IILM University, Greater NOIDA

Dr. Nidhi Puri

Physics
Solid State Physics

Solid State Physics:

Energy band in solids, Fermi Dirac Distribution, Function and Fermi level, Classification: metals, semiconductors, and insulators.

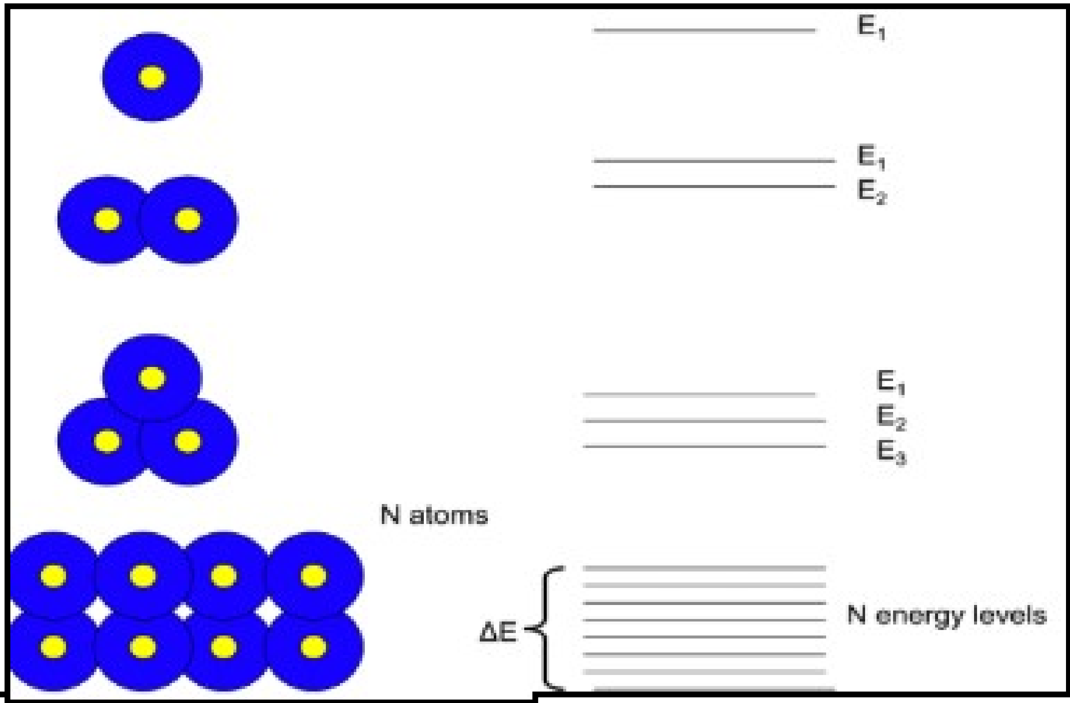
Superconductors: Temperature dependence of resistivity and critical field in superconducting materials, Meissner effect, Type I and Type II superconductors, High temperature superconductors (basic idea).

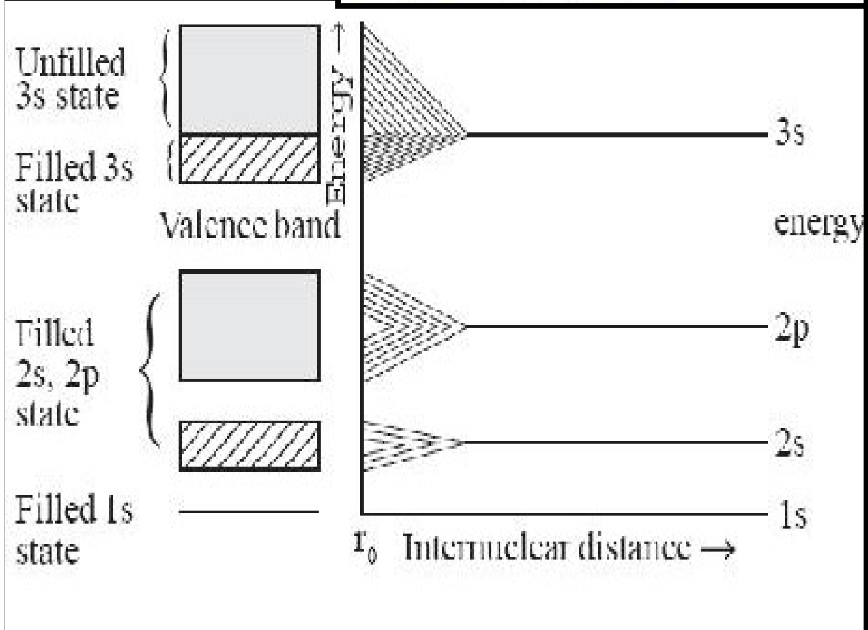
BAND THEORY IN SOLIDS

- When atoms are brought together to form a crystal, the valence electrons interact and constitute a simple system of electrons common to the entire crystal. Therefore all electrons have to occupy different energy levels, which may be brought about by the forces exerted by the nuclei of all atoms. As a result of these forces each atomic energy level splits into large number of closely spaced energy levels. A set of such closely spaced energy levels is called a band.

- Each energy band has large number of energy levels. The energy levels are filled according to Pauli Exclusion Principle which states that an energy level can accommodate only two electrons and each electron can have two possible states (spin up or spin down)

- The width of this band depends on the degree of overlap of electrons of adjacent atoms.The amount of splitting is not same for different levels. The levels filled by valence electrons are distributed to a great extent, while those filled with electrons of inner shells are distributed only slightly.





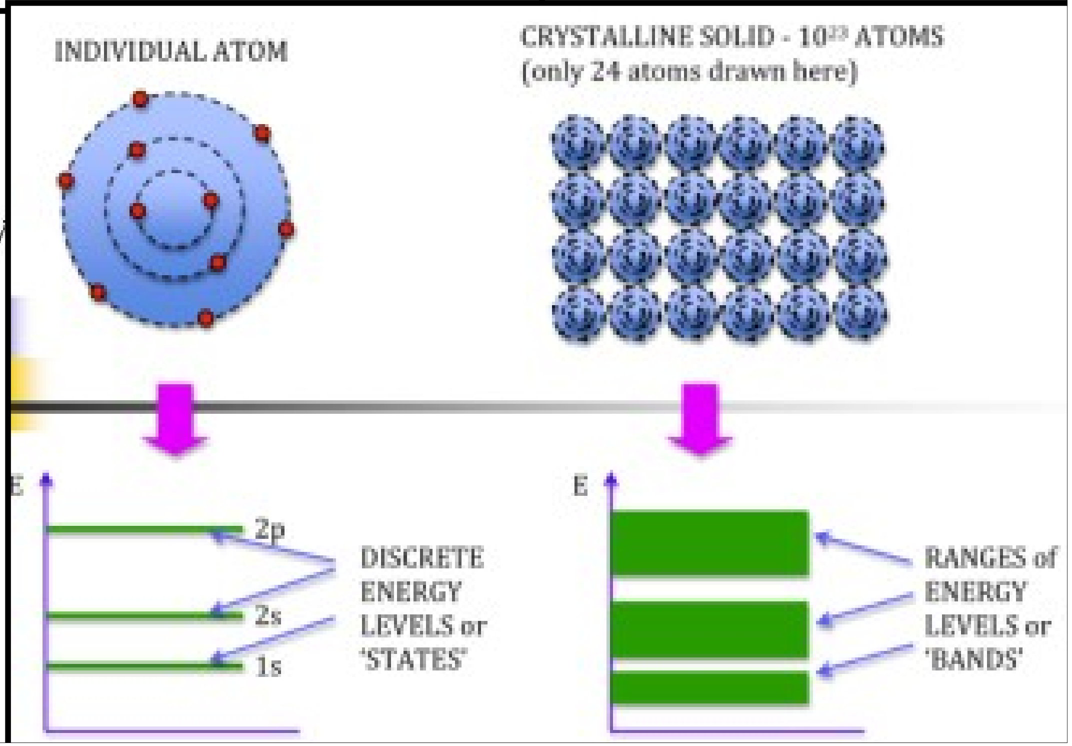


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Fig. 10 Energy level of sodium

- **VALANCE BAND**:

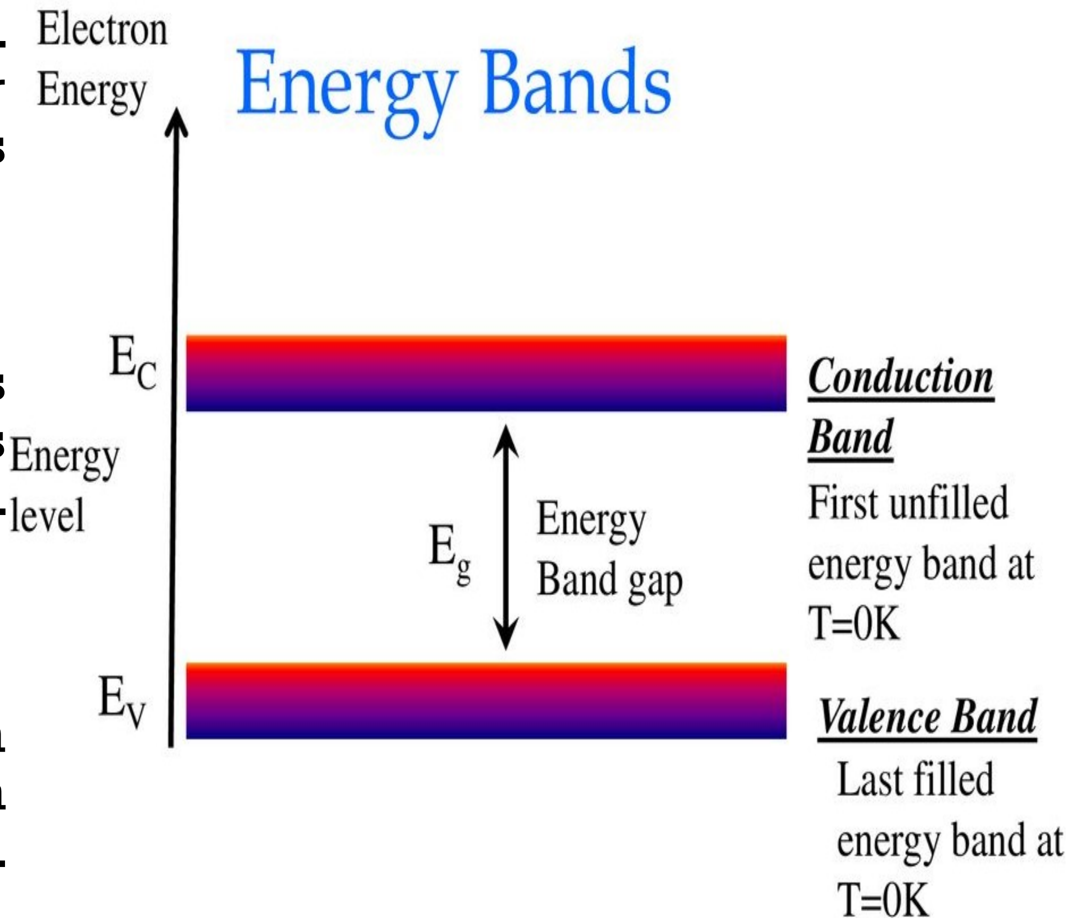
  In this band large number of free electrons are available. This band is partially or completely filled. This band is never empty.

- **CONDUCTION BAND:**

  The density of electrons in this band is very low. This band is either empty or partially filled. This band can be empty.

- **FORBIDDEN BAND:**

  The separation between valance band and conduction band is called forbidden band. This band is completely empty.



Energy Bands

Valence Band

- In this energy band there are large no of free electrons available.
- These bands never get empty.
- The major disadvantage of the electrons present in this band is that these electrons are unable to attain energy from any external source of electric field.

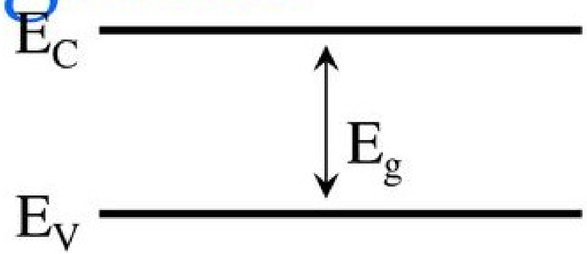
Conduction Band

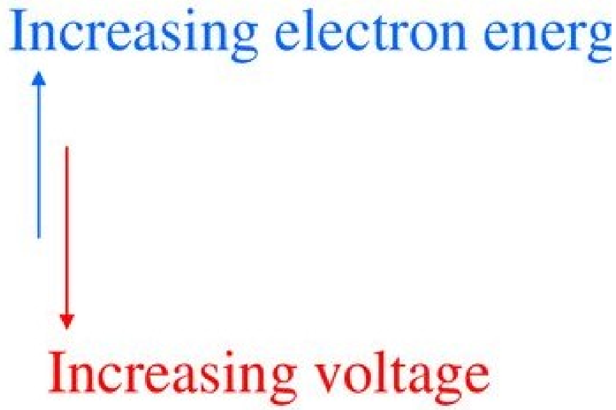
- The density of the electrons is very few.
- As compared to the electrons present in the valence energy bands, these electrons can gain energy from the external field of electric field.

Forbidden Band (or) Energy Gap

- Electrons are absent in this energy band.
- Some little amount of energy is needed for electron shifting to conduction band from valence band

Band Diagrams





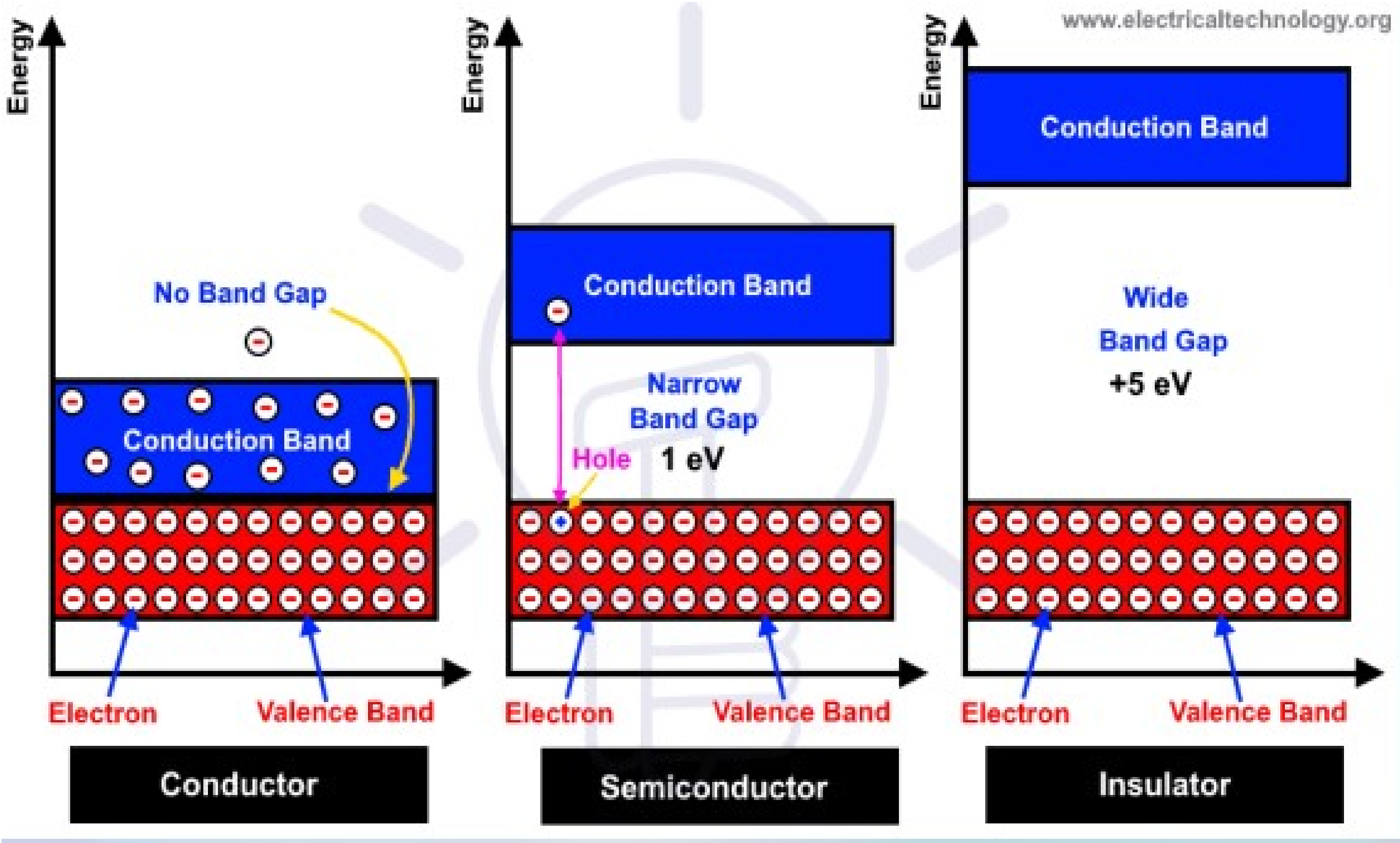
<u>Band Diagram Representation</u>
Energy plotted as a function of position

E_C → Conduction band
→ Lowest energy state for a free electron

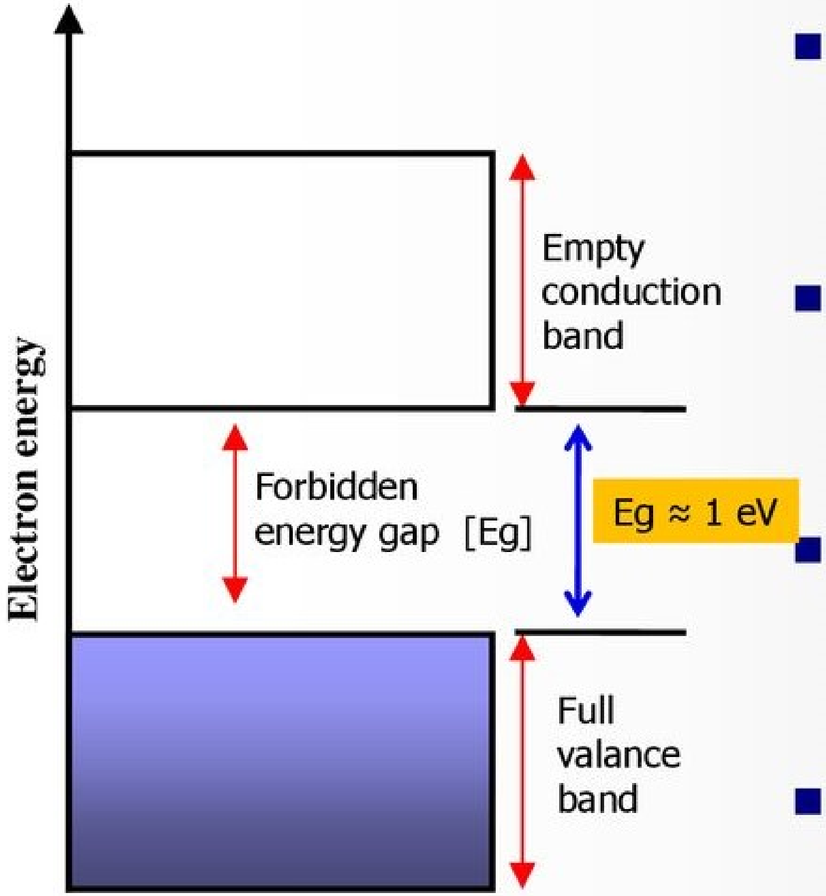
E_V → Valence band
→ Highest energy state for filled outer shells

E_G → Band gap
→ Difference in energy levels between E_C and E_V
→ No electrons (e^-) in the bandgap (only above E_C or below E_V)
→ E_G = 1.12eV in Silicon

CLASSIFICATION OF SOLIDS



.:: Semiconductor energy bands at low temperature ::.



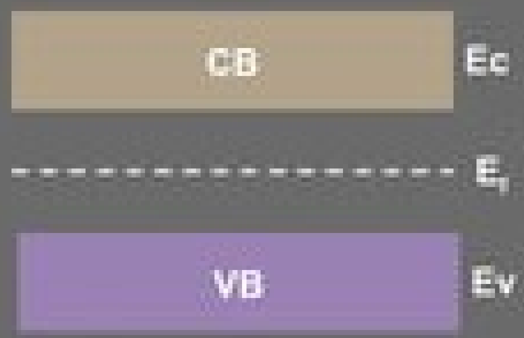
- At low temperatures the valance band is *full*, and the conduction band is empty.
- Recall that a full band can not conduct, and neither can an empty band.
- At low temperatures, s/c's do not conduct, they behave like insulators.
- The *thermal energy* of the electrons sitting at the top of the full band is much lower than that of the *Eg at low temperatures*.

Semiconductor

- Semiconductor is a material that has a resistivity value between that of a conductor and an insulator.
- There are two types of semiconductors
    - Intrinsic semiconductors
    - Extrinsic semiconductor
        - P - type semiconductor
        - N - type semiconductor

Intrinsic semiconductors

- An intrinsic semiconductor is a pure semiconductor
- The number of excited electrons and the number of holes are equal: n = p.



Extrinsic semiconductor

An extrinsic semiconductor is a semiconductor that has been doped

P - TYPE SEMICONDUCTOR

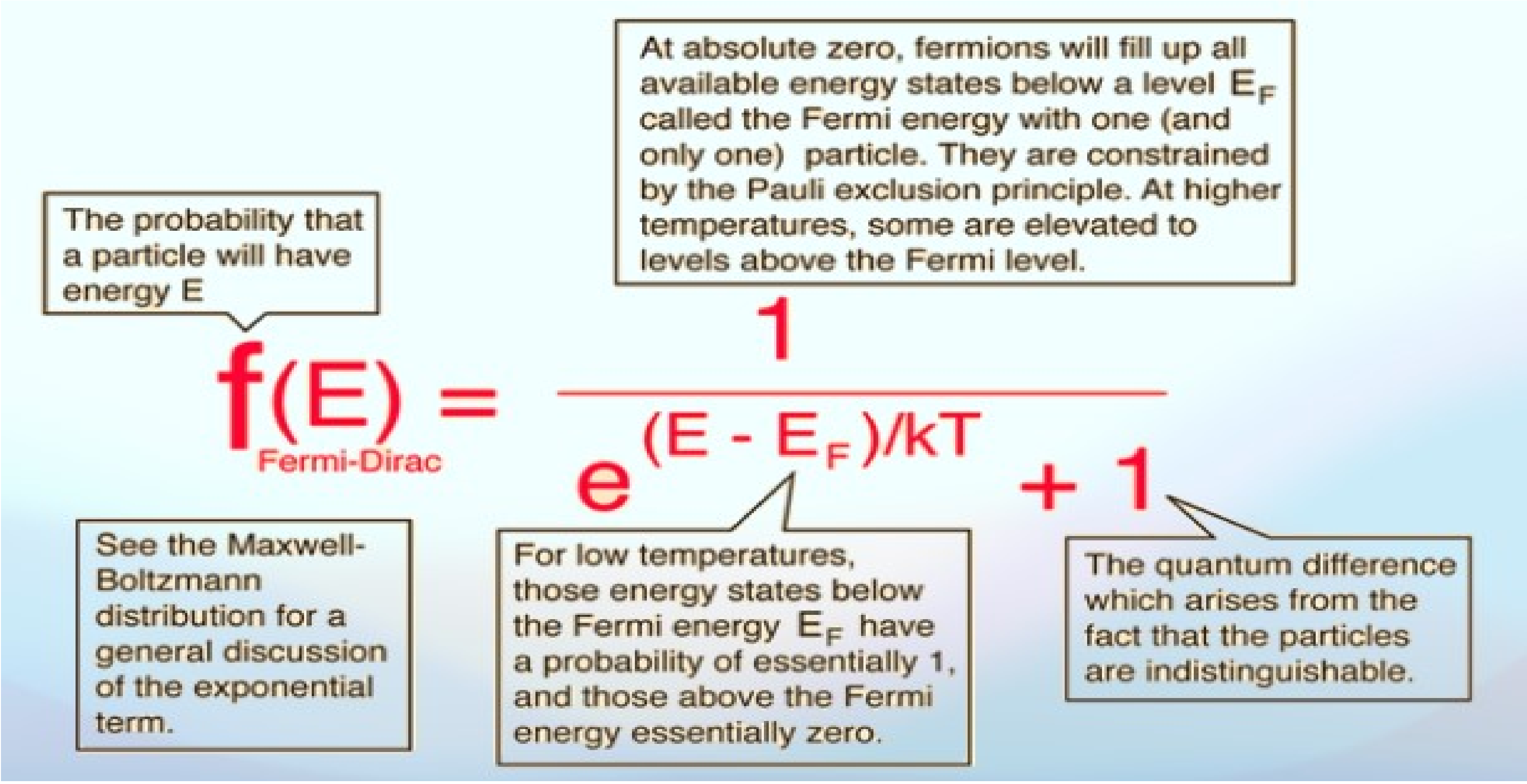
p-type semiconductors have a larger hole concentration than electron concentration

N - TYPE SEMICONDUCTOR

n-type semiconductors have a larger electron concentration than hole concentration

FERMI DIRAC DISTRIBUTION

- The electrons that occupy orbits are described by Fermi Dirac distribution. It represents the probability of occupation of a state with energy E.
- The Fermi-Dirac distribution applies to fermions, particles with half-integer spin which must obey the Pauli Exclusion Principle.



FERMI DIRAC DISTRIBUTION

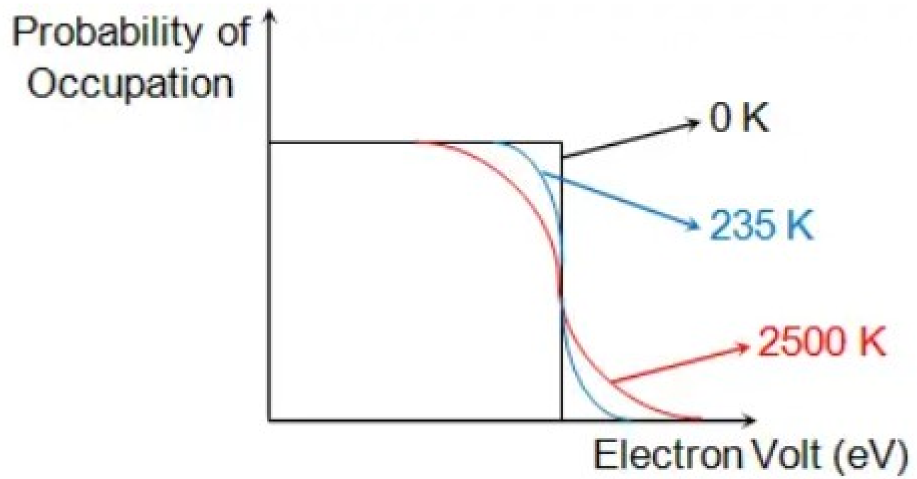
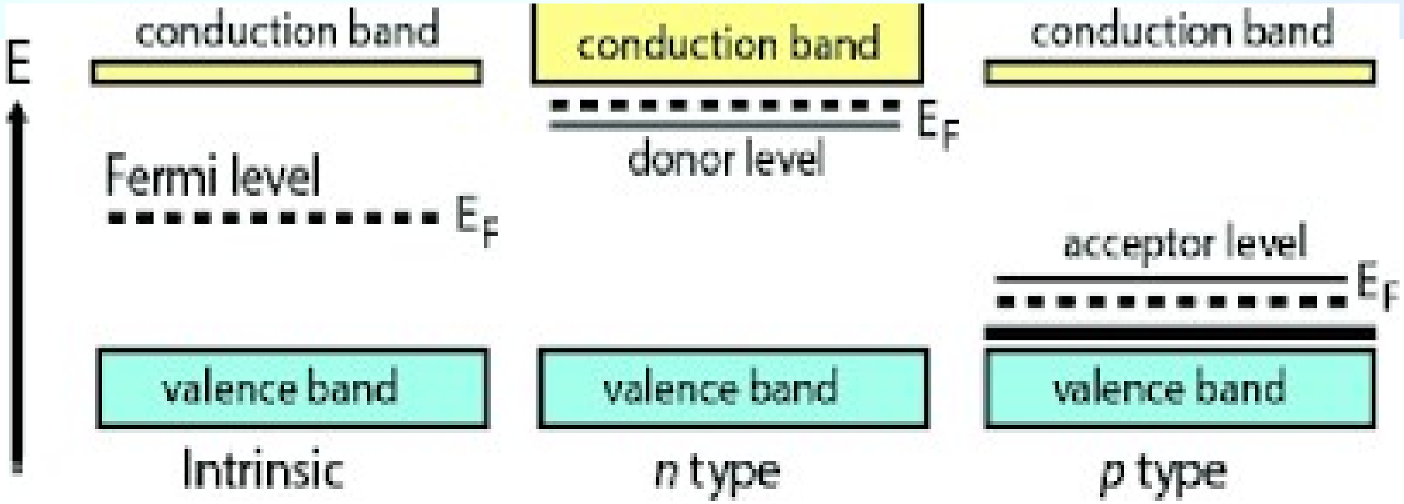


Figure 2 Fermi-Dirac Distribution Function at Different Temperatures

FERMI LEVEL

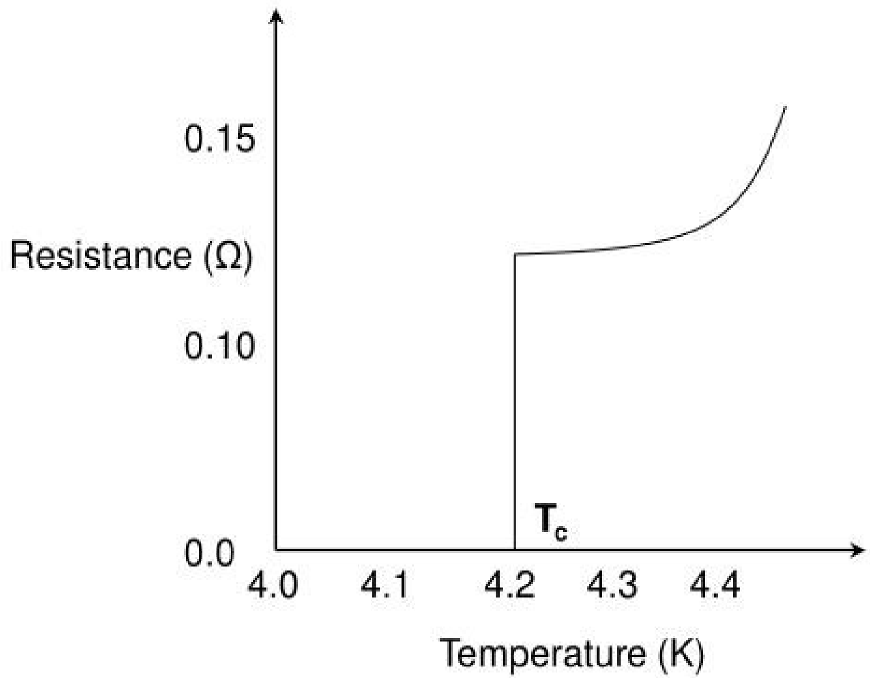
- Maximum Possible energy possessed by free electrons at absolute zero.
- Fermi energy is the measure of the energy of the least tightly held electrons within a solid
- Value of fermi energy is different for different materials.
- Fermi level is that energy level in energy-band-diagram for which the probability of occupancy becomes half.



SUPERCONDUCTING MATERIALS

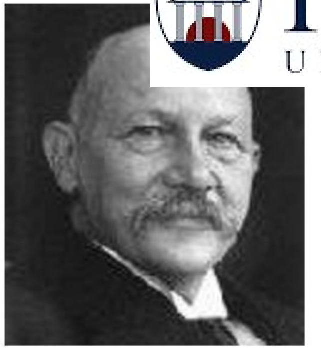
Superconductivity - The phenomenon of losing resistivity when sufficiently cooled to a very low temperature (below a certain critical temperature).

- H. Kammerlingh Onnes – 1911 – Pure Mercury

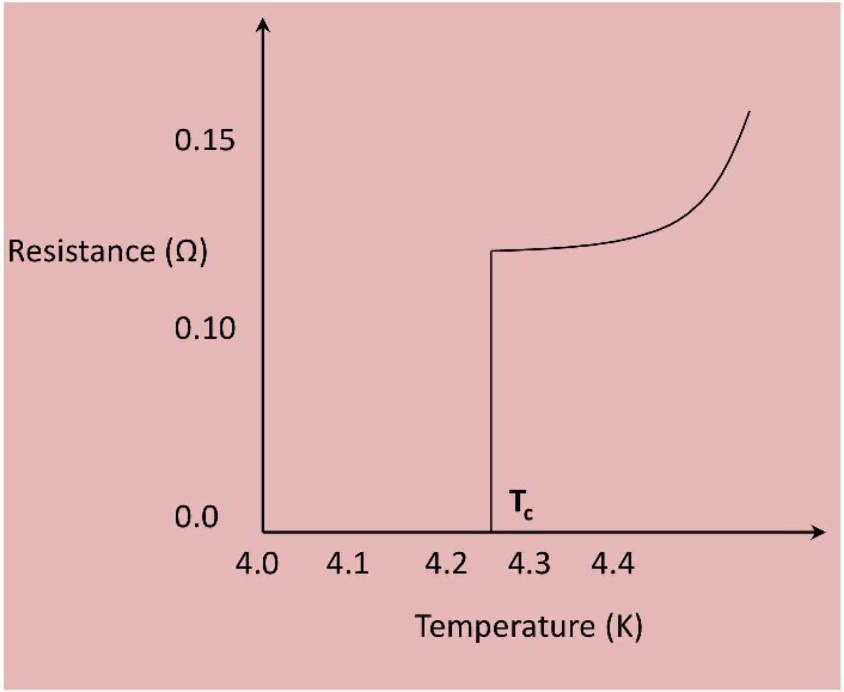


WHO FOUND IT?

- Superconductivity was discovered in 1911 by Heike Kammerlingh Onnes , who studied the resistance of solid mercury at cryogenic temperatures using the recently discovered liquid helium as 'refrigerant'.
- At the temperature of 4.2 K , he observed that the resistance abruptly disappears.
- For this discovery he got the NOBEL PRIZE in PHYSICS in 1913.
- In 1913 lead was found to super conduct at 7K.
- In 1941 niobium nitride was found to super conduct at 16K



H. Kammerlingh Onnes – 1911 – Pure Mercury



Transition Temperature or Critical Temperature (T_C)

Temperature at which a normal conductor loses its resistivity and becomes a superconductor.

- Definite for a material
- Superconducting transition reversible
- Very good electrical conductors not superconductors eg. Cu, Ag, Au
- Types

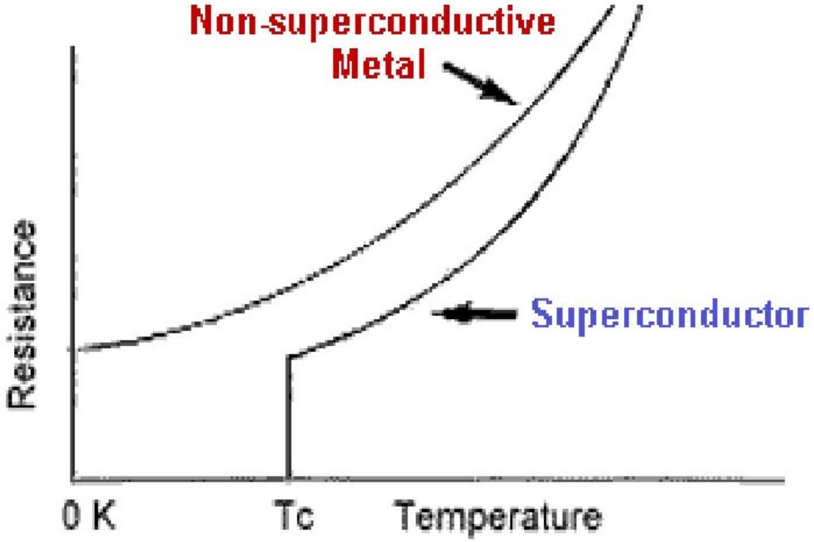
1. Low T_C superconductors
2. High T_C superconductors

SUPERCONDUCTING MATERIALS

Superconductivity - The phenomenon of losing resistivity when sufficiently cooled to a very low temperature (below a certain critical temperature).

Properties of Superconductors

- Zero Electrical Resistance
- Defining Property
- Critical Temperature
- Quickest test
- $10^{-5}\Omega cm$



Effect of Magnetic Field

The superconducting state of the material cannot exist in presence of a magnetic field of critical value even at absolute zero temperature.

- Critical magnetic field (H_C) – Minimum magnetic field required to destroy the superconducting property at any temperature

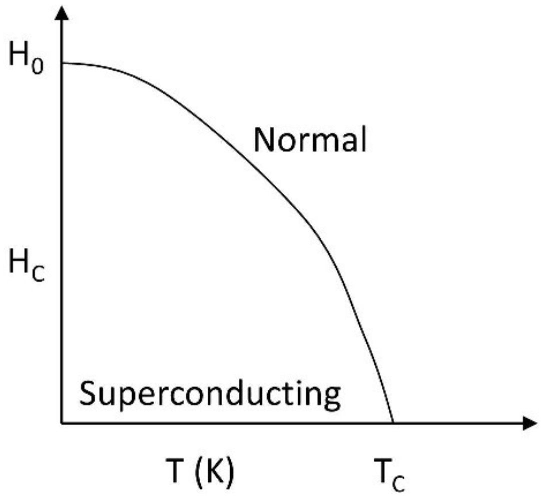
$$H_C = H_0\left[1-\left(\frac{T}{T_C}\right)^2\right]$$

H_0 – Critical field at 0K

T - Temperature below T_C

T_C - Transition Temperature

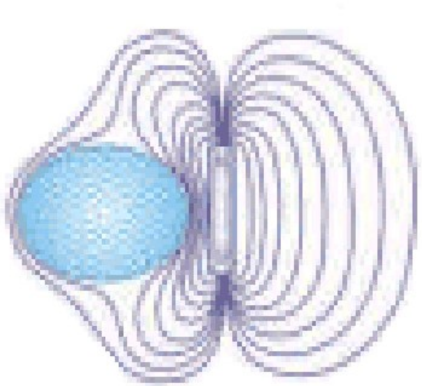
Element	H_C at 0K (mT)
Nb	198
Pb	80.3
Sn	30.9



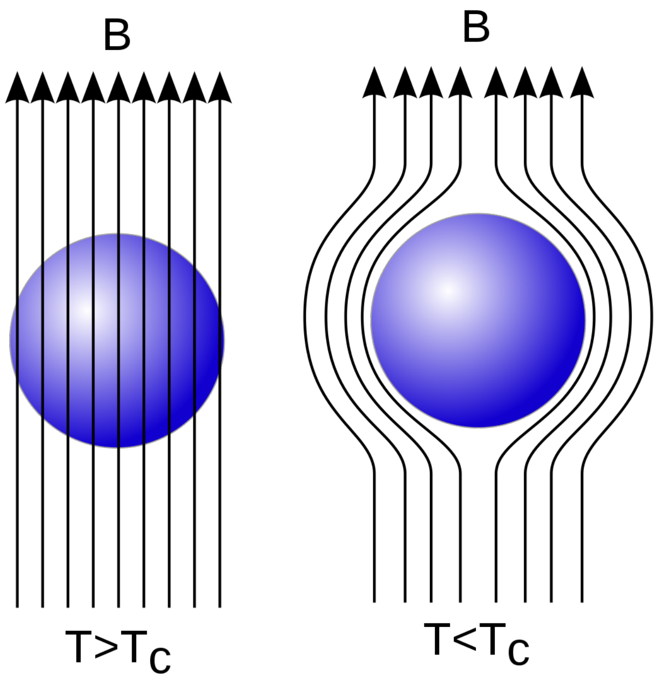
MEISSNER EFFECT

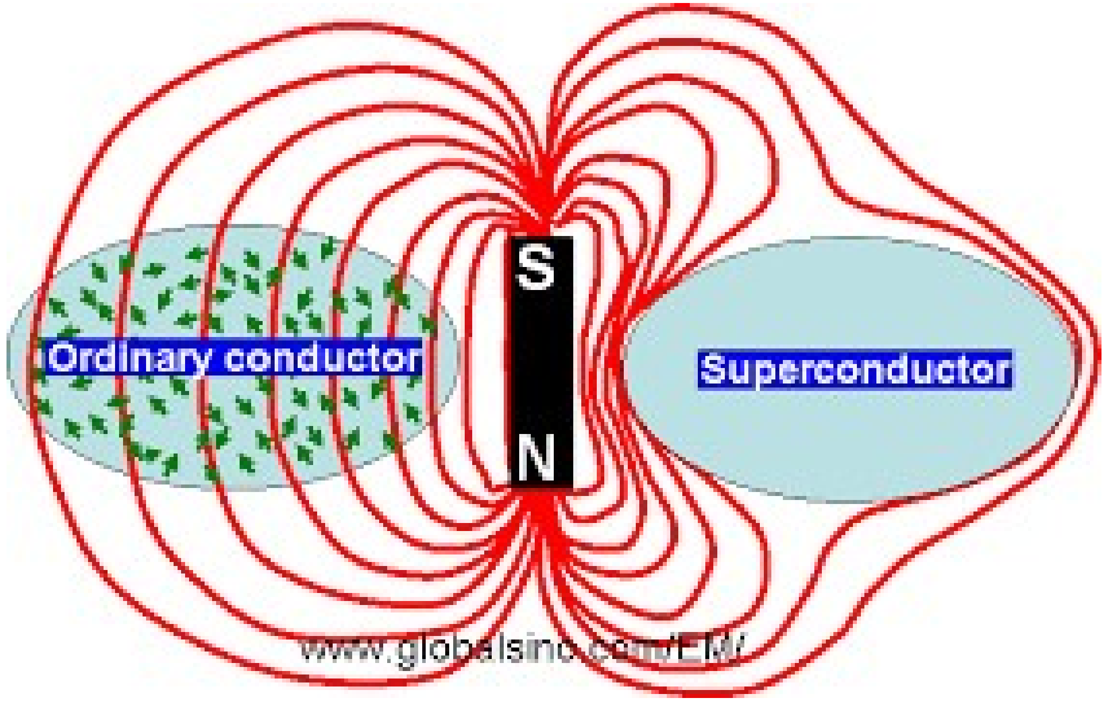
- When the superconducting material is placed in a magnetic field under the condition when $T \leq T_C$ and $H \leq H_C$, the flux lines are excluded from the material.

- Material exhibits perfect diamagnetism or flux exclusion.
- Deciding property
- $\chi = I/H = -1$
- Reversible (flux lines penetrate when T ↑ from T_C)



- Conditions for a material to be a superconductor
  i. Resistivity $\rho = 0$
  ii. Magnetic Induction B = 0 when in an uniform magnetic field
- Simultaneous existence of conditions


B
B
T>TC
T<TC


S
N
Ordinary conductor
Superconductor
www.globalsino.com/EM/

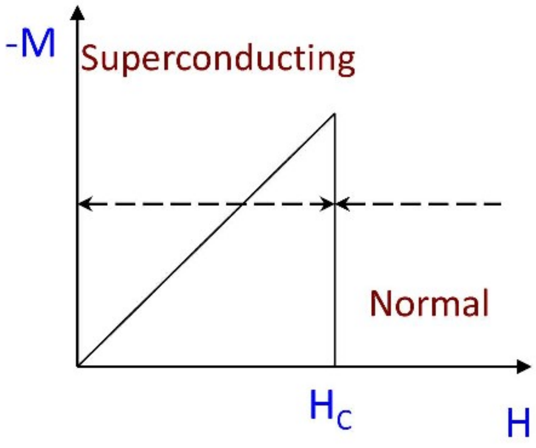
Types of Superconductors

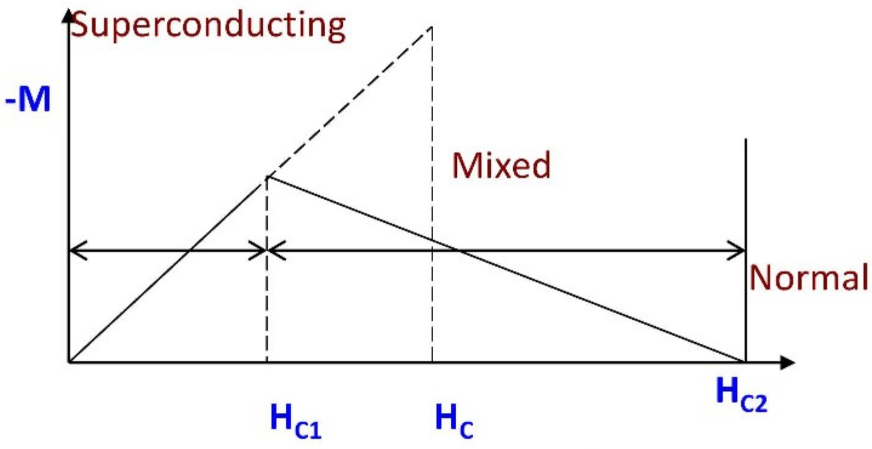
Type I

- Sudden loss of magnetization
- Exhibit Meissner Effect
- One H_C = 0.1 tesla
- No mixed state
- Soft superconductor
- Eg.s – Pb, Sn, Hg

Type II

- Gradual loss of magnetization
- Does not exhibit complete Meissner Effect
- Two H_Cs – H_{C1} & H_{C2} (≈30 tesla)
- Mixed state present
- Hard superconductor
- Eg.s – Nb-Sn, Nb-Ti





High Temperature Superconductivity (HTSC) in Copper Oxides

- As soon as the high temperature superconductivity was discovered by Bednorz and Müller in 1986, I started a theoretical work to try to clarify the electronic structures of copper oxides and the origin of superconductivity with my coworkers and graduate students.
- **At the beginning of this talk, I summarize the present status of research of high temperature superconductivity from the standpoint of spin effects,** by choosing the simplest system of cuprates (copper oxides), the lanthanum strontium copper oxides, $La_{2-x}Sr_xCuO_4$.

APPLICATIONS

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High-Temperature Superconductors

Electronics
Sensors
Supercomputers
Cryoelectronic Components

Basic Research
High-Field Magnets
SQUID Sensors
Bolometers
Particle Detectors

Medical Technique
SQUID Diagnostics
Magnetic Resonance Imaging (MRI)

Microwave Technique
Filters
Antenna
Resonators
Delay Lines
Active Components

Power Engineering
Generators
Motors
Transformers
Current Limiters
Switchers
Cables
Energy Storages

Traffic Engineering
Magnetic Transport Systems
Ship's Engines
Maglev Trains

Superconductors

In Medical areas

- magnetic resonance imaging
- biotechnical engineering.

In Electronics

- SQUIDs
- transistors
- Josephson Junction devices
- circuitry connections
- particle accelerators
- sensors

In Industrial

- separation
- magnets
- sensors and
- magnetic shielding

e.t.c.