INTRODUCTION TO SUPERCONDUCTIVITY

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LECTURE 1

GENERALITIES ABOUT SUPERCONDUCTIVITY

Superconductivity – a little history.

1908	Kamerlingh Onnes liquefies helium
1911	Kamerlingh Onnes discovers superconducting in Hg at $\sim 4K$
1933	Meissner effect
1935-50	phenomenological theory (London, Ginzburg – Landau)
1957	BCS Theory (based on phonon mechanism)
1979	"non-phonon" superconductivity discovered in $CeCu_2Si_2$
1986	superconductivity at temperature $> 90\text{K}$.
2000-	applications to quantum computing etc.
2015	phonon superconductivity > 200K.

What is superconductivity?

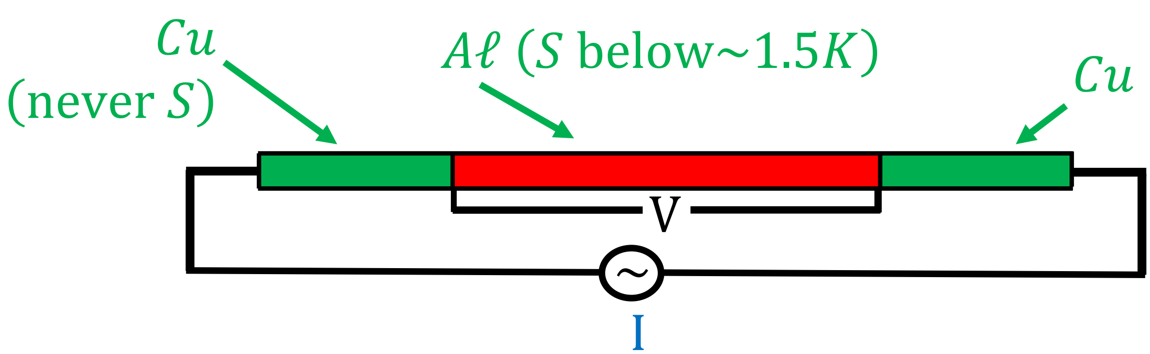
3 qualitative differences between superconducting (S) and normal (N) state:

1. Zero resistance (persistent currents)

2. Perfect diamagnetism (Meissner effect)

3. Zero Peltier coefficient

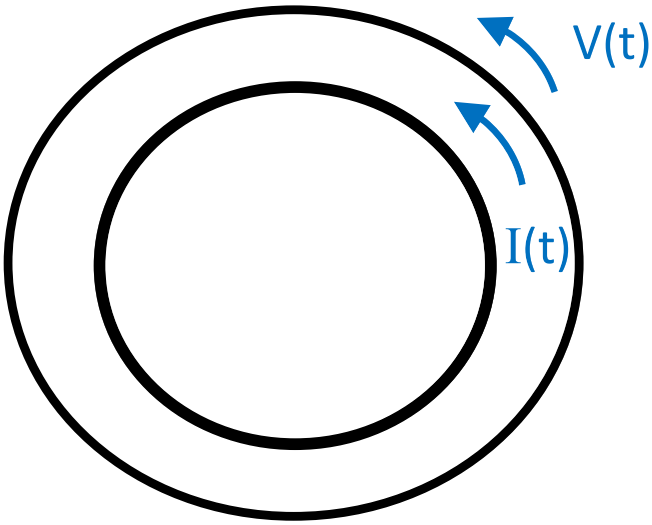
1. Zero resistance:

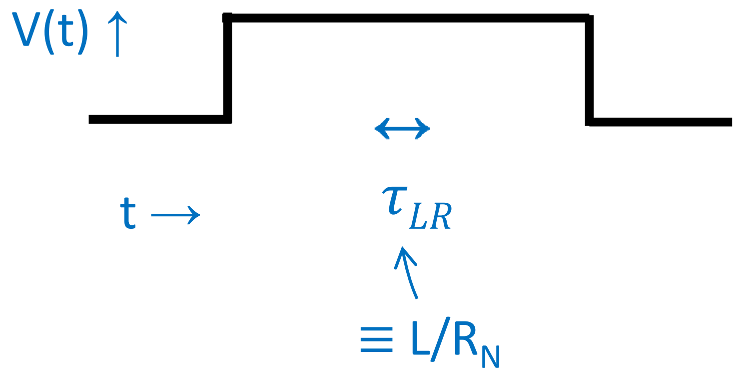


R of $A\ell \equiv \mathrm{V/I}$

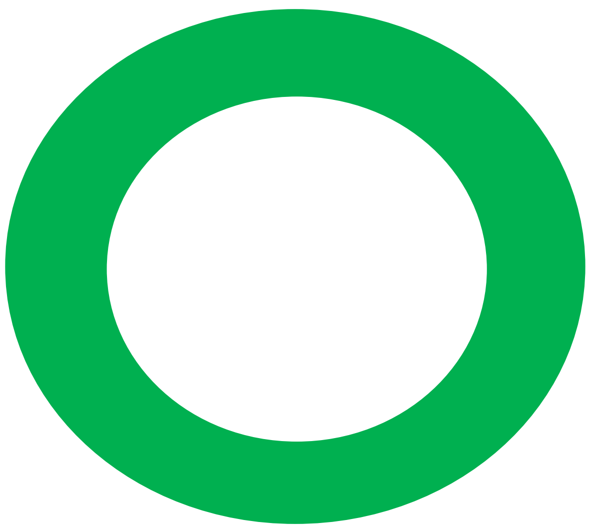
In S state, $\mathrm{V} = 0$ so $R = 0$

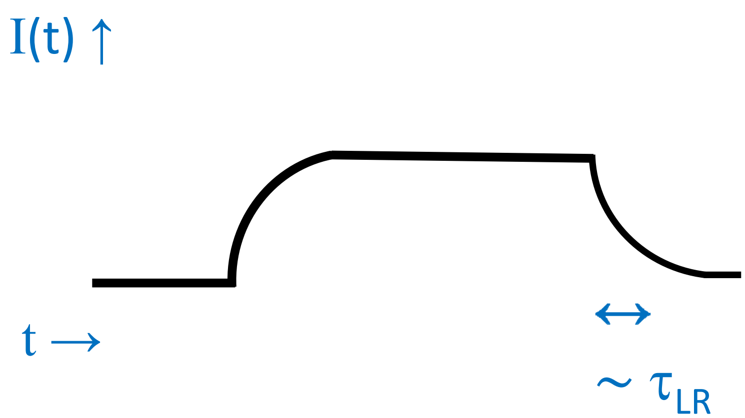
1. Zero resistance (persistent currents)



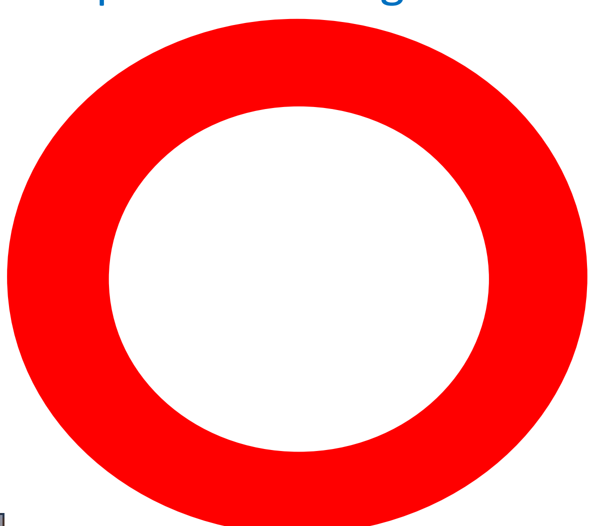


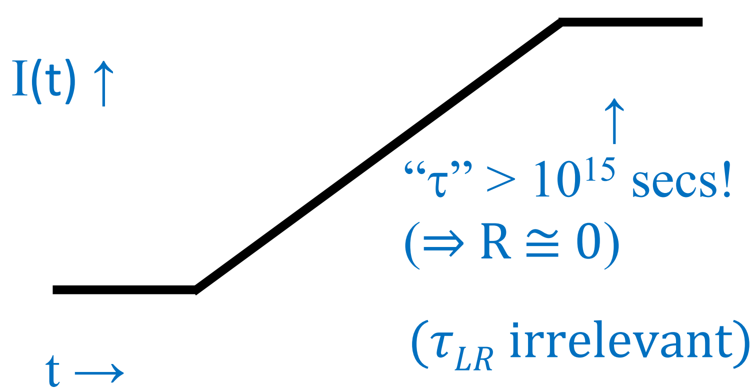
A. Normal state



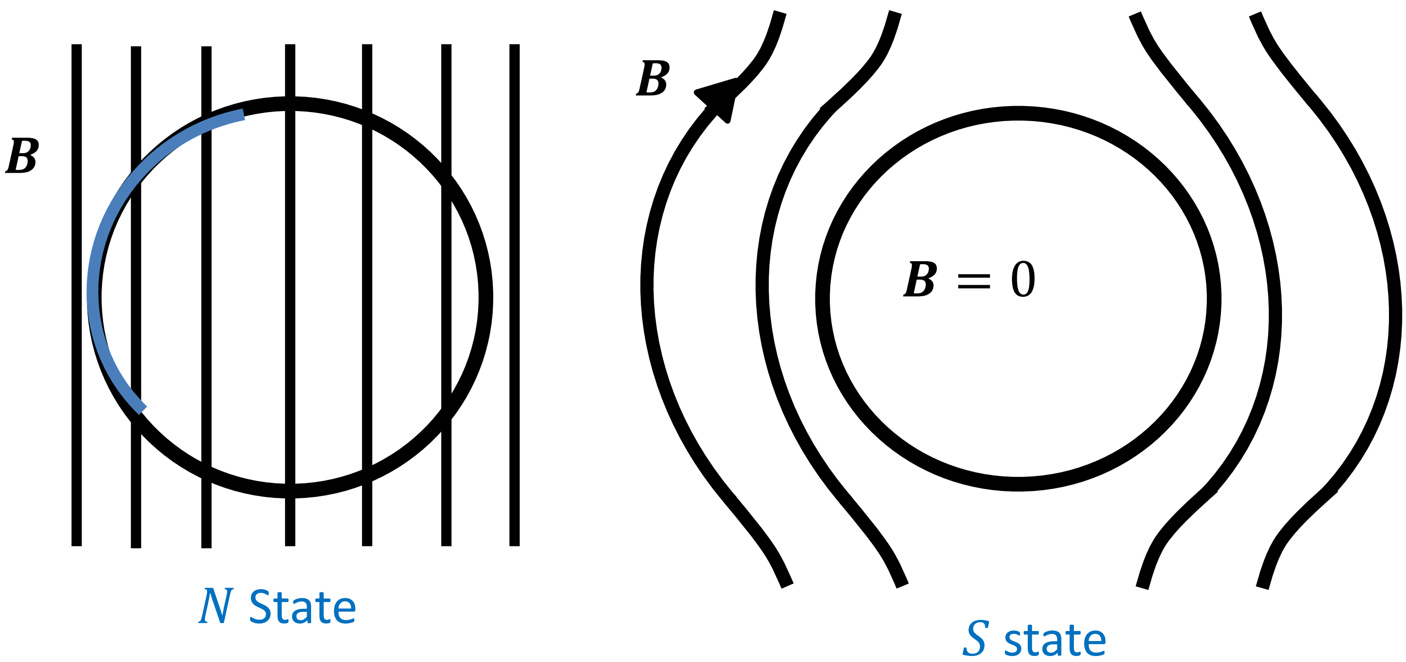


B. Superconducting state



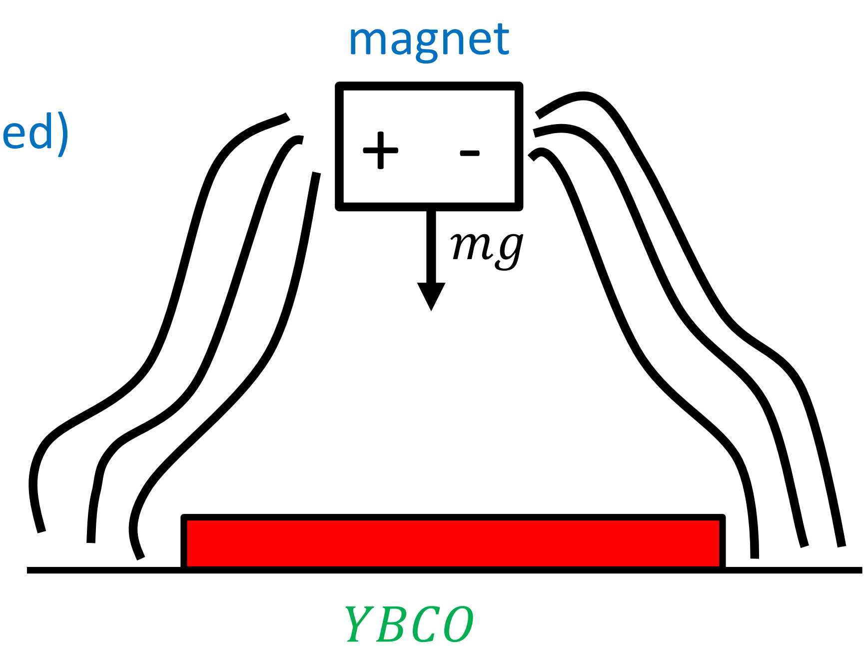


2. Perfect diamagnetism (Meissner effect):



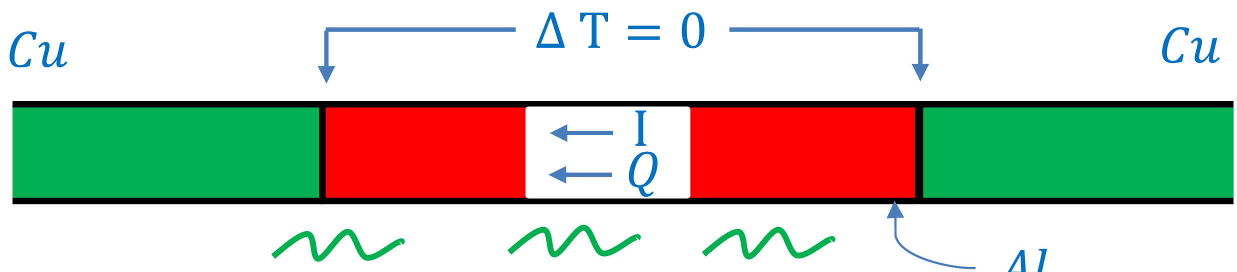
Hence:

(oversimplified)



Is the Meissner effect simply a consequence of zero resistance? No!
(Meissner effect is a thermal equilibrium phenomenon, persistent currents ("zero resistance") are metastable)

3. Zero Peltier coefficient:



$\mathrm{I} \equiv$ electrical current

$Q \equiv$ heat current

In N state, Peltier coefficient $\Pi \propto Q/I|_{\Delta T=0}$
i.e. it is a measure of heat current associated with electrical current: $\Pi \neq 0$ except by pathology.

In S state, $\Pi = 0 \Rightarrow$ transport of electric charge without any transport of heat.

All 3 qualitative properties of S state set in discontinuously at "transition temperature" T_c.

Q: Where do we find superconductivity?

A.: almost everywhere!

- elemental metals (mostly towards middle of periodic table: best conductors (Cu, Ag, Au...) do not become S)
- ordered metallic compounds (e.g. Nb_3Sn)
- disordered alloys
- semiconductors
- materials with complex crystal structures, e.g. fullerenes, ferropnictides, cuprates, organics

(e.g.) C_{60} LaOFeAs YBCO "ET"

however,

(a) no well-confirmed case of a material which is insulating in its N state becoming S.

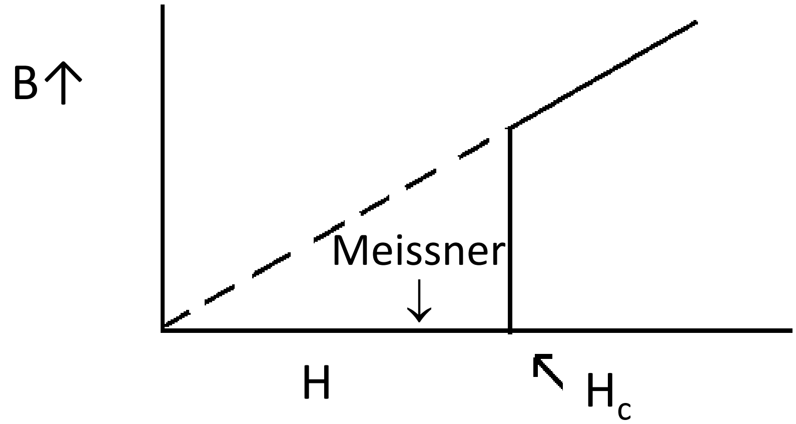
(b) Superconductivity very insensitive to nonmagnetic disorder but rapidly destroyed by magnetic impurities.
(example: pure Mo has $T_c \sim 1K$, but a few ppm of Fe(magnetic) drives T_c to 0).

Isotope effect: in "classic" (pre-1979) superconductors (only), usually $T_c \propto M^{-1/2}$.

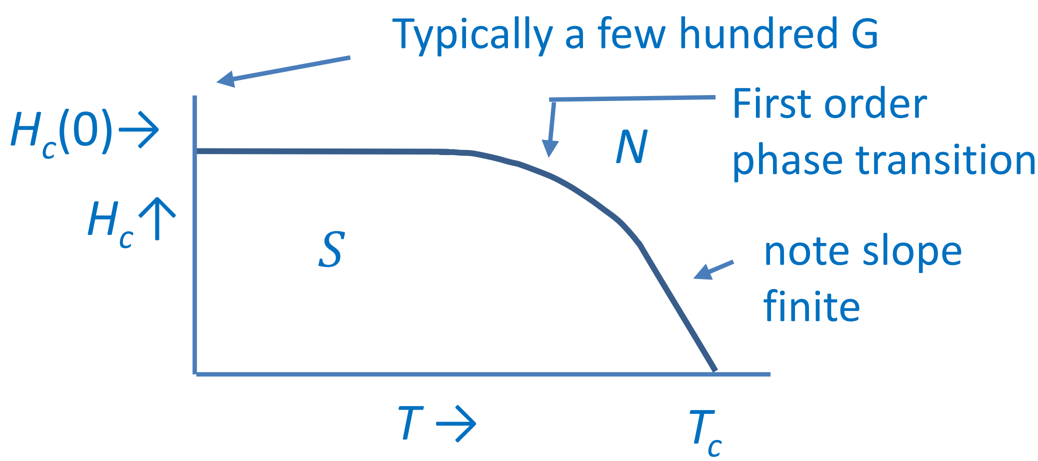
isotopic mass

Magnetic behavior: type I and type II superconductivity

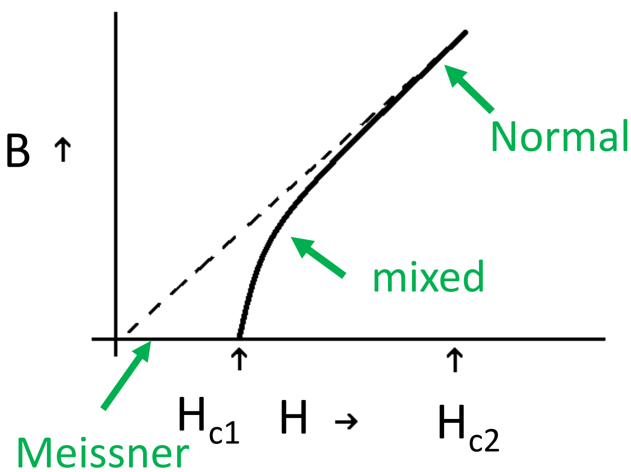
Type I :

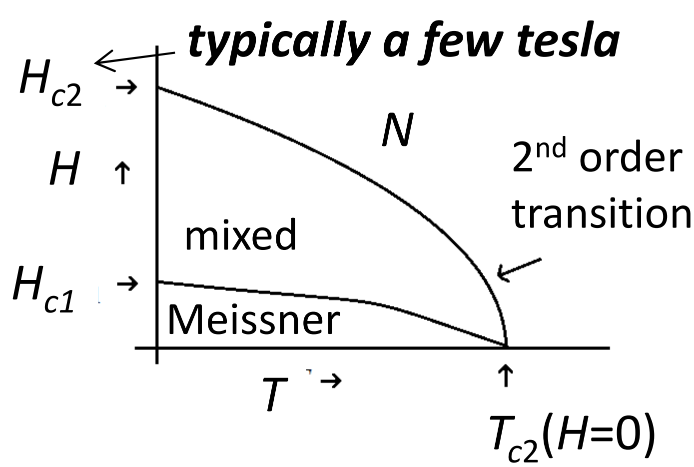


Temperature-dependence:



Type II :





(Anticipate: in mixed phase, magnetic field "punches through" in form of vortices, bulk remains S).

Elemental metals and some simple compounds type I, "exotic" materials almost invariably type II.