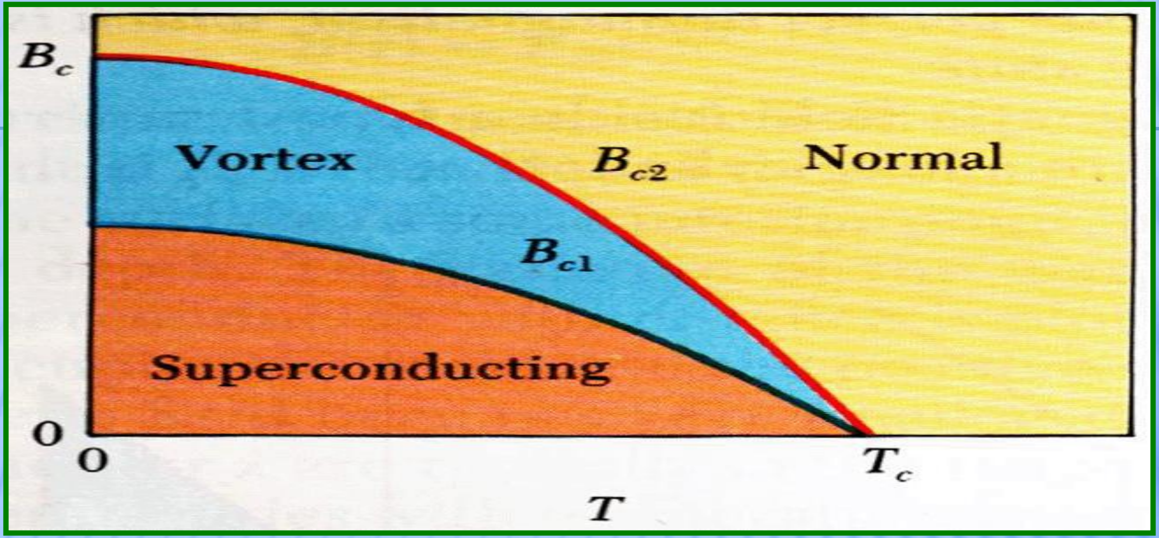
Type II Superconductor

- **By the 1950, it was established another class of superconductors known as type II superconductors.**

- **These materials are characterized by two critical magnetic fields, designated as B_{c1} and B_{c2},**

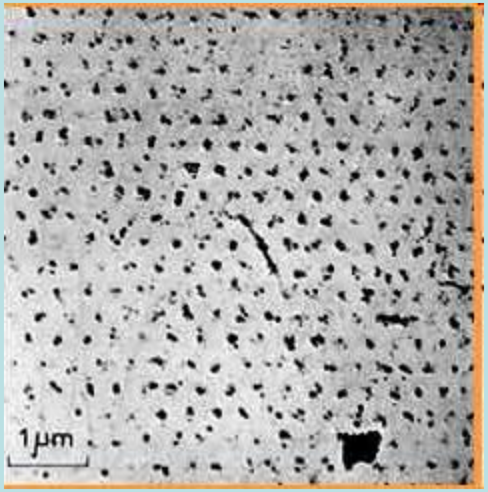


- **At the applied field $B < B_{c1}$, the material is entirely superconducting and there is no flux penetration, just as in case of type I superconductors.**

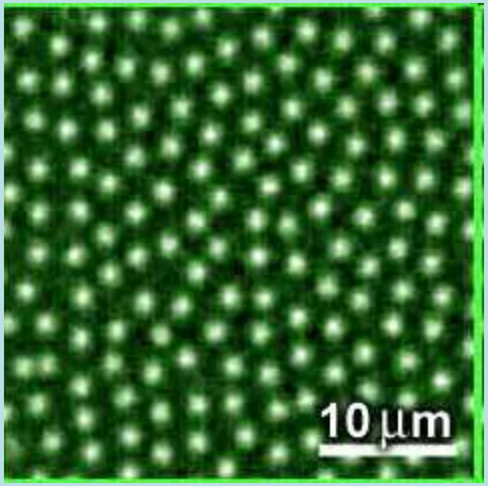
- **At $B > B_{c2}$, the flux penetrates entirely and the superconducting state is destroyed like in type I materials.**

- **For $B_{c1} < B < B_{c2}$, the material is in a mixed state referred to as the Vortex state.**

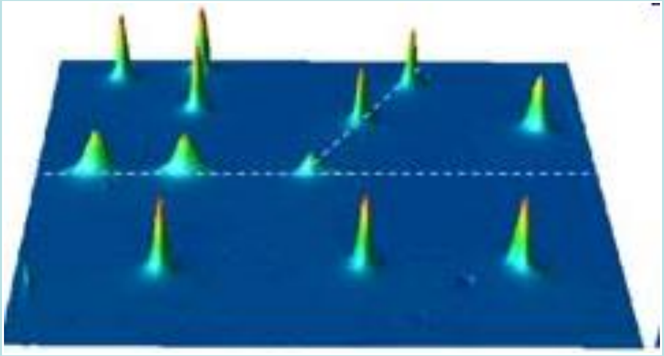
- **In the Vortex State, the material can have zero resistance and has partial flux penetration.**



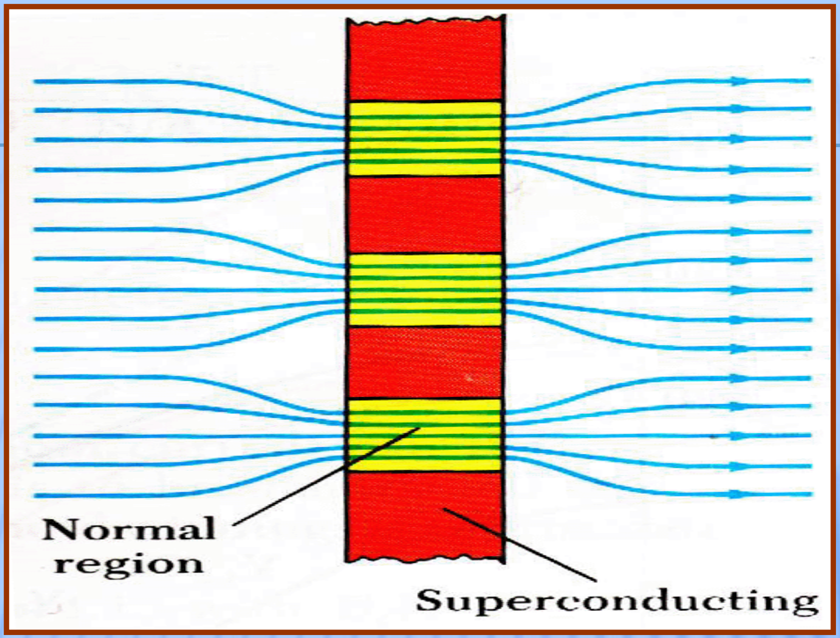
U. Essmann and H. Traubl e
Max-Planck Institute, Stuttgart
Physics Letters 24A, 526 (1967)



Magneto-optical image of Vortex lattice, 2001
P.E. Goa et al.
University of Oslo
Supercond. Sci. Technol. 14, 729 (2001)



Scanning SQUID Microscopy of half-integer vortex, 1996
J. R. Kirtley et al. IBM Thomas J. Watson Research Center
Phys. Rev. Lett. 76, 1336 (1996)



- The Vortex regions are essentially filaments of normal material that run through the sample oriented parallel to the external magnetic field.

- As the strength of the applied field **B** increases the number of filaments increases until the field reaches the upper critical value B_{c2}, and the sample becomes normal.

- One can view the Vortex State as a cylinder swirl of supercurrents surrounding a cylindrical normal material core, which allows some flux to penetrate the interior of the type II superconductor.

- **Associated with each vortex filament is magnetic field, which is greatest at the core center and falls of exponentially out side the core with the characteristic penetration depth λ.**

- **The supercurrents are the "source" of B for each vortex.**

- **Type II superconductors are compounds formed from elements of the transition and actinide series.**

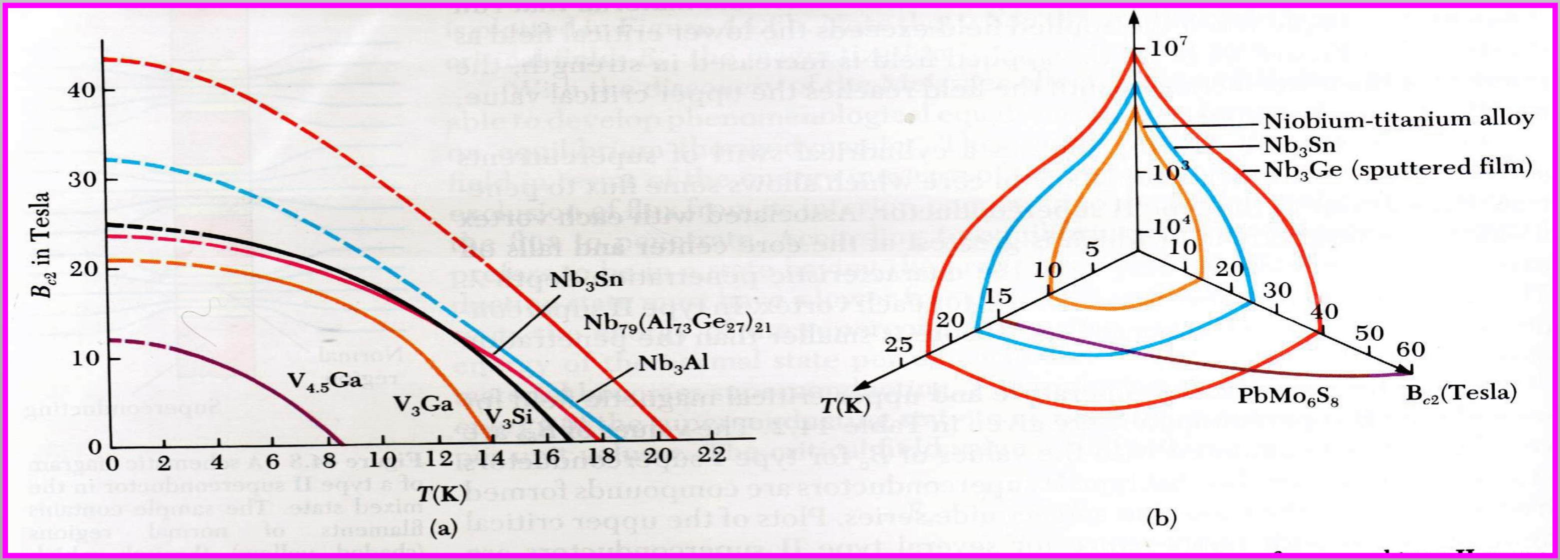
- **The values of the critical fields B_{c2} are very large compared to the values of B_c for type I superconductors, as shown in the following Table.**

Superconductor	T_c	$B_{c2}(0)$ in Tasla
Nb_3Al	18.7	32.4
Nb_3Sn	18.0	24.5
Nb_3Ge	23	38
NbN	15.7	15.3
NbTi	9.3	15
$Nb_3(AlGe)$	21	44
V_3Si	16.9	23.5
V_3Ga	14.8	20.8
PbMoS	14.4	60

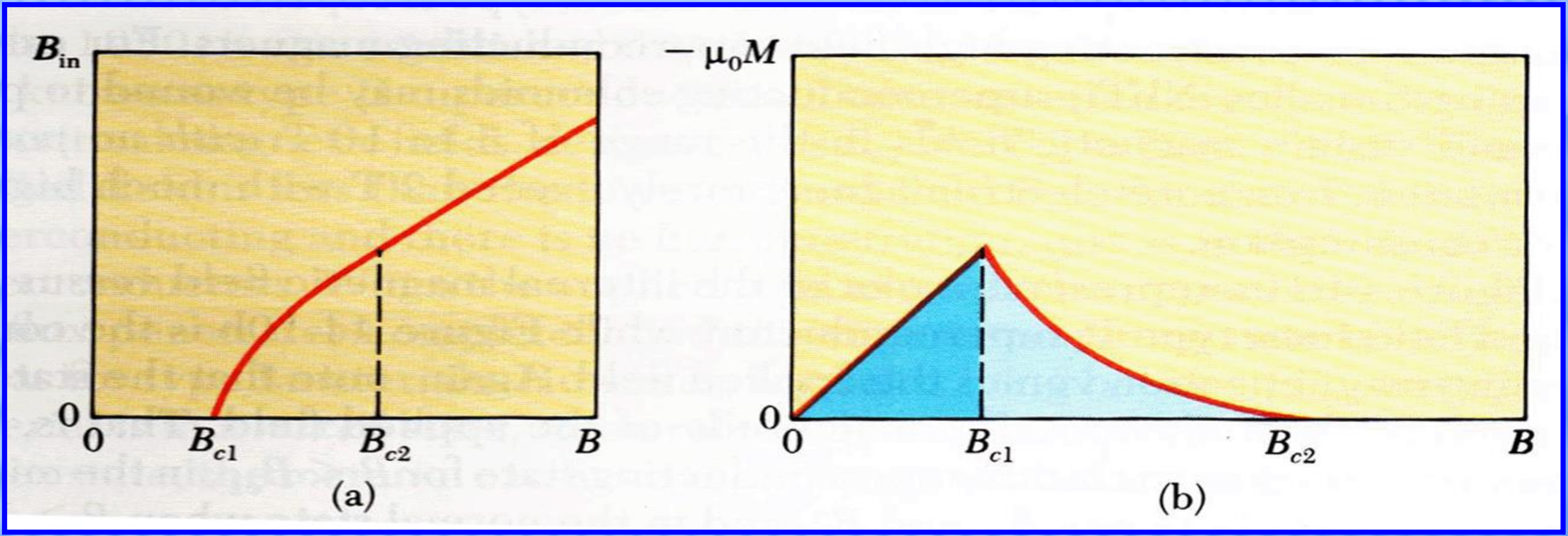
- For example, the upper critical field for the alloy Nb3(AlGe) is B_{c2} = 44 T, and its critical temperature is T_c = 21 K. For this reason, type II superconductors are well suited for constructing high-field superconducting magnets.

- For example, using the alloy NbTi, superconducting solenoids may be wound to produce and sustain magnetic fields in the range of 5 to 10 T *with no power consumption.* Iron core electromagnets rarely exceed 2T with much higher power consumption.

- Plots of B_{c2} vs. T, and the three-dimensional plot of T_c with both B_{c2} and critical current density, J_c, for several type II superconductors.



- The Figure below shows the magnetic behavior of a type II superconductor. (a) Plot of the internal field B_{in} versus the applied field **B**. (b) Plot of the magnetization **M** versus the applied field **B**.



- **When a type II superconductor is in the mixed state, sufficiently large currents can lead to a motion of vortices perpendicular to the direction of the current.**

- **This vortex motion corresponds to a change in flux with time, and produces resistance in the material.**

- **By adding impurities or other special inclusions, one can effectively pin the vortices and prevent their motion, to produce zero resistance for the mixed state of the superconductor.**

- **Coherence Length, ξ, is an important parameter associated with superconductivity. One can think of the coherence length as the smaller dimension over which superconductivity can be established or destroyed.**

- **Alternatively, one can view the coherence length as the distance over which the electrons in a cooper pair remain together.**

- **Typical values of the penetration depth λ and ξ at T = 0 K for selected superconductor are given in the following Table:**

Superconductor	λ (nm)	ξ (nm)
AL	16	160
Cd	110	760
Pb	37	83
Nb	39	38
Sn	34	23

- **According to Ginzburg-Landau (G-L) Theory :**
- **If ξ > λ , the superconductor will be type I. Most pure metals fall into this category.**

- **On the other hand, if ξ < λ , the material is a type (II) superconductors.**