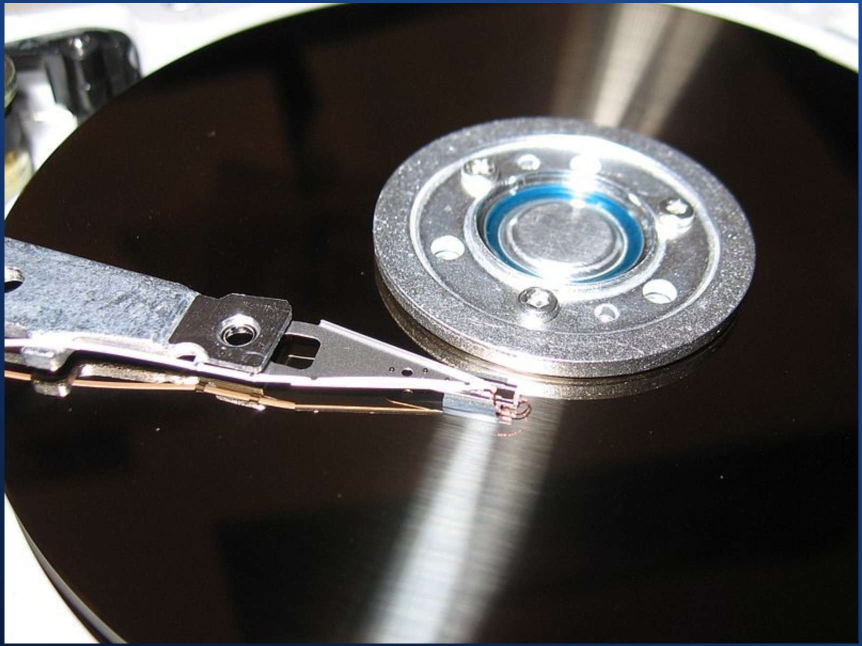
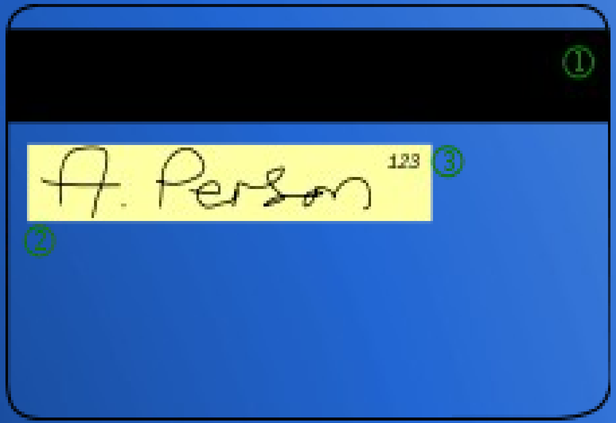
III.magnétisme et supraconductivité

AlNiCo permanent magnet

Magnetic recording devices



Hard disk

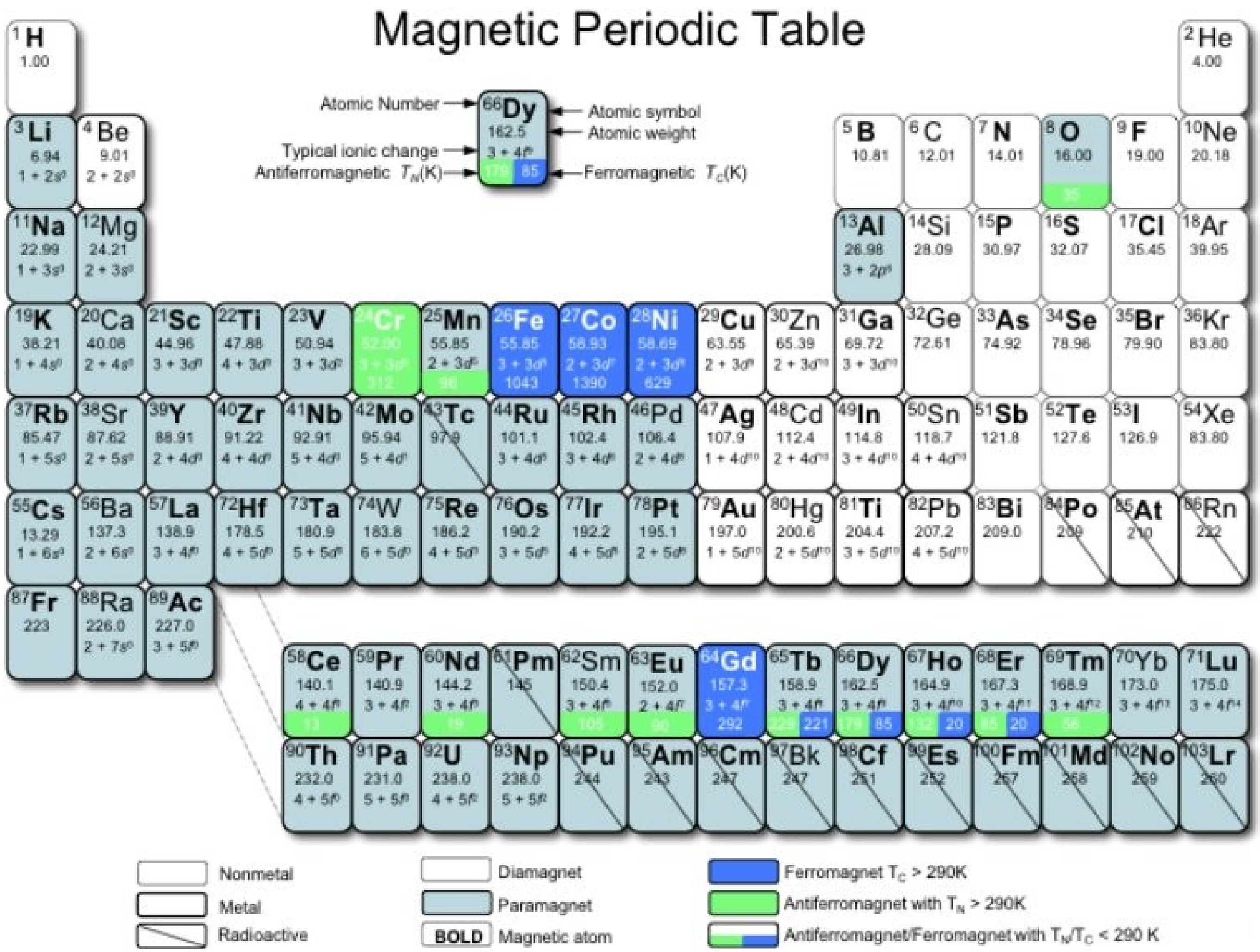


Magnetic stripe on credit card

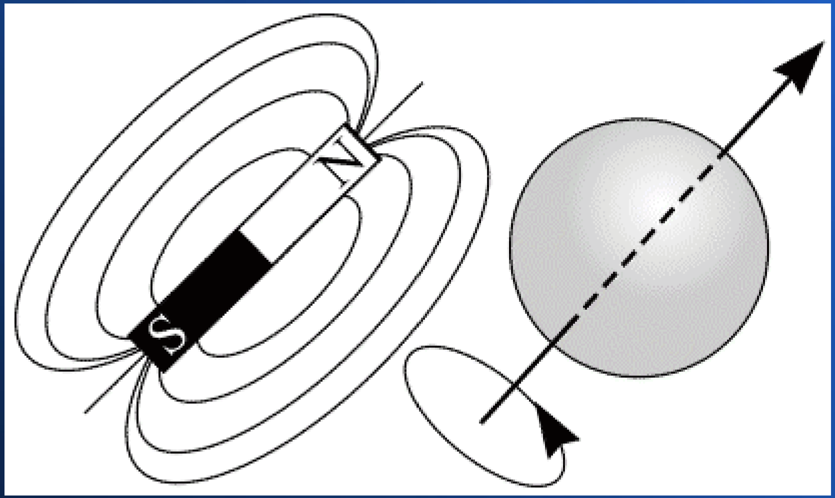
The periodic table

Atomic magnetic moment

Magnetism is a property of unfilled electronic shells :
Most atoms (bold) are concerned but only 22 magnetic in condensed matter



Magnetic moments of isolated atoms



$$\mathbf{m_J} = g m_B \mathbf{J} \ ,$$

Transition metal atoms

Element Name and Symbol	Atomic Number	Common Oxidation States	Electron Configuration	
Scandium (Sc)	21	+3	Sc: [Ar] $4s^2 3d^1$	Sc: [Ar] 4s: ↑↓ 3d: ↑ _ _ _ _
Titanium (Ti)	22	+4	Ti: [Ar] $4s^2 3d^2$	Ti: [Ar] 4s: ↑↓ 3d: ↑ ↑ _ _ _
Vanadium (V)	23	+2, +3, +4, +5	V: [Ar] $4s^2 3d^3$	V: [Ar] 4s: ↑↓ 3d: ↑ ↑ ↑ _ _
Chromium (Cr)	24	+2, +3, +6	Cr: [Ar] $4s^1 3d^5$	Cr: [Ar] 4s: ↑ 3d: ↑ ↑ ↑ ↑ ↑
Manganese (Mn)	25	+2, +3, +4, +6, +7	Mn: [Ar] $4s^2 3d^5$	Mn: [Ar] 4s: ↑↓ 3d: ↑ ↑ ↑ ↑ ↑
Iron (Fe)	26	+2, +3	Fe: [Ar] $4s^2 3d^6$	Fe: [Ar] 4s: ↑↓ 3d: ↑↓ ↑ ↑ ↑ ↑
Cobalt (Co)	27	+2, +3	Co: [Ar] $4s^2 3d^7$	Co: [Ar] 4s: ↑↓ 3d: ↑↓ ↑↓ ↑ ↑ ↑
Nickel (Ni)	28	+2	Ni: [Ar] $4s^2 3d^8$	Ni: [Ar] 4s: ↑↓ 3d: ↑↓ ↑↓ ↑↓ ↑ ↑
Copper (Cu)	29	+2	Cu: [Ar] $4s^1 3d^{10}$	Cu: [Ar] 4s: ↑ 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓
Zinc (Zn)	30	+2	Zn: [Ar] $4s^2 3d^{10}$	Zn: [Ar] 4s: ↑↓ 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓

Hund's rules (Hercules lectures/VSimonet)

Atomic magnetic moment

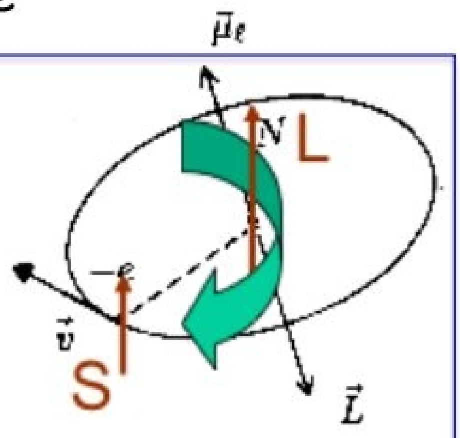
Several e- in an atom: $\hat{L} = \sum_{ne-} \hat{l} \quad \hat{S} = \sum_{ne-} \hat{s}$

Combination of the orbital and spin angular momenta of the different electrons : related to the filling of the electronic shells in order to minimize the electrostatic energy and fulfil the exclusion Pauli principle

Hund's rules

1 : $S = \sum_{ne-} m_s$ maximum

2 : $L = \sum_{ne-} m_l$ maximum in agreement with 1st rule



Spin-orbit coupling : relativistic expression of the magnetic induction effect on the spin of the e- from its orbital motion $\lambda \hat{L}.\hat{S}$ ⟹ $\hat{J} = \hat{L} + \hat{S}$

total angular momentum

3 : $J = |L - S|$ for less than ½ filled shell $\quad J = |L + S|$ for more than ½ filled shell

Hund's rules (2)

Atomic magnetic moment

A given atomic shell (multiplet) is defined by 4 quantum numbers :
L, S, J, M_J with $-J<M_J<J$

Application of Hund's rules:

Dy^{3+} : 9 electrons

m_s	1/2	1/2	1/2	1/2	1/2	1/2	1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2
m_l	3	2	1	0	-1	-2	-3	3	2	1	0	-1	-2	-3

$L = 5$, $S = 5/2$, $J = 15/2$, M_J $(-15/2 < M_J < 15/2)$

the ground state is 16-fold degenerated

Total magnetic moment

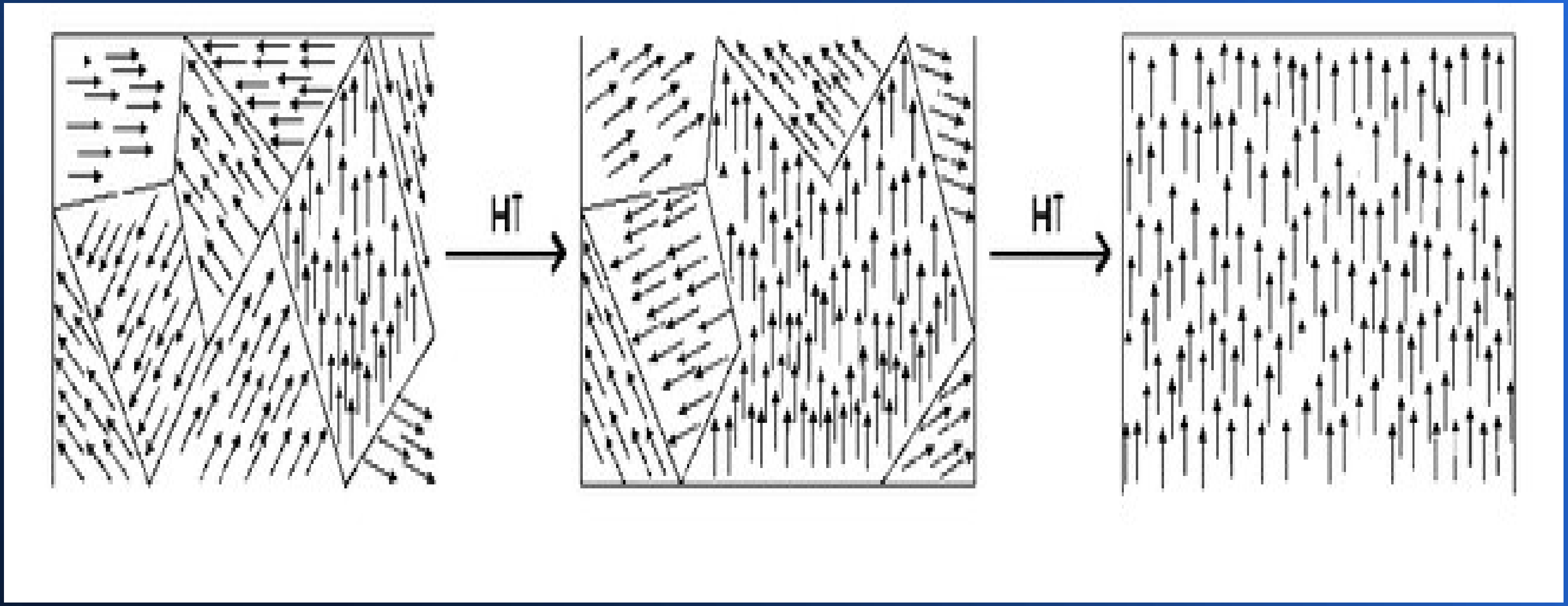
$$\hat{M} = -\mu_B(\hat{L} + 2\hat{S})$$

$$\hat{M} = -g\mu_B\hat{J}$$

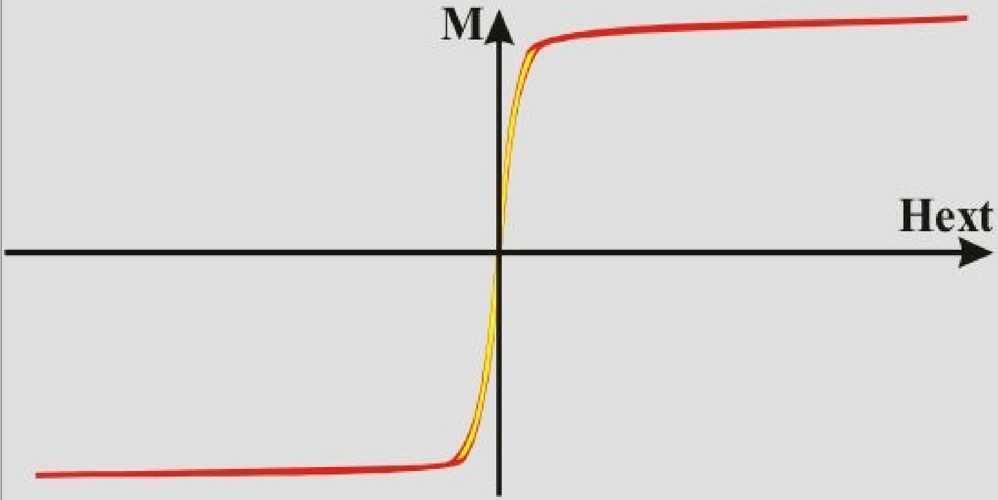
with the Lande g-factor

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$

Domains in a ferromagnet



Matériaux doux

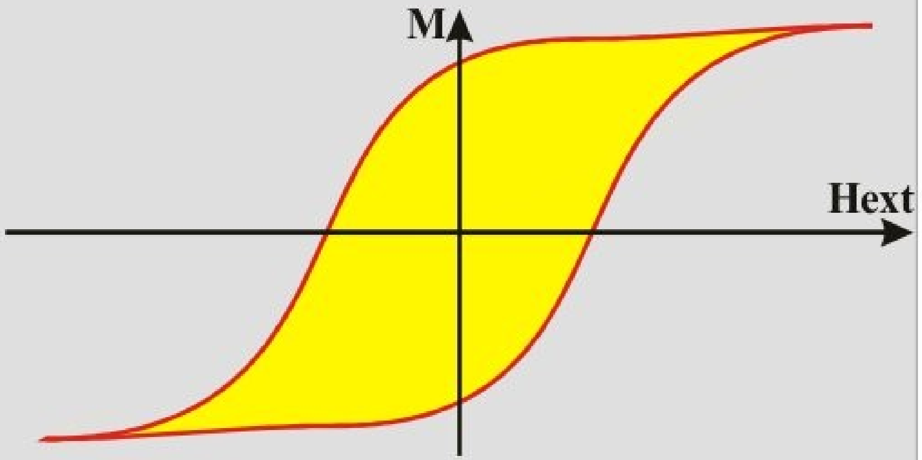


Transformateurs

Guides de flux

Blindage magnétique

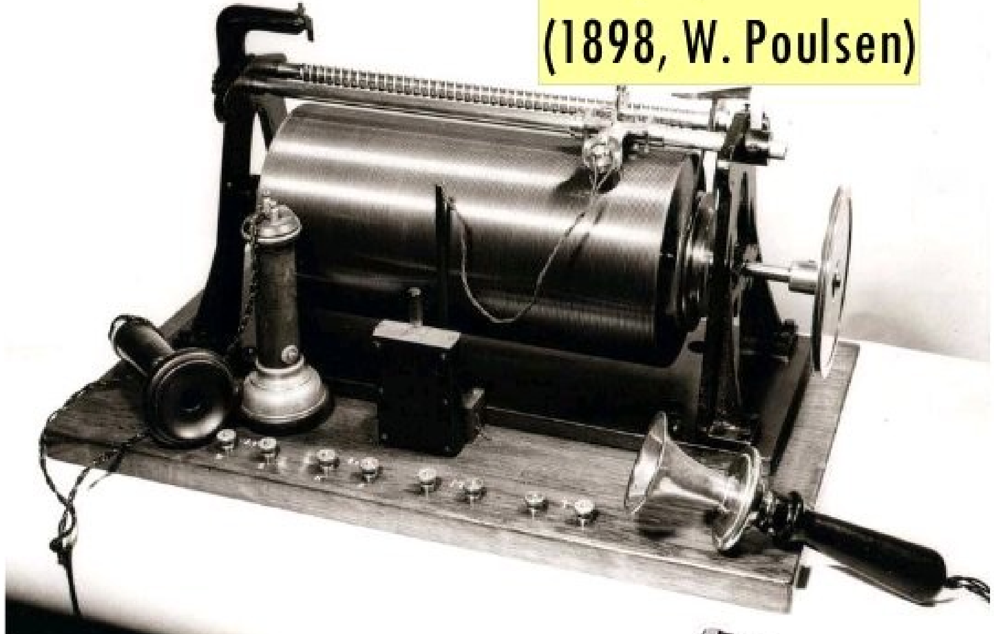
Matériaux durs



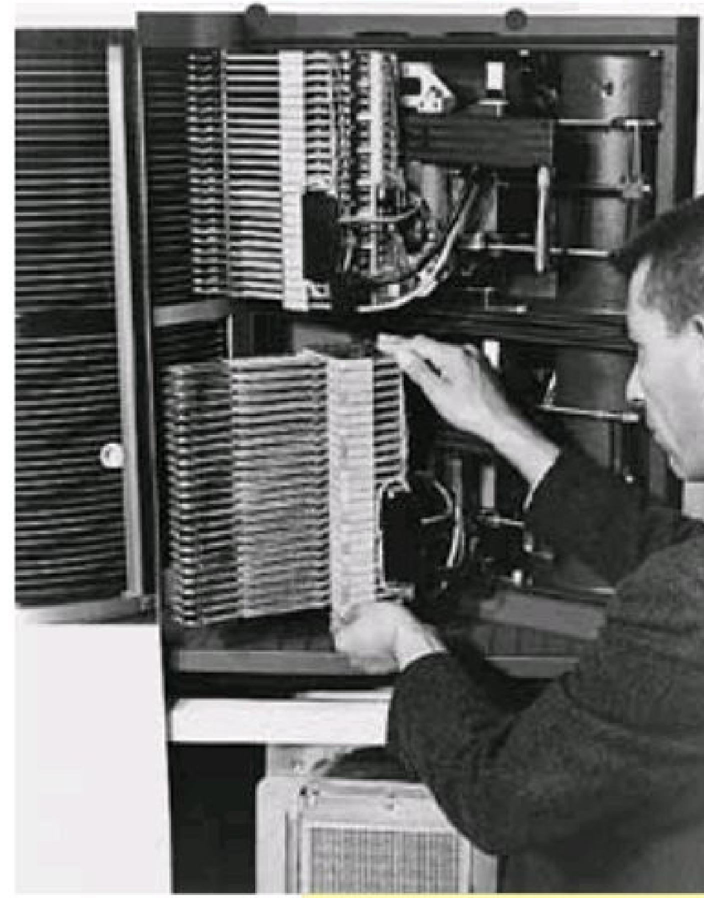
Aimants permanents, moteurs

Enregistrement magnétique

ENREGISTREMENT MAGNETIQUE – Historique

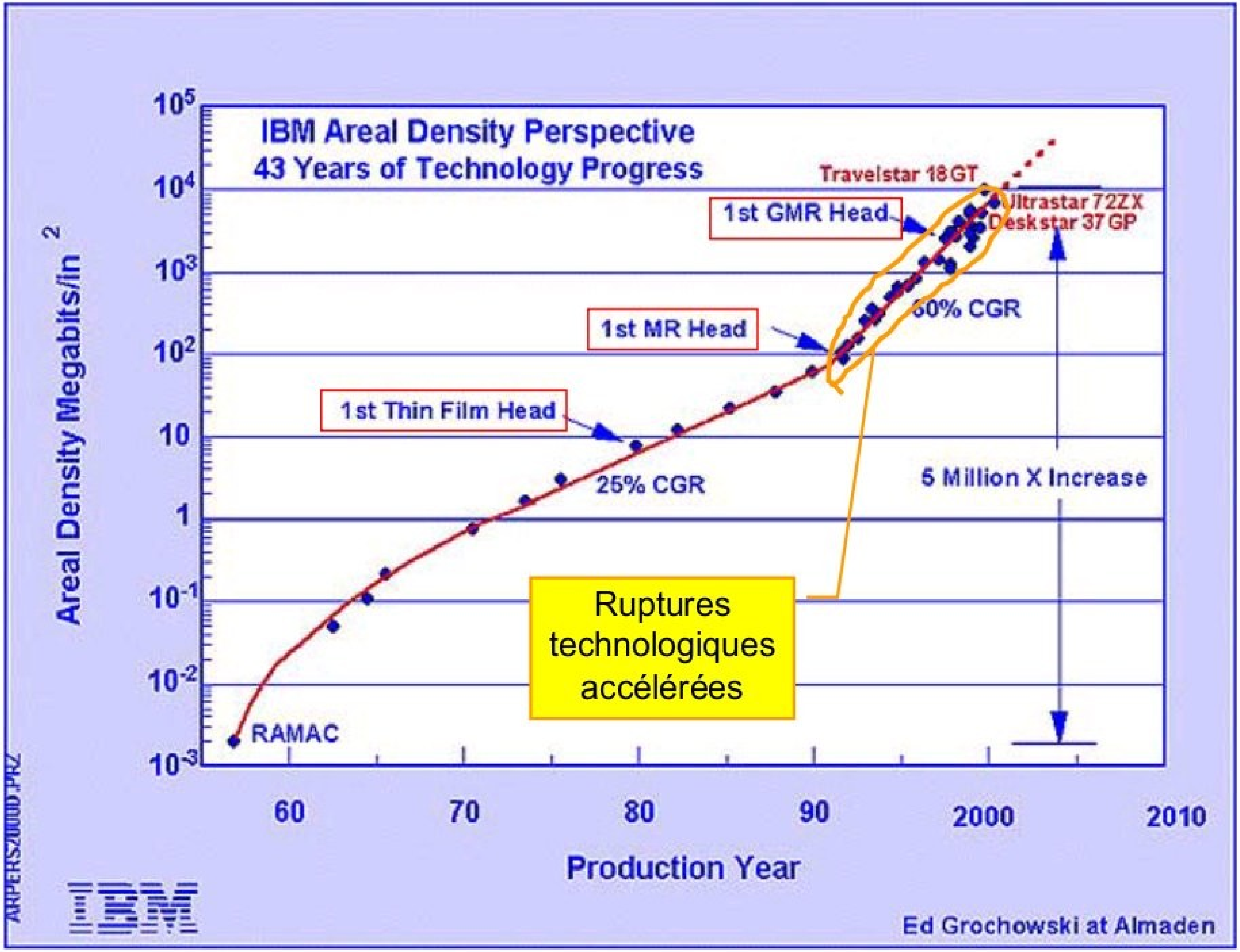


Télégraphone
(1898, W. Poulsen)

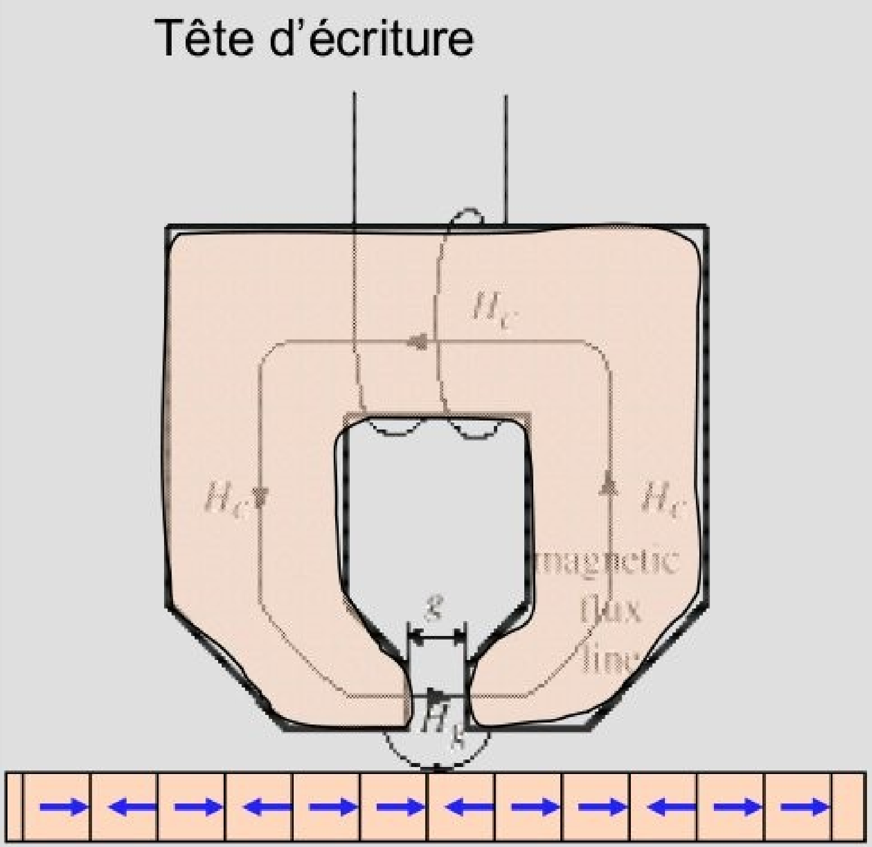


RAMAC (IBM, 1956)
2 kbit/in^2
50 disques Ø 60 cm
Total 5Mo

Disque dur actuel
(>200Go)

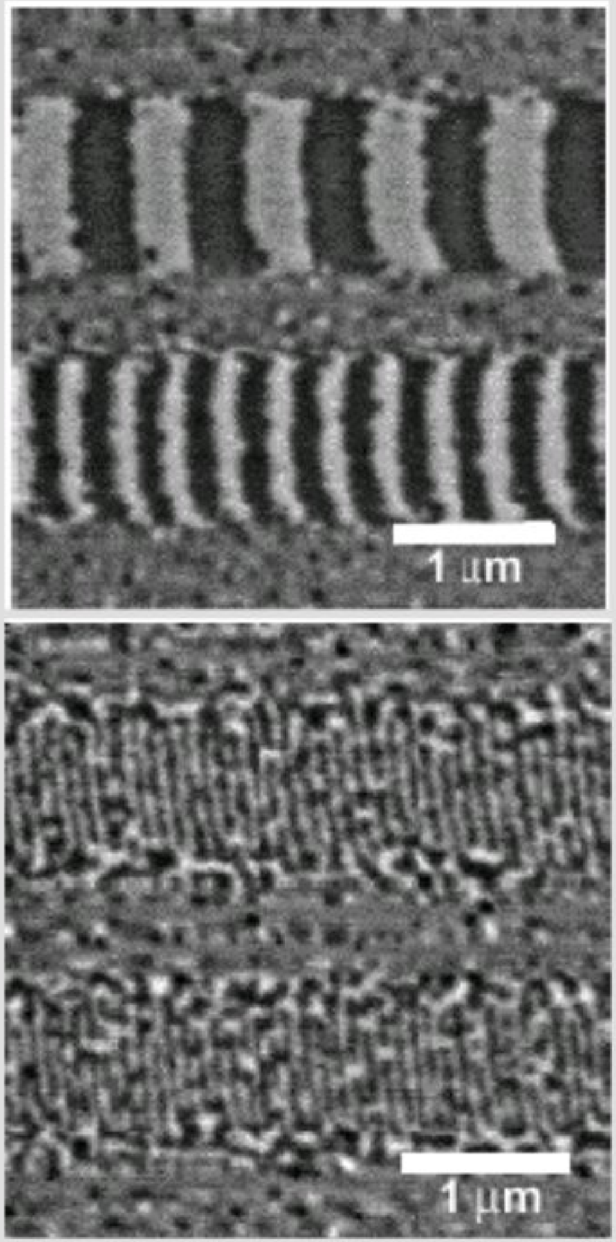

IBM Areal Density Perspective
43 Years of Technology Progress
Areal Density Megabits/in2
Production Year
Travelstar 18GT
Ultrastar 72ZX
Deskstar 37GP
1st GMR Head
1st MR Head
1st Thin Film Head
60% CGR
25% CGR
5 Million X Increase
RAMAC
Ruptures technologiques accélérées
ARPERS2000D.PRZ
IBM
Ed Grochowski at Almaden

Principe du stockage



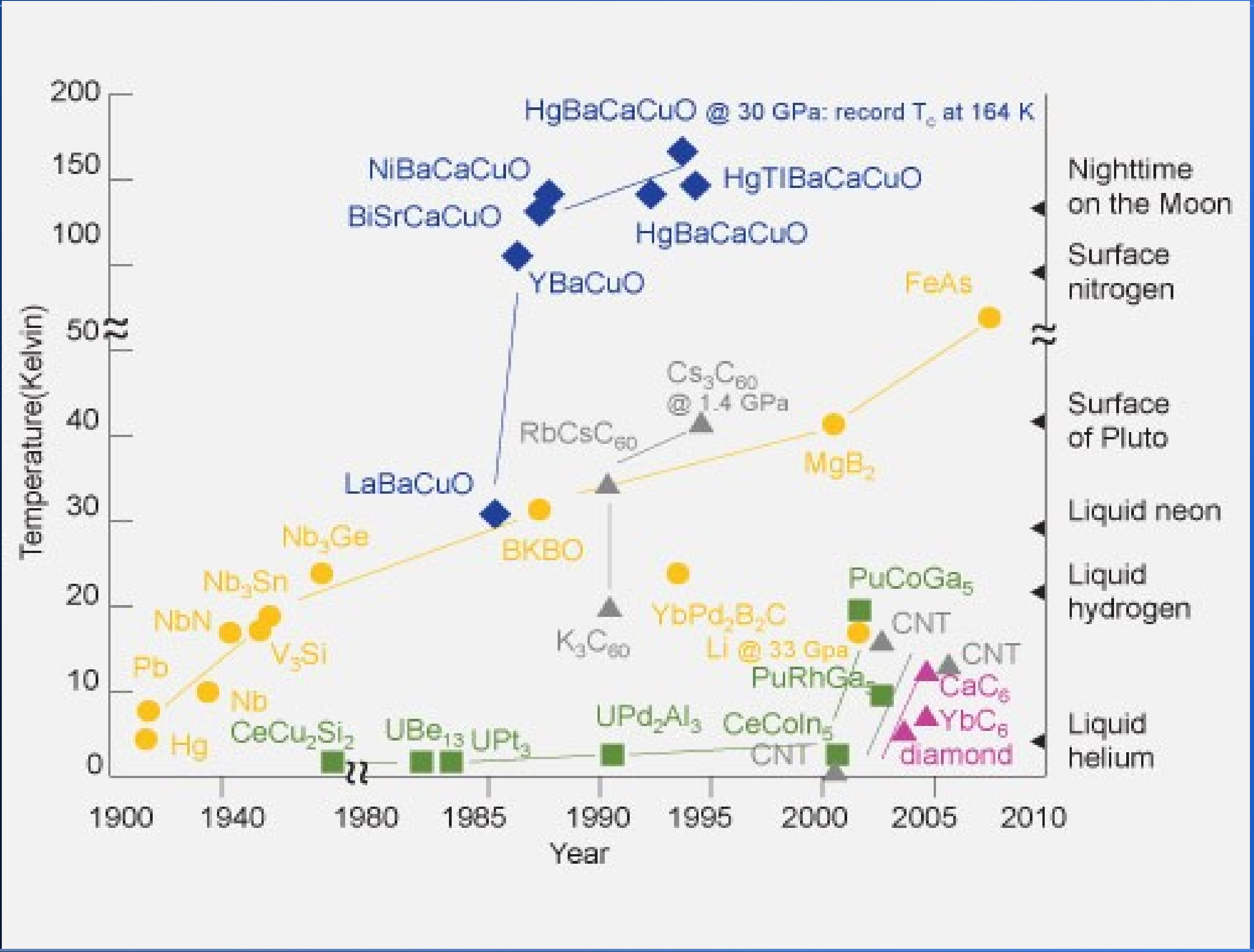
Vue en coupe du disque dur

Vue du disque dur

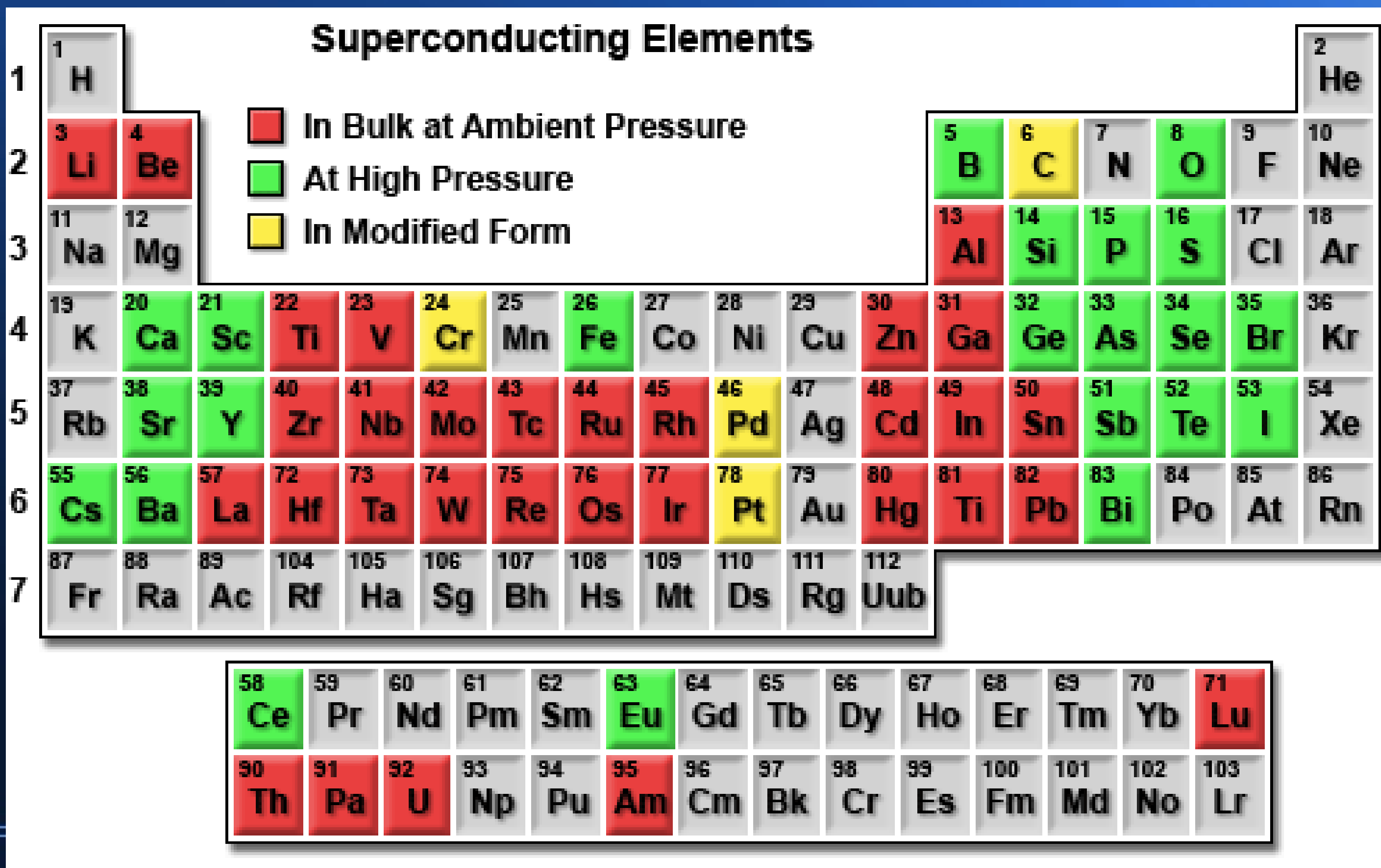


superconductivity

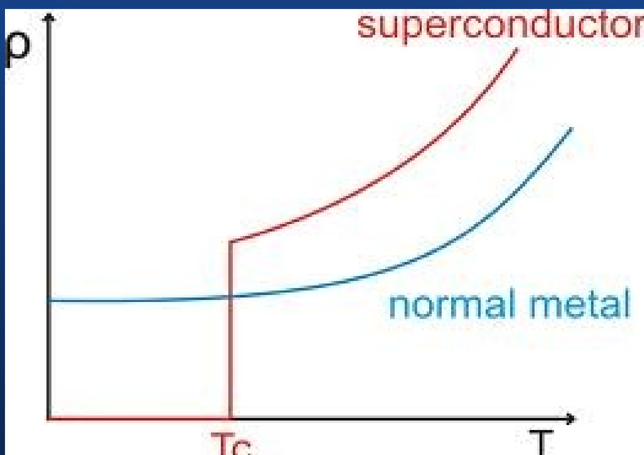
superconducting compounds and their Tc



Superconducting elements



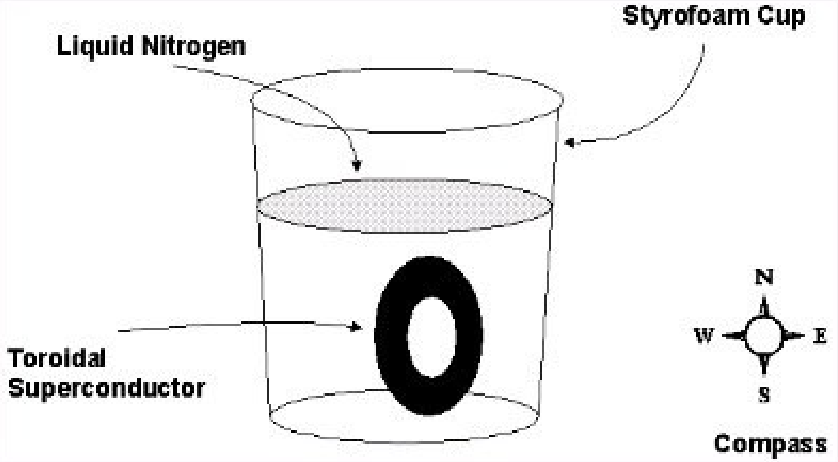
permanent current loops



Fifth Experiment: Superconducting Energy Storage Ring

The S6 Superconductor Energy Storage Kit is simple to understand.The fundamental property of superconductors is its complete lack of resistance to electrical current. This property can be exploited by using a ring (toroid) of superconductor material to store electrical power. Once the current is induced in the toroidal, its lack of resistance allows the induced current to flow forever. These permanent currents in a superconductor are called persistent currents. The current also produces a magnetic field around the superconductor, creating a powerful electromagnet.

The primary component in the S6 kit is a superconductor toroid (see **Figure 4**). To perform the experiment, the toroidal is completely immersed in liquid nitrogen (see **Figure 5**).



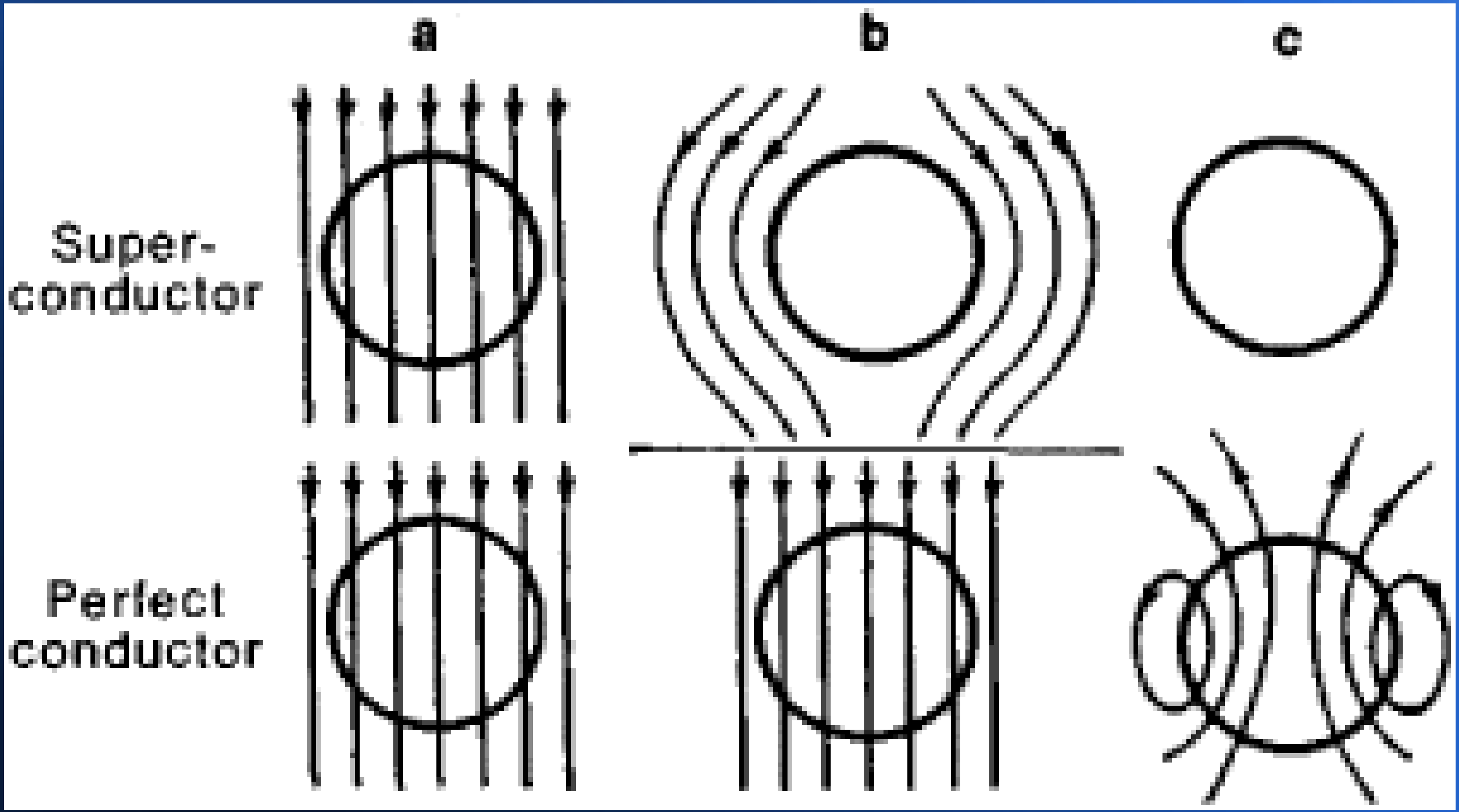
A current is induced in the toroidal ring by passing a rare earth magnet through the opening of the toroidal. The toroidal may be momentarily removed from the liquid nitrogen to perform this operation, then quickly placed back into the liquid nitrogen.

The induced current can be detected by measuring the deflection of a compass needle held in close proximity to the superconducting toroidal.

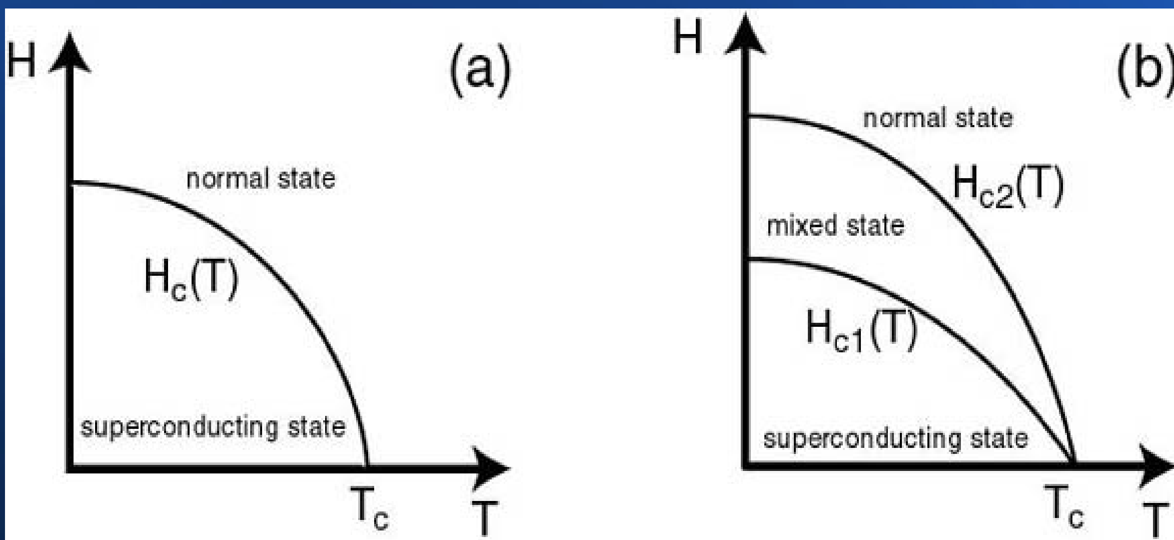
The S6 kit's experimenter's guide provides equations and procedures for estimating the current in the superconductor based on the deflection of the compass needle.

While in theory the current in the toroidal should flow forever, because of flux creep and flux flow there is a small exponential decay of the stored electrical current. It has been estimated that in 1023 years the stored current will decrease to approximately 50% of its initial value.

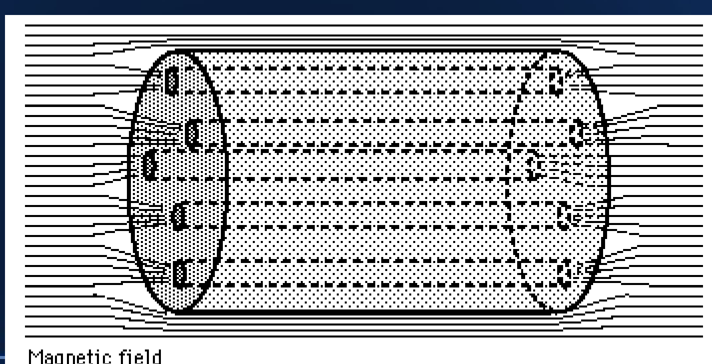
Meissner effect for a sphere



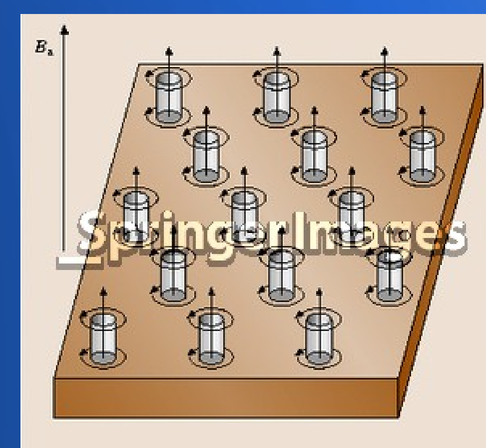
Type I and type II



The critical temperature versus Magnetic field in Type I and in Type II superconductors

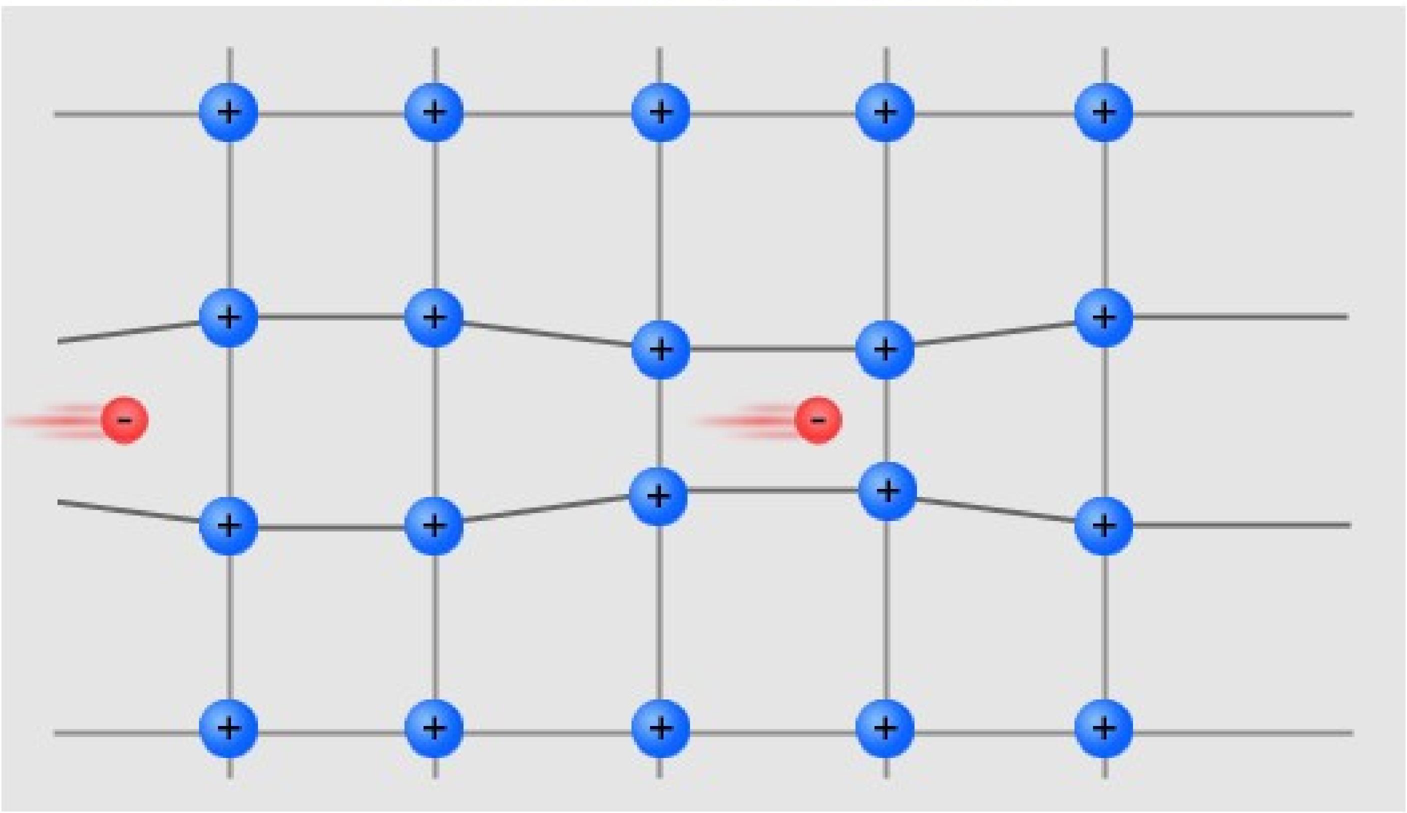


The mixed state (magnetic flux forming a vortex lattice)



BCS theory

Cooper pairs make super conductors



At extremely low temperatures, an electron can draw the positive ions in a superconducting material towards it. This movement of the ions creates a more positive region that attracts another electron to the area.

The building block for the BCS state is a boson, the Cooper pair : a pair of electrons of opposite spin that form a bound state due to their interaction via phonons

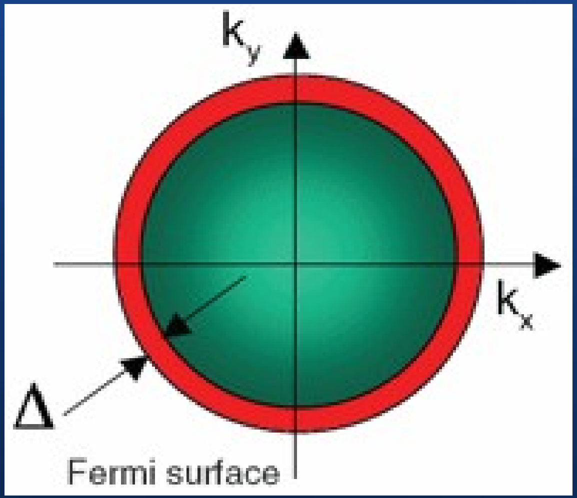
Superconductivity arises due to the electron-phonon Interaction !

The waltz of the Cooper pairs

$$\left|\Psi_{BCS}^{(r)}\right\rangle = \prod_{\mathbf{k}} \frac{\left(u_{\mathbf{k}} + g_{i} v_{\mathbf{k}} c_{\mathbf{k}\uparrow}^{\dagger} c_{-\mathbf{k}\downarrow}^{\dagger}\right)}{\sqrt{\left|u_{\mathbf{k}}\right|^{2} + g_{i}^{2}\left|v_{\mathbf{k}}\right|^{2}}} |0\rangle$$

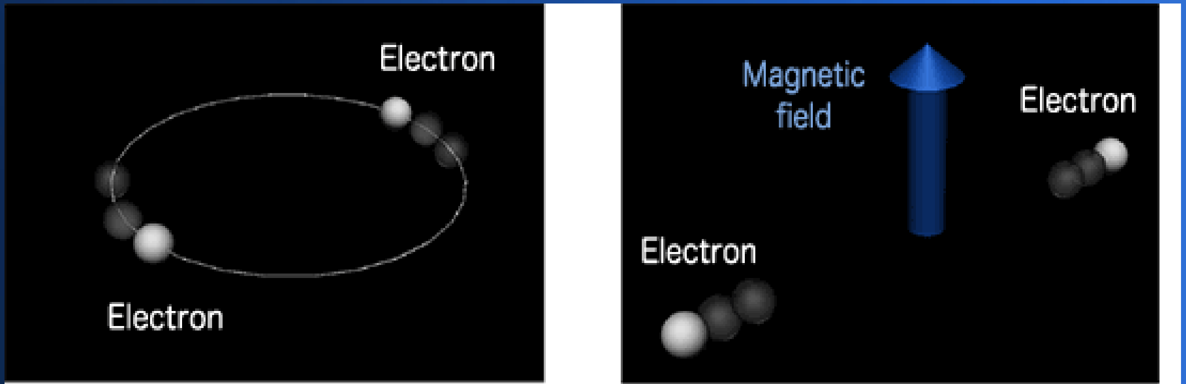
The BCS wavefunction

The ground state is stable because there is an energy gap



Cooper pairs can be broken up by increasing the temperature
or
increasing the magnetic field
or
increasing the electrical current

Figure showing the gap : the region (red) of forbidden energy



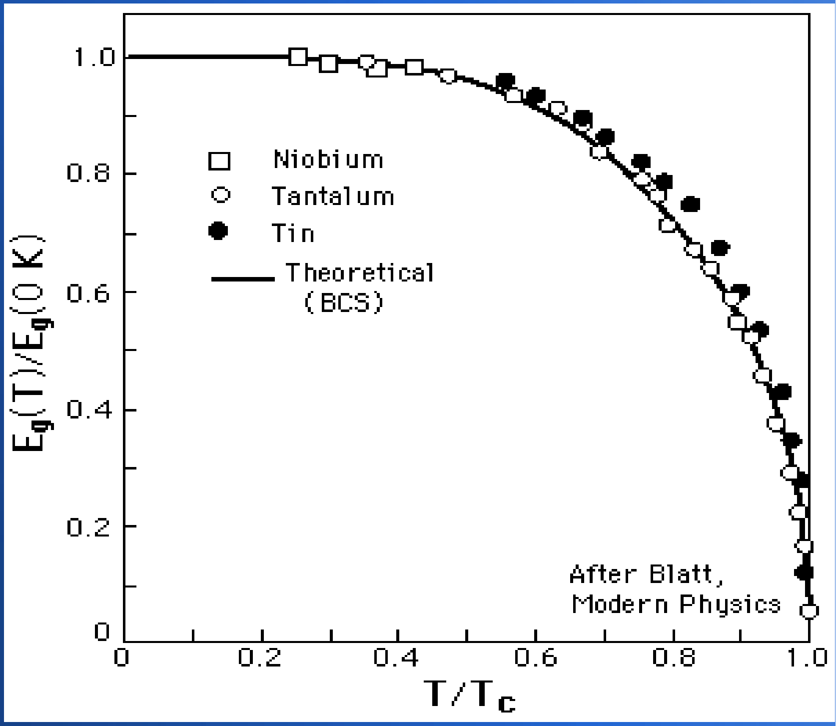
(A)Cooper pair (electron pair) exists stably in a superconducting state.

(B)Cooper pair (electron pair) is destroyed by a magnetic field, leading to the disappearance of superconductivity.

The BCS equations for the gap and for Tc

$$k_B T_c = 1.14 E_D e^{-1/N(0)V}.$$

The critical temperature
and the zero temperature gap
depend
1) on the Debye energy ED
2) on the density of states at the Fermi level N(0)
3) on the effective electron-electron attraction V



$$\Delta(T=0) = 2\hbar\omega_D e^{-1/n(0)V_{BCS}}$$

Web site for nonspecialists

http://www.supraconductivite.fr/fr/index.php#supra-intro