Magnetism

- a mysterious force of nature
and some of its consequences

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Magnets in Nature

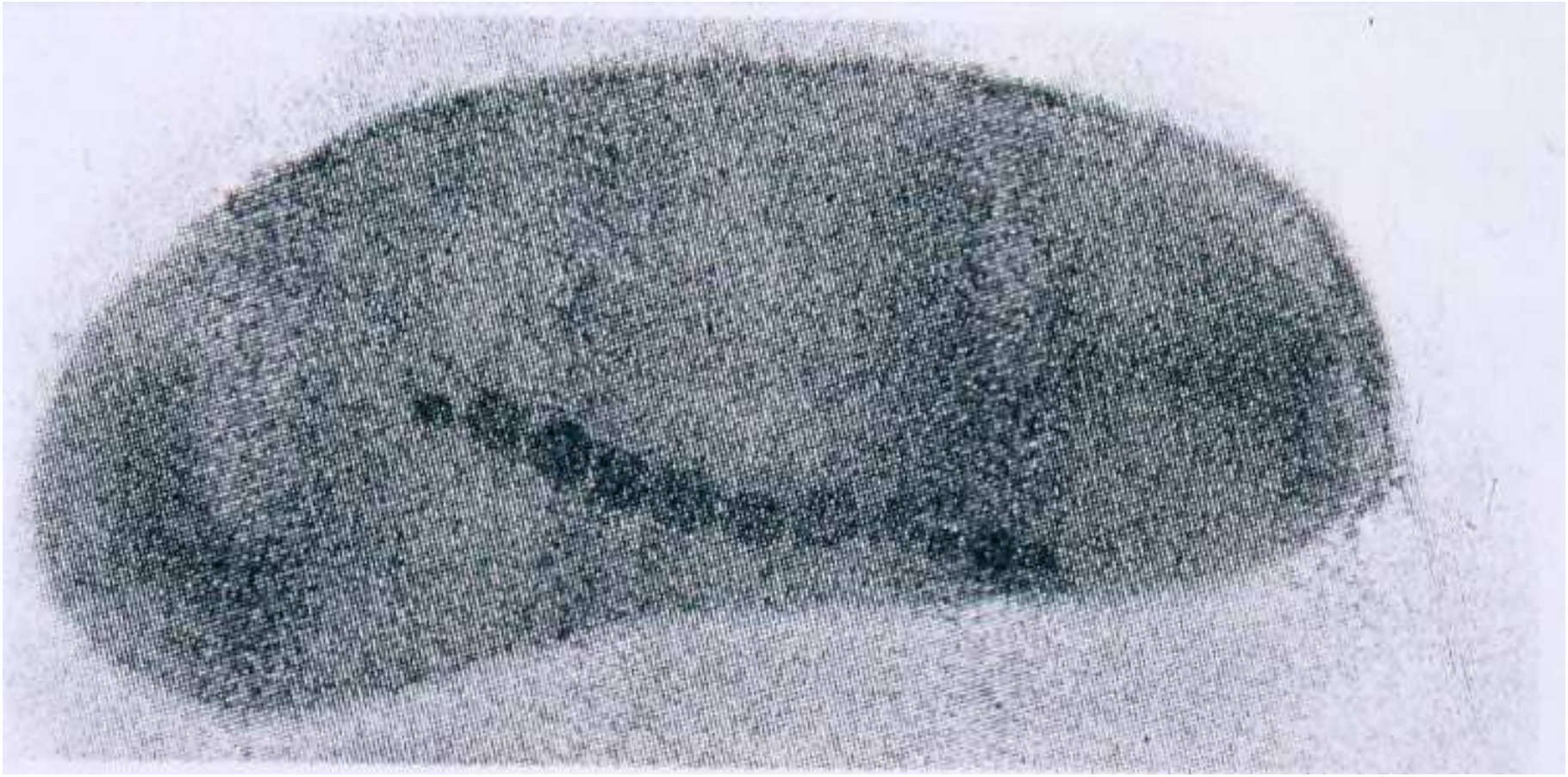
A magnetic rock – lodestone (Fe_3O_4)

The name ‘magnet’ comes from Magnesia in Greece, where lodestone is found

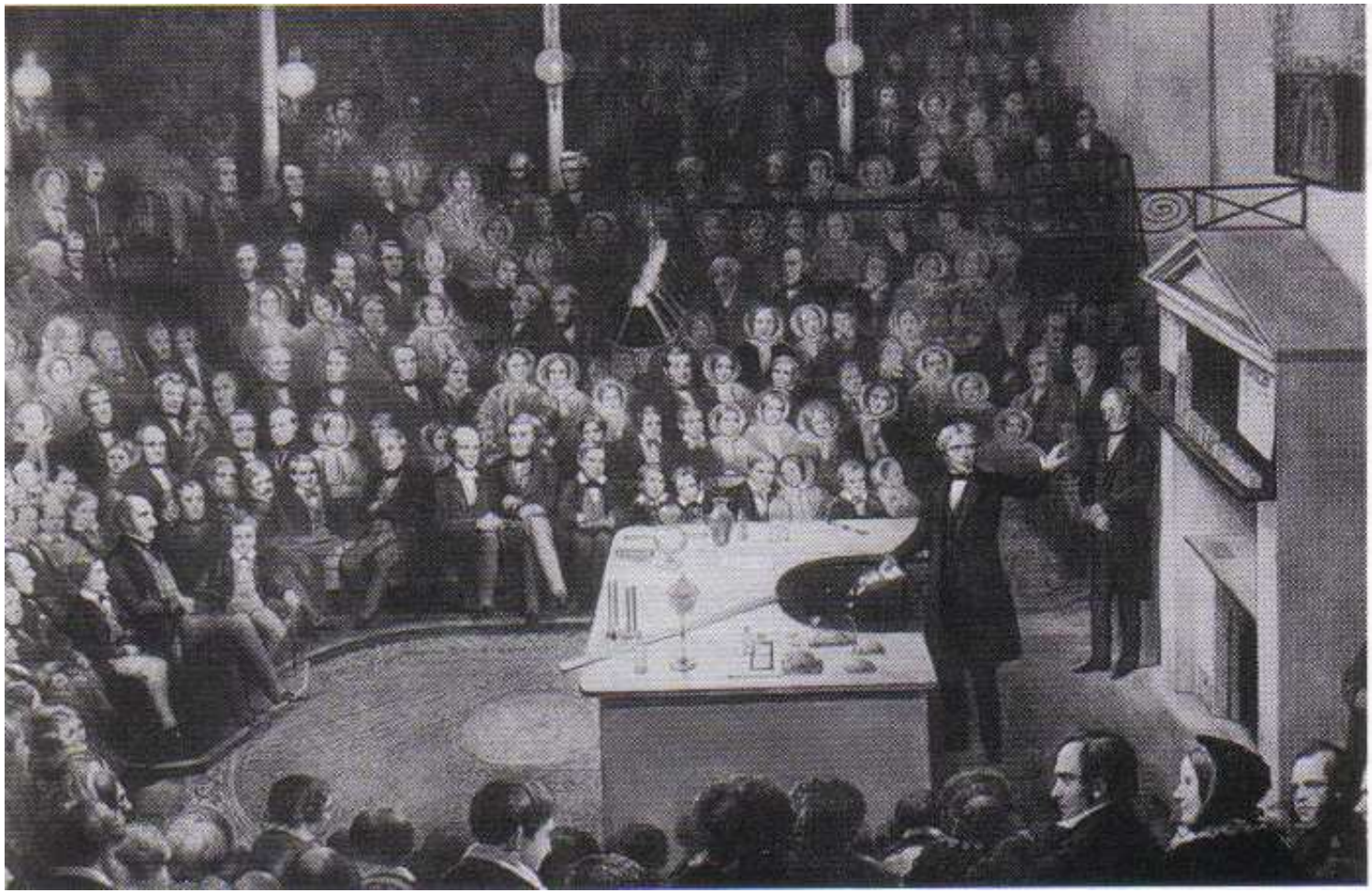
Picture from Wikipedia

Magnets in Nature

Magnetite particles in bacteria



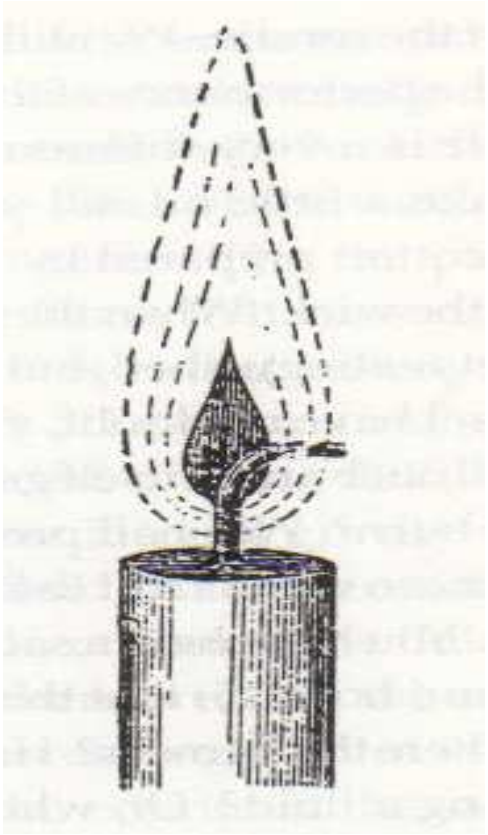
In 1851 Michael Faraday gave the Christmas Lectures for young people at the Royal Institution



He wanted to illustrate chemistry and physics with an everyday (1851) object

What did he choose?

A candle!

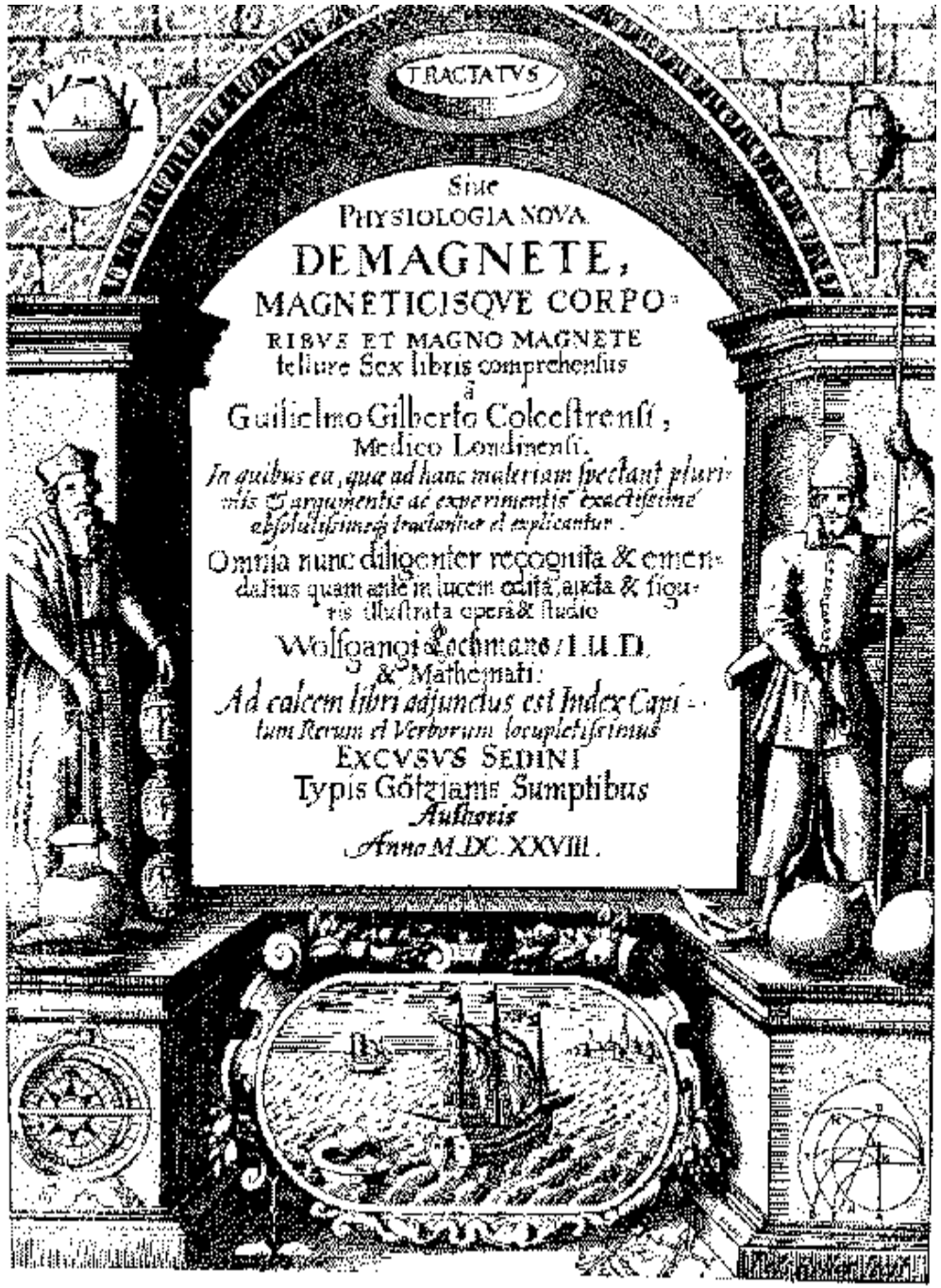


The Christmas Lectures today

What everyday object would Faraday use now?

An iPod??

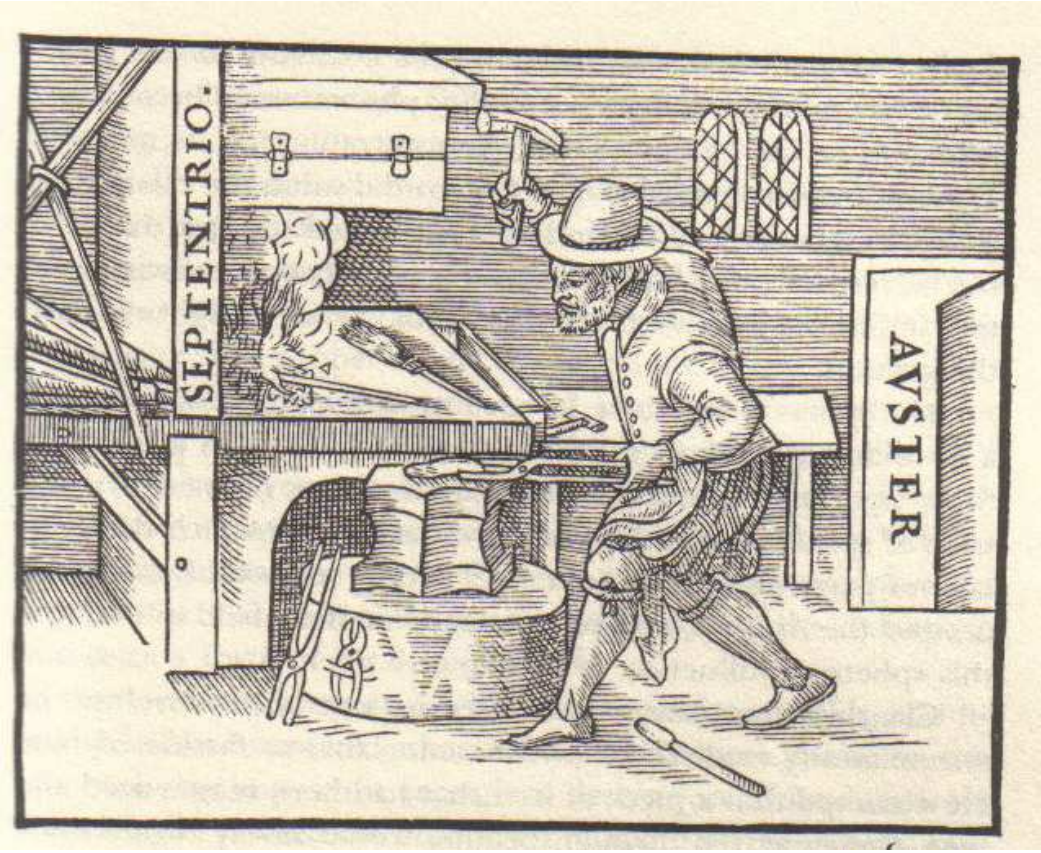
And how does it work? **MAGNETISM!**



The first serious experimental work on magnetism: William Gilbert, 1628

Beating wrought iron induces magnetism

Magnetic domains align in the earth's field when the material is malleable



From Gilbert, de Magnete

Some other insights from Gilbert

Lodestone loses its magnetism on heating:
"fire destroys the magnetic virtues in a stone, not because it takes away any parts specially attractive, but because the consuming force of the flame mars by the demolition of the material the form of the whole"

Only a few solids are magnetic "why has nature been so stingy as to provide only a small number…"

A piece of wrought iron has a North and South pole and, if cut in half, each of the fragments has, too

Atomic magnets- how they line up

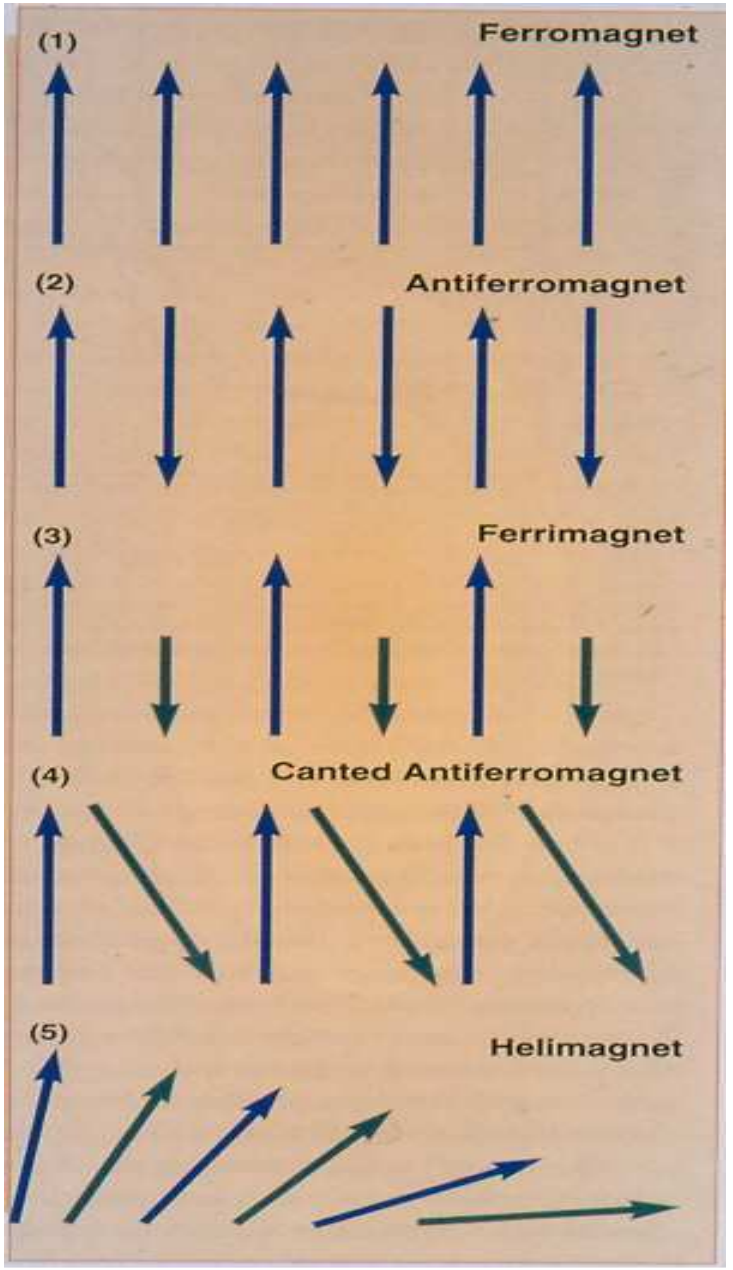
Ferromagnet

Antiferromagnet

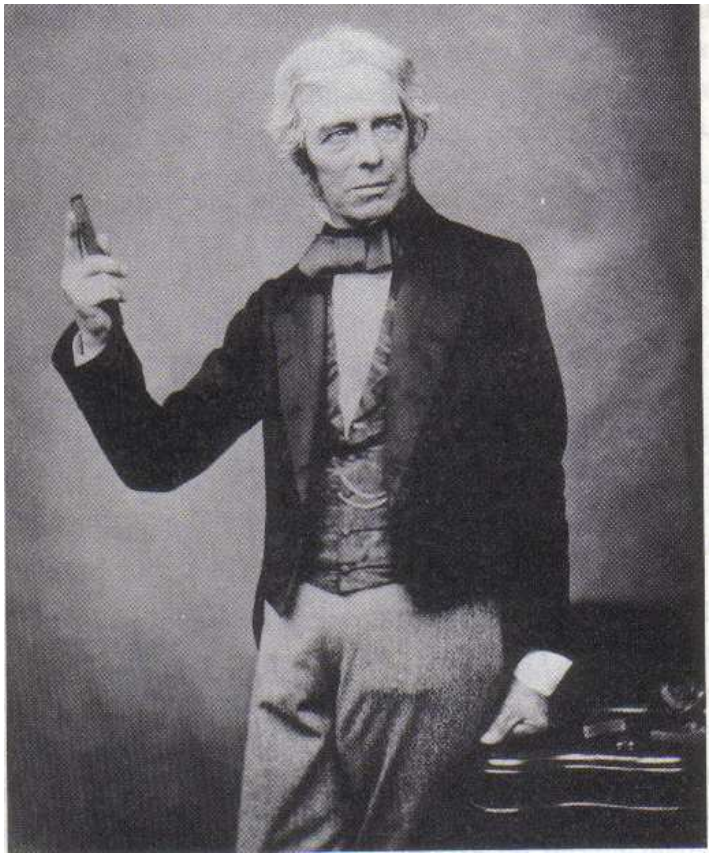
Ferrimagnet

Canted antiferromagnet

Helimagnet



Further insights came from this man
Michael Faraday



1791- 1867

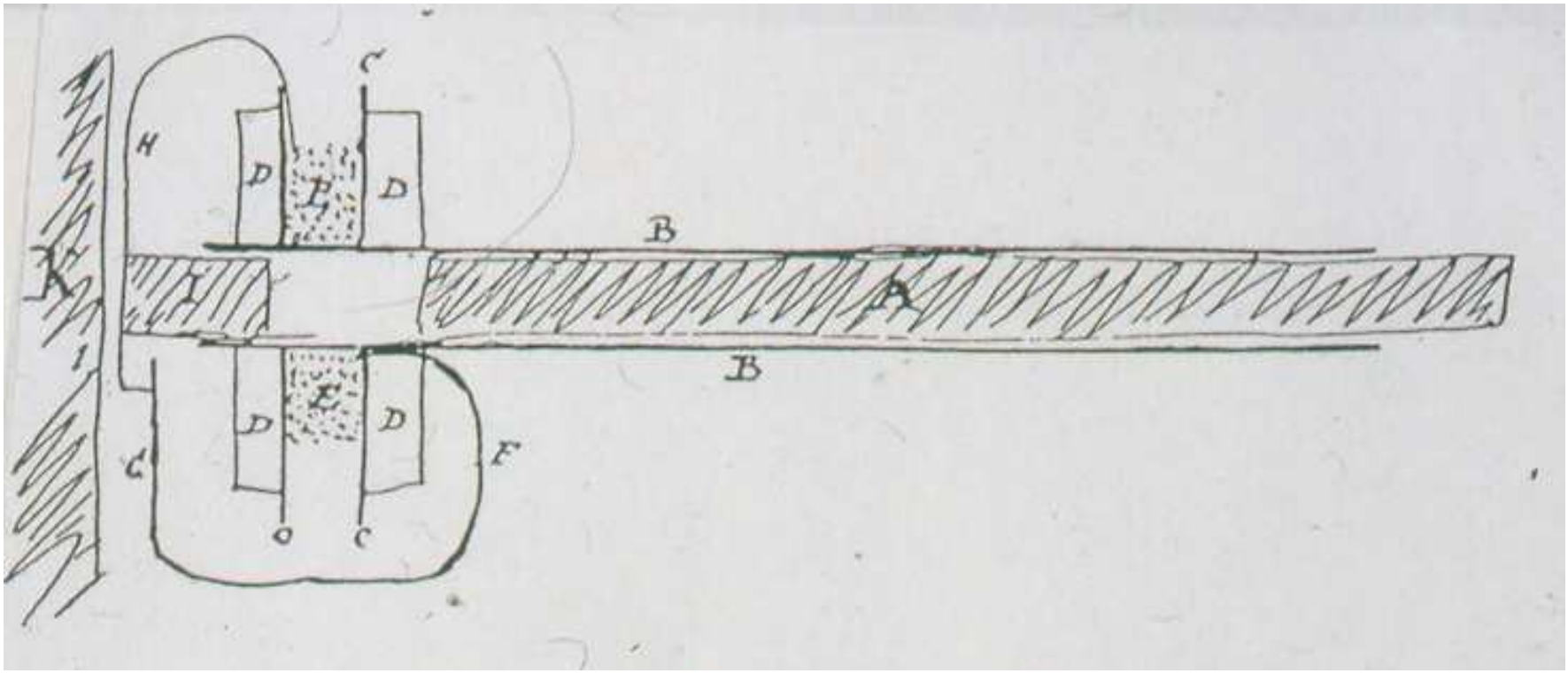
Magnetism and electricity
- electromagnetic induction
  electric motors and generators

Lines of magnetic flux
- concept of 'fields' (Maxwell)

Paramagnetism and diamagnetism
- universal property of matter

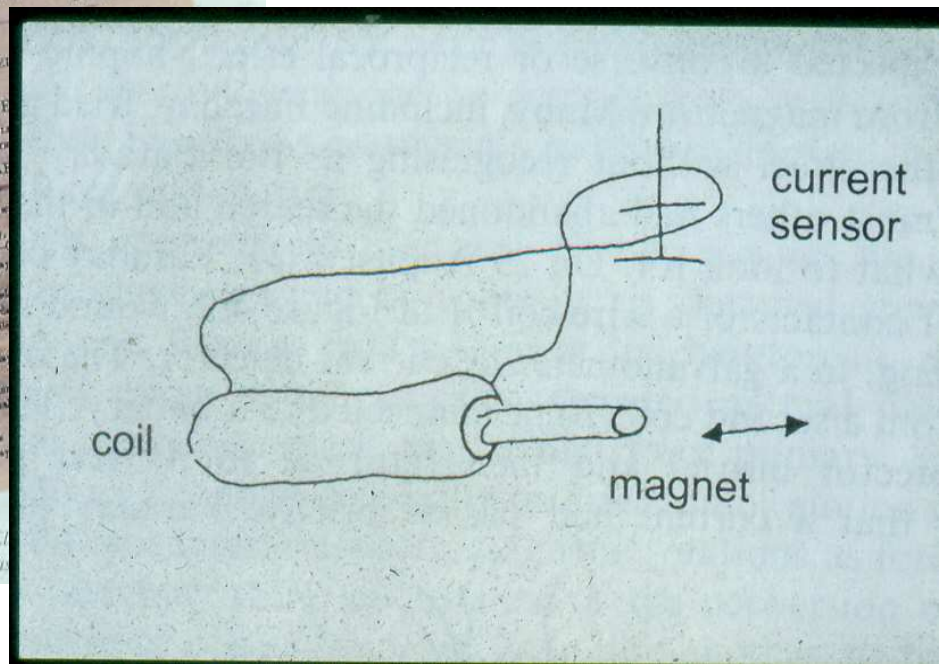
Magnetism and light
- light as electromagnetic radiation

Moving a magnet through a coil generates electricity



Faraday's sketch from his notebook

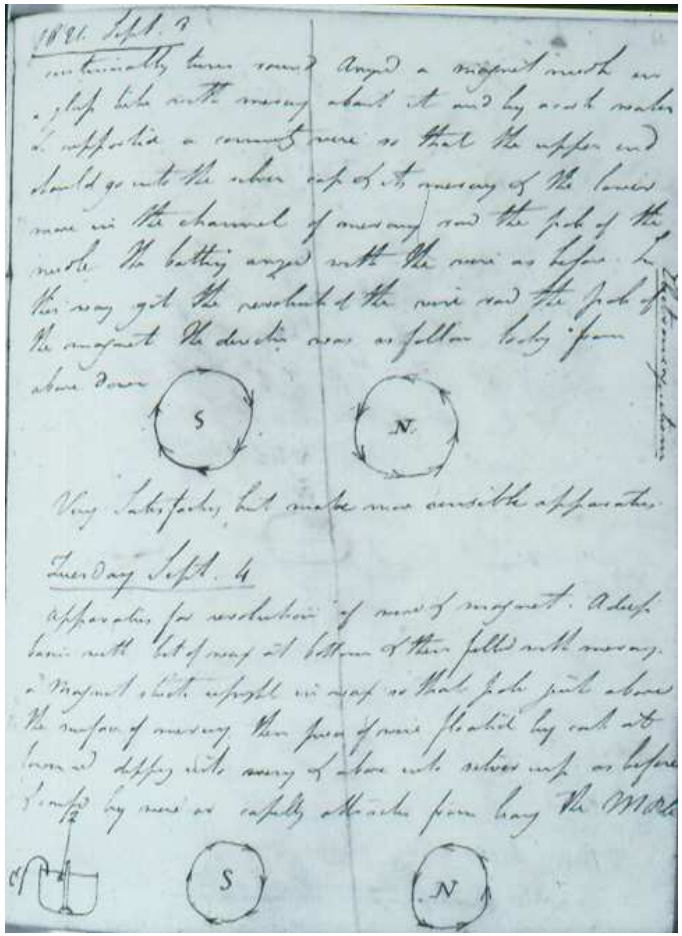
The apparatus and how it works



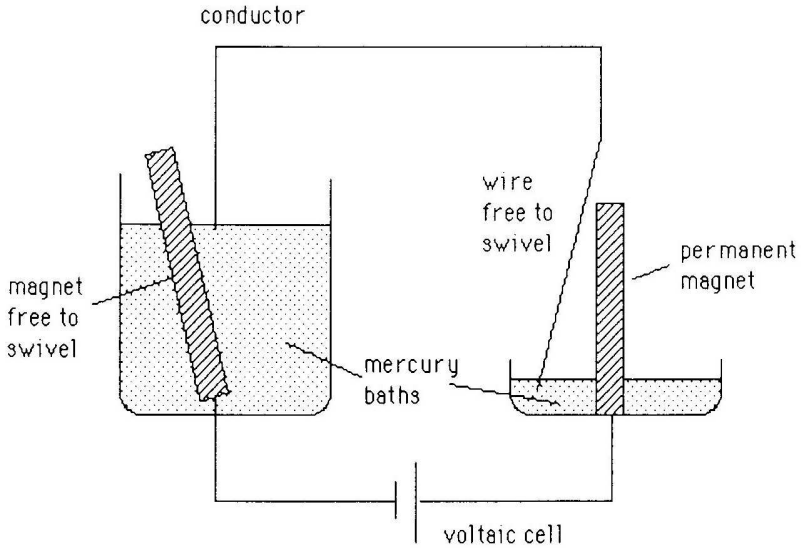
From the Faraday Museum,
Royal Institution, London

The world's first electricity generator!

Electromagnetic rotation



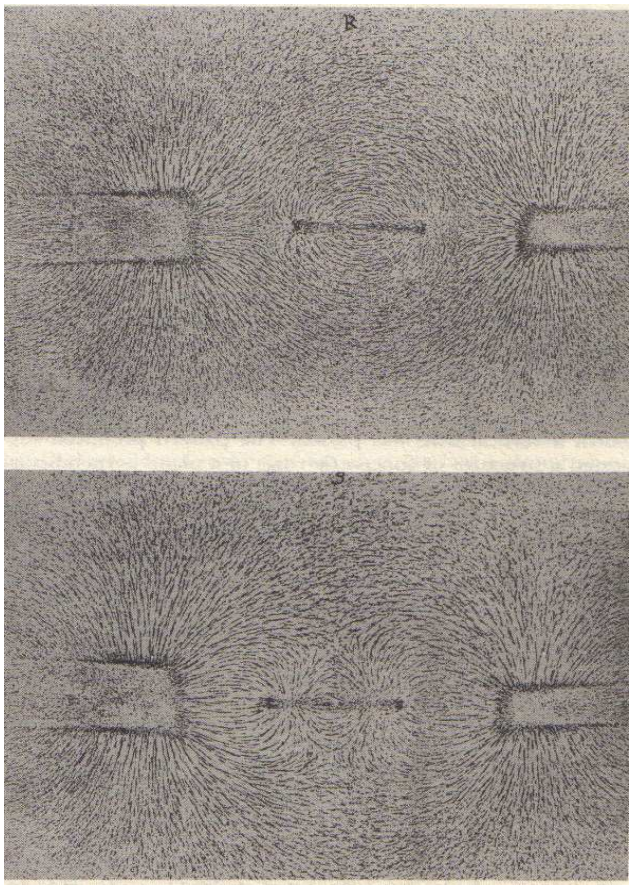
Faraday's notebook



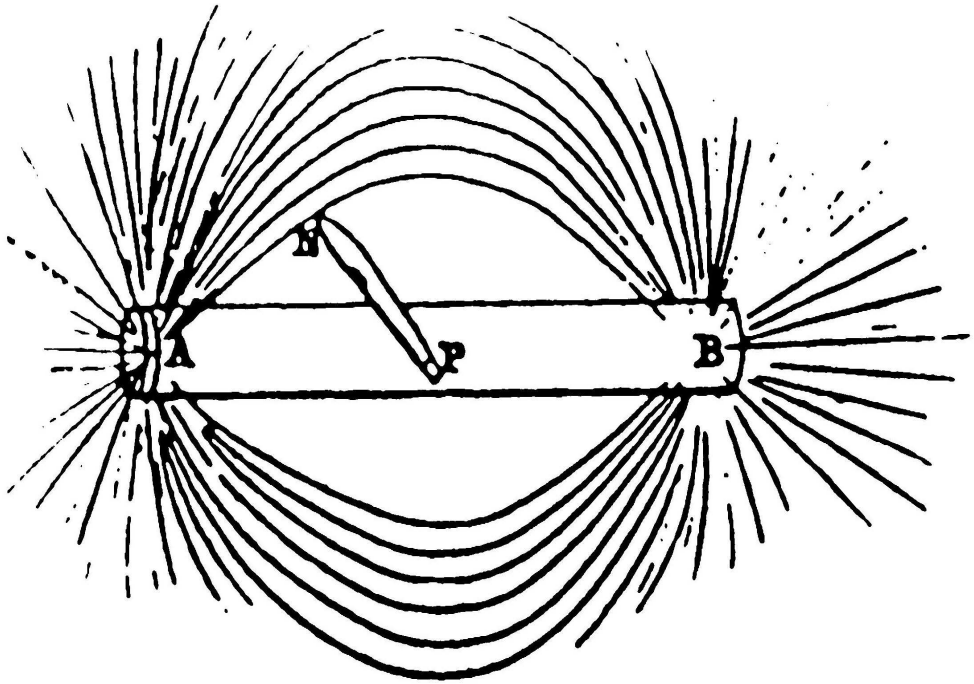
Experimental setup

The world's first electric motor!

Lines of magnetic flux

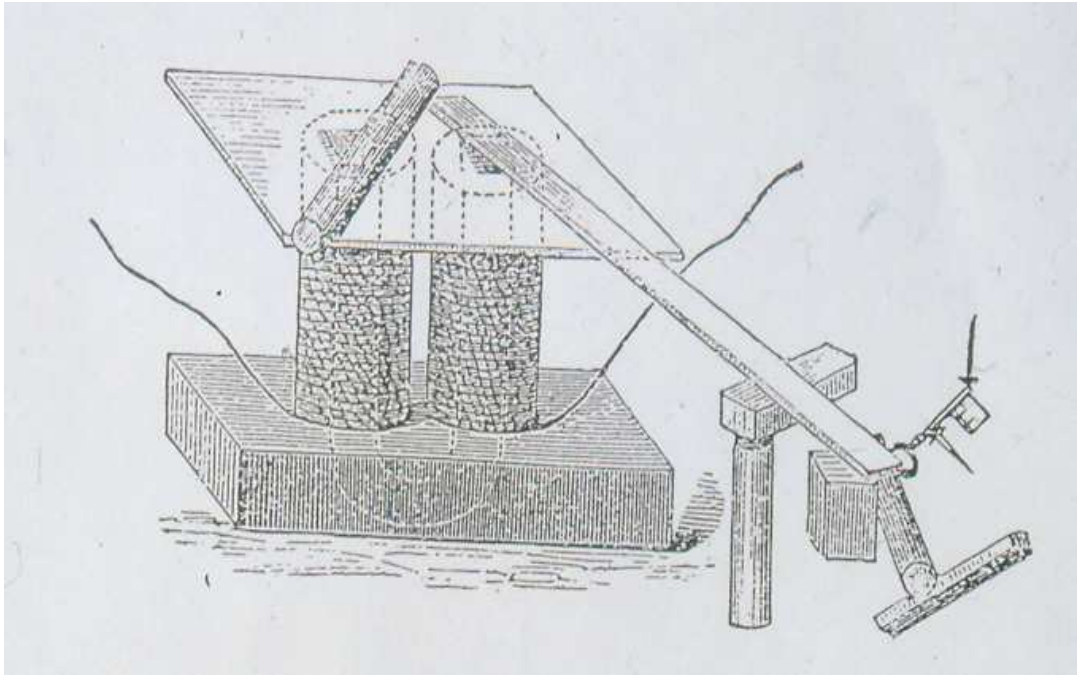


Iron filings experiment

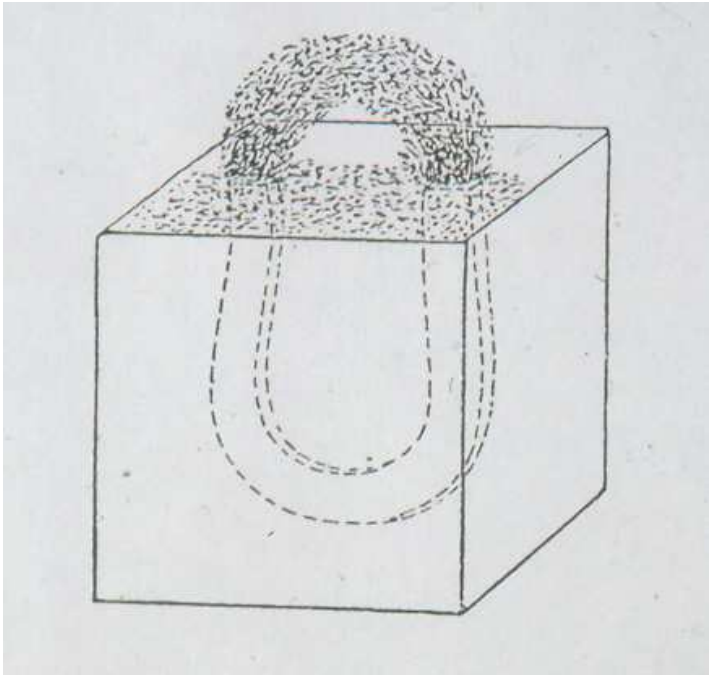


Published sketch

Two demonstration experiments



Electromagnet attracts many objects – even through glass!



Throwing iron filings at a box containing a hidden magnet

Paramagnetism and diamagnetism

Search for diamagnetism:
Faraday's 'great electromagnet'

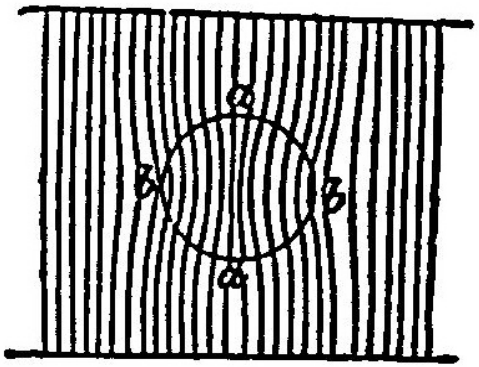


Fig. 1.

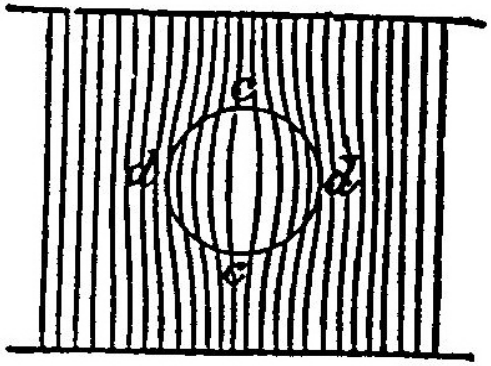


Fig. 2.

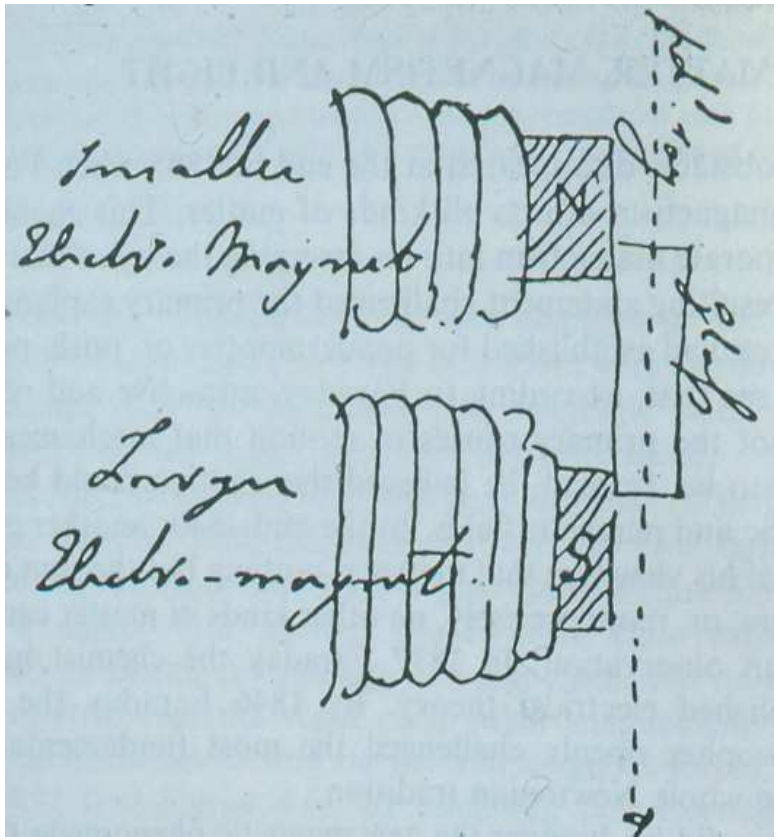
Magnetic flux lines in
para- & diamagnets

The world's biggest superconducting electromagnet

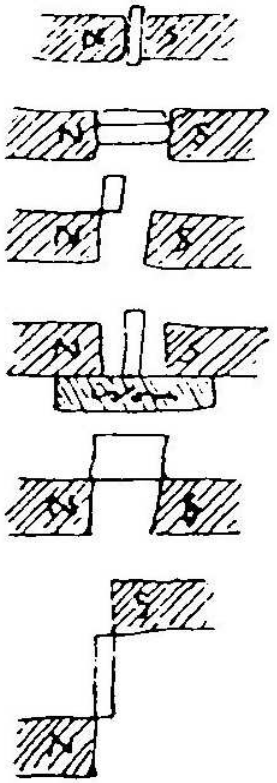
Faraday's 'Magnetic Laboratory'

Watercolour by Charlotte Moore

Magnetism and light



Faraday's notebook



Arrangements of magnet pole-pieces and glass

A modern magneto-optic light modulator based on the Faraday effect

What kind of materials behave as ferro- or ferrimagnets?

- **A few metallic elements**
  - iron, nickel
- **Intermetallic compounds**
  - $LaCo_5$
- **Ternary oxides (ferrimagnets)**
  - Magnetite (Fe_3O_4), Garnets ($Y_3Fe_5O_{12}$), Magnetoplumbites ($PbFe_{12}\ O_{19}$)

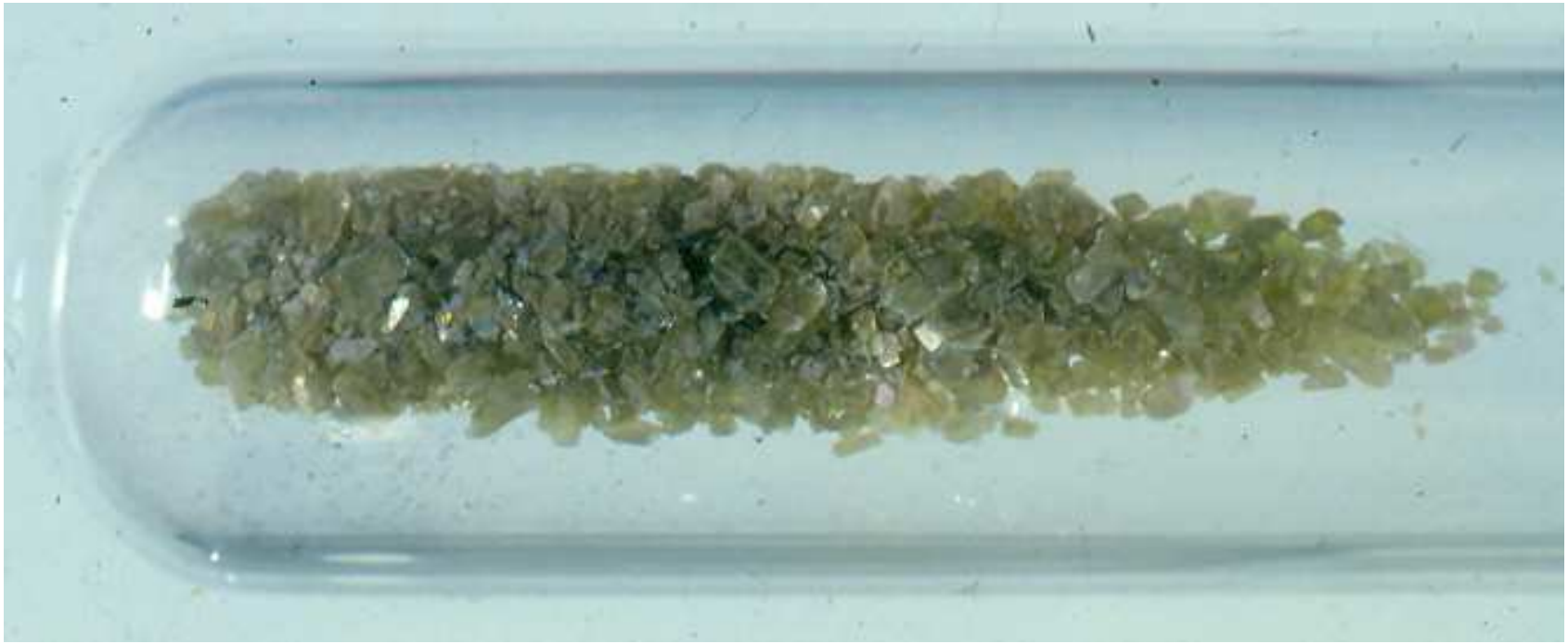
These are all opaque metals or semiconductors

Are there any magnets that are electrical insulators and hence transparent?

Very few!

In 1976 we made some – they were also soluble because they contain molecules

A_2CrCl_4: transparent ferromagnets

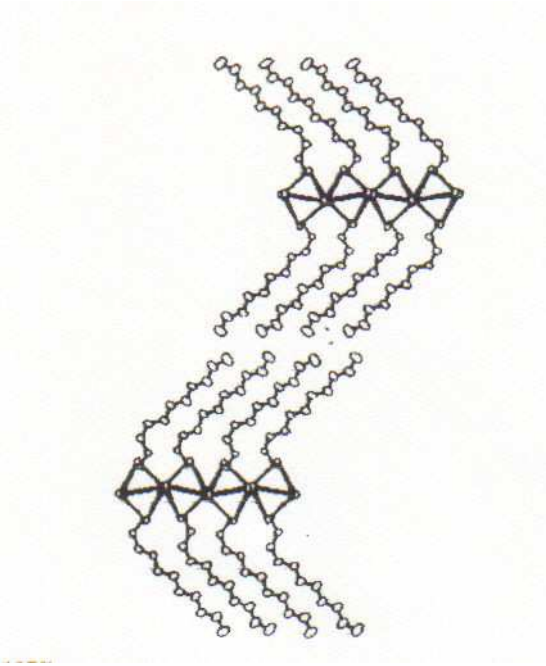


Bellitto and Day 1976

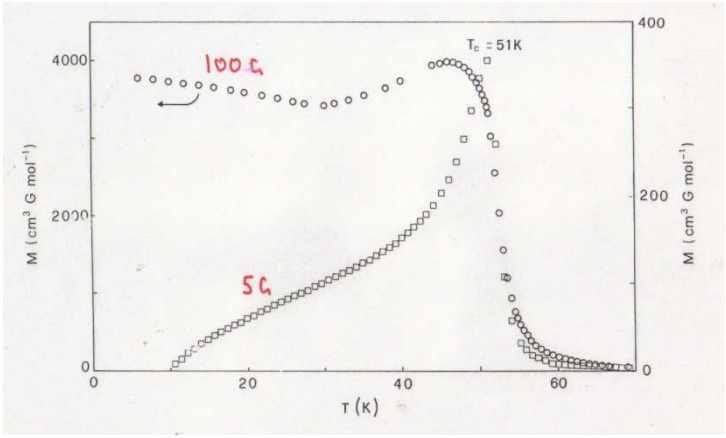
Solvent-soluble ferromagnets

$(C_nH_{2n+1}NH_3)_2CrX_4$

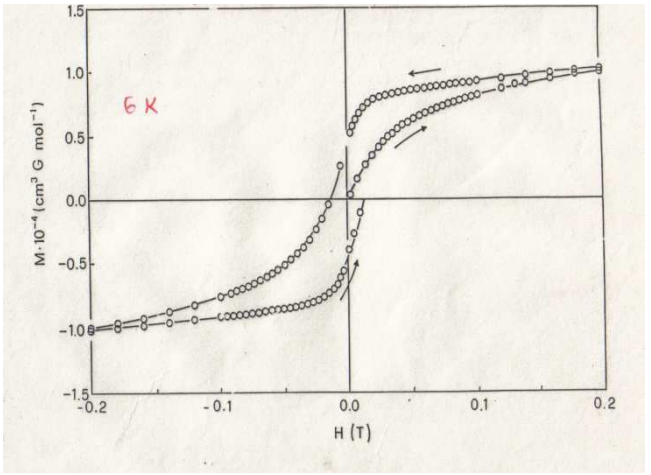
Crystal structure



Bellitto and Day 1978

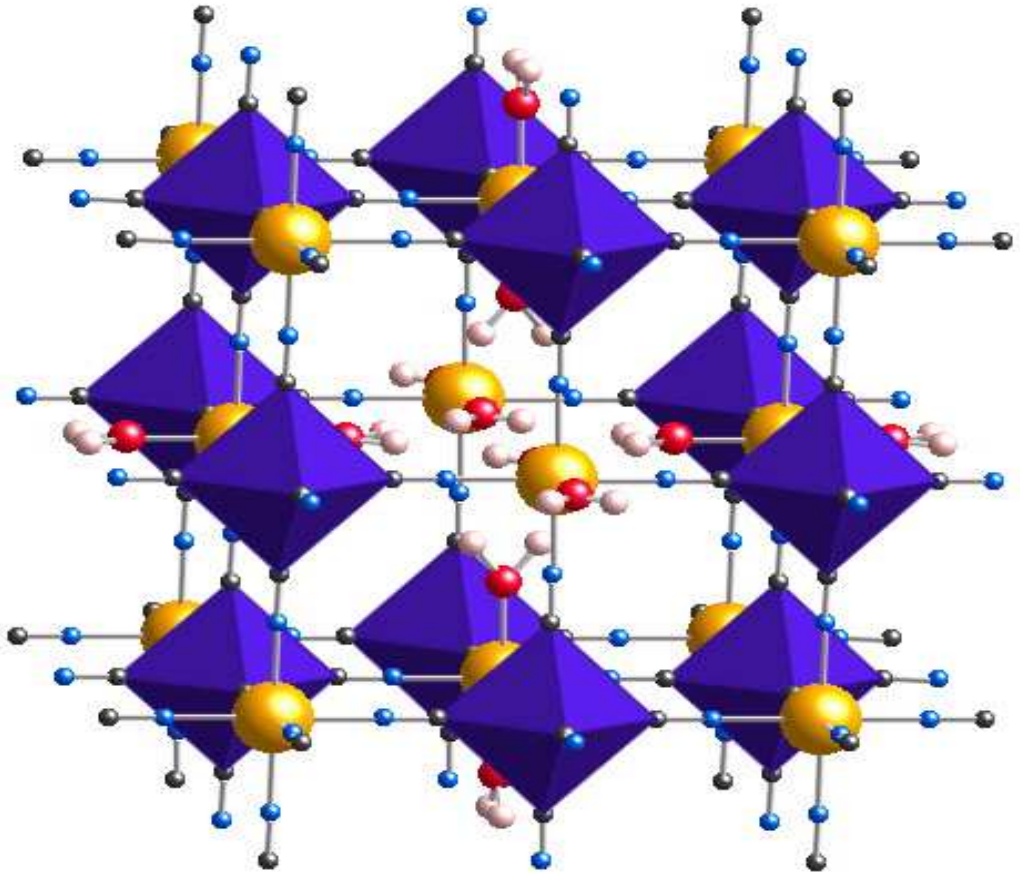


Magnetisation



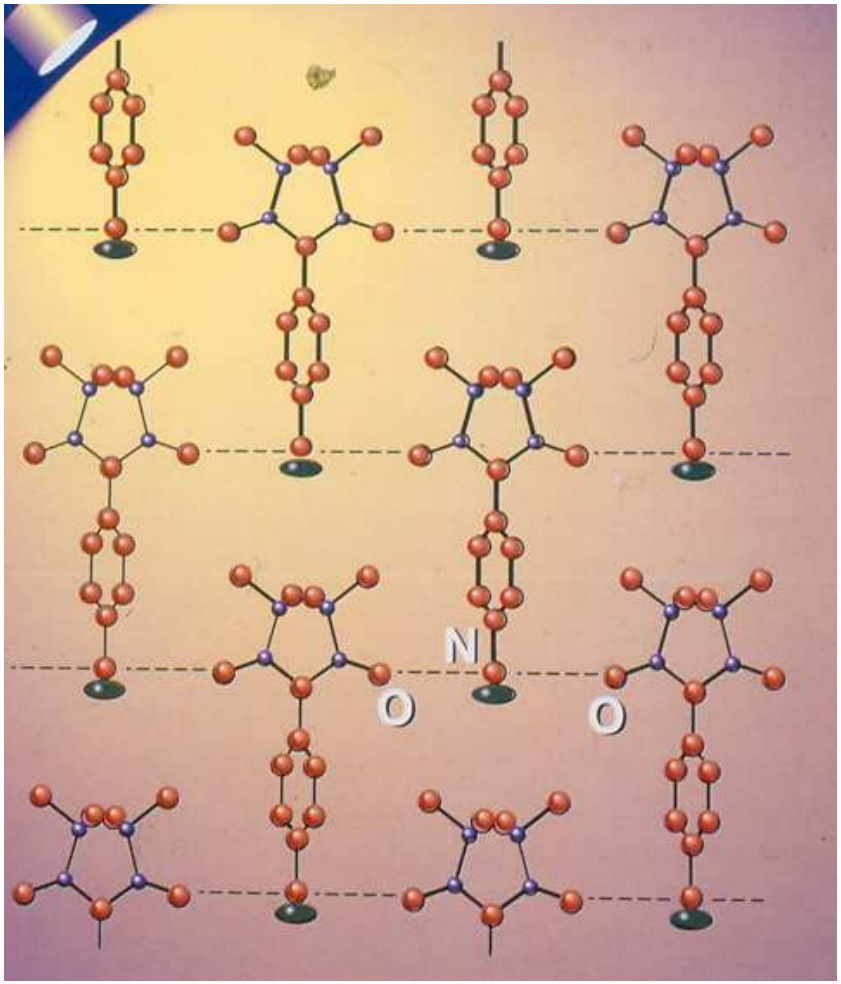
Hysteresis

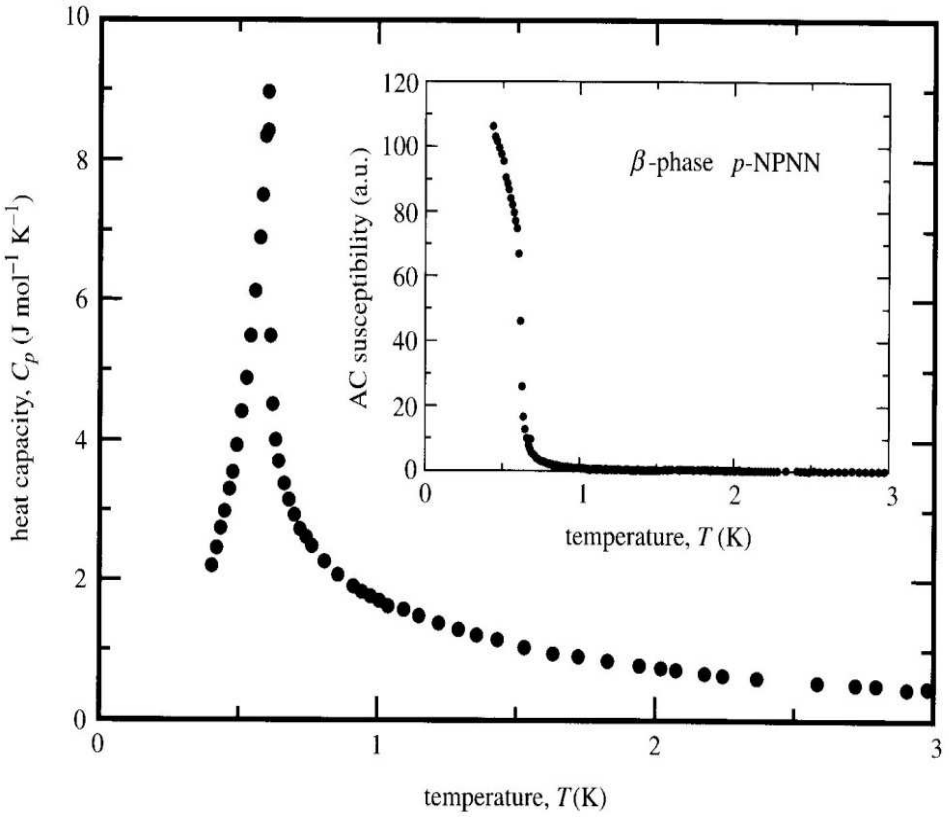
Prussian Blue (first made in 1704) was first shown to be a ferromagnet in the 1970s



Guedel et al, 1973; Mayoh and Day, 1975

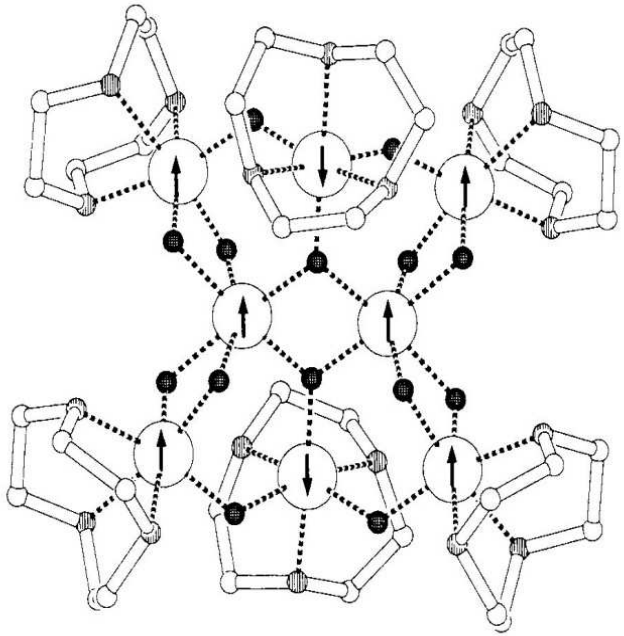
The first purely organic ferromagnet
p-nitrophenyl-nitronylnitroxide





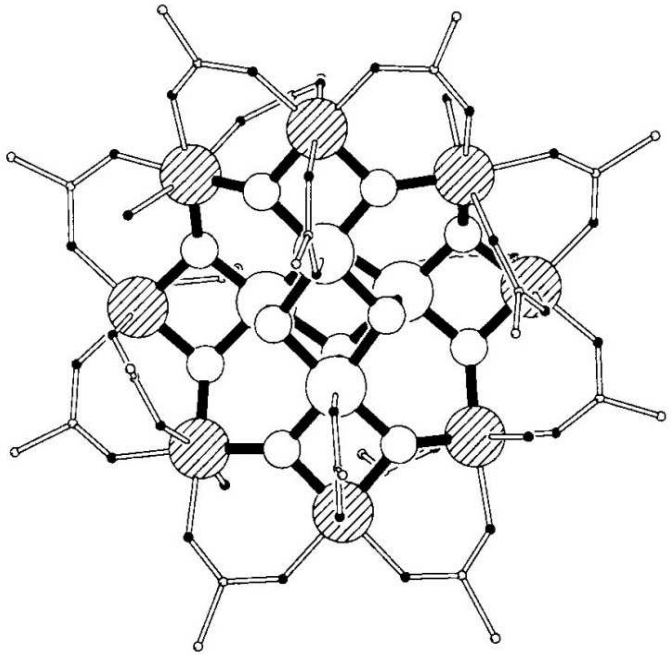
Kinoshita et al 1991

Single molecule magnets



Fe_8

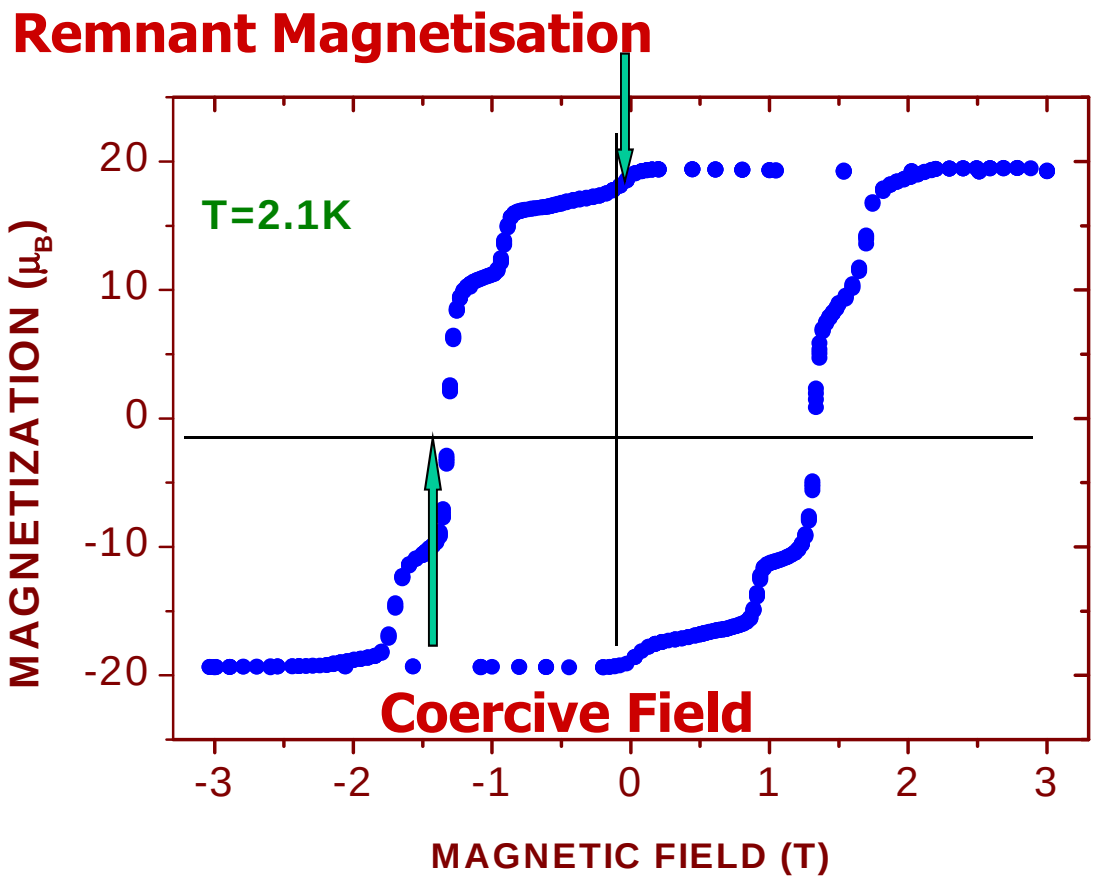
Wieghardt 1984
Gatteschi 1993



Mn_{12}

Lis 1980
Sessoli & Gatteschi 1993

Mn_{12} is a 'hard' magnet



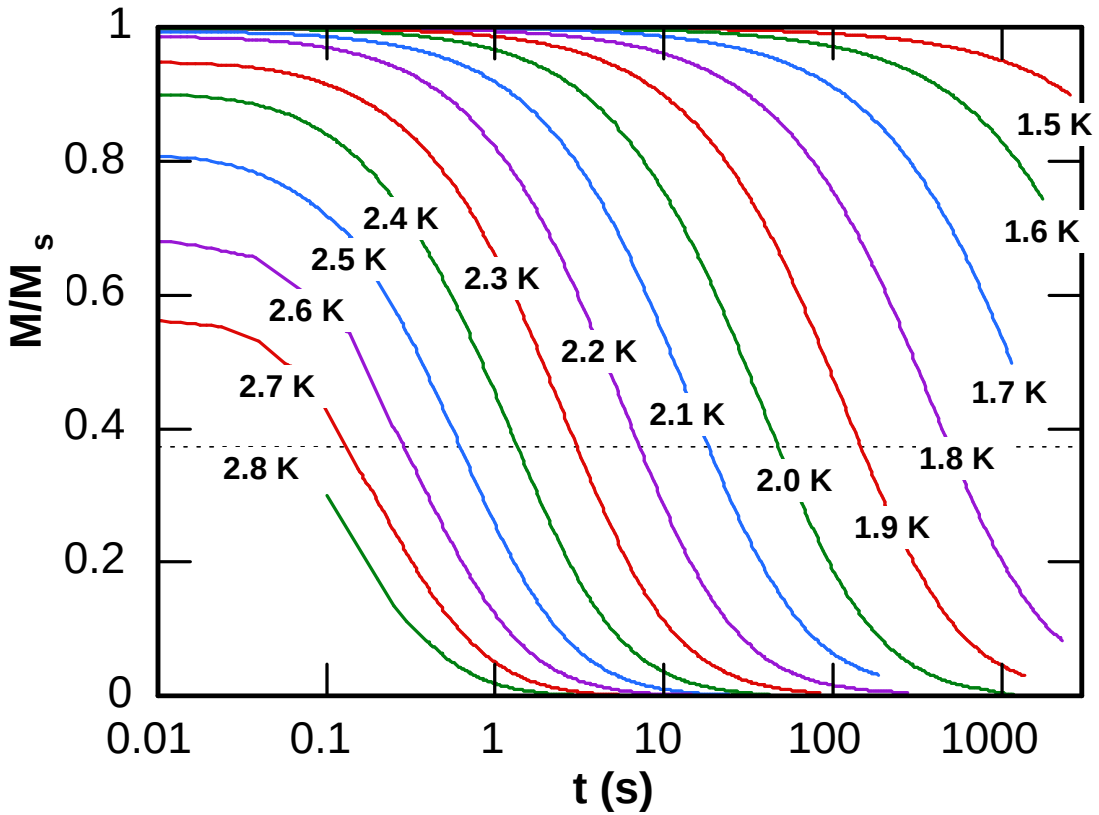
Bistability : in zero field the magnetisation can be positive or negative depending on the sample history

Sessoli & Gatteschi 1993

Mn_{12}

The magnetisation relaxes very slowly at low temperature

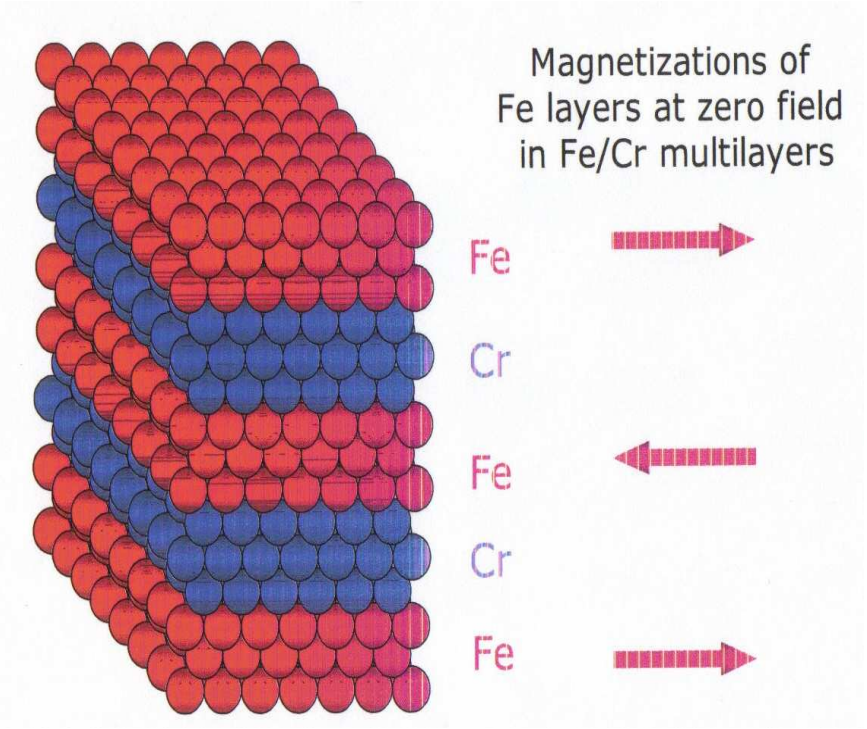
Can this molecule be used to store information??

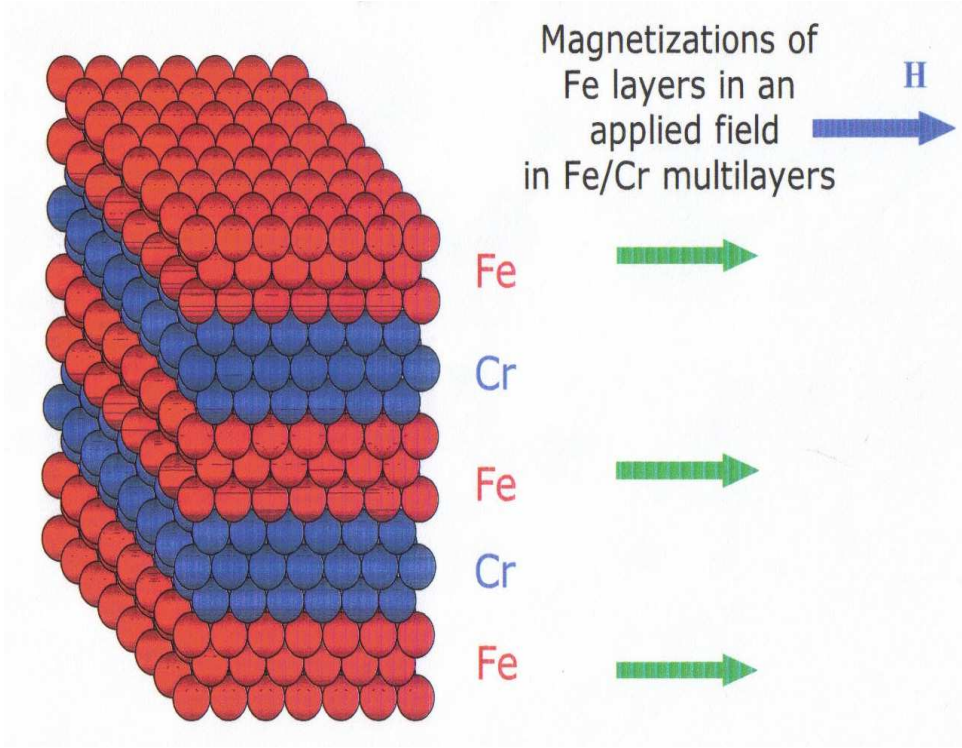


Magnetisation *vs.* time at low temperature

Wernsdorfer et al 2000

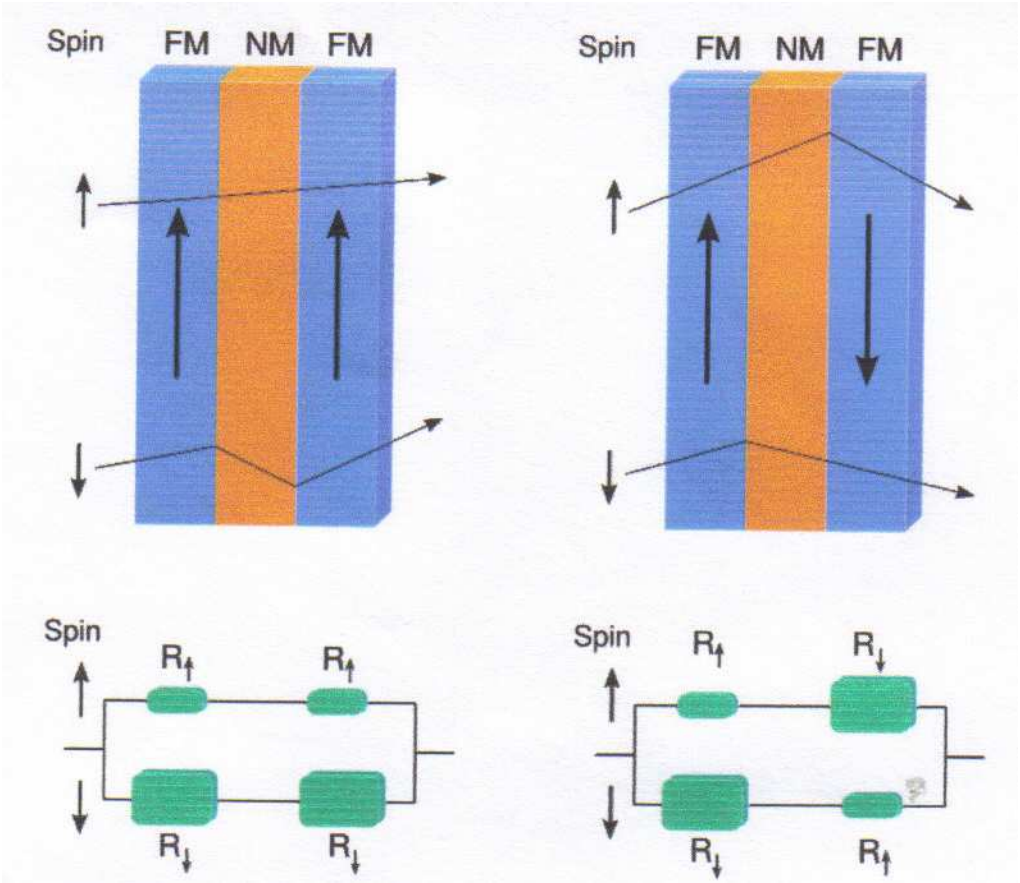
Another way to store information using magnetism





Grunberg 1986

The two magnetic arrangements have different electrical resistance



Giant magnetoresistance

And this is the basis of the iPod!

Three cheers for magnetism!