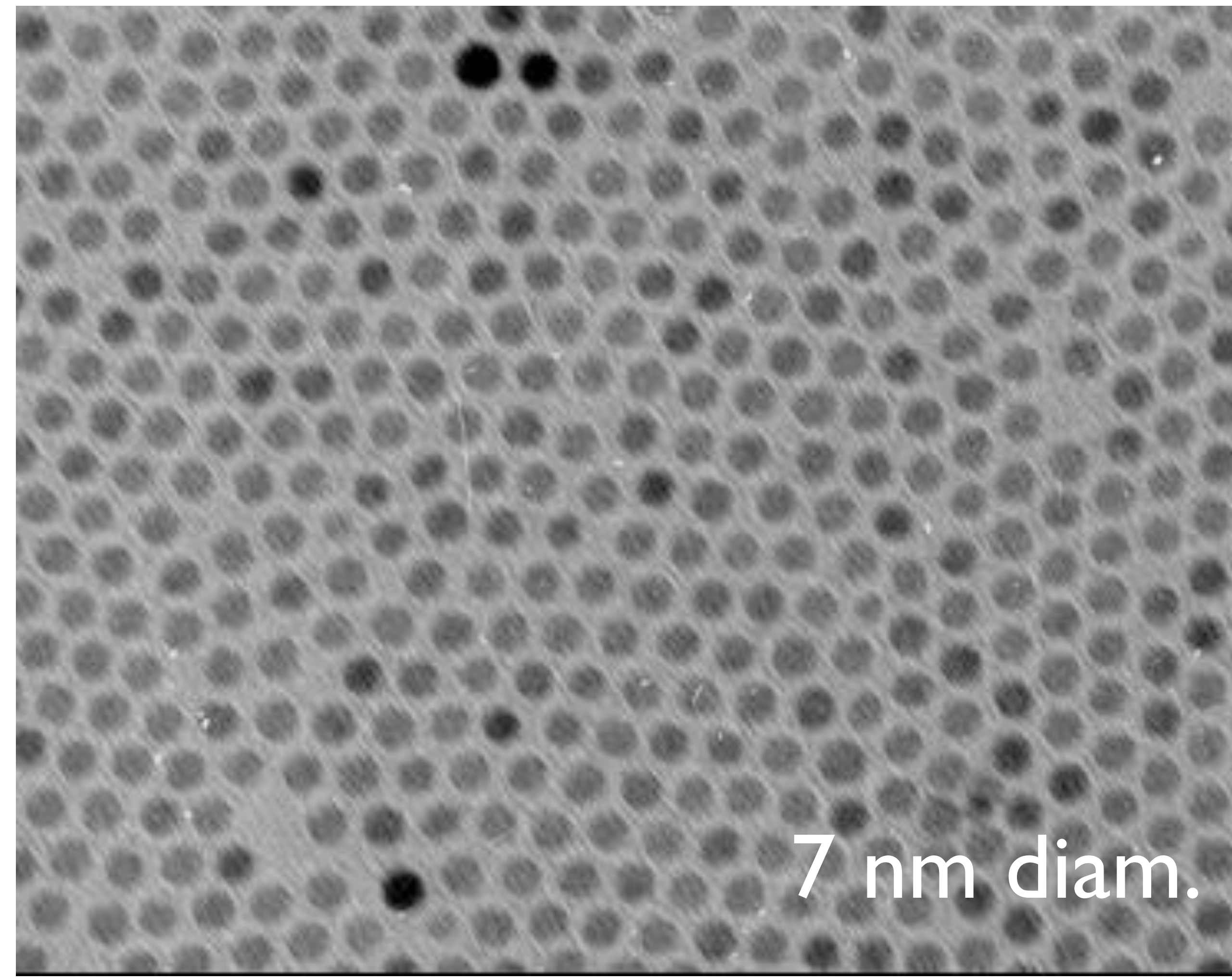


Magnetic Memories and Disk Storage

Permanent magnets are used for many things:



Ferromagnetic Fe



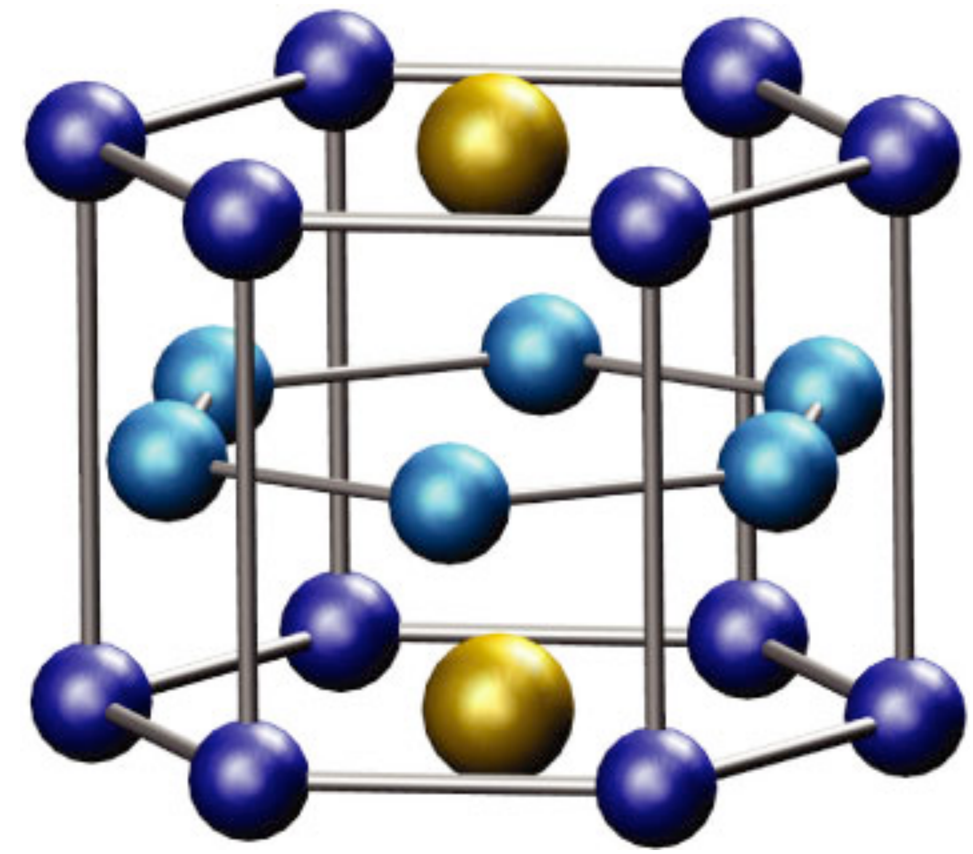
SUPERparamagnetic Fe_3O_4!

Magnetic Nanoparticles

Permanent magnets are used for many things.

Some interesting new magnetic materials that exhibit large magnetization:

$Nd_2Fe_{14}B$



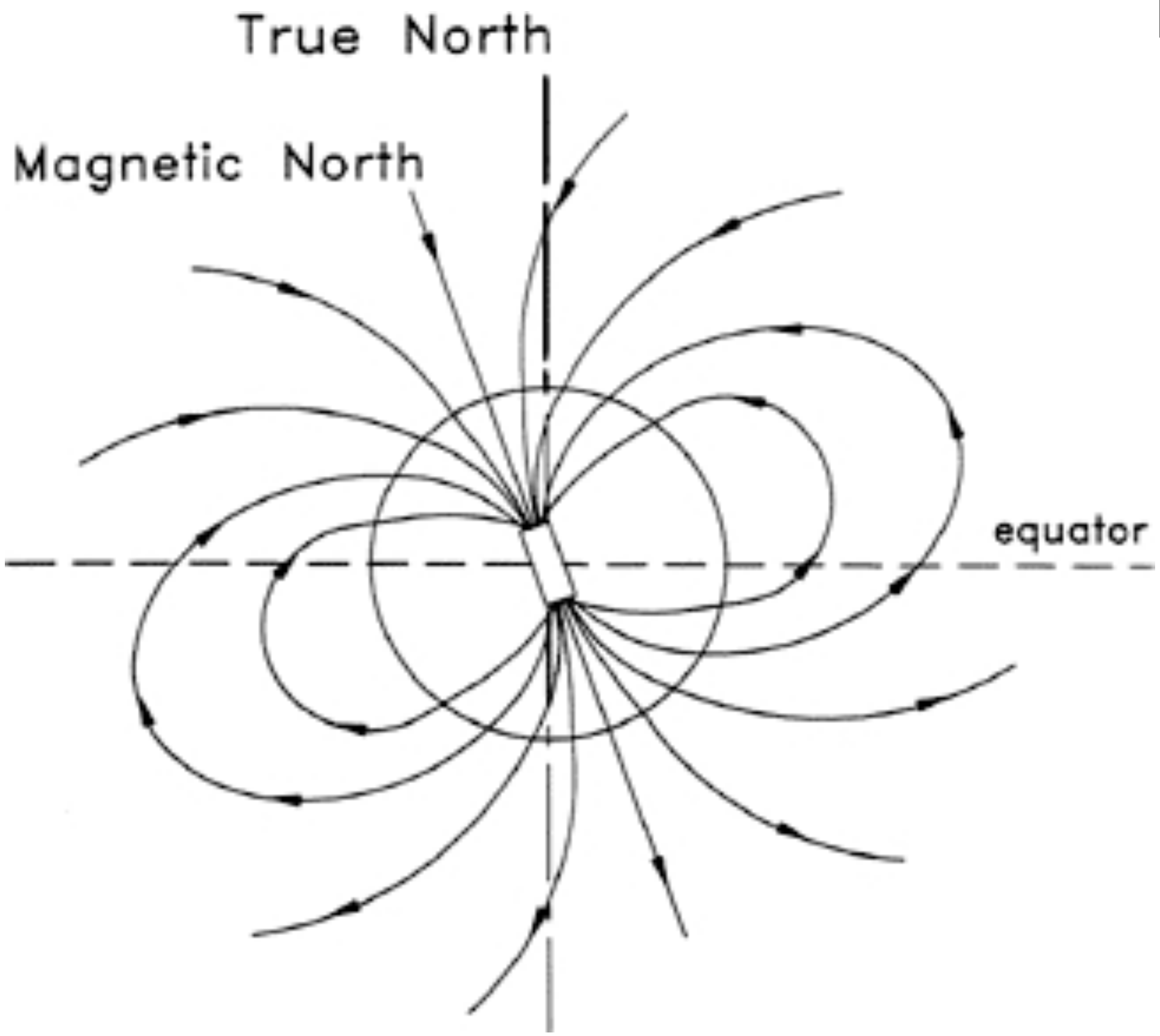
YCo_5

$SmCo_5$

Sm_2Co_{17}

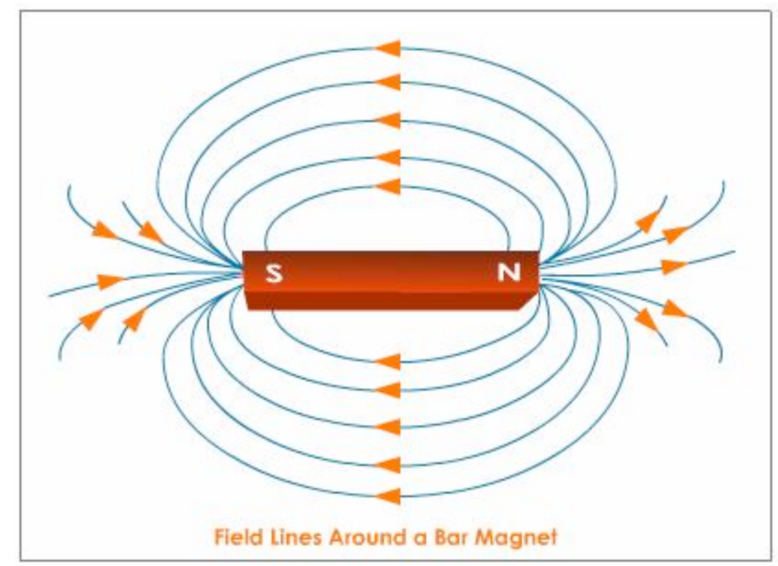
$Sm_2(Co,Fe,Cu,Zr)_{17}$

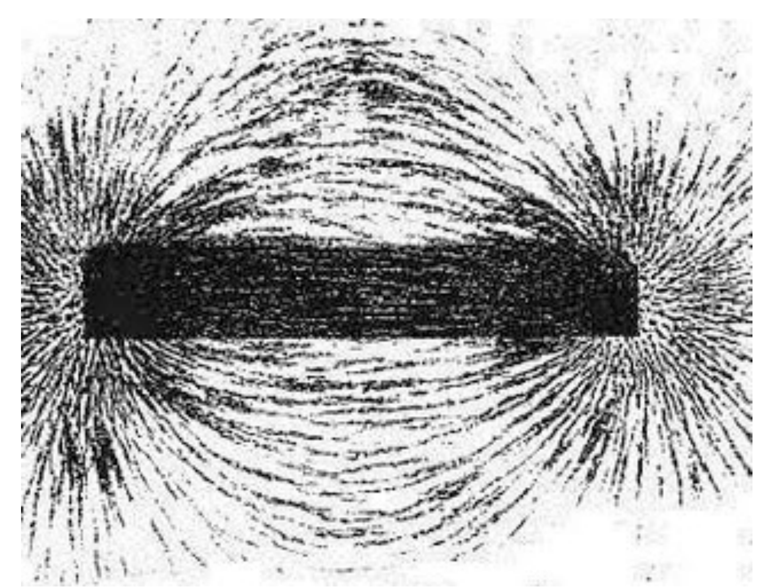
Permanent Magnets and Fields



The Earth's Magnetic Field

Permanent magnets can create external magnetic fields

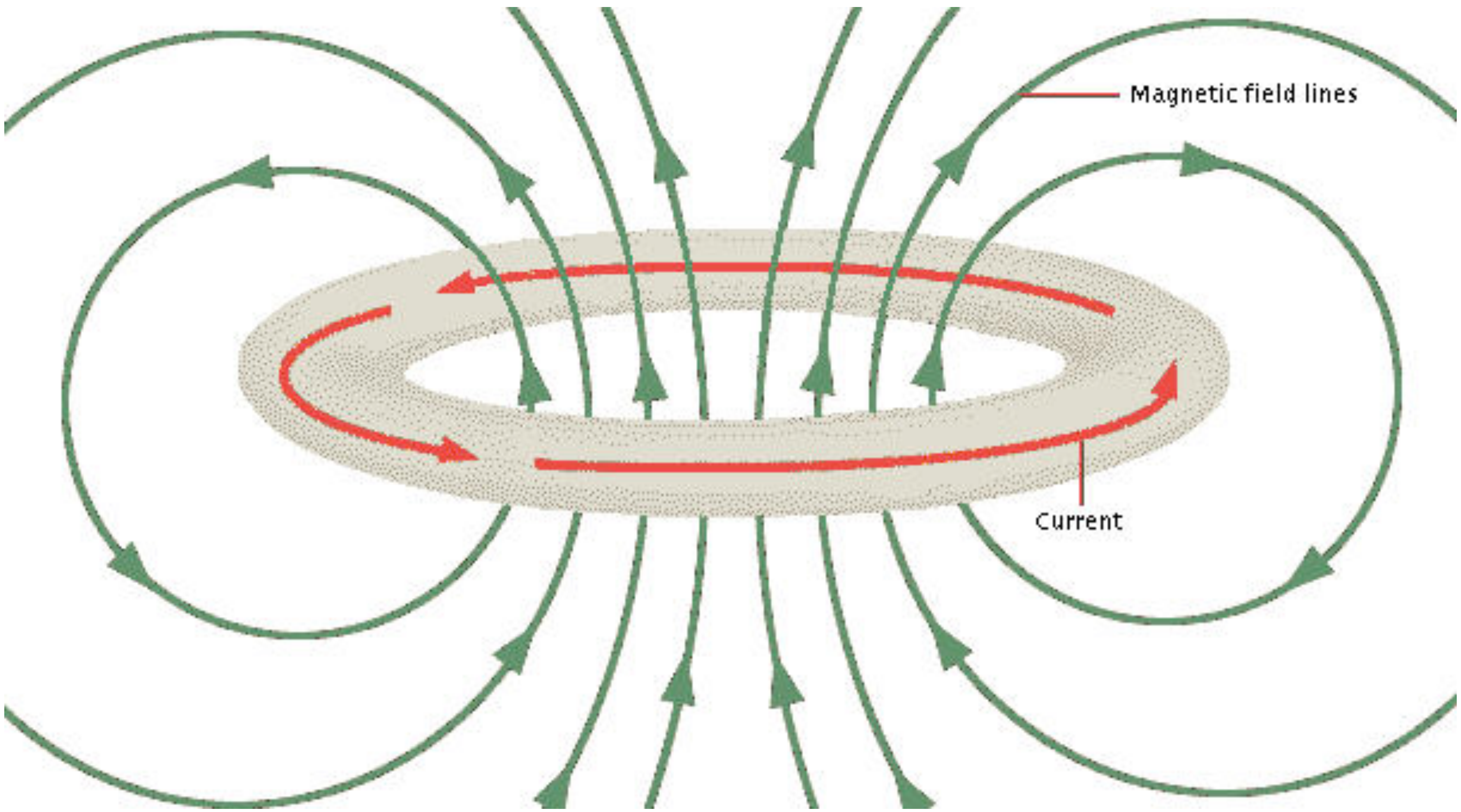




Magnetic Induction $B = \mu_0(1 + \chi)H$

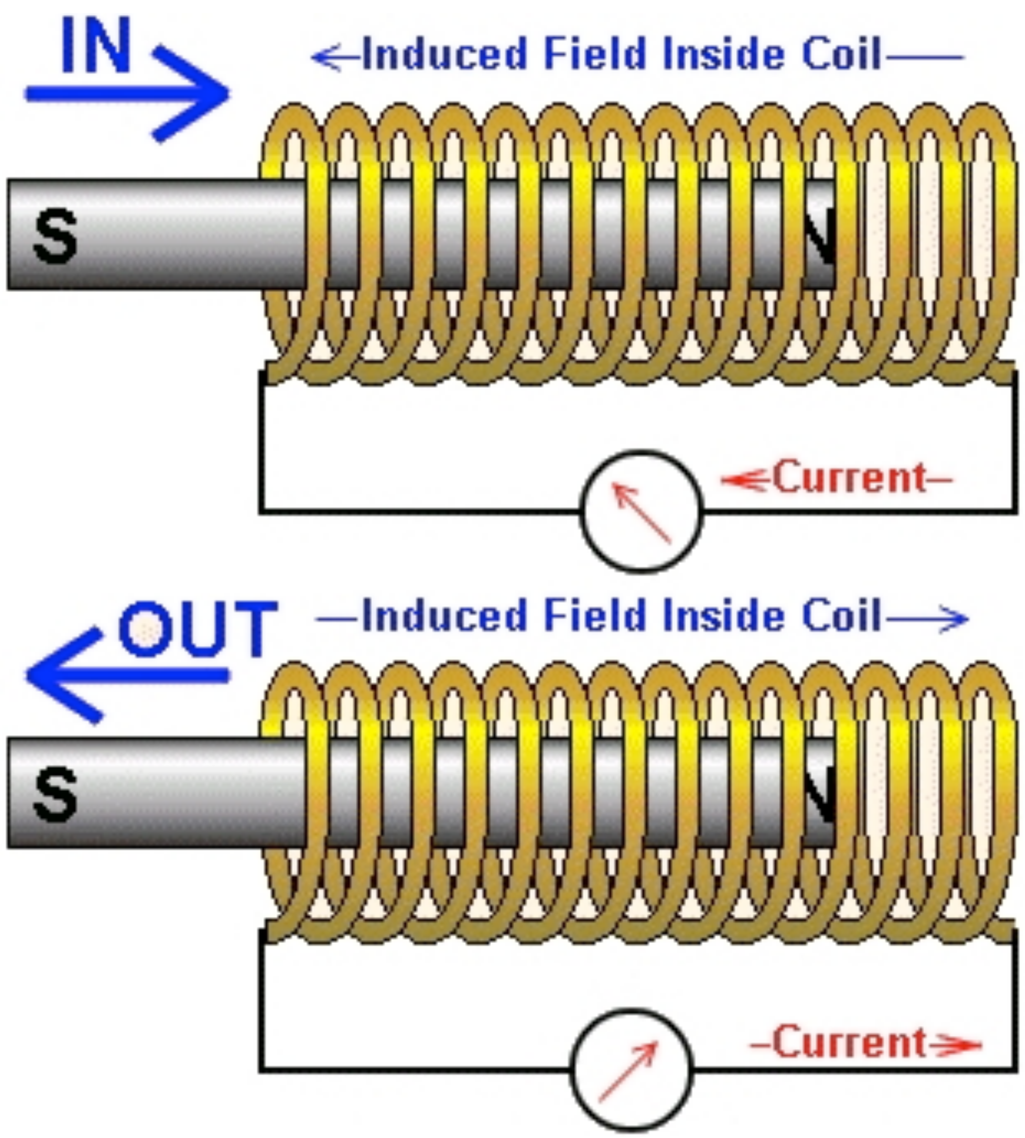
Source	Magnitude of B (Tesla)
A hair dryer	$\sim 10^{-7}$-10^{-3}
Earth's Magnetic Field	$\sim 5 \times 10^{-5}$
A small bar magnet	$\sim 10^{-2}$
At a sunspot	~ 0.3
MRI body scanner magnet	~ 2
Research Physics Labs	~ 50
At the surface of a neutron star	$\sim 10^{8}$

Electrical currents can be used to create magnetic fields

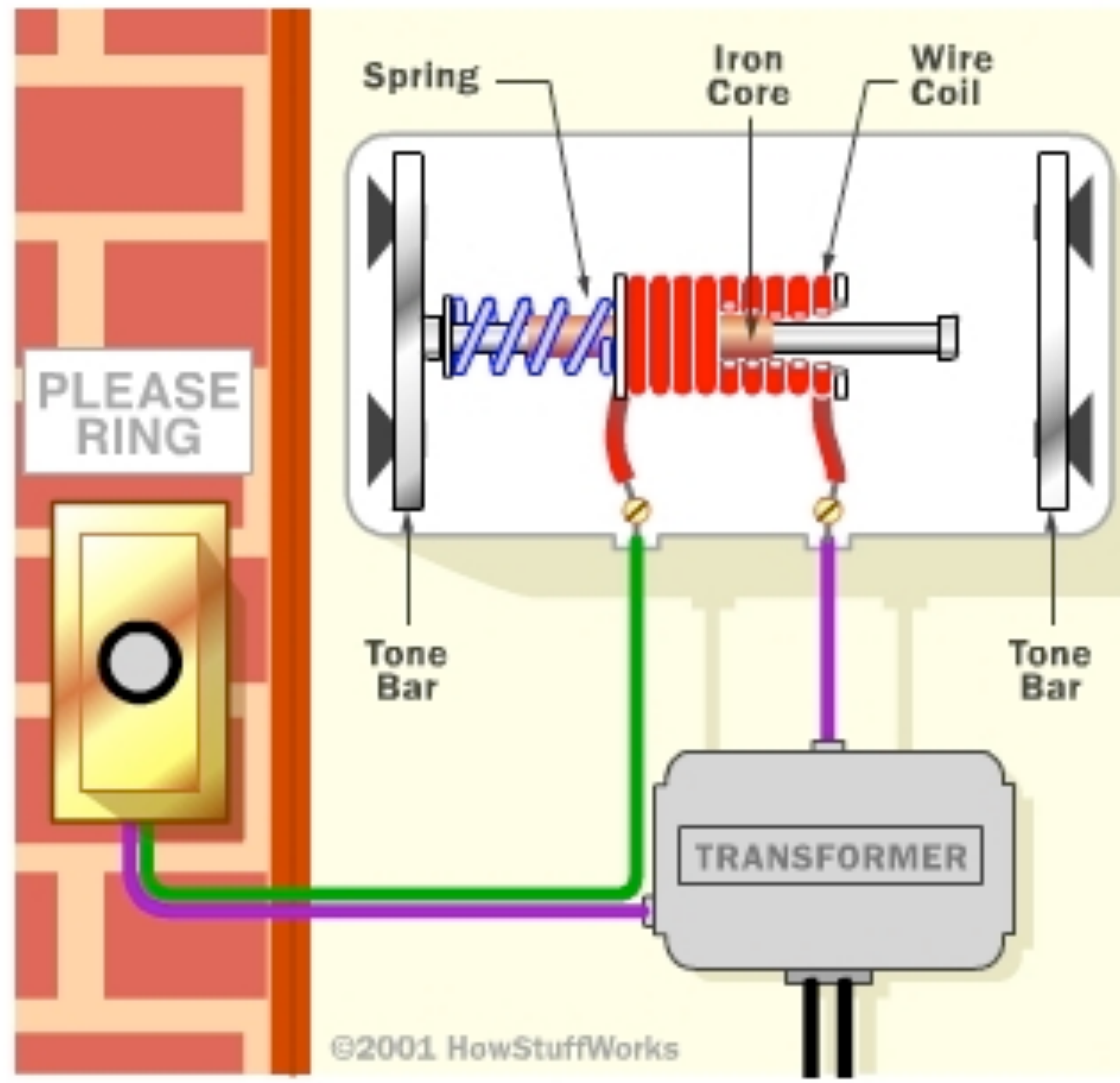


Biot-Savart Law

Electrical currents can be used to create magnetic fields



a solenoid



chime door bell

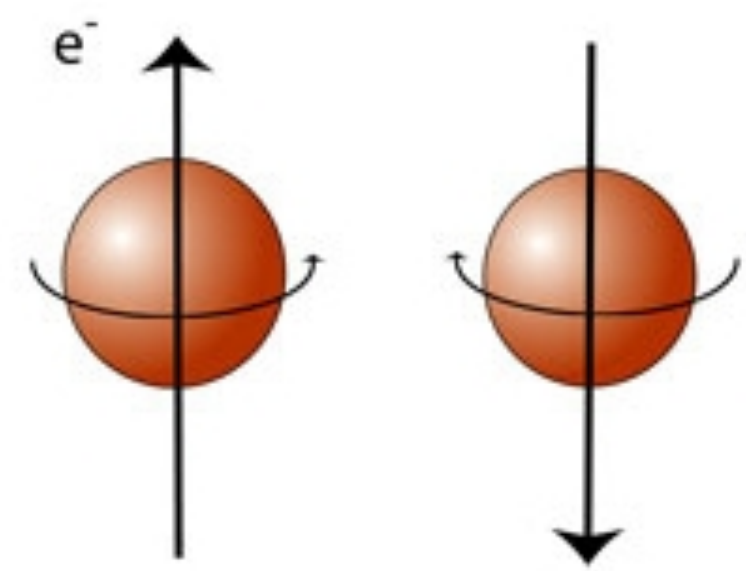
Electrical currents can be used to create magnetic fields

B field strength is proportional to the current in the wires.

The strength of the B field is limited by the maximum current: iR loss limits amount of current in wires.

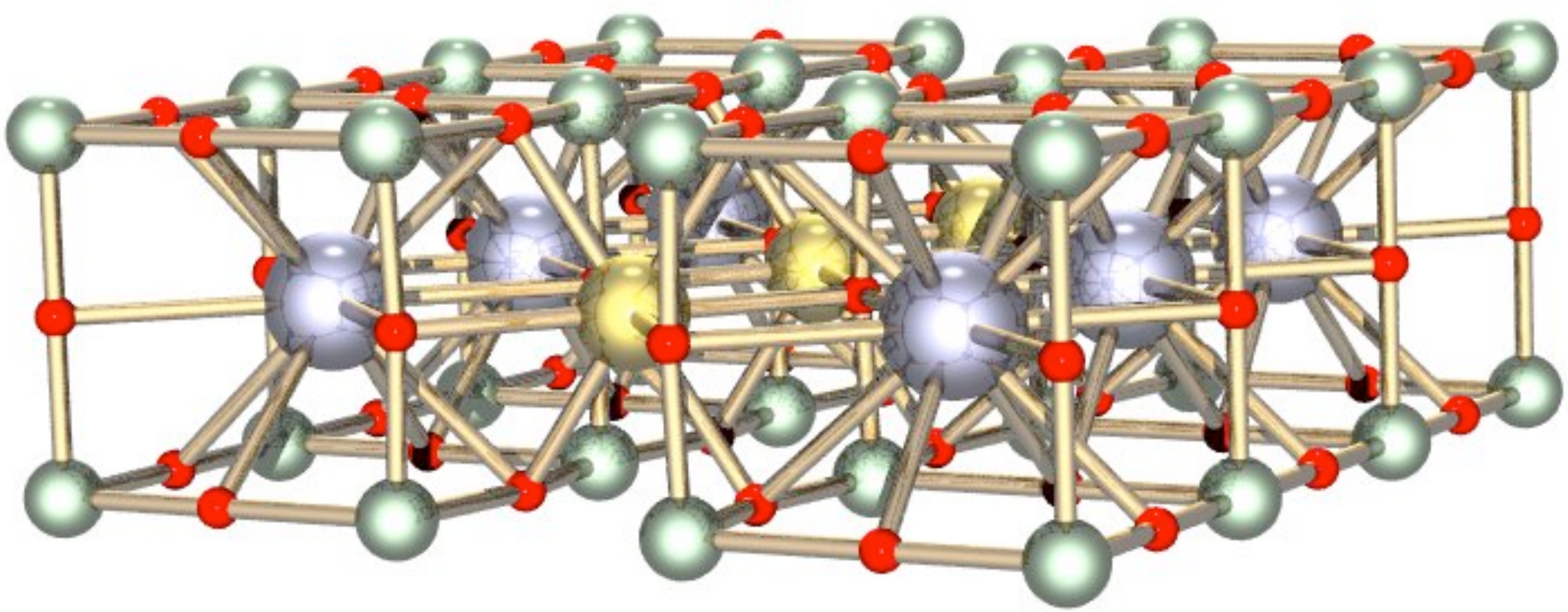
What if R = 0? Superconductivity!

Pb is a superconductor at 7K. R=0.
Electrons move as "Cooper Pairs".



High Temperature Superconductors (HTS)

"High" means 50K. Examples of high-T_c cuprate superconductors include $La_{1.85}Ba_{0.15}CuO_4$, and $YBa_2Cu_3O_7$ (Yttrium-Barium-Copper-Oxide or YBCO), which is famous as the first material to achieve superconductivity above the boiling point of liquid nitrogen (92K). And $Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO) which is superconductive at110K.



$YBa_2Cu_3O_7$ (Yttrium-Barium-Copper-Oxide or YBCO)

High Temperature Superconductors (HTS)

Karl Müller and Johannes Bednorz received the 1987 Nobel Prize in Physics for HTS Superconductors, BUT:

"The question of how superconductivity arises in high-temperature superconductors is one of the major unsolved problems of theoretical condensed matter physics (as of 2011). The mechanism that causes the electrons in these crystals to form pairs is not known."

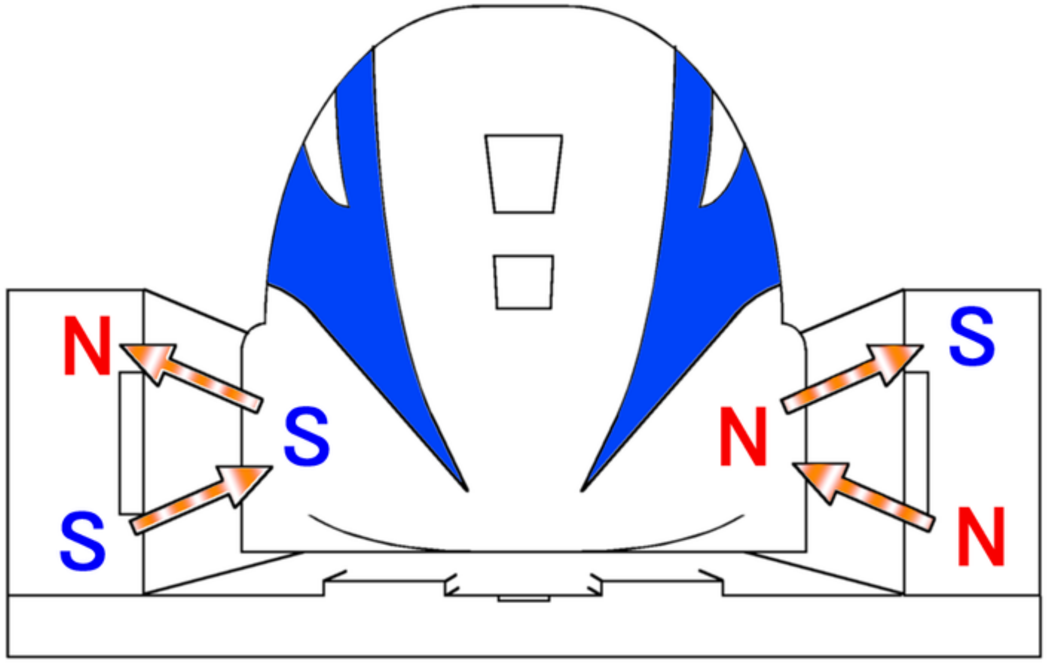
Superconductivity Application: MagLev Trains

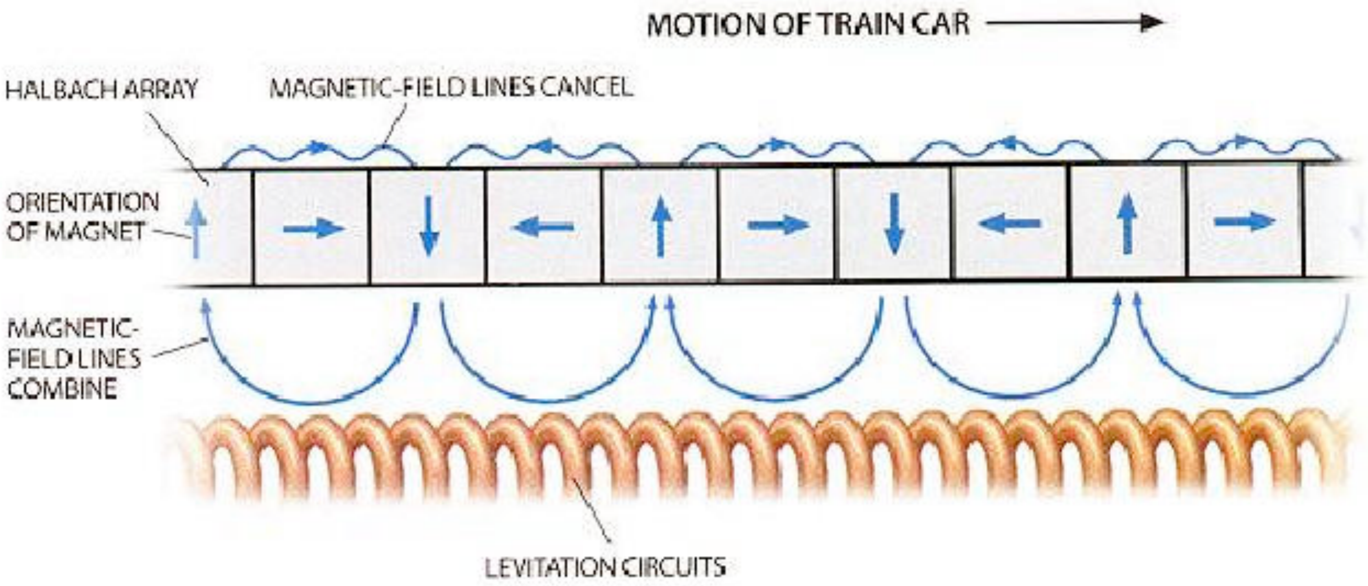
Shanghai Transrapid MagLev Train: 431 km/h (268 mph)
(Transrapid is a German Company)

Superconductivity Application: MagLev Trains

JR MagLev Train: 581 km/h (368 mph)

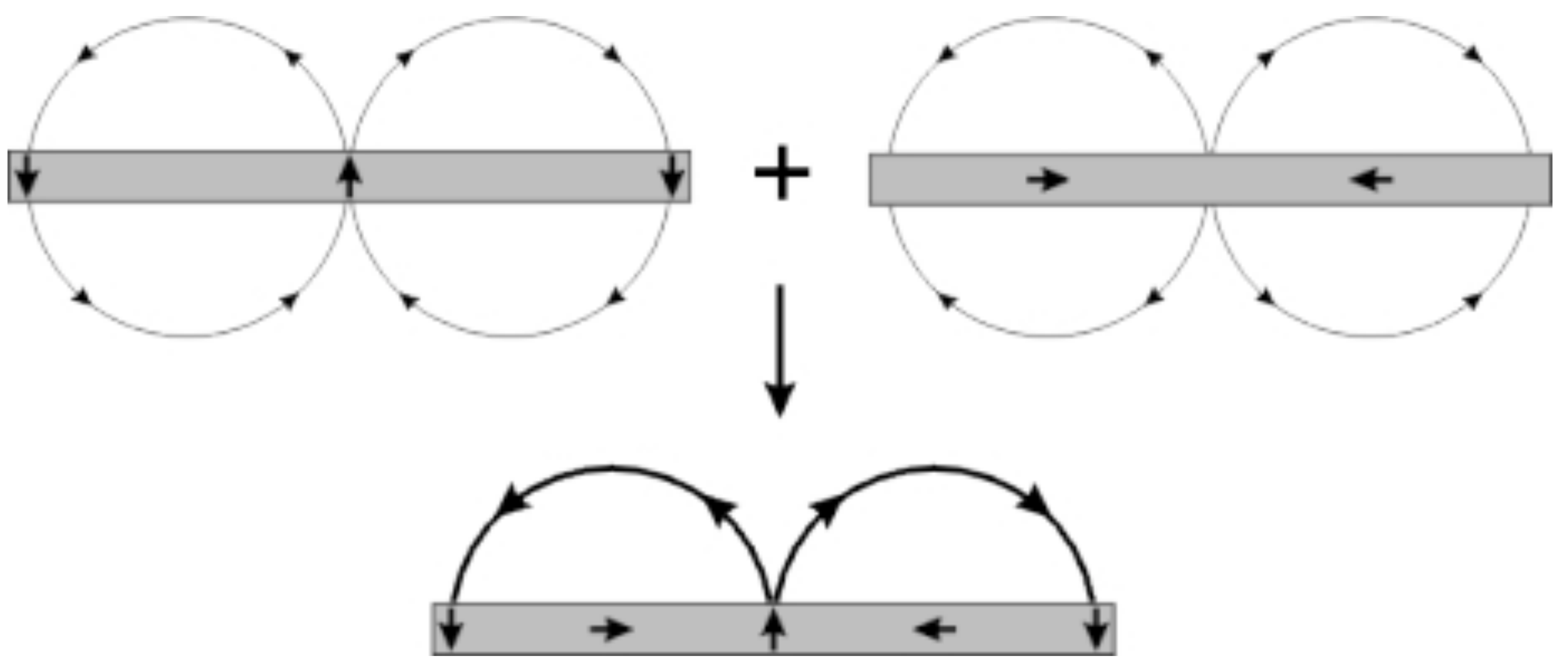
Halbach Arrays

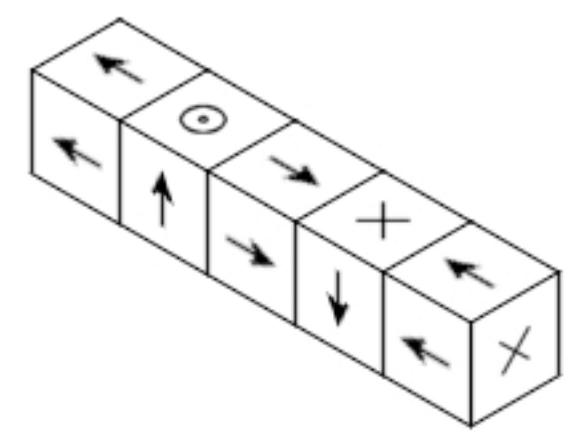




Halbach Arrays

A Halbach array is a special arrangement of permanent magnets that augments the magnetic field on one side of the array while cancelling the field to near zero on the other side.





In the diagram, the magnetic field is enhanced on the top side and cancelled on the bottom side (a one-sided flux).

Halbach arrays are used on MagLev Trains

From the website of Applied Levitation (Santa Barbara):

Stabilized Permanent Magnet (SPM) Suspension Technology

- **High-strength neodymium-iron-boron permanent magnets** arranged in opposing Halbach arrays (Figure 1) provide levitation with a gap-size of 3 - 8 cm at all speeds (no power requirement for levitation).

  The polarities of individual magnets in the array (indicated by arrows) are arranged such that the fields reinforce each other on the "active" face, producing a very strong magnetic field. On the "inactive" face, the magnetic fields essentially cancel each other, leaving almost no field at all.

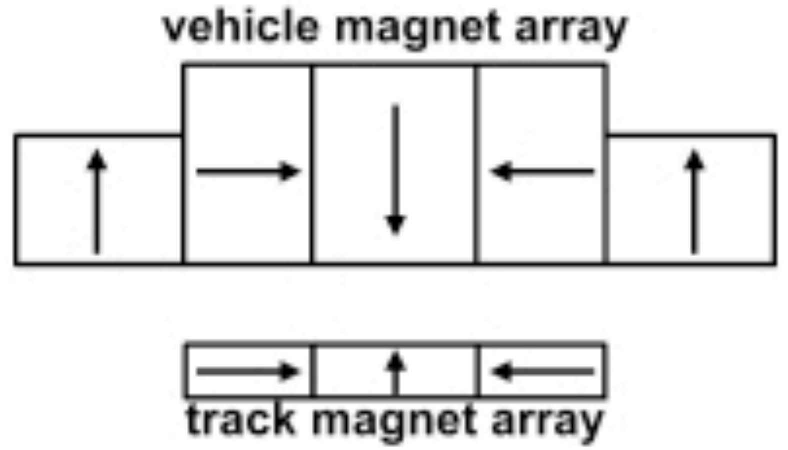


Figure 1. Levitator Configuration

Halbach Arrays

Halbach arrays are ALSO used in Refrigerator Magnets!