Insulating State of Granular Superconductors in a Strong Coupling Regime

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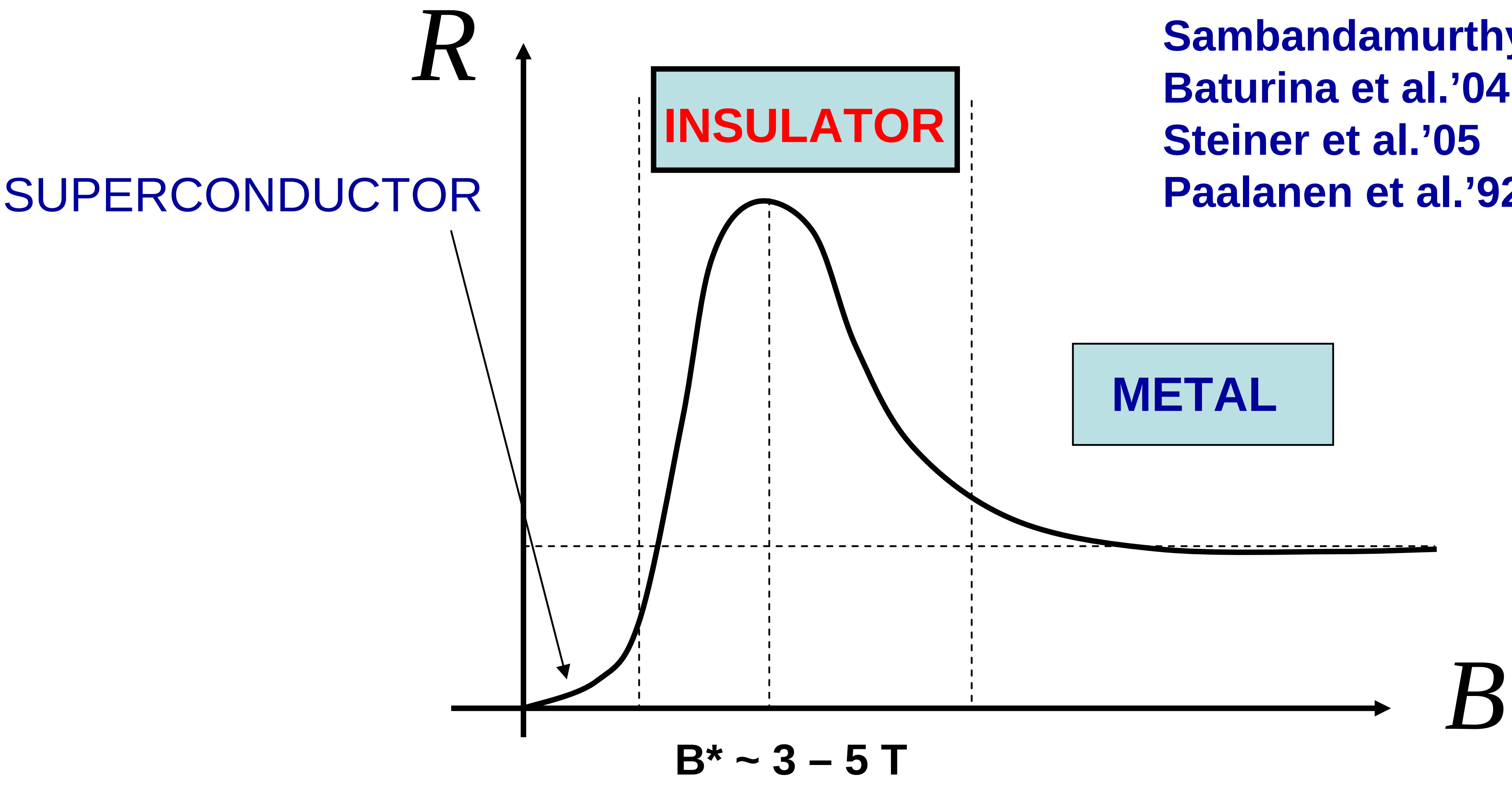
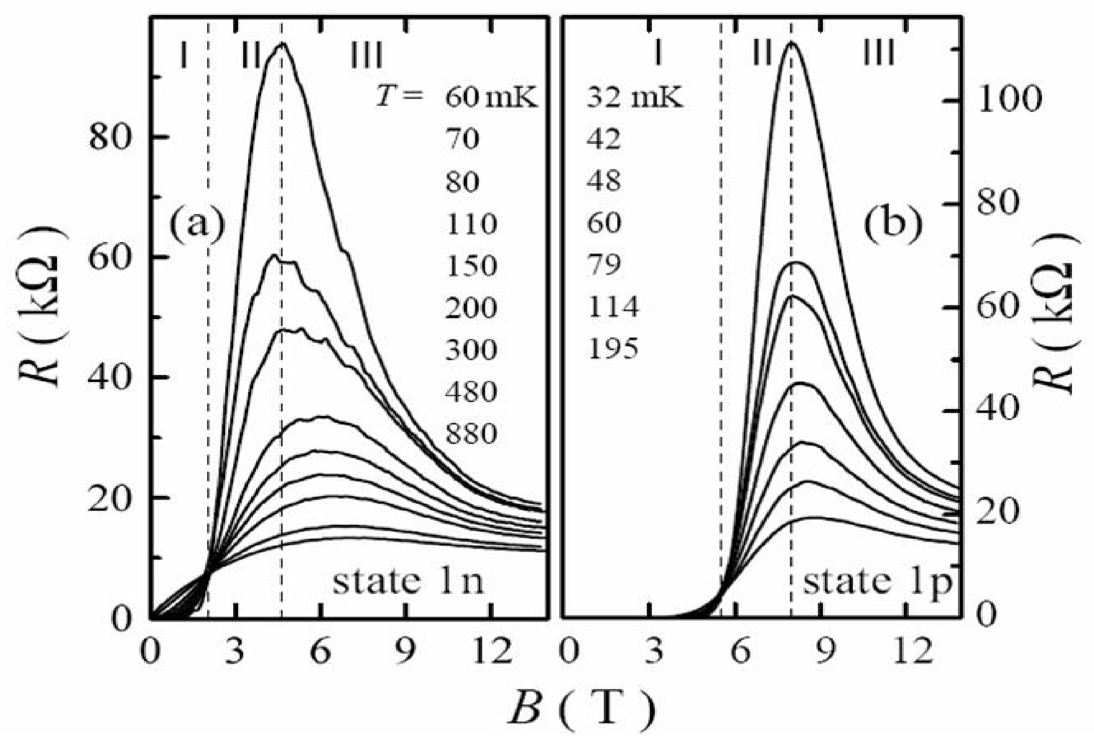
Insulating state of granular superconductors in a strong coupling regime



EXPERIMENT:
Gantmakher et al.’00
Sambandamurthy at al.’04
Baturina et al.’04
Steiner et al.’05
Paalanen et al.’92

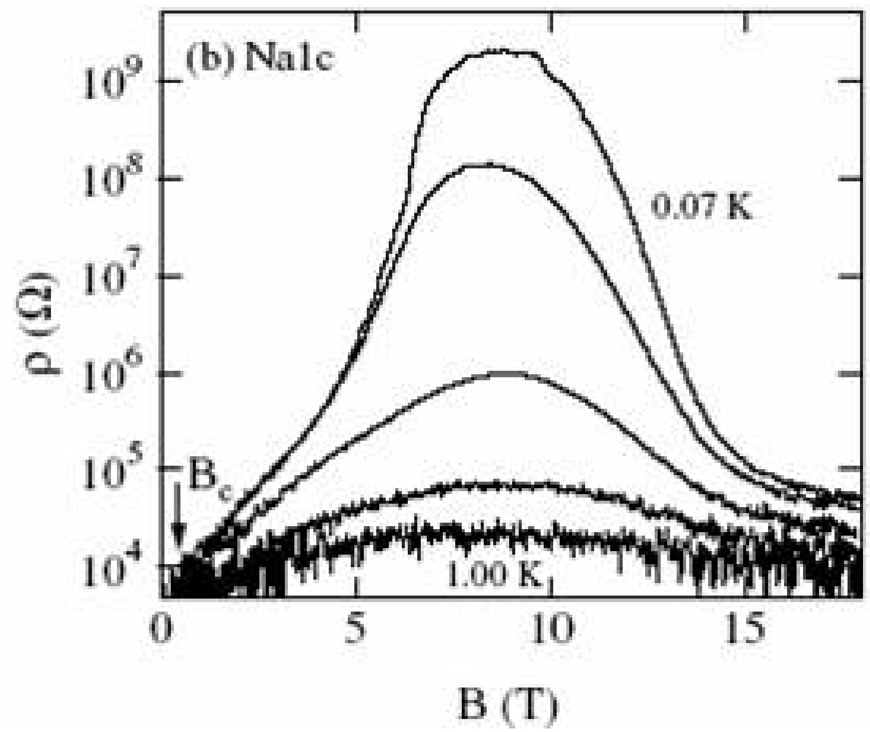
Insulating State of Granular Superconductors

B normal **B parallel**



V. Gantmakher, et al '00

In-O films, perpendicular B

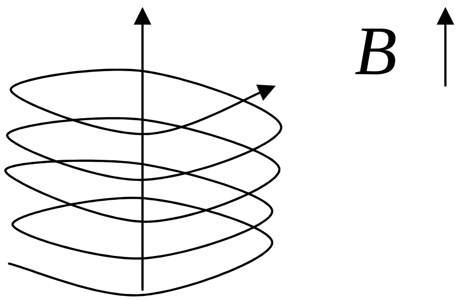


G. Sambandamurthy et al '04

normal film conductance > 1 (metal !)

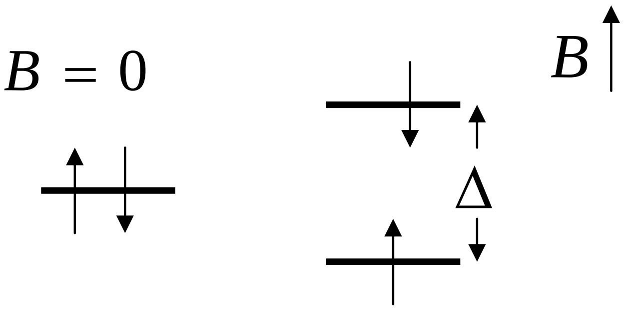
Effect of magnetic field on superconductivity

Orbital



(grain) - $B_C^{or}\xi R \approx \Phi_0$

Zeeman



$\mu_B B_C^Z \approx \Delta$

$$\frac{B_C^{or}}{B_C^Z} \approx \frac{R_C}{R}$$

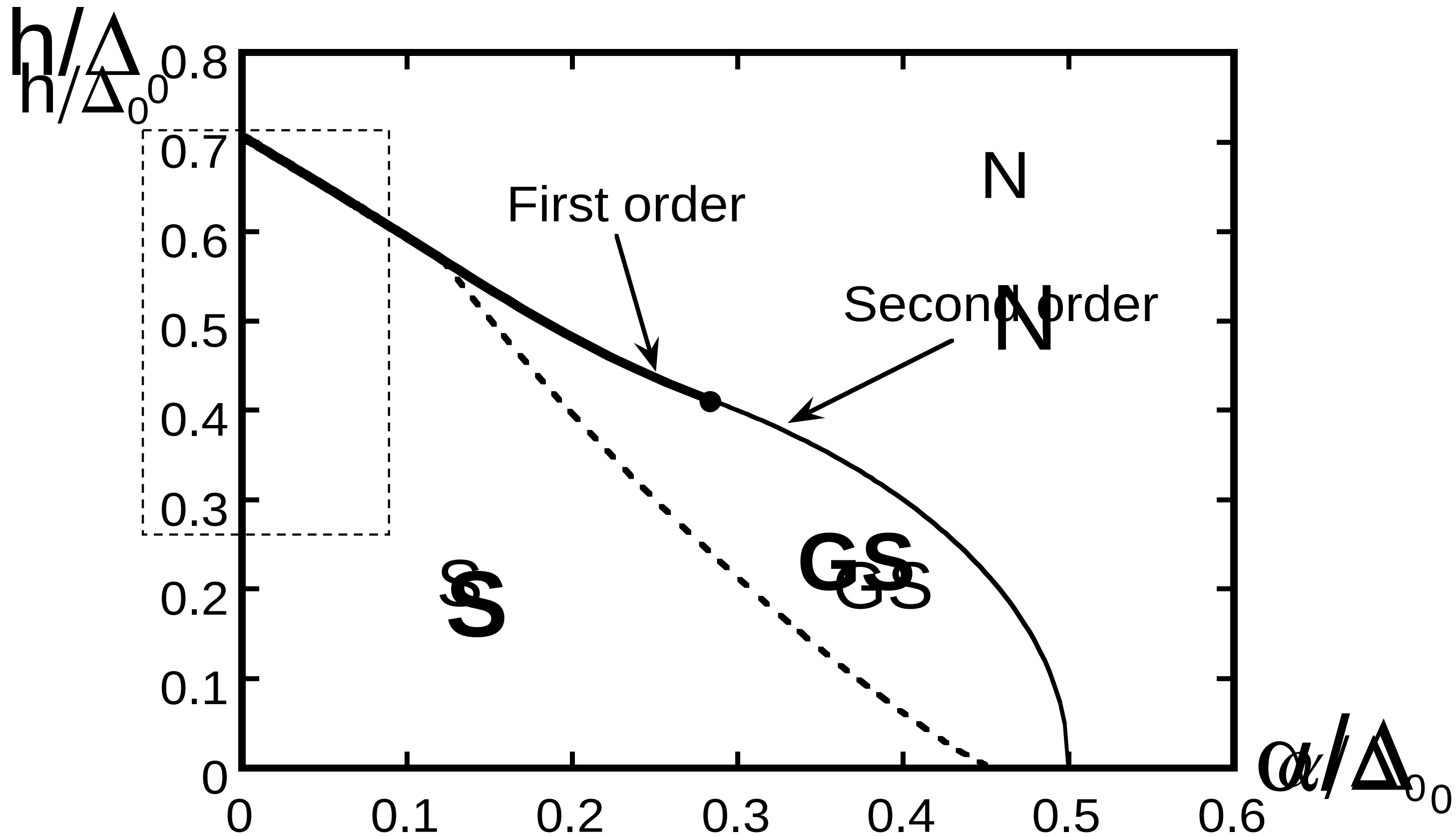
$$R_C = \xi(\varepsilon_F \tau)^{-1}$$ - **critical sample size**

coherence length (ξ); elastic mean free time (τ)

$R > R_C$ - orbital

$R < R_C$ - Zeeman

Phase diagram single superconducting grain at T = 0

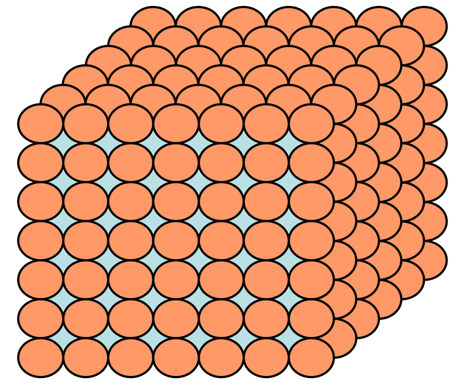


S – gapful superconducting state
GS – gapless state

h – Zeeman energy
α – pairbreaking parameter

Superconductor – Insulator transition in granular metals

Efetov ' 80



$E_c \sim E_J$ - **SI transition**

Insulating state possible for $E_c > E_J$

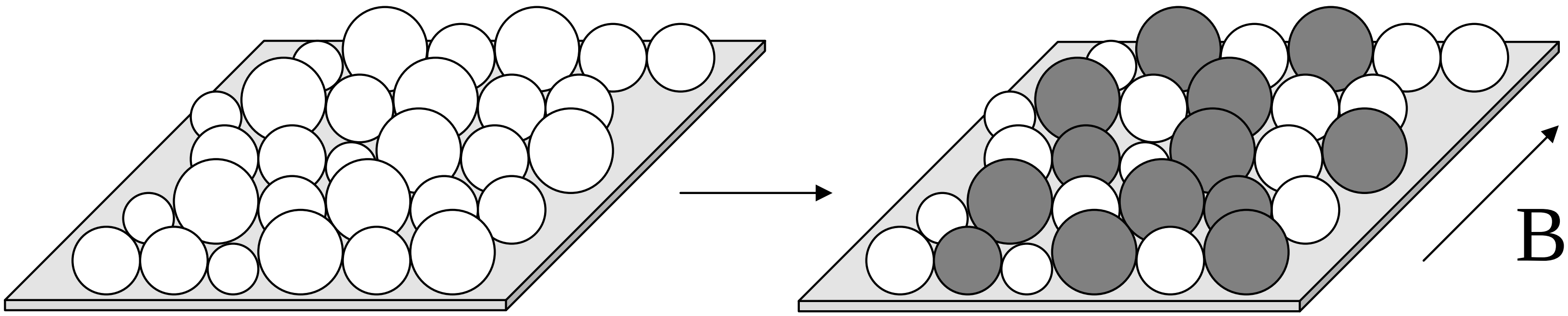
experiment: g > 1, $E_c \rightarrow E_c^{eff} \sim \Delta/g$

$E_J \sim g\,\Delta \rightarrow E_J >> E_c^{eff} \rightarrow$ **superconducting state**

We need different model !

Insulating State of Granular Superconductors

no magnetic field **applied magnetic field**



- **grains of slightly different sizes**
- **magnetic field → change relative fraction of superconducting and normal grains**

↓

In **2D** exist range of relative concentrations of sites where simultaneously **neither black no white sites percolate**

Insulating state: theoretical description

$g_{ns} >> g_{nn}$, g_{ss}

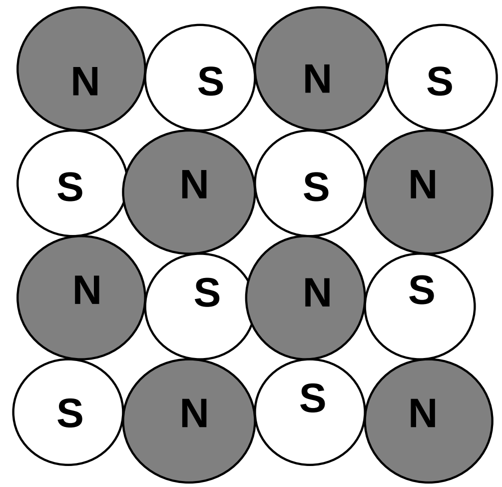
$$S = \sum_i S_{c_i} + S_{ns}$$

for g_{ns} >> 1

$$S \sim \int d\tau \int d^2 q E_c(q) \, | \Phi^g_q(\tau) |^2$$

$$E_c(q) = (E_c^{-1} + B[1 - E_q])^{-1},$$

Due to magnetic field :



$$B \sim g / \Delta_0,$$

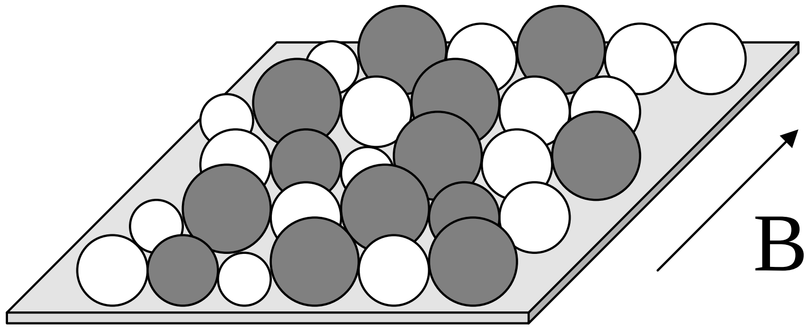
$$E_q = \frac{1}{2} \sum_a \cos qa$$

Insulating State of Granular Superconductors

Insulating state with gap in electron spectrum:

$$\Delta \sim (\Delta_0/g)\ln(gE_C/\Delta_0)$$

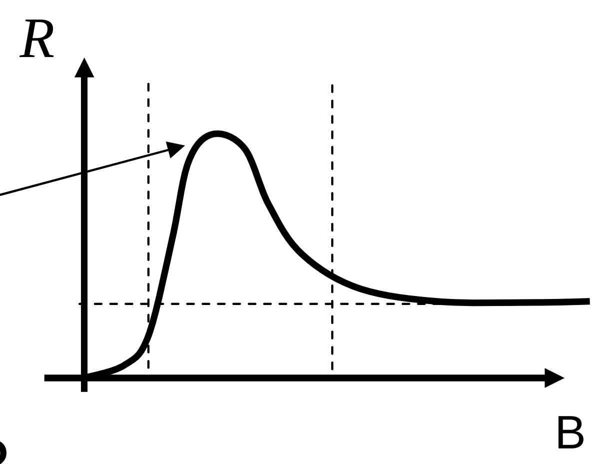
applied magnetic field



Δ_0 **- gap without magnetic field**

g **- conductance,** E_C **- charging energy**

Conductivity : $\sigma \sim \exp(-\Delta/T)$

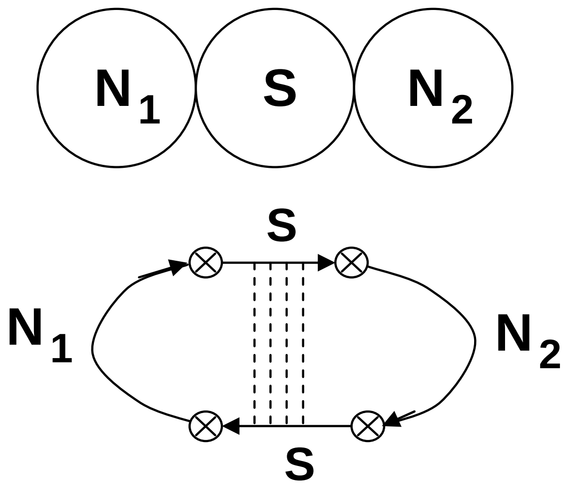


What is the applicability of this result ?

Stability of insulating state

with respect to formation of **normal** state

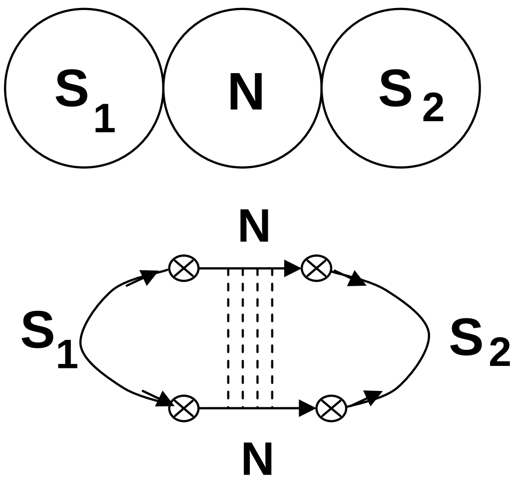
Electron tunneling via virtual state



small for $g < \sqrt{\Delta_0/\delta}$

with respect to formation of **superconducting** state

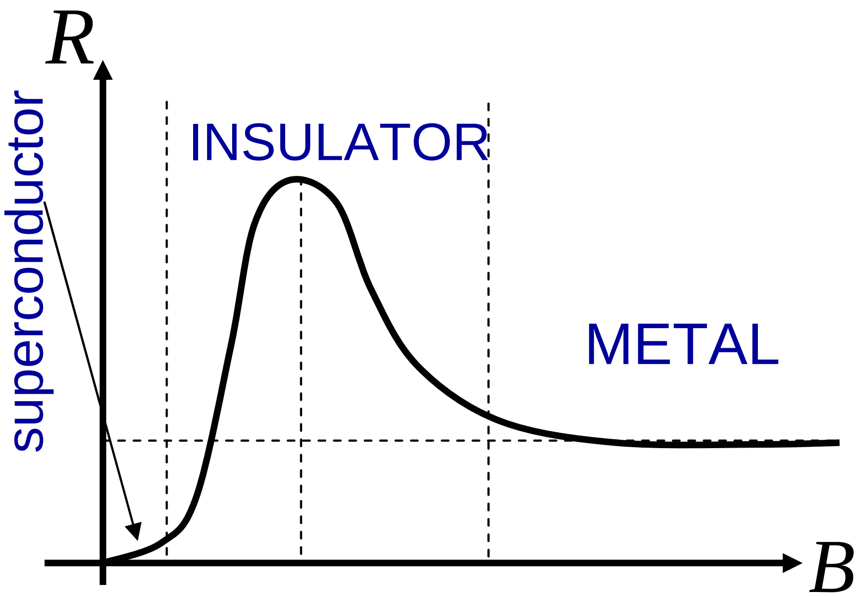
Cooper pair tunneling

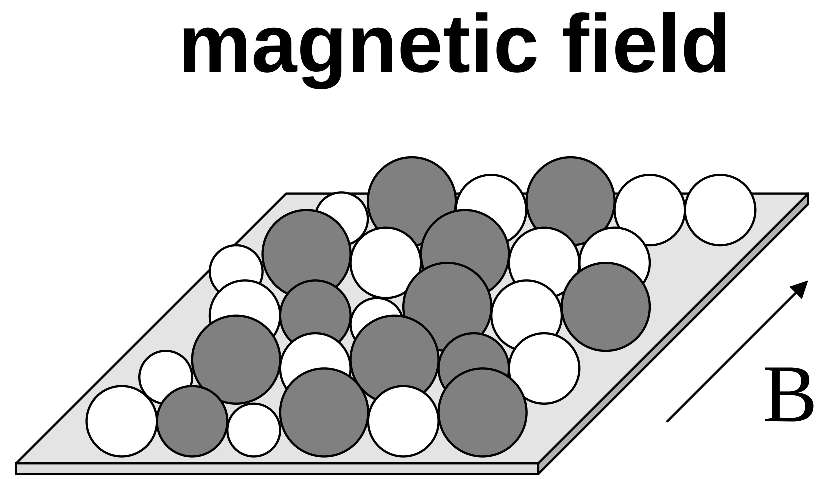


small for $g < \left(\Delta_0/\delta\right)^{1/3}$

Insulating state is stable for : $g < \left(\Delta_0/\delta\right)^{1/3}$

Summary





stable for :

$$g < \left(\Delta_0/\delta\right)^{1/3}$$

$$\sigma : \exp\left(-\Delta/T\right)$$

$$\Delta : \left(\Delta_0/g\right)\ln\left(gE_C/\Delta_0\right)$$