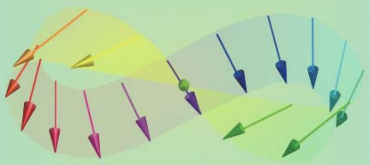
Introductory Nanotechnology

~ Basic Condensed Matter Physics ~



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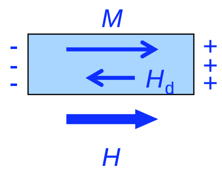
Quick Review over the Last Lecture 1

Magnetisation curve :



H_d :

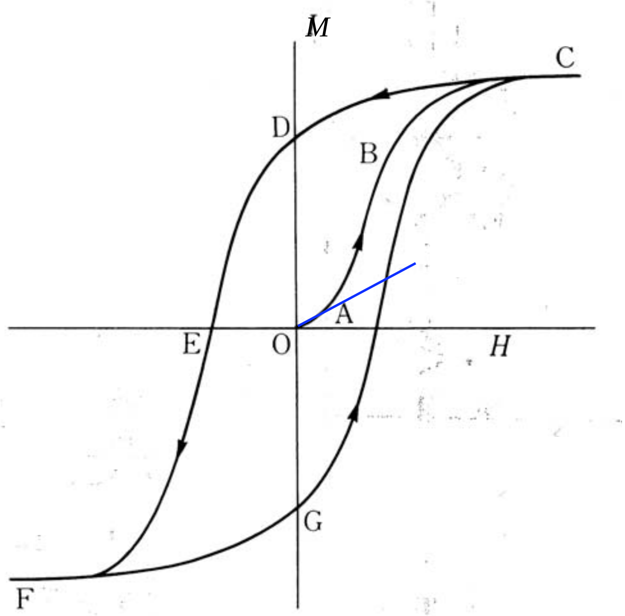


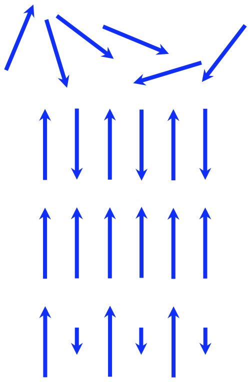
Fig. 1.12. Hysteresis loop.

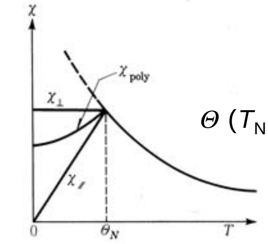
Quick Review over the Last Lecture 2

Origin of magnetism :

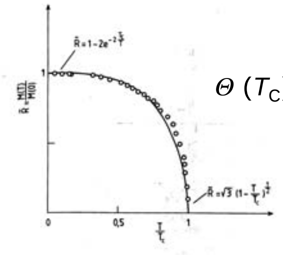
( ) is equivalent to a ( ).

Dipole moment arrangement :





Θ (T_N) : temperature



Θ (T_C) : temperature

Quick Review over the Last Lecture 3

Stable magnetic domain configuration is defined to minimize total energy :

$U = U_{mag} + U_{ex} + U_a$

U_{mag} : energy

maximum when appear at the edge.

minimum when no appear at the edge.

U_{ex} : energy

maximum for

minimum for

U_a : energy

maximum for

minimum for

Contents of Introductory Nanotechnology

First half of the course :

Basic condensed matter physics

1. Why *solids* are *solid* ?
2. What is the *most common atom* on the earth ?
3. How does an electron travel in a material ?
4. How does lattices vibrate thermally ?
5. What is a *semi*-conductor ?
6. How does an electron tunnel through a barrier ?
7. Why does a magnet attract / retract ?
8. What happens at interfaces ?

Second half of the course :

Introduction to nanotechnology (nano-fabrication / application)

What Happens at Interfaces ?

- Electric Dipole Moment
- Dielectric Polarisation

What Happens at Interfaces ?

Injector \ Medium	Normal metals	Semi-conductors	Insulators	Ferro-magnets	Super-conductors
Normal metals		✓Schottky barrier	✓Tunneling		
Semi-conductors	✓Schottky barrier	✓*pn* junction	✓Tunneling		
Insulators					
Ferro-magnets					
Super-conductors					

Thermoelectrical Effects

Seebeck effect :

Thermal voltage induced at an interface of

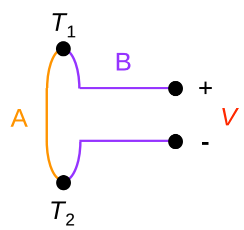
metal / metal or semiconductor / semiconductor

with different temperature.

$$V = \int_{T_1}^{T_2} \left[S_B(T) - S_A(T)\right] dT \approx (S_B - S_A)(T_2 - T_1)$$

S : Seebeck constant (= 0 for a superconductor)

→ Thermocouples to measure temperature



Peltier effect :

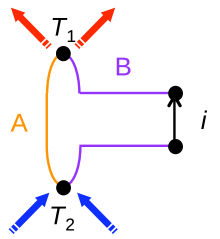
Reverse of the Seebeck effect ;

Heat emission / absorption induced by a voltage.

$$\dot{Q} = (\Pi_{B--} - \Pi_A)i$$

Π : Peltier constant

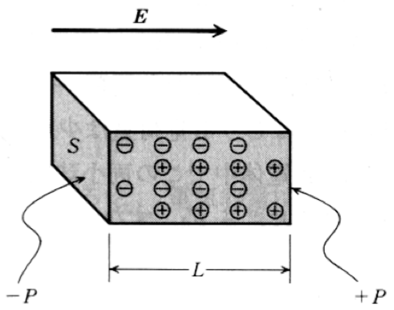
→ Peltier device for cooling



Dielectrics and Dielectric Polarisation

In an insulator, an electric field application induces dielectric polarisation :

because electrons cannot move freely like metals.



Dielectric polarisation :

$$P = \frac{\sum_i m_{qi}}{SL}$$

m_q : electric dipole moment

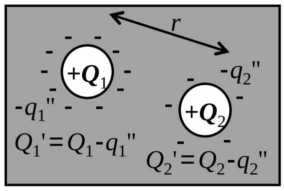
$m_q = \alpha E$ (α : polarisability)

$P = \varepsilon_0 \chi_e E$ (χ_e : electric susceptibility)

In a dielectrics, the Coulomb interaction is written as

$$F = \frac{Q_1' Q_2'}{4\pi\varepsilon_0 r^2} = \frac{(Q_1 - q_1'')(Q_2 - q_2'')}{4\pi\varepsilon_0 r^2} \equiv \frac{Q_1 Q_2}{4\pi\varepsilon r^2}$$

(ε : dielectric constant)

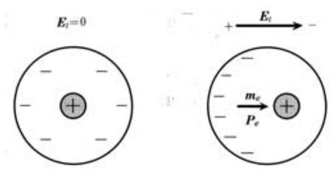


* M. Sakata, *Solid State Physics* (Baifukan, Tokyo, 1989).

Dielectric Polarisations

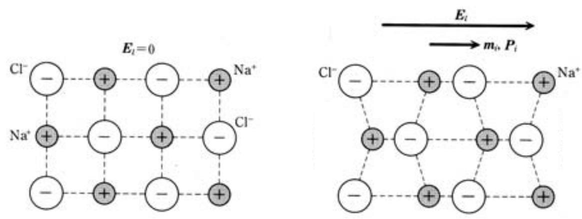
Electron polarisation :

Induced by relative displacement of atom position and electron gravity centre under an electric field.



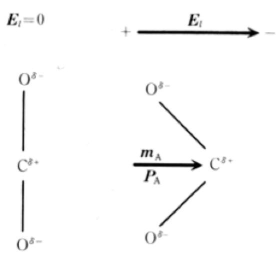
Ion polarisation :

Induced by relative displacement of + / - ions under an electric field.



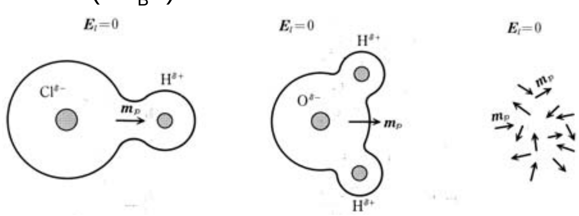
Atom polarisation :

Induced by difference in electronegativity in a molecule under an electric field.



Orientational polarisation :

Maintained in a polar molecule and aligned under an electric field ($> k_B T$).



* M. Sakata, *Solid State Physics* (Baifukan, Tokyo, 1989).

Spin Injection

Spin-polarised electron injection into a non-magnetic metal or semiconductor : *

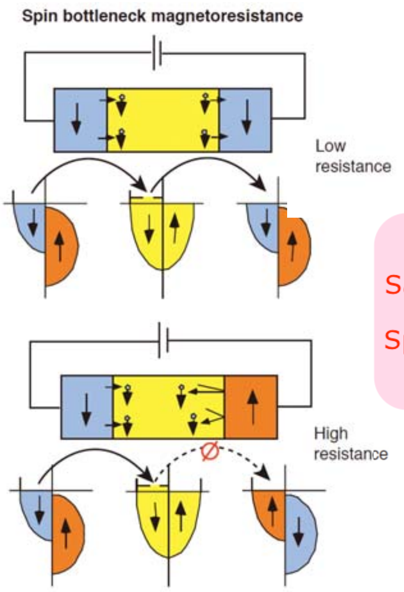
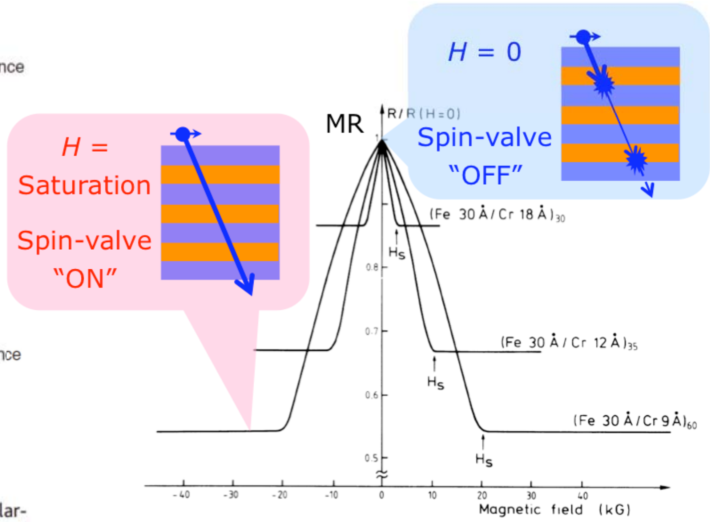


Fig. 2. Schematic representations of spin-polarized transport from a ferromagnetic metal, through a normal metal, and into a second ferromagnetic metal for aligned and anti-aligned magnetic moments. ∅, disallowed channel.

Giant magnetoresistance (GMR) :

[3 nm Fe / 0.9 nm Cr] × 60 **

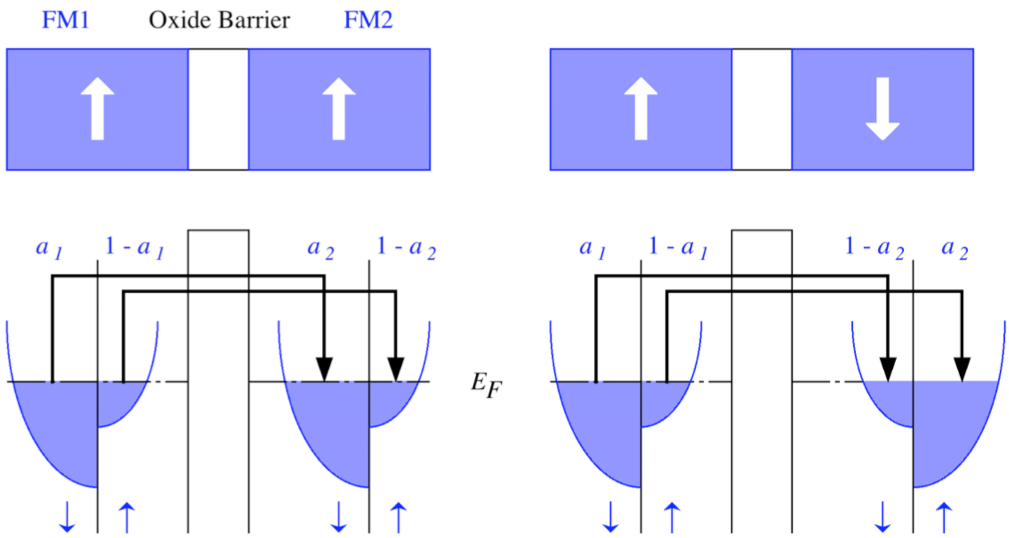


50 % resistance change at 4.2 K

* G. A. Prinz, *Science* **282**, 1660 (1998);

Magnetic Tunneling

Spin-dependent electron tunneling :



$$\begin{cases} G^p \propto a_1 a_2 + (1-a_1)(1-a_2) \\ G^a \propto a_1(1-a_2) + (1-a_1)a_2 \end{cases}$$

$$\frac{R^a - R^p}{R^p} = \frac{2P_1P_2}{1-P_1P_2} \qquad P = \frac{N_\uparrow(E_F) - N_\downarrow(E_F)}{N_\uparrow(E_F) + N_\downarrow(E_F)}$$

* M. Jullière, *Phys. Rep.* **54A**, 225 (1975).

Superconducting Elements

In the periodic table,

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pd	Bi	Po	At	Rn
Fr	Ra																
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Superconductors and high-pressure-phase superconductors

Superconducting transition temperature :

Al : 1.19 K, Nb : 9.2 K, In : 3.4 K, Sn : 3.7 K, Pb : 7.2 K

Superconductors

Major properties :

Zero electrical dc resistance : H. K. Onnes in 1911 (Hg)

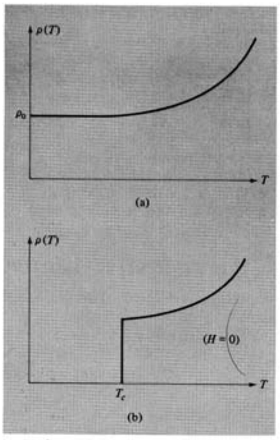


Figure 34.1
(a) Low-temperature resistivity of a normal metal ($\rho(T) = \rho_0 + BT^5$) containing nonmagnetic impurities (b) Low-temperature resistivity of a superconductor (in zero magnetic field) containing nonmagnetic impurities. At T_c, ρ drops abruptly to zero.

→ Superconducting phase transition at T_c

→ BCS theory

Persistent current :

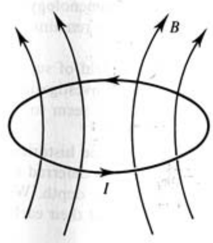
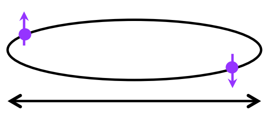


FIGURE 1.1
Schematic diagram of persistent current experiment.

Cooper pair :



~ 1 μm

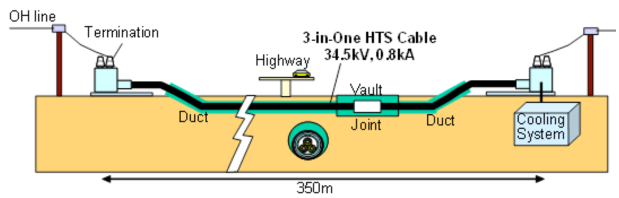
* N. W. Ashcroft and N. D. Mermin, *Solid State Physics* (Thomson Learning, London, 1976);

Superconductor Applications

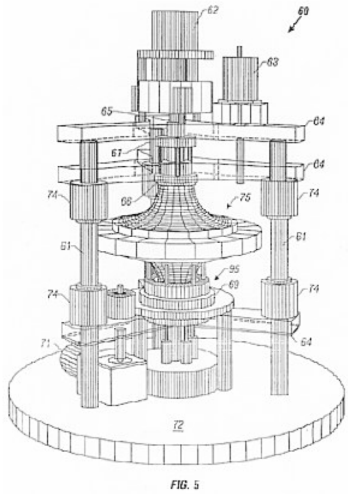
Using a persistent current,

Superconducting cable :

Structure of "3-in-One" Superconducting Cable



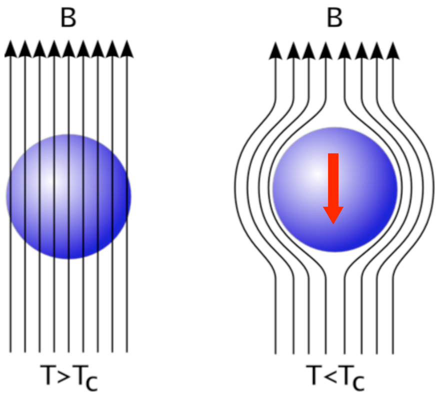
Superconducting flywheel :

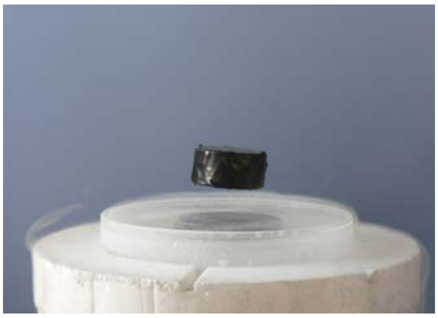


* http:// www.sei.co.jp/; ** U.S. Patent 6,231,011 B1.

Meissner Effect

Expulsion of a magnetic field from a superconductor :





→ Perfect diamagnetism

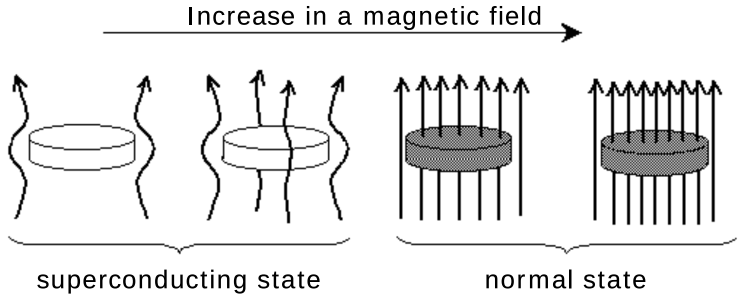
→ London equation

→ Magnetic levitation (581 km/h, 2003)

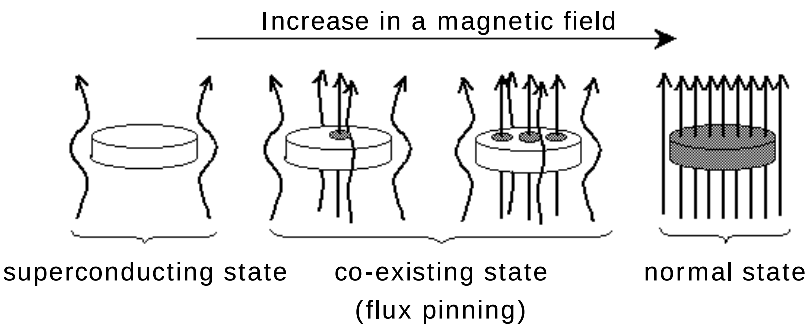
* http://www.wikipedia.org/;

Type I / II Superconductors

Type I superconductors : *e.g.*, Ti, Pb, ...



Type II superconductors : *e.g.*, Nb, V, $YBa_2Cu_3O_{7-\delta}$, $Bi_2Sr_2Ca_2Cu_3O_{10}$, ...



* http://www.wikipedia.org/

Magnetic Field Dependence of Type I / II Superconductors

Flux penetration in type I and II superconductors :

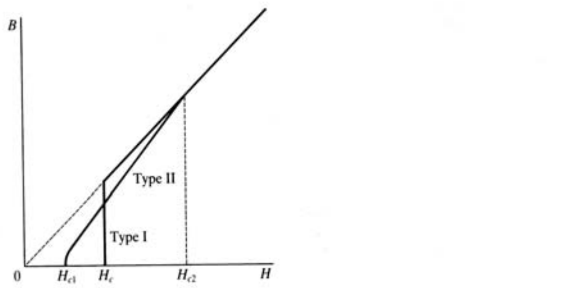
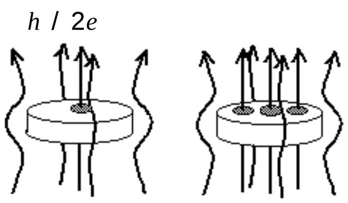


FIGURE 1.5
Comparison of flux penetration behavior of type I and type II superconductors with the same thermodynamic critical field H_c. $H_{c2} = \sqrt{2}\kappa H_c$. The ratio of B/H_{c2} from this plot also gives the approximate variation of R/R_n, where R is the electrical resistance for the case of negligible pinning, and R_n is the normal-state resistance.

Flux quantization in a type II superconductor :



* M. Tinkham, *Introduction to Superconductivity* (McGraw-Hill, New York, 1996).

Superconductor / insulator / superconductor junction :

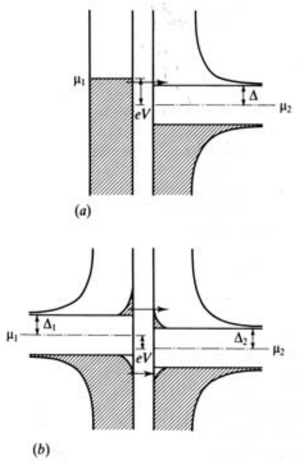
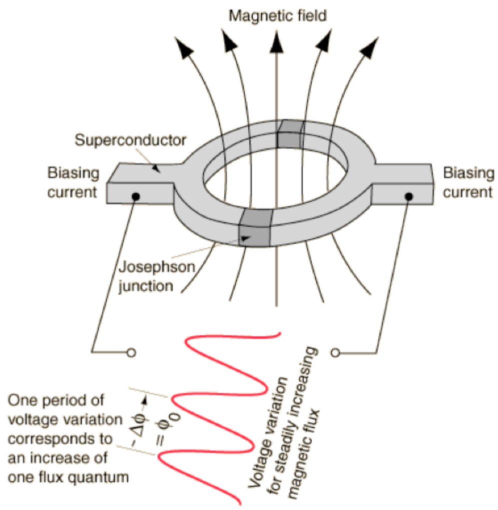


FIGURE 3.6
Example of semiconductor model description of electron tunneling. Density of states is plotted horizontally vs. energy vertically. Shading denotes states occupied by electrons. (*a*) *N-S* tunneling at $T = 0$, with bias voltage just above the conduction threshold, i.e., eV slightly exceeds the energy gap Δ. Horizontal arrow depicts electrons from the left tunneling into empty states on the right. (*b*) *S-S* tunneling at $T > 0$, with bias voltage below the threshold for conduction at $T = 0$, i.e., with $eV < \Delta_1 + \Delta_2$. Horizontal arrows depict tunneling involving thermally excited electrons or holes, respectively.

Superconducting quantum interference device (SQUID) :



Cooper pairs in both superconductors can be represented by wavefunctions, of which phase difference generates a Josephson current across the junction.

→ magnetic field sensor

Quantum phase → macroscopic current

* M. Tinkham, *Introduction to Superconductivity* (McGraw-Hill, New York, 1996);