Quick Review over the Last Lecture 1

Magnetisation curve:

Fig. 1.12. Hysteresis loop.
Quick Review over the Last Lecture 2

Origin of magnetism:

( ) is equivalent to a ( ).

Dipole moment arrangement:

\[
\theta (T_N) : \text{temperature}
\]

\[
\theta (T_C) : \text{temperature}
\]

Quick Review over the Last Lecture 3

Stable magnetic domain configuration is defined to minimize total energy:

\[ U = U_{\text{mag}} + U_{\text{ex}} + U_a \]

- \( U_{\text{mag}} \): energy
  - maximum when magnetic poles appear at the edge.
  - minimum when no magnetic poles appear at the edge.

- \( U_{\text{ex}} \): energy
  - maximum for antiparallel
  - minimum for parallel

- \( U_a \): energy
  - maximum for hard axis
  - minimum for easy axis
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 do 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?**

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<tr>
<th>Medium</th>
<th>Normal metals</th>
<th>Semiconductors</th>
<th>Insulators</th>
<th>Ferromagnets</th>
<th>Superconductors</th>
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<tr>
<td>Normal metals</td>
<td></td>
<td>✓ Schottky barrier</td>
<td>✓ Tunneling</td>
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<td>Semiconductors</td>
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<td>✓ $pn$ junction</td>
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</tbody>
</table>

**Thermoelectrical Effects**

**Seebeck effect:**
Thermal voltage induced at an interface of metal / metal or semiconductor / semiconductor with different temperature.

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

$S$ : Seebeck constant (= 0 for a superconductor)
→ Thermocouples to measure temperature

**Peltier effect:**
Reverse of the Seebeck effect;
Heat emission / absorption induced by a voltage.

\[ \dot{Q} = (\Pi_B - \Pi_A)i \]

$\Pi$ : 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**:

\[ P = \sum_{i} \frac{m_{qi}}{SL} \]

- \( m_{qi} \): electric dipole moment
- \( \mathbf{P} = \varepsilon_0 \chi_e \mathbf{E} \) (\( \chi_e \): electric susceptibility)

In a dielectrics, the Coulomb interaction is written as

\[
F = \frac{Q_1'Q_2'}{4\pi\varepsilon_0 r^2} = \frac{Q_1Q_2}{4\pi\varepsilon r^2}
\]

(\( \varepsilon \): dielectric constant)

---

**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 (>\( k_B T \)).

---

Spin Injection

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

Giant magnetoresistance (GMR):

\[ \left[ 3 \text{ nm Fe} \right] / \left[ 0.9 \text{ nm Cr} \right] \times 60 \]**

50% resistance change at 4.2 K

Magnetic Tunneling

Spin-dependent electron tunneling:

\[ G^p \propto a_i a_2 + (1 - a_i)(1 - a_2) \]
\[ G^u \propto a_i (1 - a_2) + (1 - a_i) a_2 \]

\[ \frac{R^u - R^p}{R^p} = \frac{2P_i P_2}{1 - P_i P_2} \]

\[ P = \frac{N_i(E_F) - N_i(E_F)}{N_i(E_F) + N_i(E_F)} \]

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


Superconducting Elements

In the periodic table,

Superconducting transition temperature:

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

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)

- Cooper pair: \( \sim 1 \mu m \)

Persistent current:

\[ \rightarrow \text{Superconducting phase transition at } T_c \]

\[ \rightarrow \text{BCS theory} \]

Superconductor Applications

Using a persistent current,

Superconducting cable:

Superconducting flywheel:


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, ...

Increase in a magnetic field

- superconducting state
- normal state

Type II superconductors: e.g., Nb, V, YBa$_2$Cu$_3$O$_{7-\delta}$, Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10}$, ...

Increase in a magnetic field

- superconducting state
- co-existing state (flux pinning)
- normal state

Magnetic Field Dependence of Type I / II Superconductors

Flux penetration in type I and II superconductors:

![Graph showing the magnetic field dependence of type I and II superconductors.]

Flux quantization in a type II superconductor:

\[ \frac{h}{2e} \]

Josephson Junction

Superconductor / insulator / superconductor junction:

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

Quantum phase → macroscopic current

Superconducting quantum interference device (SQUID):