(KTXFI2EBNF) Physics II. Lecture

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Slides, Moodle, GitHub

- I had no time to translate the Hungarian text on the images into English. Sorry — it's coming soon...

Where are we? I

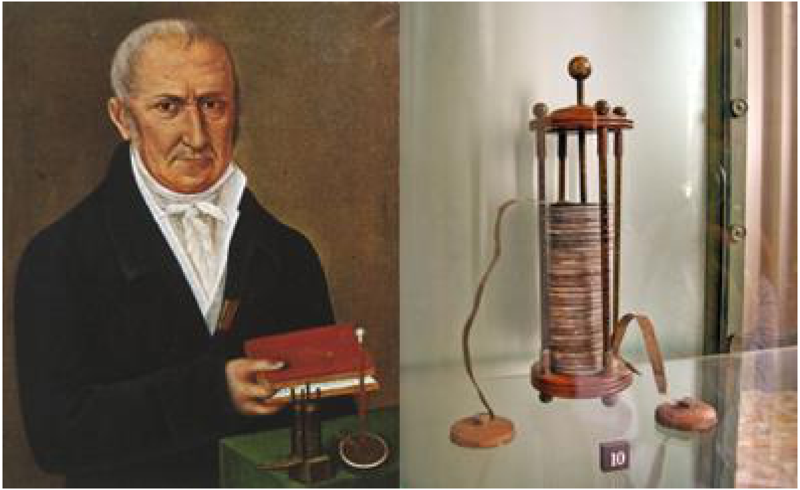
- ~~Motion of charged particles in electromagnetic fields.~~
- ~~Elements of quantum mechanics. Heisenberg's uncertainty principle. The stationary Schrödinger equation and its applications.~~
- ~~Limits of the classical conceptual framework. Thermal radiation. Photoelectric effect. Compton effect. The dual nature of electromagnetic radiation. The dual nature of particles.~~
- ~~Moving reference frames. Inertial forces in accelerating reference frames. Elements of special relativity. Dirac-equation, antimatter.~~
- ~~The classical theory of atomic structure (Rutherford, Franck-Hertz experiment, Bohr model, quantum numbers, Pauli exclusion principle).~~
- ~~Physics of condensed matter. Metallic bonding. Electrical conduction in metals based on the free electron model and the wave model. Hall effect. Band theory of solids.~~

Where are we? II

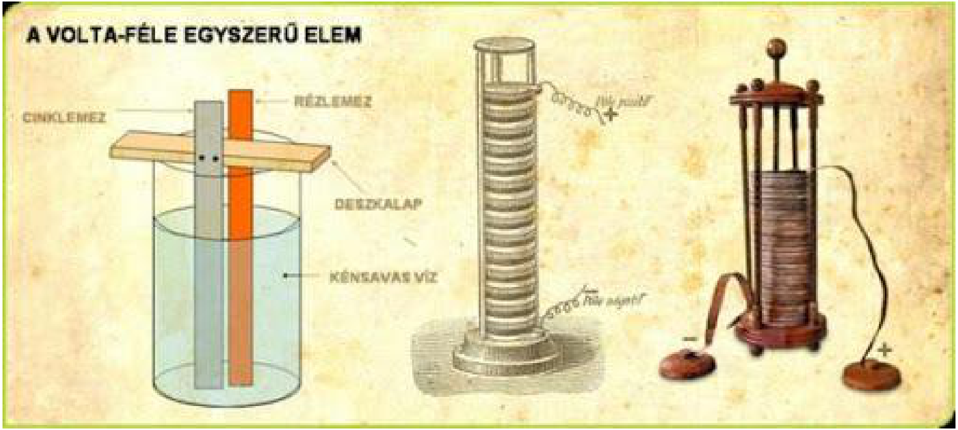
- ~~Semiconductors. Elements of Fermi-Dirac statistics.~~ **Thermoelectric phenomena. Magnetic properties.**
- **Ferroelectricity. Piezoelectricity and electrostriction. Liquid crystals. Superconductivity.**
- Luminescence. Lasers. Basic knowledge of nuclear physics. Basic knowledge of particle physics.

Contact and Contact Potential I

Contact and Contact Potential II

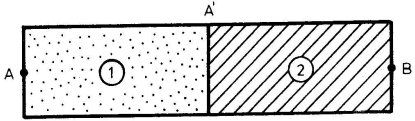


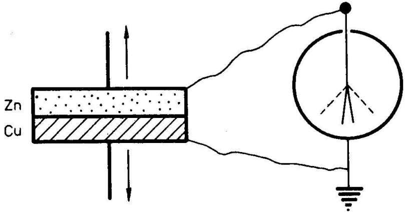
Contact and Contact Potential III



Contact and Contact Potential IV

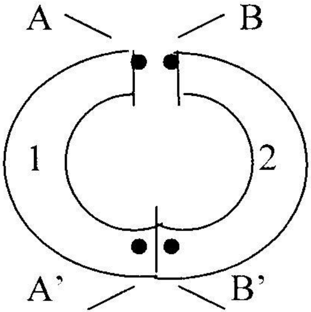
- When two different metals are brought into contact, a contact (or Volta) potential U_k arises between external points near the contact surfaces.





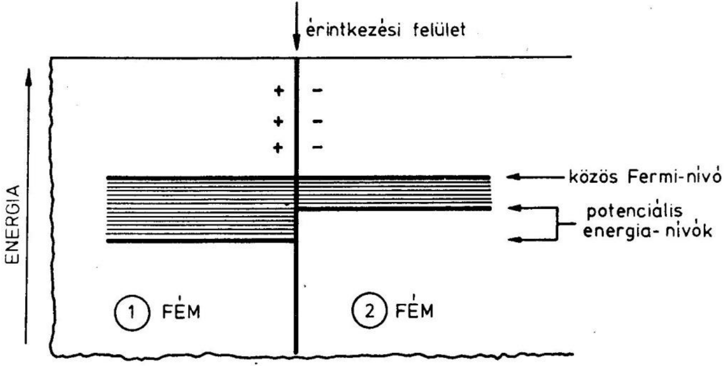
Contact and Contact Potential V

- Volta potential: potential difference between external points near different metal surfaces.
- Galvani potential: potential difference between internal points close to the interface inside the metals.



Contact and Contact Potential VI

- Contact potential originates from differing Fermi levels and work functions; electrons flow until an electric double layer with voltage $U_k = \phi_1 - \phi_2$ stops further net transfer.

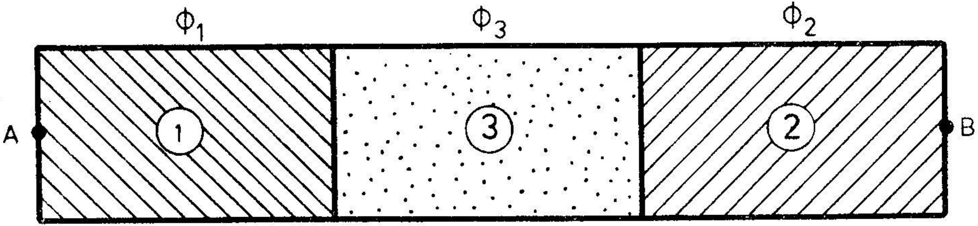


Contact and Contact Potential VII

- Volta's Contact Potential Series
  - Volta ordered metals according to contact potentials: Al – Zn – Pb – Sn – Sb – Bi – Fe – Cu – Ag – Au – Pt – C.
  - This ordering is known as Volta's contact potential series.

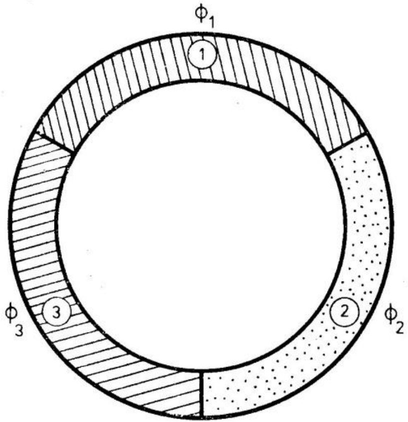
Contact and Contact Potential VIII

- If a third metal with contact potential Φ_3 is inserted between a first metal with contact potential Φ_1, and a second metal with contact potential Φ_2, so that they are in mutual contact, then the contact potential difference between points A and B will be the same as if only metals 1 and 2 were present.



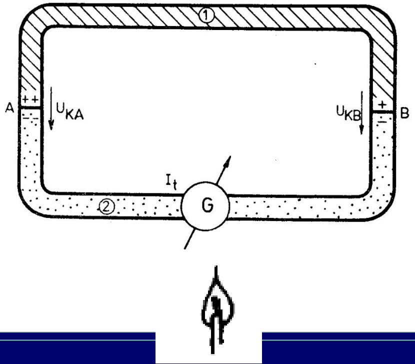
Contact and Contact Potential IX

- In closed circuits of dissimilar conductors, contact potentials sum to zero; no net current flows solely from differing contact potentials.



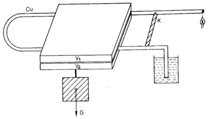
Thermoelectric Phenomena: Seebeck and Peltier Effects I

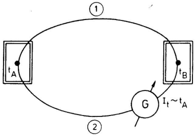
- **Seebeck effect**: a closed circuit made of two different metals with junction temperatures t_A and t_B produces an electromotive force $U_t = \alpha(t_A - t_B)$ and a thermoelectric current $I_t = U_t/R$.
- α is the Seebeck coefficient (V/K).

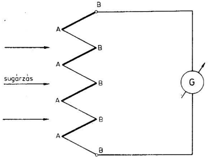


Thermoelectric Phenomena: Seebeck and Peltier Effects II

- Applications: thermomagnet, thermobattery, thermocross

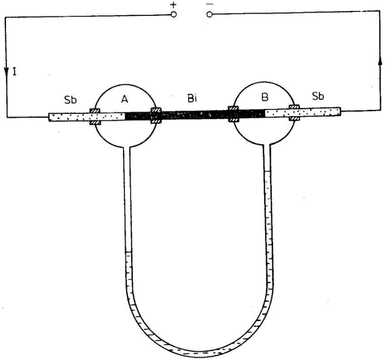




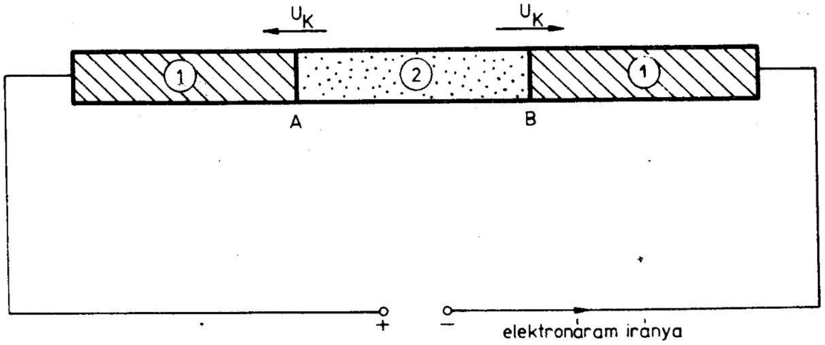


Thermoelectric Phenomena: Seebeck and Peltier Effects III

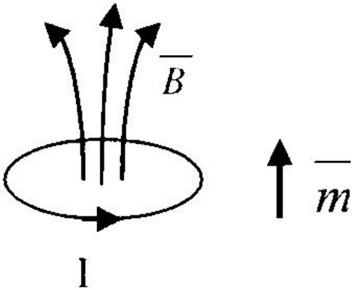
- **Peltier effect**: when a DC current I flows through a junction, heating or cooling occurs at the junction with heat $Q = \Pi I \tau$, where Π is the Peltier coefficient (V).
- Thermoelectric coefficients are related: $\Pi = \alpha t$ (Kelvin relation).



Thermoelectric Phenomena: Seebeck and Peltier Effects IV



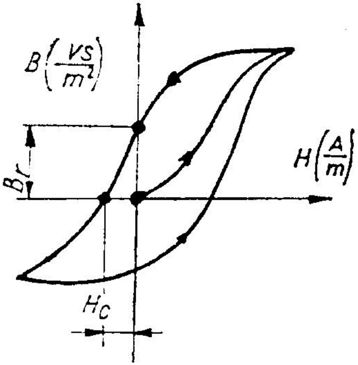
- Magnetic Properties of Solids



- Orbiting electrons produce loop currents and hence magnetic dipole moments.
- Magnetization $\mathbf{M}$ is magnetic moment per unit volume: $\mathbf{M} = \mathbf{m}/V$.
- In materials: $\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$, and $\mathbf{B} = \mu_0\mu_r\mathbf{H}$; susceptibility $\kappa = \mu_r - 1$ links $\mathbf{M}$ to $\mathbf{H}$.

- Dia-, Para-, and Ferromagnetism
  - **Diamagnetism**: $\kappa < 0$, induced magnetization opposes external field.
  - **Paramagnetism**: small positive κ, aligns with the applied field.
  - **Ferromagnetism**: large κ, strong, field-dependent magnetization and hysteresis; Curie temperature marks transition to paramagnetism.

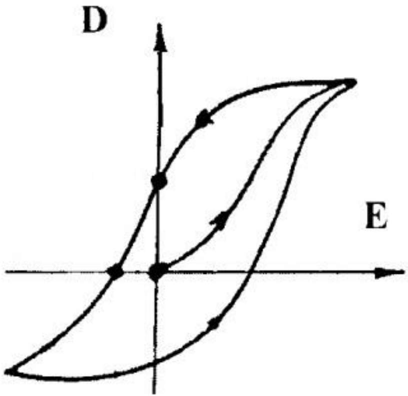
- Hysteresis and Magnetic Materials



  - Hysteresis loop shows saturation, remanence, and coercivity.
  - Small loop area: soft magnetic material; large area: hard magnetic material.
  - High coercivity and remanence make good permanent magnets.

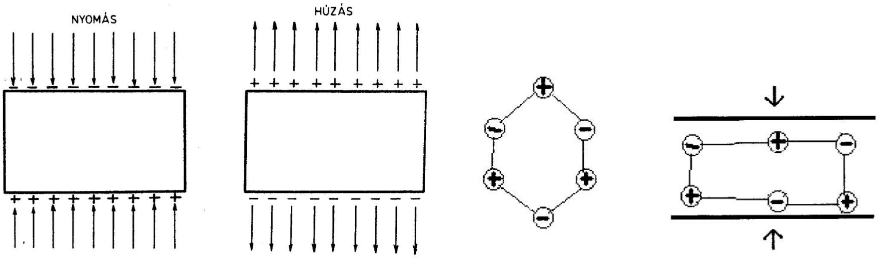
- Magnetostriction and Applications
  - Magnetostriction: dimensional changes of a ferromagnet in varying magnetic fields; source of mechanical vibration and audible noise in transformers.

- Ferroelectricity, Piezoelectricity, Electrostriction



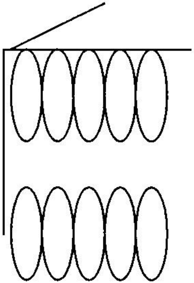
- **Ferroelectricity**: dielectric materials that exhibit spontaneous polarization with hysteresis, analogous to ferromagnetism.

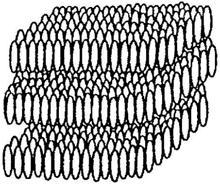
- **Piezoelectricity**: mechanical deformation induces electric polarization (Curie brothers, 1880).

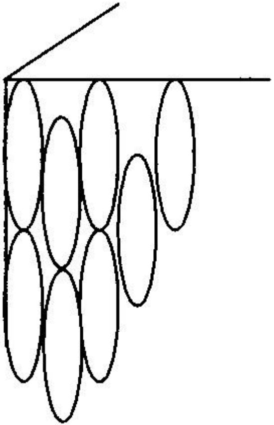


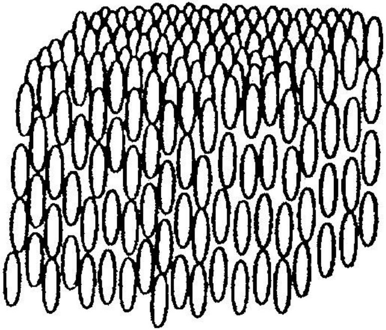
- **Electrostriction**: deformation of a dielectric under an applied electric field; related but distinct from piezoelectricity.

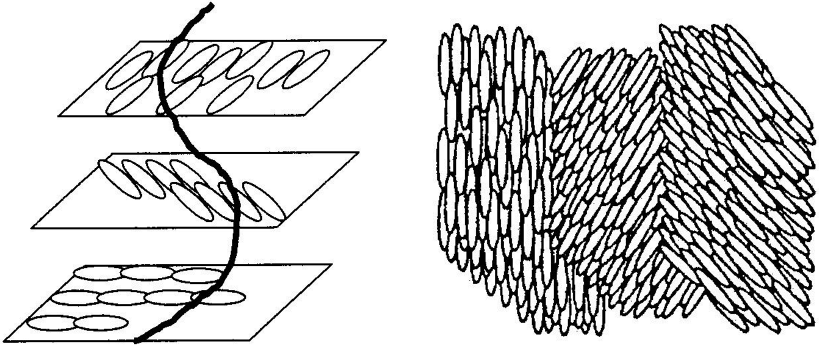
- Liquid Crystals
  - Liquid crystal state: macroscopically fluid, microscopically ordered (between crystalline and liquid).
  - Types: smectic (layered), nematic (rod-like, orientational order), cholesteric (helical stacking).
  - LCD operation principles and types summarized.

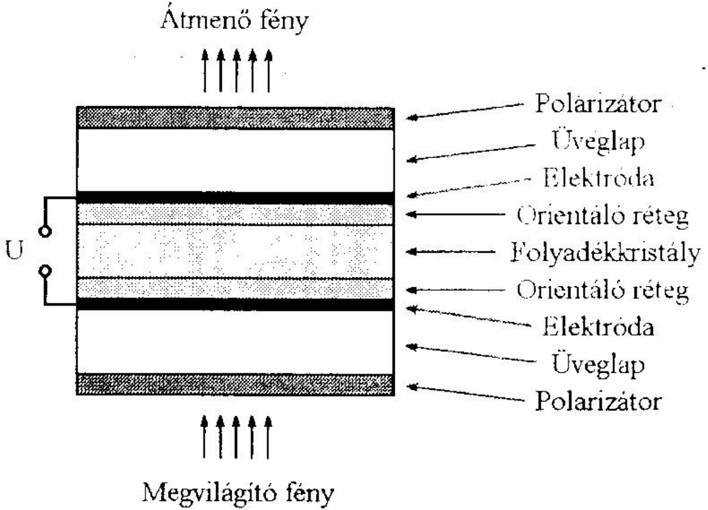











Átmenő fény
Polarizátor
Üveglap
Elektróda
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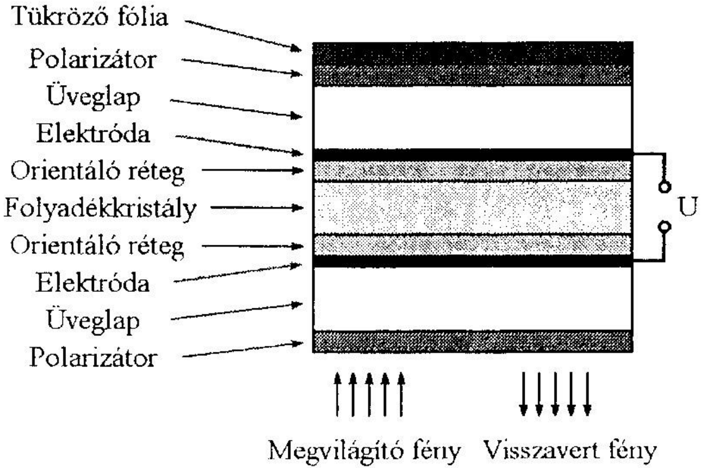
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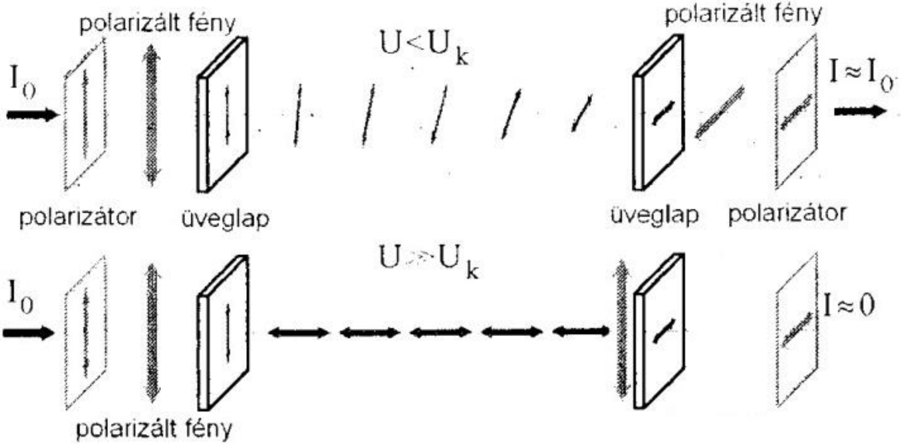
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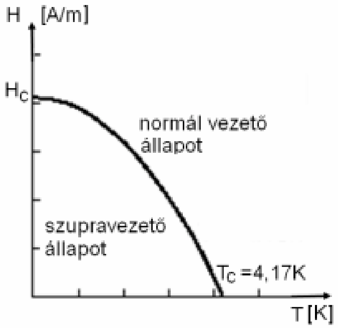
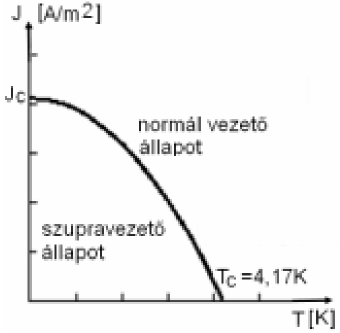
Superconductivity I

- Superconductivity: Historical Experiments
  - Kamerlingh-Onnes liquefied helium and discovered that resistance of some metals (e.g., Hg) drops abruptly to zero below a critical temperature T_c (Hg: 4.17 K).
  - Definition: superconductors have (practically) zero electrical resistance below T_c.

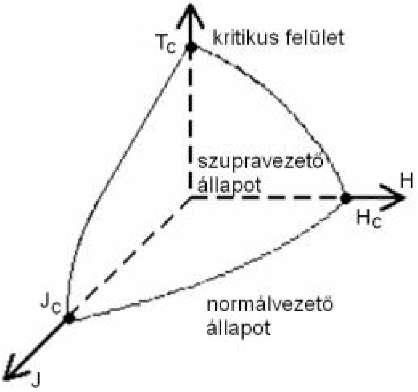
Superconductivity II

- Consequences and Properties
  - Persistent currents: a current in a superconducting ring can flow for extremely long times without decay.
  - Critical magnetic field and critical current density limit superconductivity.





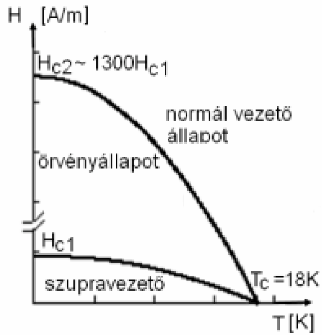
Superconductivity III



Ólom	T_c=7,2 K
Lantán	T_c=4,9 K
Higany	T_c=4,17 K
Alumínium	T_c=1,175 K
Cink	T_c=0,85 K
Urán	T_c=0,2 K

Superconductivity IV

- Type I and Type II Superconductors
  - **Type I**: typically pure elemental superconductors with a single critical field.
  - **Type II**: alloys and compounds showing mixed state (vortices) between lower and upper critical fields; often higher T_c.



Nióbium	T_c=9,25 K
Technécium	T_c=7,8 K
Vanádium	T_c=5,4 K
Nb_3Ge	T_c=23,2 K
Nb_3Si	T_c=19 K
Nb_3Sn	T_c=18,1 K
Nb_3Al	T_c=18 K
V_3Si	T_c=17,1 K

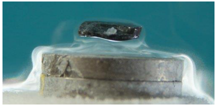
Superconductivity V

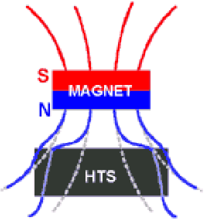
- High-Temperature Superconductivity (HTSC)
  - 1986: Bednorz and Müller discovered copper-oxide ceramics with T_c above liquid nitrogen temperature (77 K), initiating HTSC research.

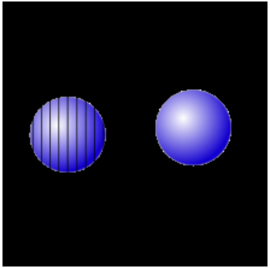
$Hg_{0,8}Tl_{0,2}Ba_2Ca_2Cu_3O_{8,33}$	$T_c = 138\ K$
$HgBa_2Ca_2Cu_3O_8$	$T_c = 133\ K$
$HgBa_2Ca_3Cu_4O_{10}$	$T_c = 125\ K$
$Tl_2Ba_2Ca_2Cu_3O_{10}$	$T_c = 127\ K$
$Bi_2Sr_2Ca_2Cu_3O_{10}$	$T_c = 110\ K$
$YBa_2Cu_3O_7$ (YBCO)	$T_c = 93\ K$
$Y_2Ba_4Cu_7O_{15}$	T_c=93 K.

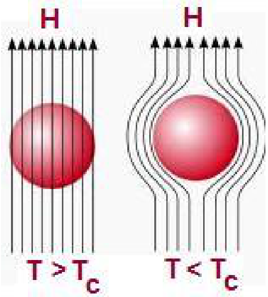
Superconductivity VI

- Meissner–Ochsenfeld Effect
  - Superconductors expel magnetic flux when transitioning into the superconducting state — perfect diamagnetism (Meissner effect).







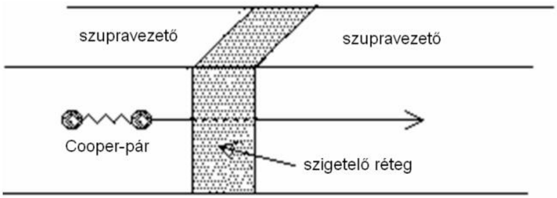


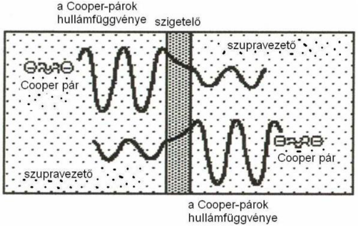
Superconductivity VII

- BCS Theory and Cooper Pairs
  - Bardeen–Cooper–Schrieffer (BCS) theory (1957): electrons form Cooper pairs via phonon-mediated attraction, leading to a superconducting gap and Bose-like behavior of pairs.

Superconductivity VIII

- Josephson Effect
  - Josephson predicted tunneling of Cooper pairs across an insulating barrier between two superconductors, leading to DC and AC Josephson effects.





The End

Thank you for your attention!