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SMR. 758 - 34

SPRING COLLEGE IN CONDENSED MATTER
ON QUANTUM PHASES
(3 May - 10 June 1994)

SUPERCONDUCTOR - INSULATOR TRANSITION IN InO_x

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These are preliminary lecture notes, intended only for distribution to participants.

SUPERCONDUCTOR-INSULATOR TRANSITION IN InO_x

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and

Univ. of Jyväskylä 1992→

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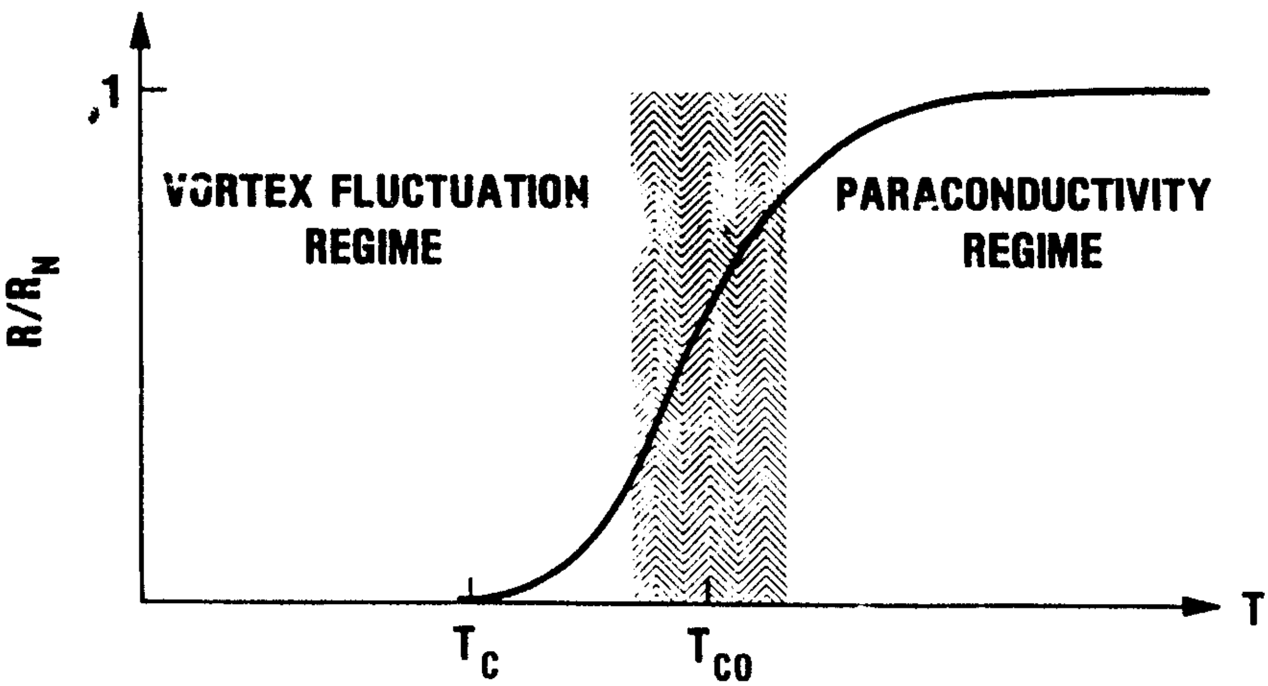
RESISTIVE TRANSITION OF A TWO—DIMENSIONAL SUPERCONDUCTOR



Orderparameter $\Delta e^{i\phi}$

Δ amplitude

ϕ phase

granular superconducting thin film

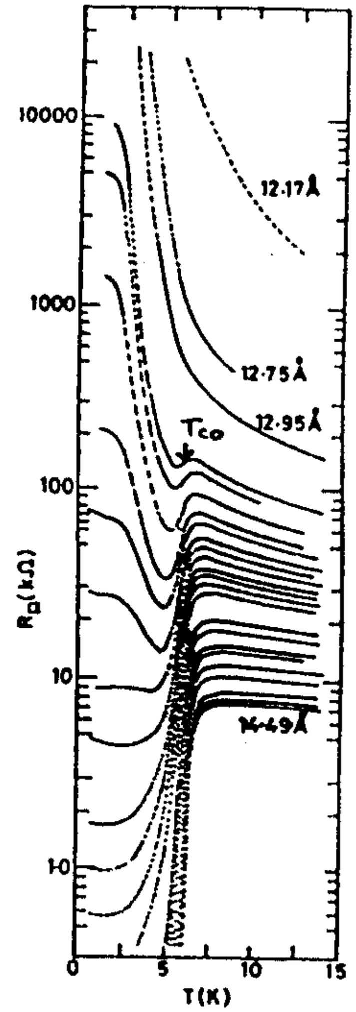


Fig. 2. **Resistance per square $R_\square$ in kΩ versus temperature for different amorphous Ga thin films. (After Ref. [8]).**

Thesis Statement

For sufficiently thin homogeneously disordered films,

the true superconducting phase transition

(i.e., where LRO is established and the dc resistance is zero)

is dominated by phase fluctuations.

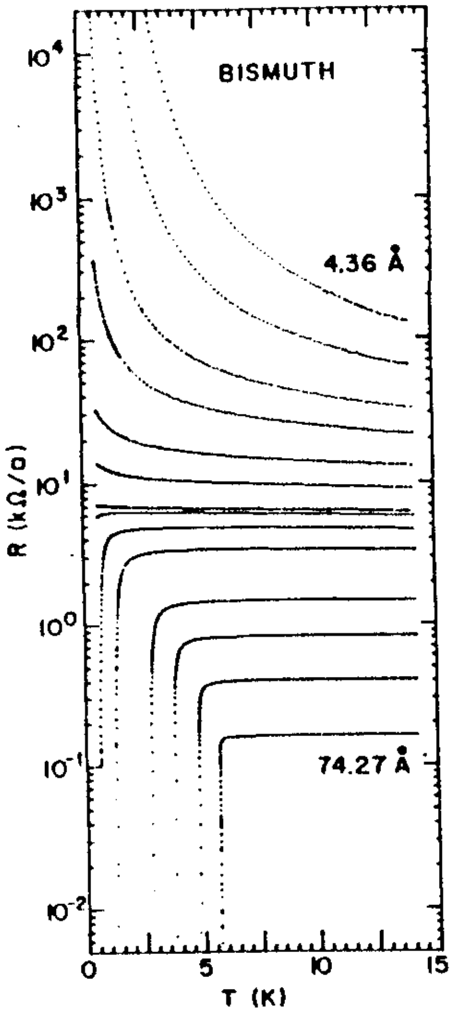
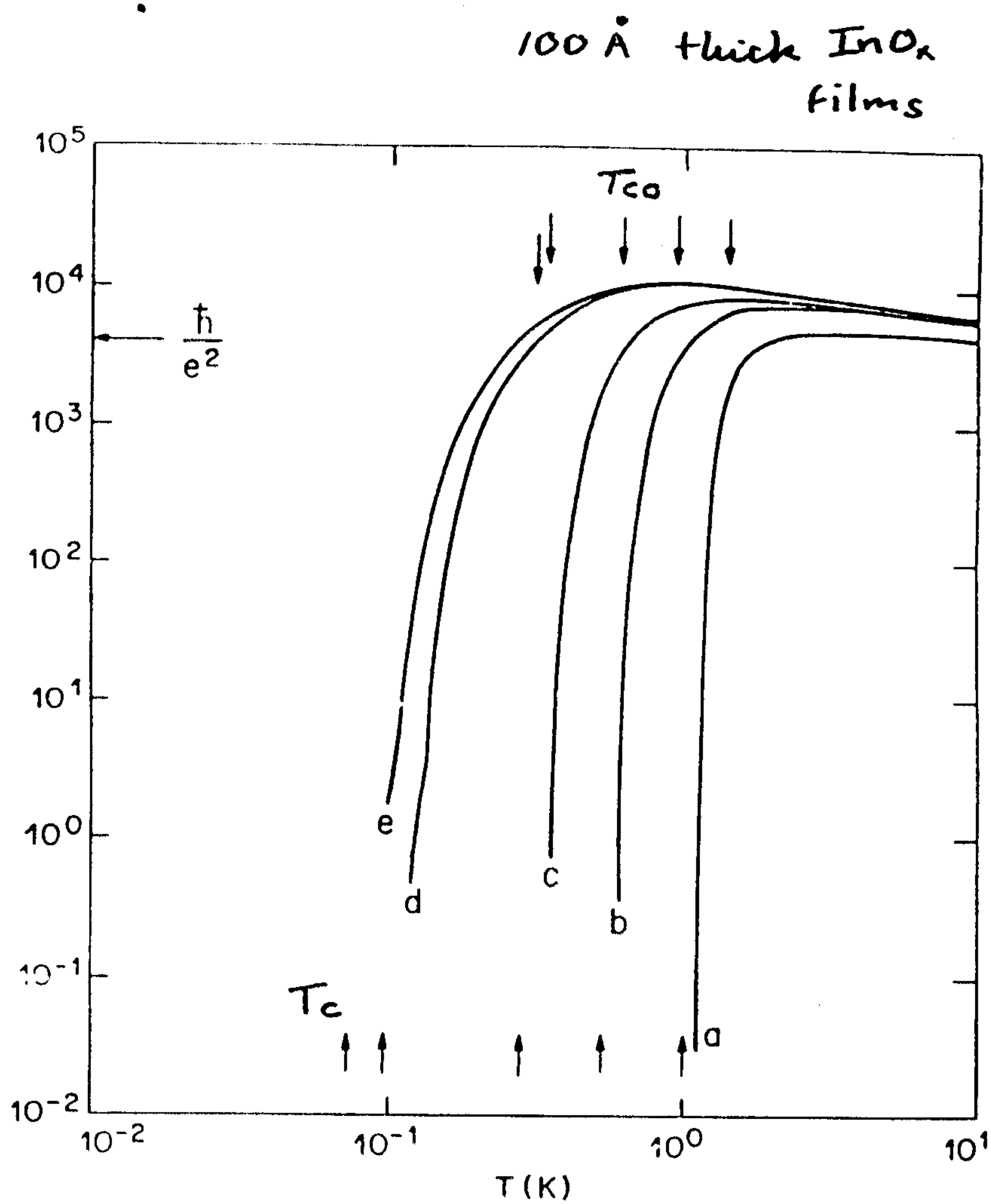


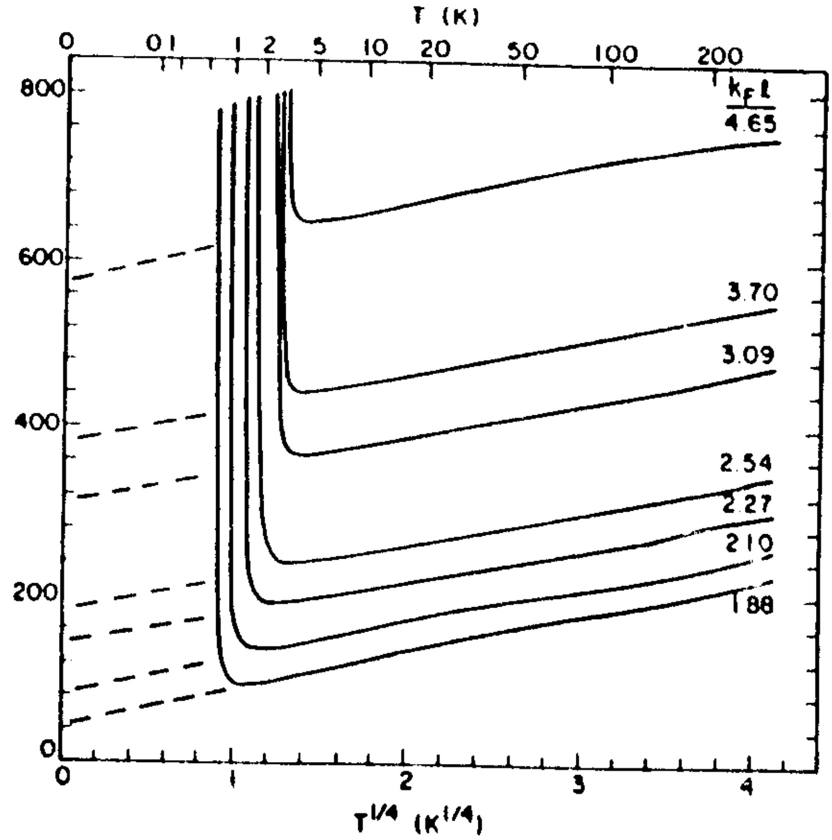
FIG. 1. Evolution of the temperature dependence of the sheet resistance $R(T)$ with thickness for a Bi film deposited onto Ge. Fewer than half of the traces actually acquired are shown. Film thicknesses shown range from 4.36 to 74.27 Å.

D.B. Haviland, Y. Liu, A.M. Goldman PRL 62, 2180 ('89)



100 Å thick InO$_x$ films
T_{co}
$\hbar/e^2$
$R\ (\Omega/\square)$
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
T_c
a
b
c
d
e
10^{-2}
10^{-1}
10^0
10^1
T (K)

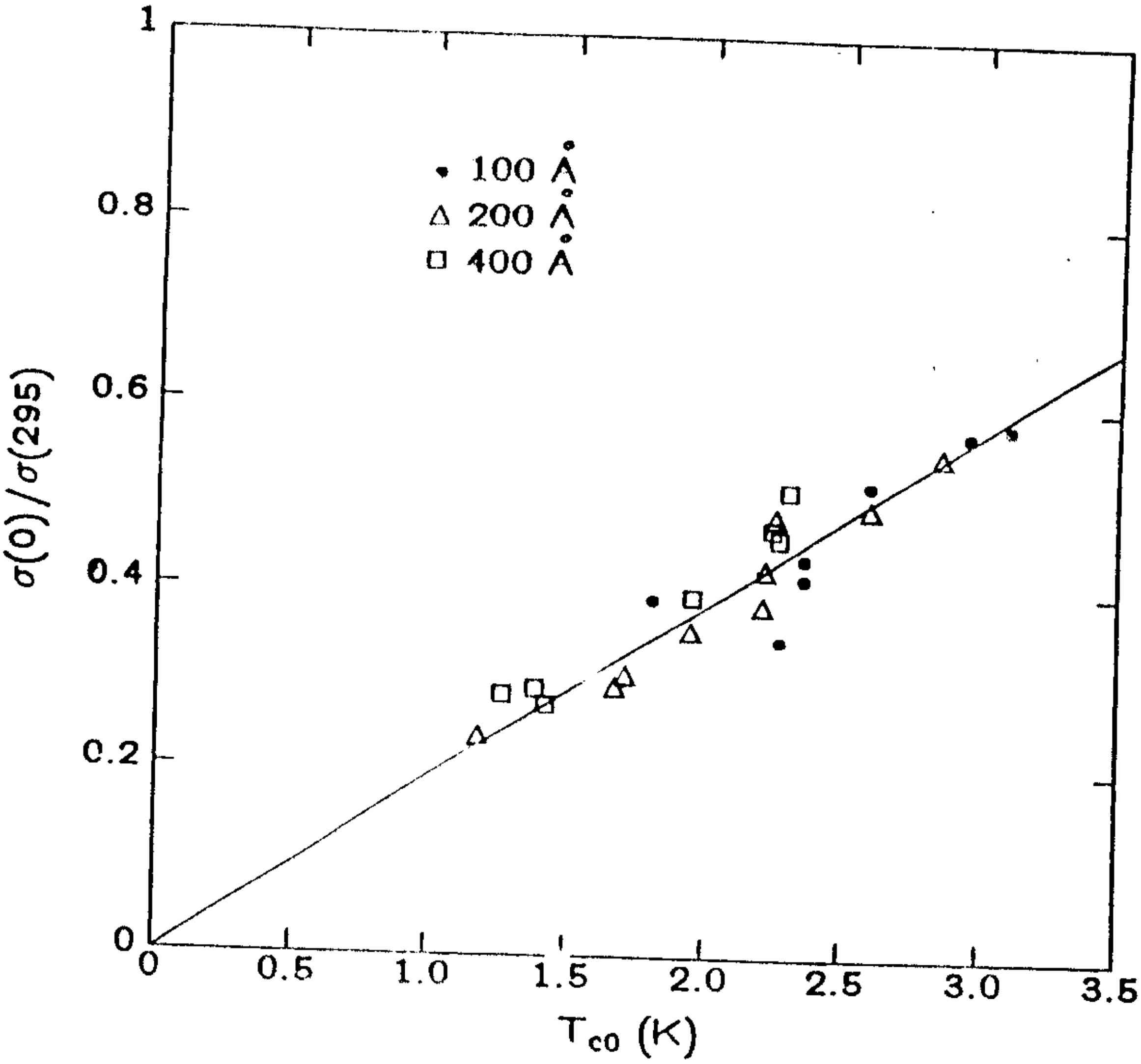
$$\sigma = \frac{e^2}{\hbar}\left(\frac{1}{\xi_L} + \frac{B}{\ell(T)}\right) \quad ; \quad \ell(T) = A\left(\frac{\epsilon_F}{T}\right)^p$$



$$\frac{1}{\xi} \ll \frac{B}{\ell(T)}$$

FIG. 2. Temperature dependence of the electrical conductivity of sample B at various stages of anneal with $k_F l$ values given. Extrapolated dashed lines give $\sigma(0)$.

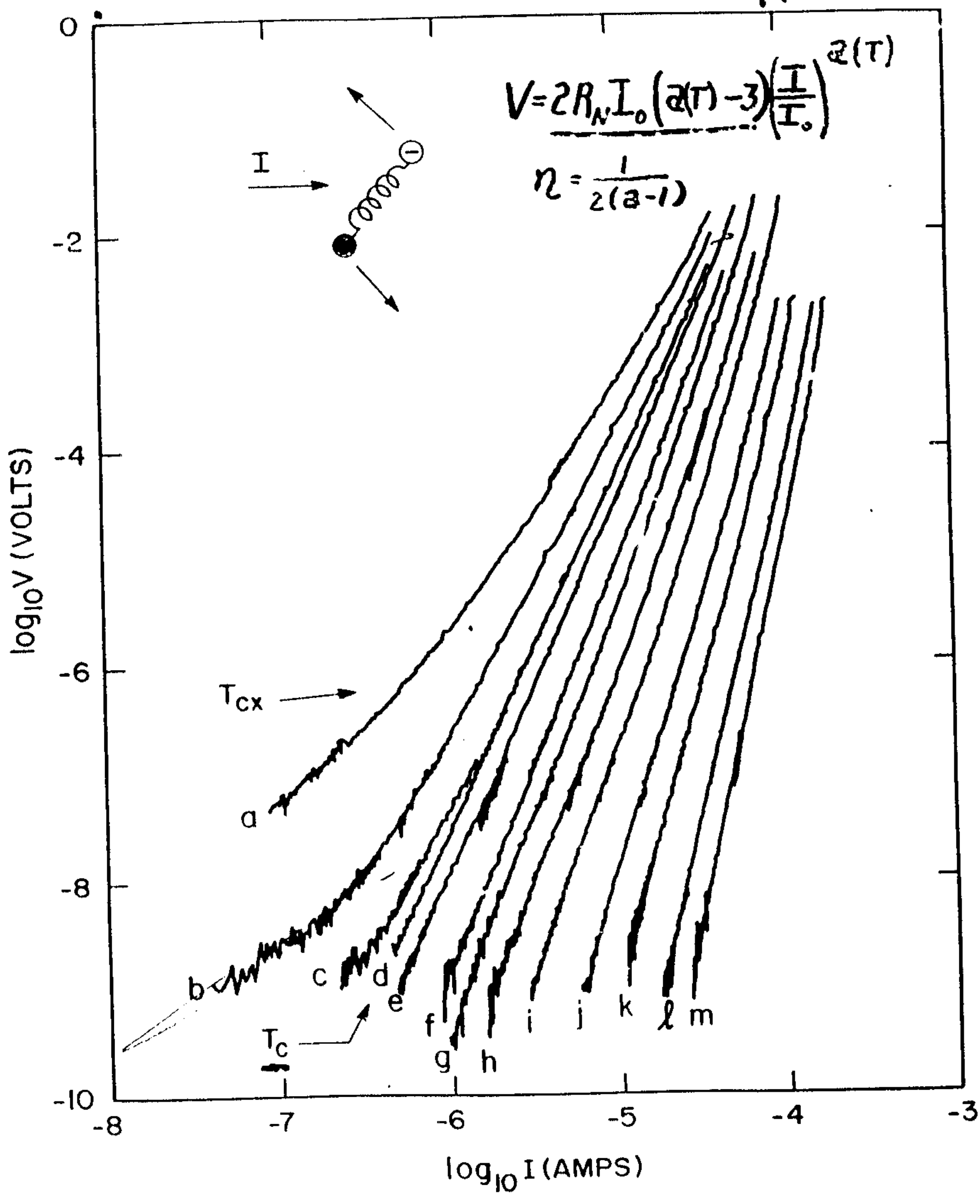
A.T. Fiory & A.F. Hebard, PRL (1984).

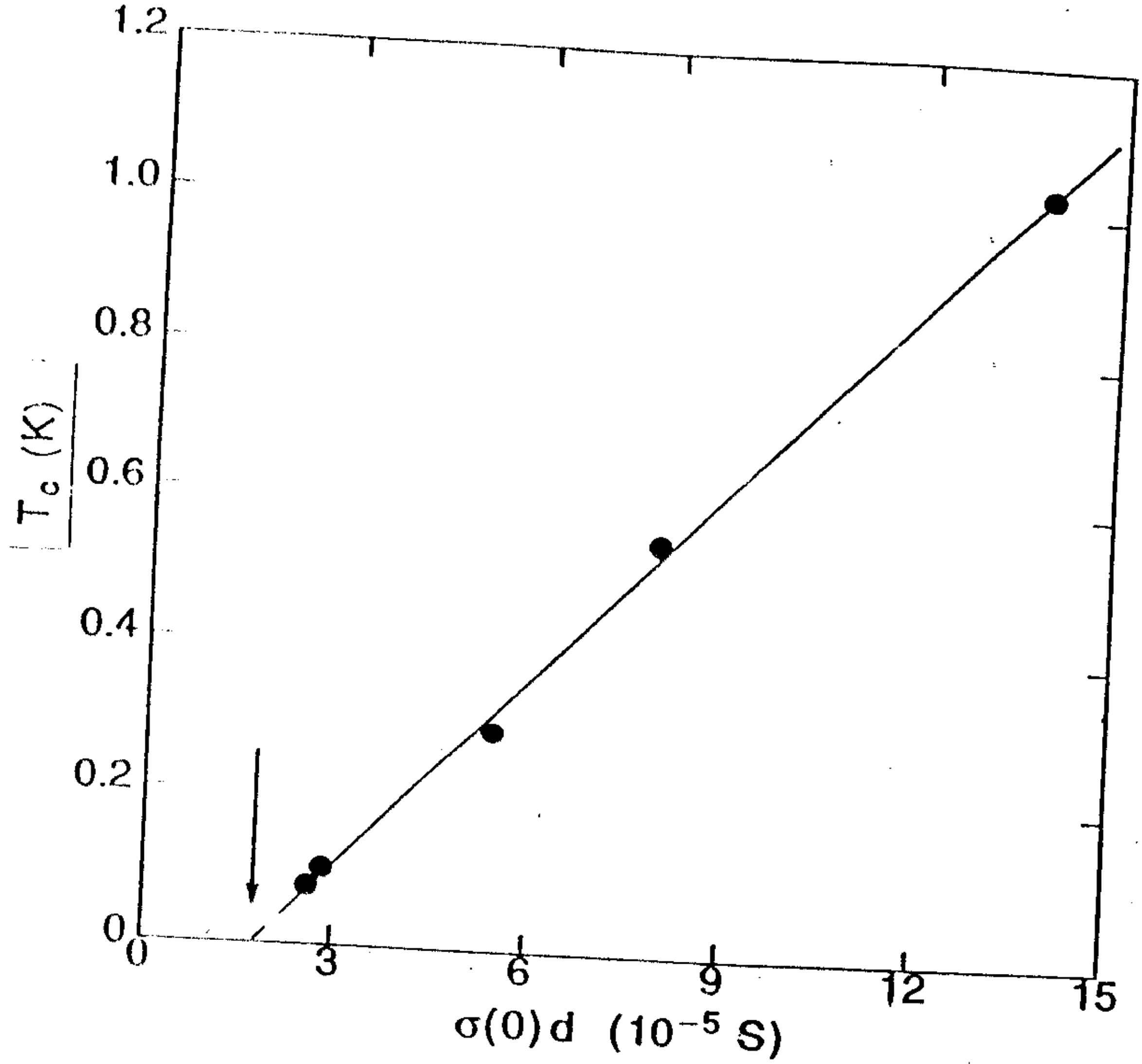


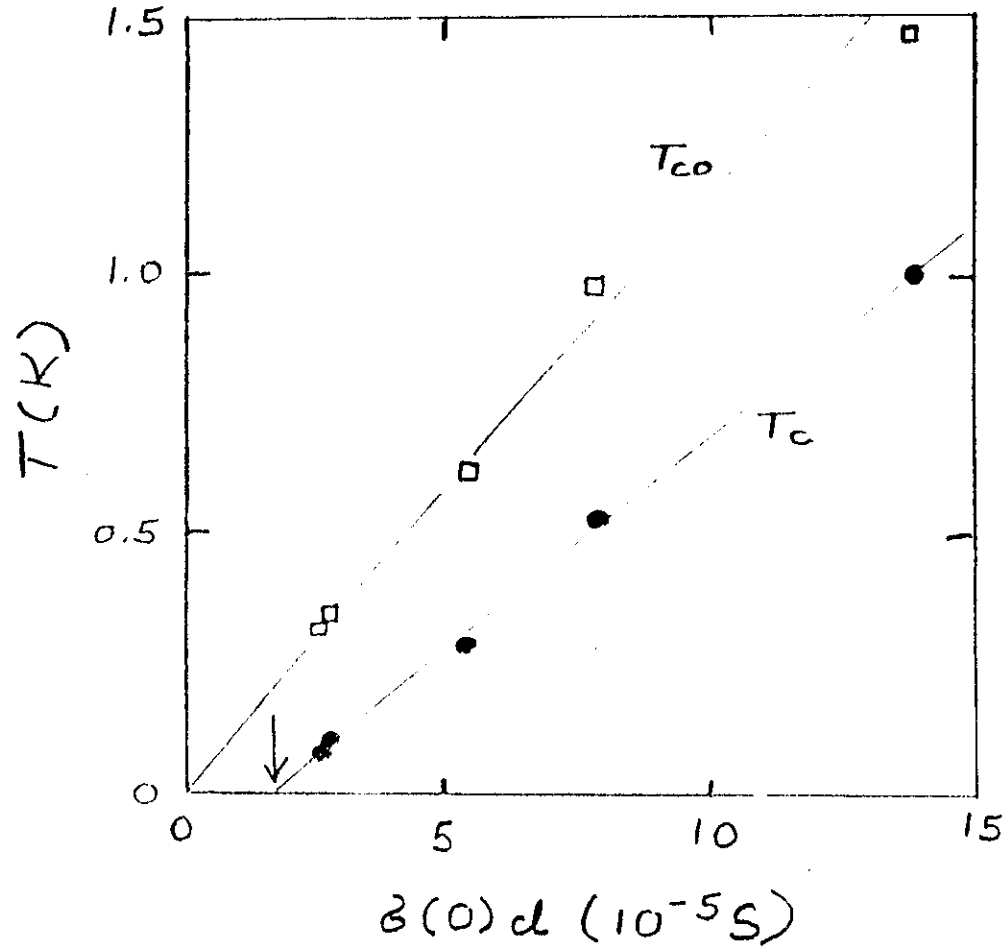
• 100 Å
△ 200 Å
□ 400 Å
σ(0)/σ(295)
0
0.2
0.4
0.6
0.8
1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
T_{c0} (K)

Determination of T_c - transition

- vortex - antivortex unbinding
- Kosterlitz - Thouless type



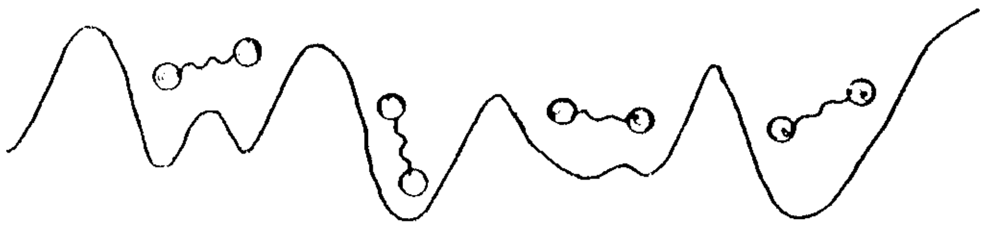

1.2
1.0
0.8
0.6
0.4
0.2
0
T_c (K)
0
3
6
9
12
15
σ(0)d (10^{-5} S)



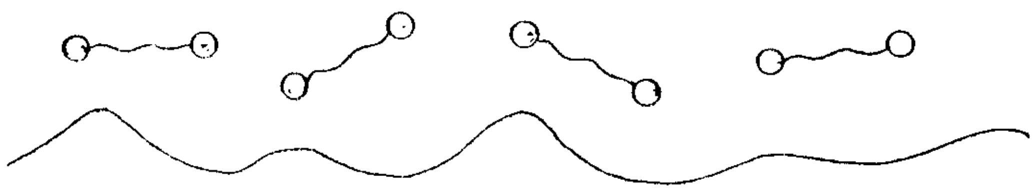
1.5
1.0
0.5
0
T (K)
T_{co}
T_c
0
5
10
15
σ(0) d (10^{-5} S)

Cooper Pairs in a Random Potential

- Insulating ($\Delta > \Delta_c$)



- Superconducting ($\Delta < \Delta_c$)



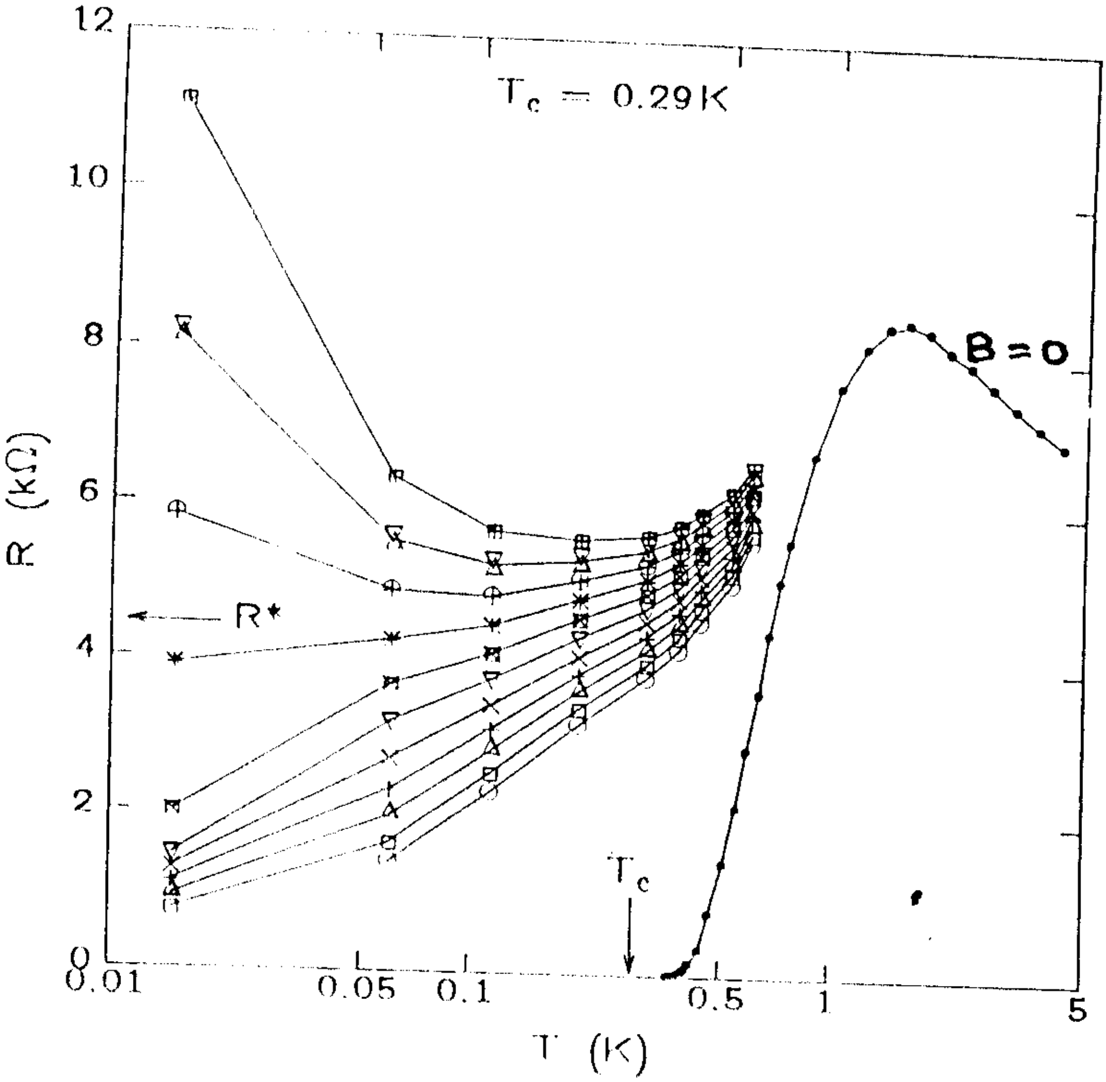
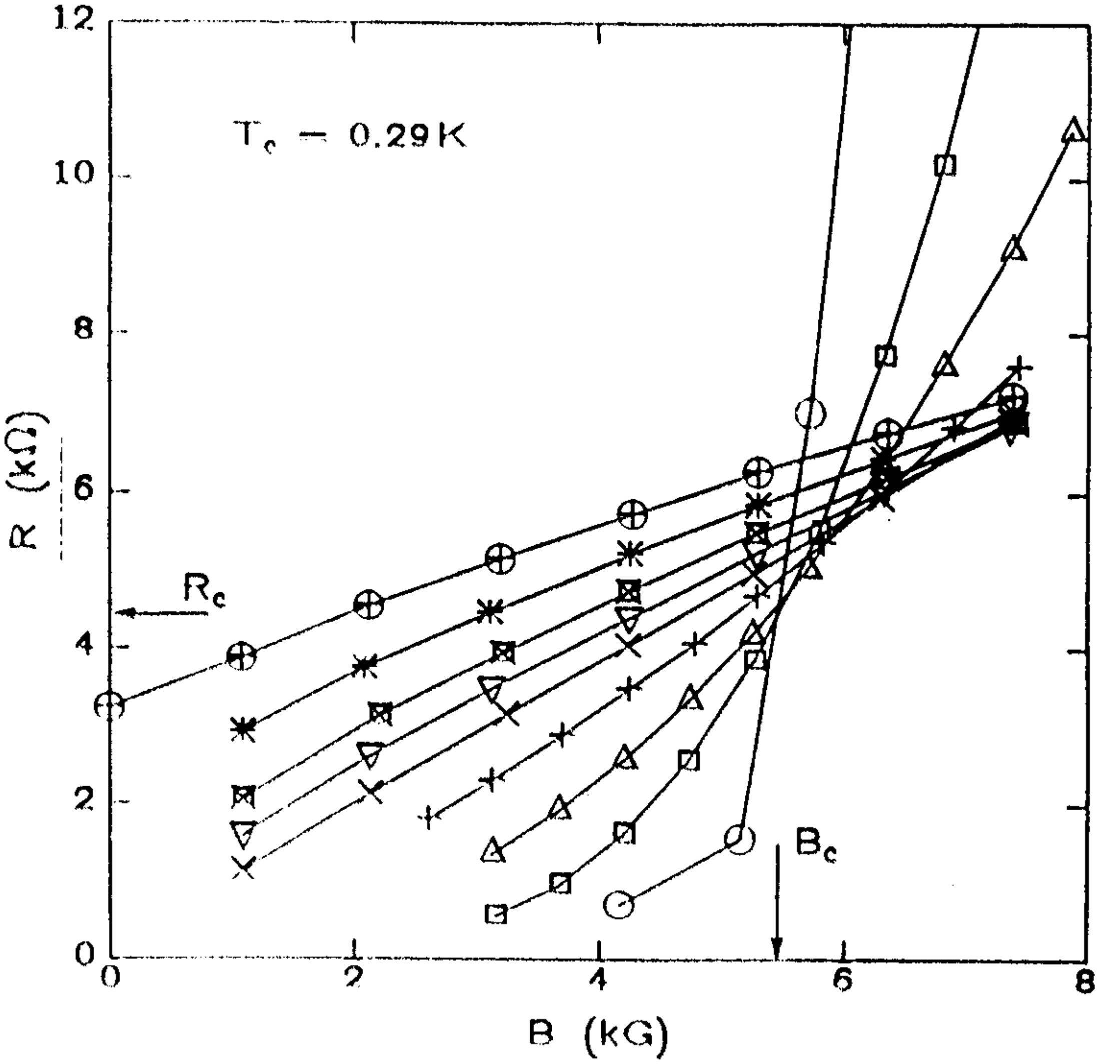
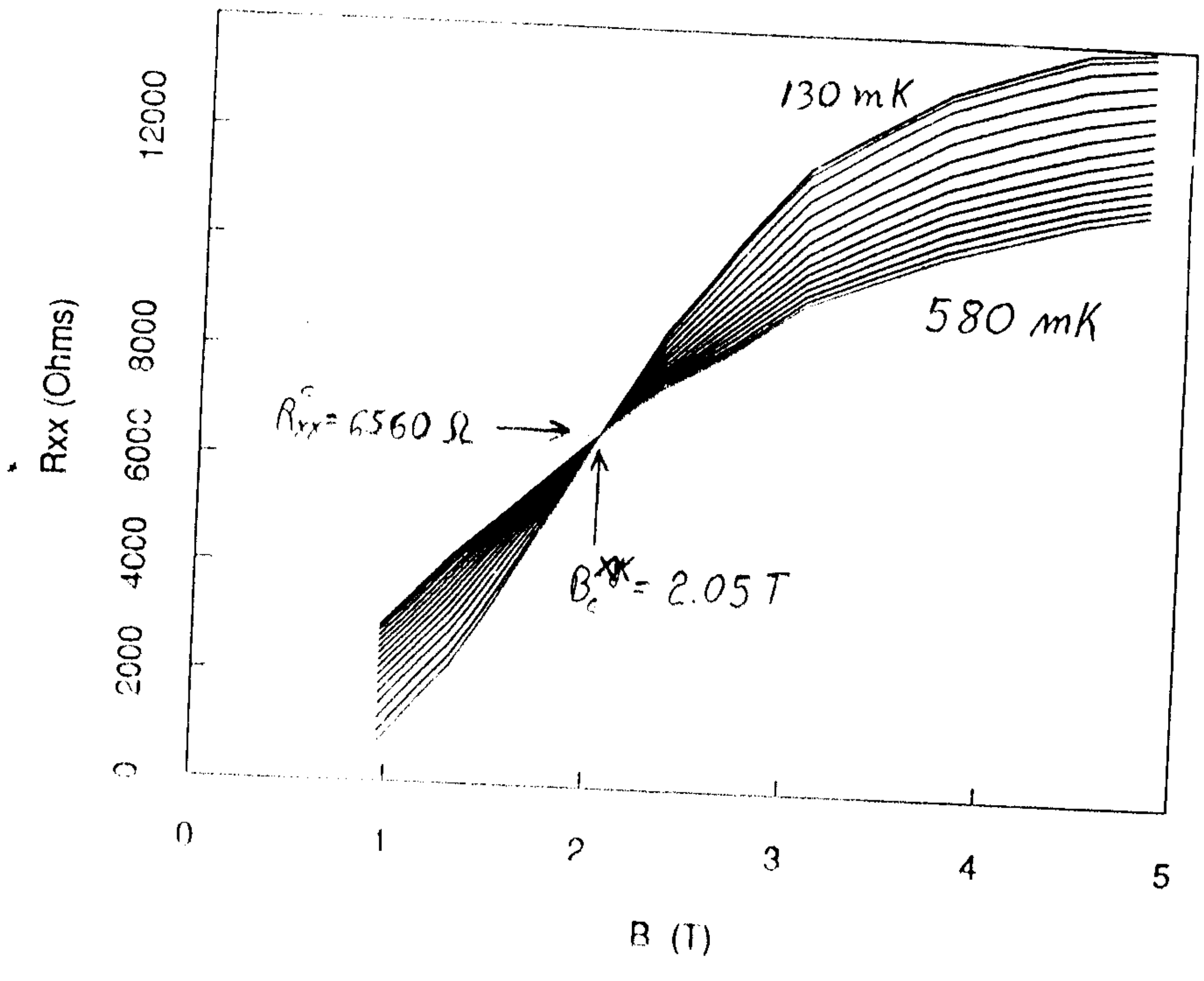


Figure 1

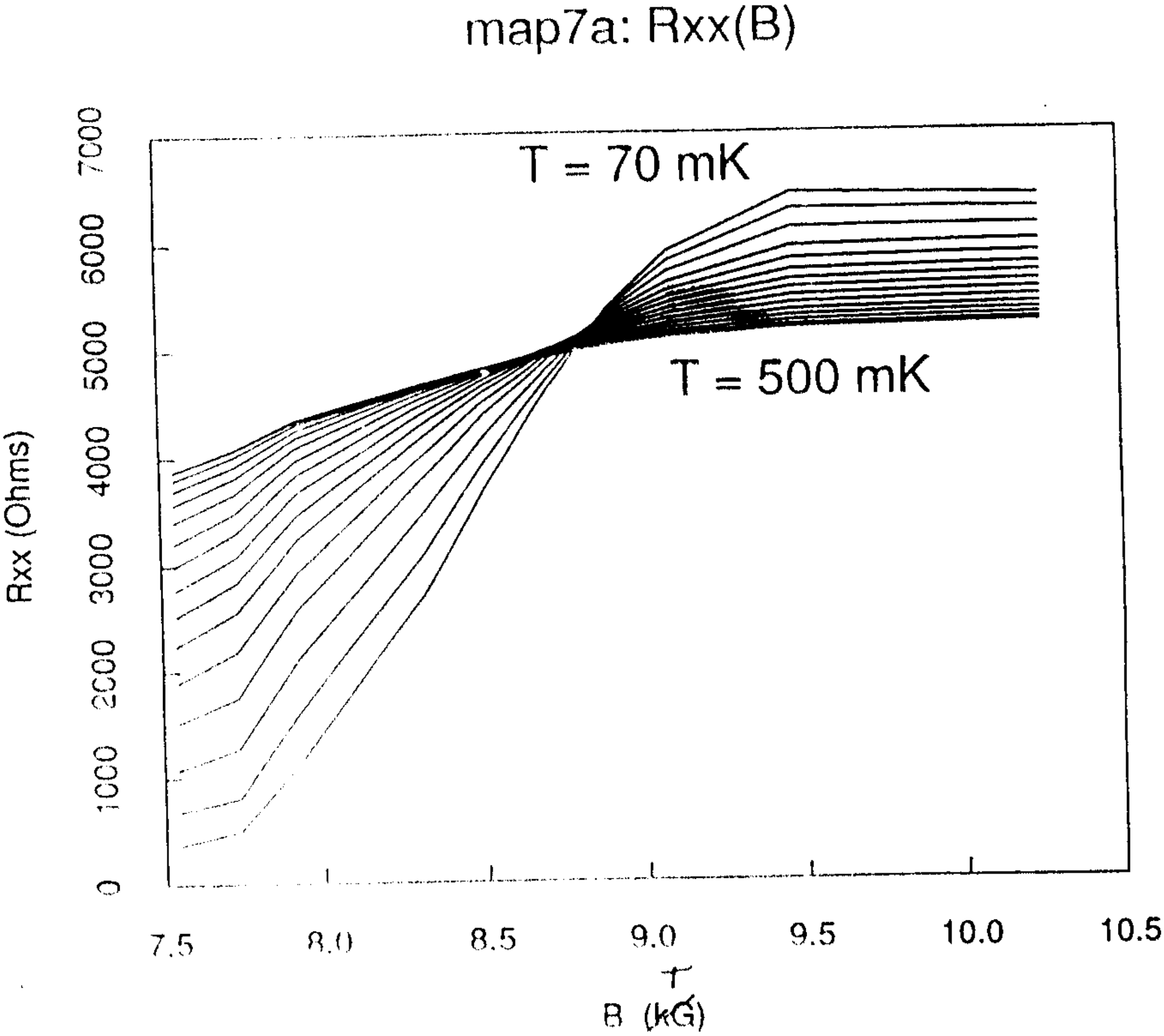


$T_c = 0.29K$
R_c
B_c
R (kΩ)
B (kG)
0
2
4
6
8
10
12

map8a: Rxx(B)



Rxx (Ohms)
0
2000
4000
6000
8000
12000
0
1
2
3
4
5
B (T)
130 mK
580 mK
R_{xx}^c = 6560 Ω
B_c = 2.05 T



map7a: Rxx(B)
T = 70 mK
T = 500 mK
Rxx (Ohms)
0
1000
2000
3000
4000
5000
6000
7000
7.5
8.0
8.5
9.0
9.5
10.0
10.5
B (kG)

Scaling Theory Exponents

- Scaling length ξ and frequency Ω: $(B = 0, T = 0)$

$$\xi \sim (\Delta_c - \Delta)^{-\nu}, \ \Omega \sim \xi^{-z}$$

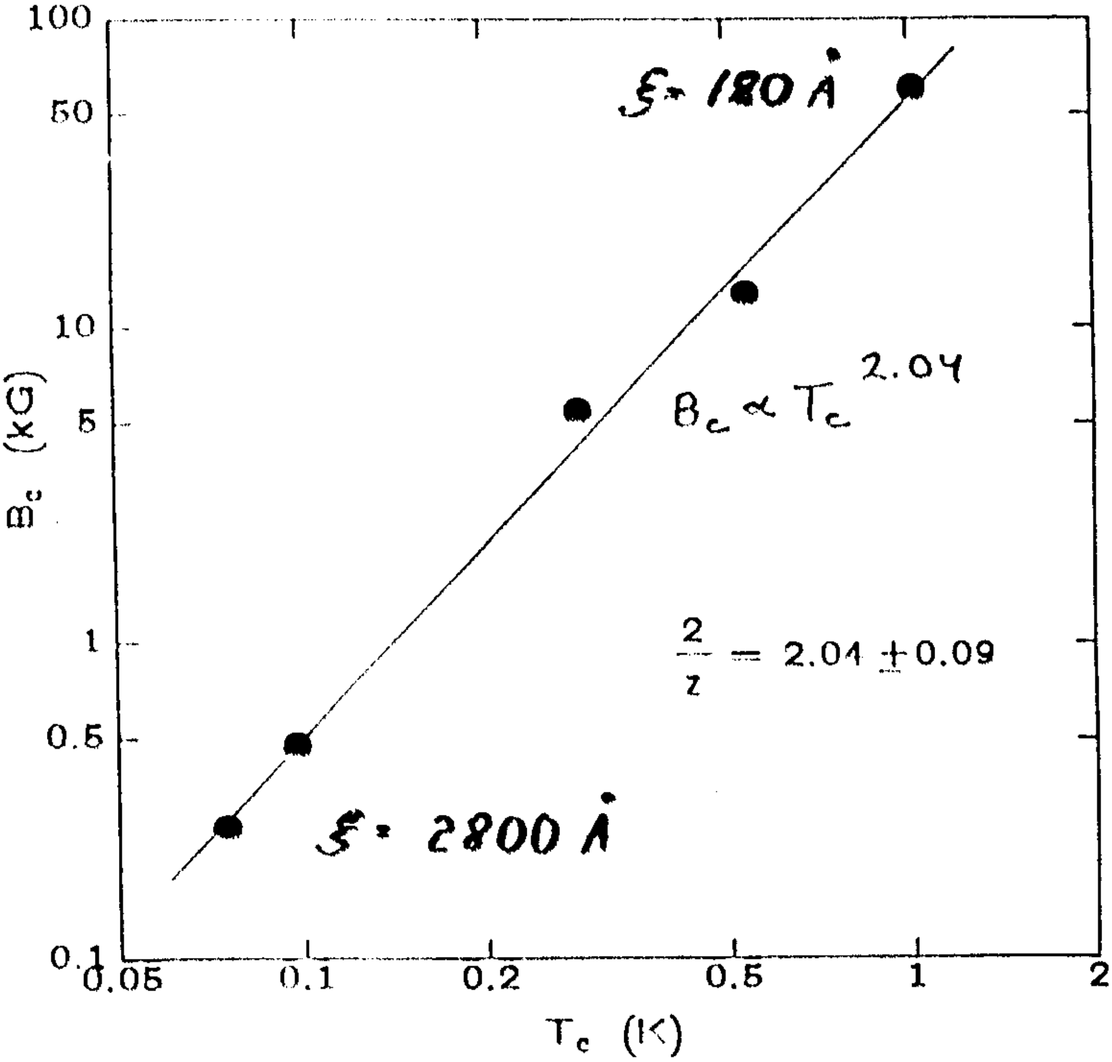
- Scaling dependence of T_c and B_c:

$$T_c \sim \Omega, \ B_c \sim \xi^{-2}$$

- An experimental measurement of the dynamical exponent Z derives from

$$B_c \sim T_c^{2/z}$$

(The theoretical prediction is $Z = 1$)

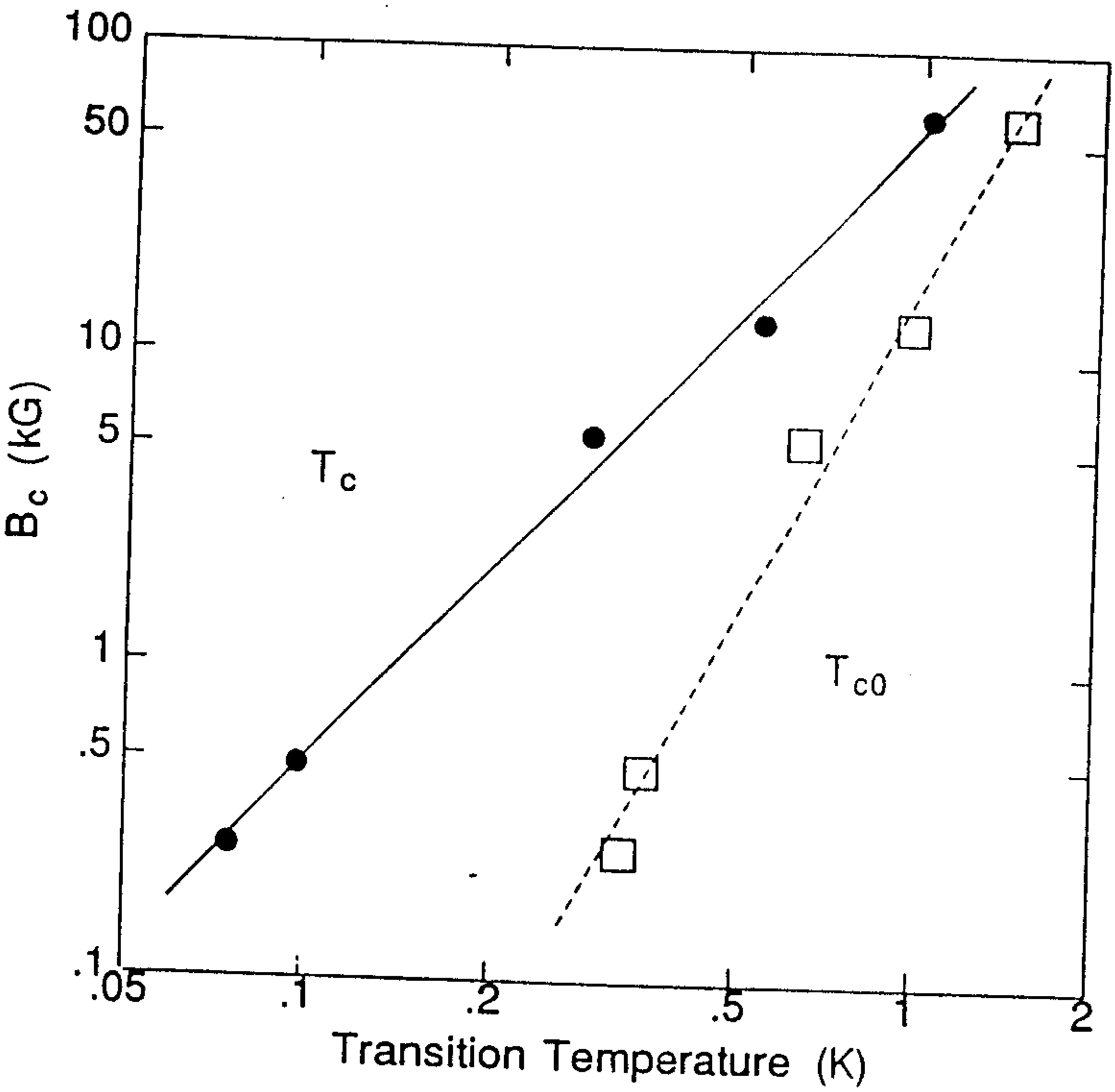

ξ = 180 Å
ξ = 2800 Å
$B_c \propto T_c^{2.04}$
$\frac{2}{z} = 2.04 \pm 0.09$
B_c (kG)
T_c (K)
100
50
10
5
1
0.5
0.1
0.05
0.1
0.2
0.5
1
2

$$\xi_0 \approx \frac{v_F}{T_{c0}}$$

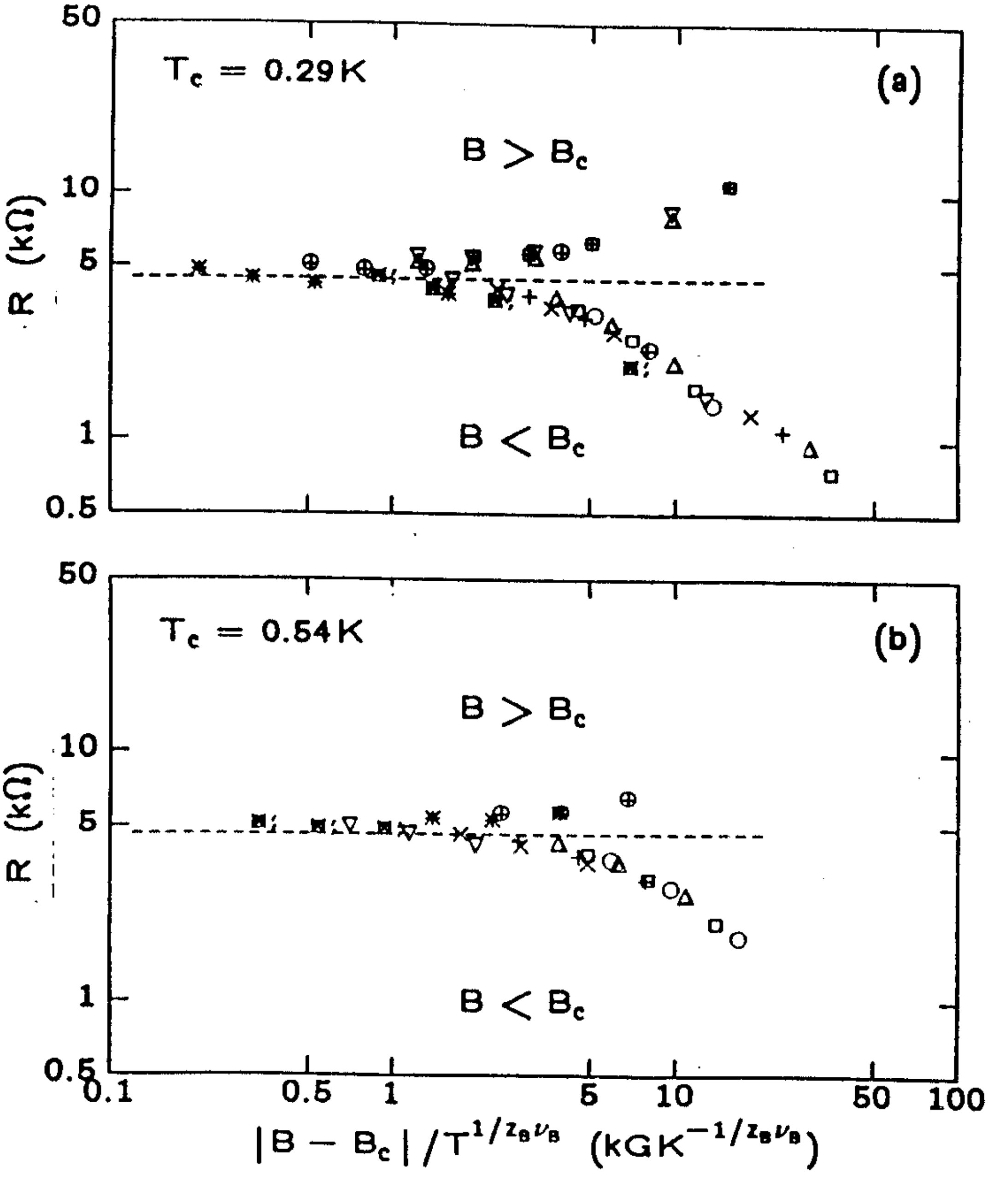
$$B_c \sim \xi_0^{-2}$$

$$\Rightarrow \quad T_{c0} \sim B_c^2 \; ?$$

This is not true experimentally



100
50
10
5
1
.5
.1
B_c (kG)
T_c
T_{c0}
.05
.1
.2
.5
1
2
Transition Temperature (K)

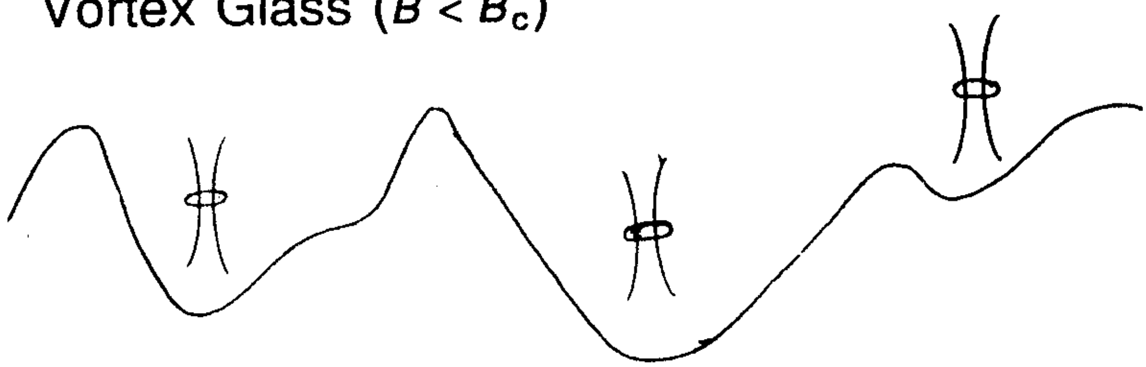


$T_c = 0.29$ K
(a)
$B > B_c$
$B < B_c$
$T_c = 0.54$ K
(b)
$B > B_c$
$B < B_c$
R (kΩ)
50
10
5
1
0.5
0.1
0.5
1
5
10
50
100
$|B - B_c| / T^{1/z_B \nu_B}$ $(kG K^{-1/z_B \nu_B})$

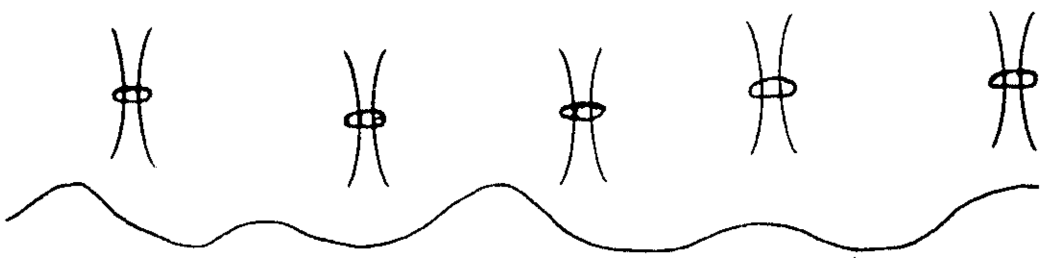
$\nu_B = 1.3$
$z_B = 1$

Quantum Vortices in a Random Potential

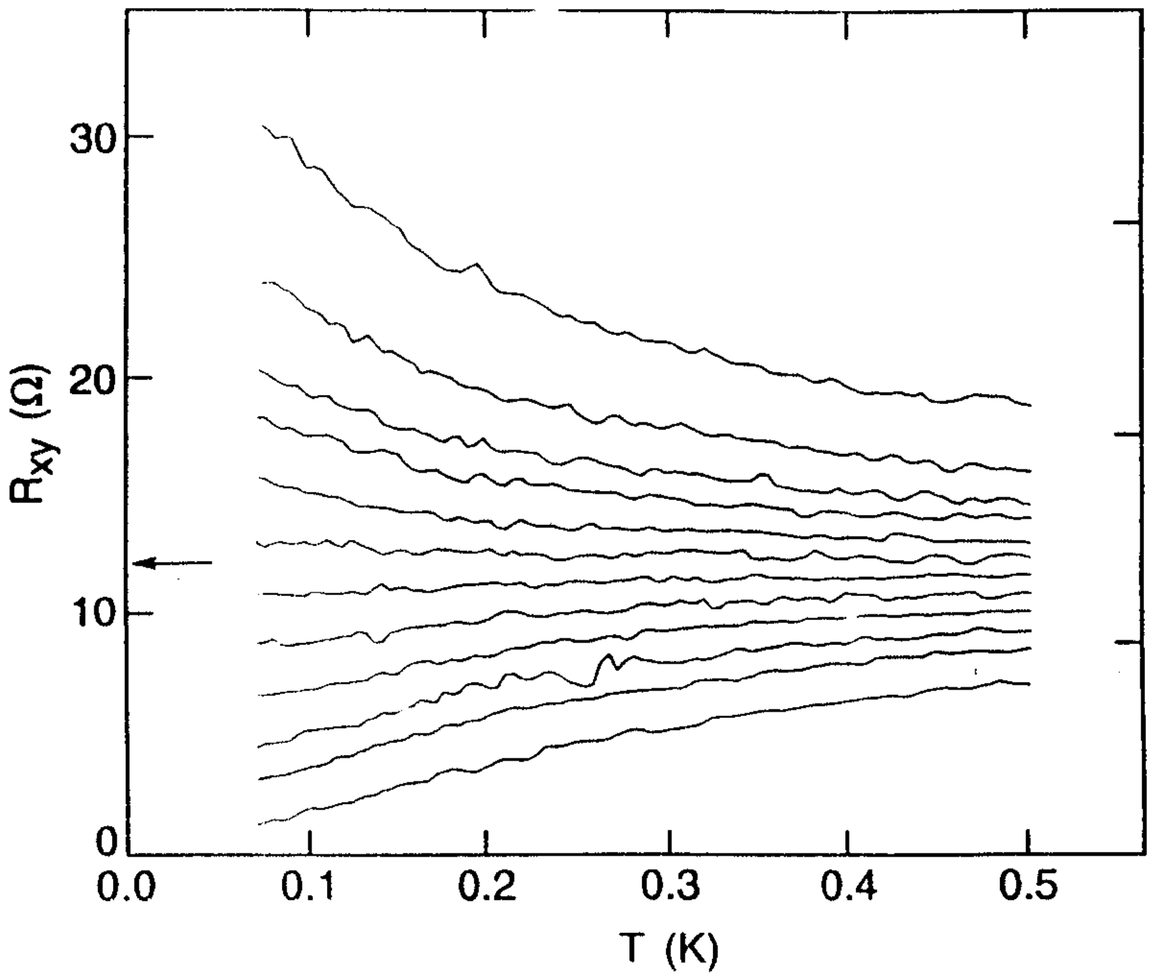
- Vortex Glass ($B < B_c$)



- Bose Insulator ($B > B_c$)

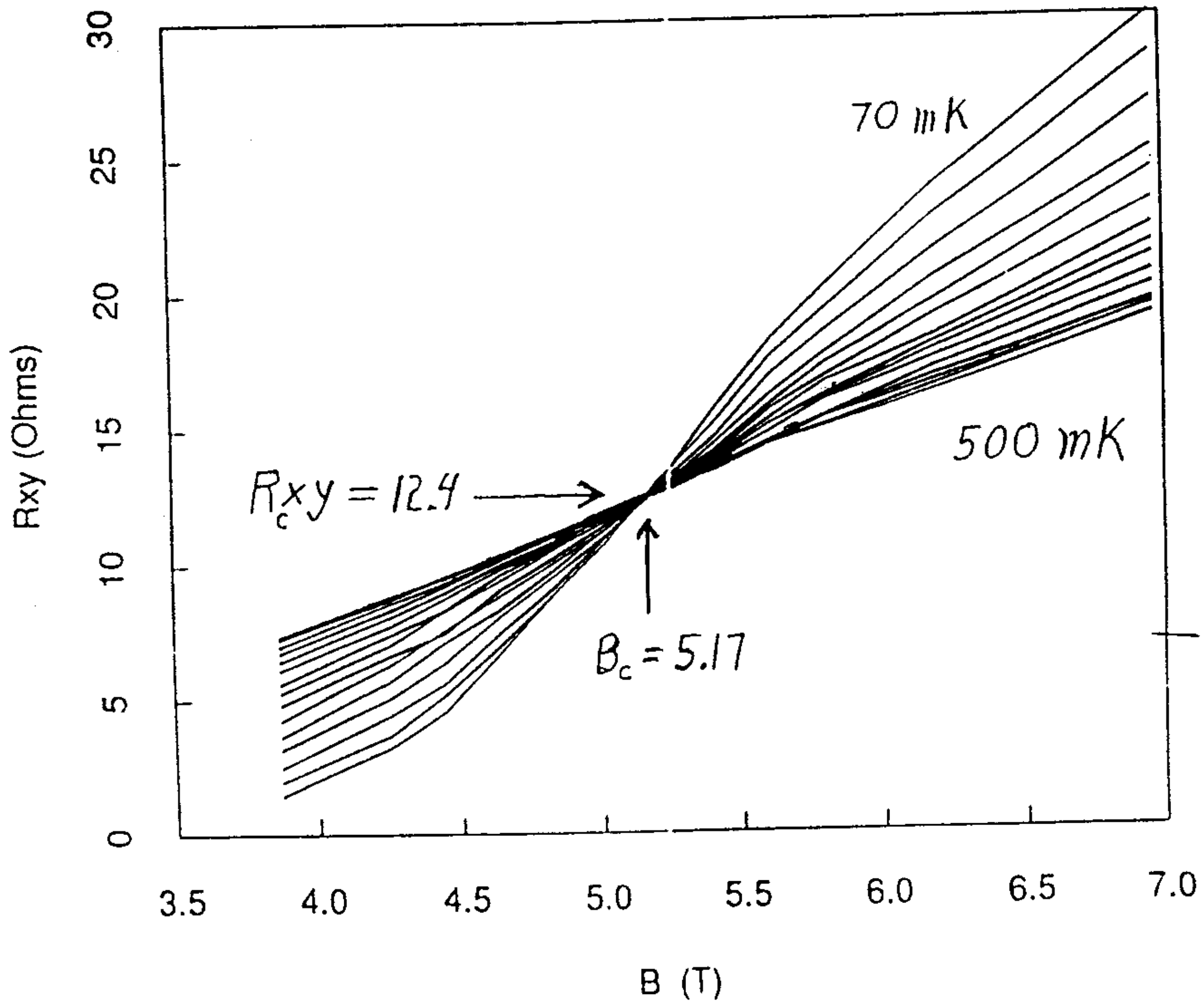


$$R_{xy} = \frac{B}{ne}$$



GON 2M20482 .5 BJ

map7b: Rxy(B)



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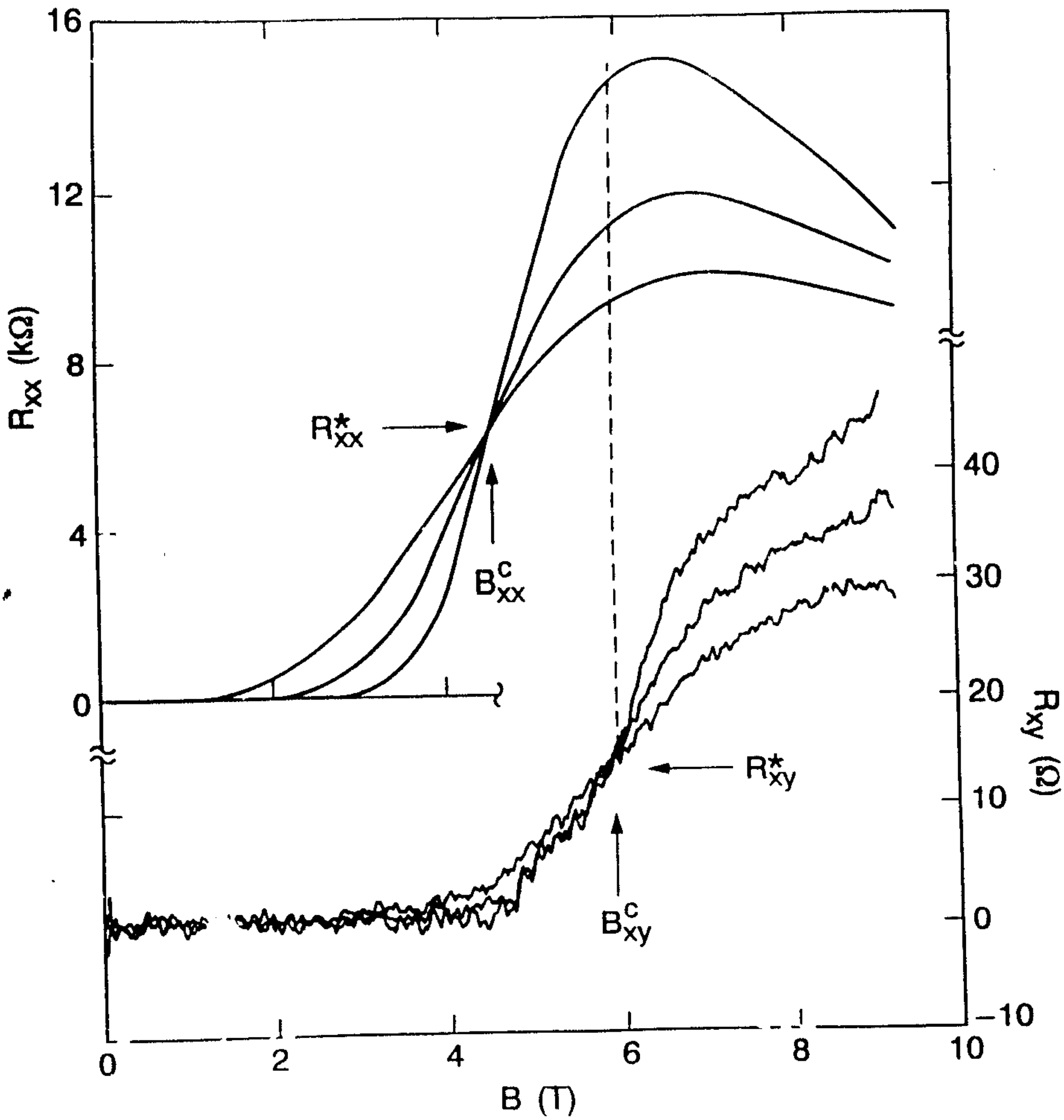
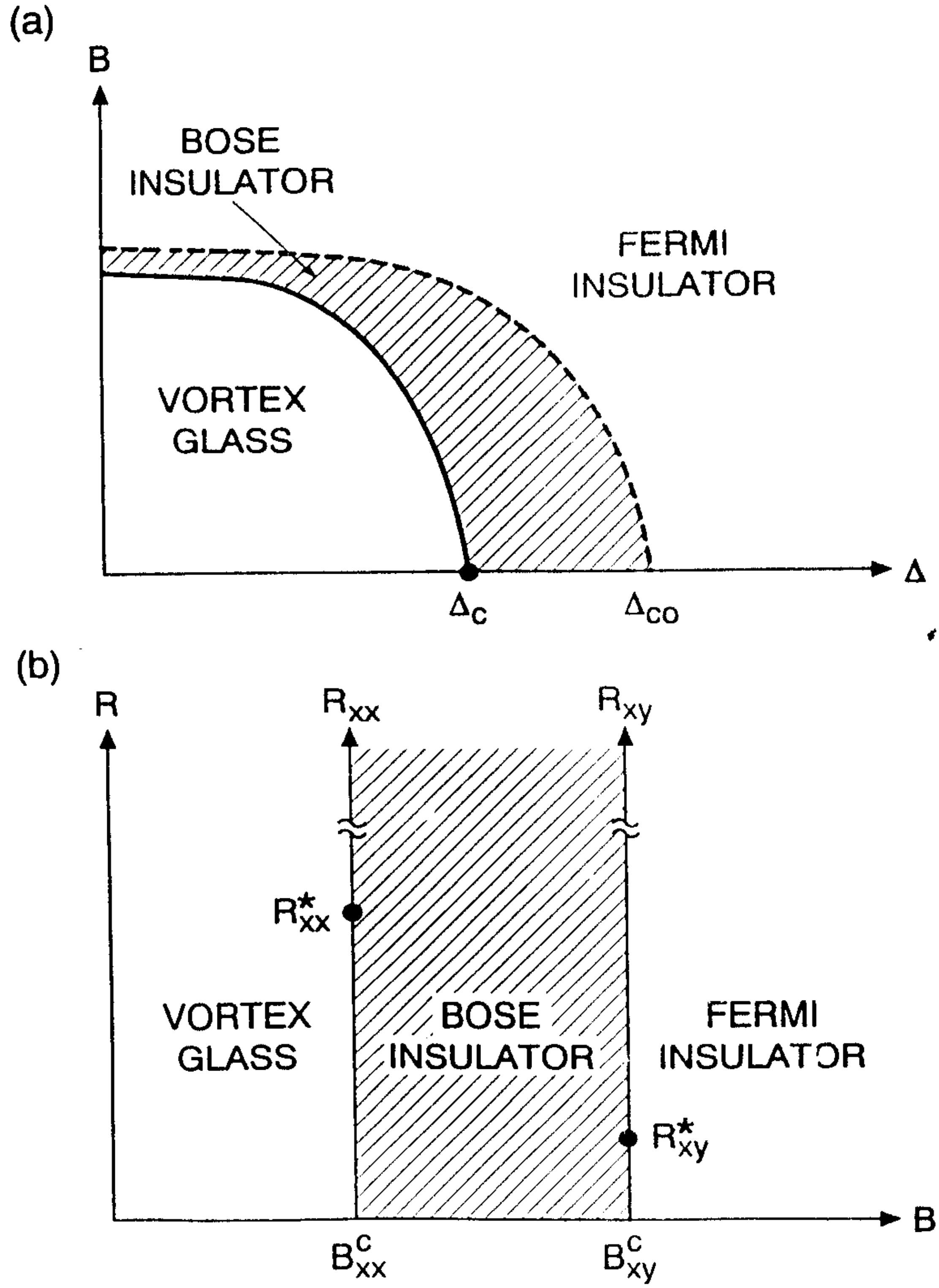


GON 2M20482 .6 BJ


(a)
B
BOSE
INSULATOR
FERMI
INSULATOR
VORTEX
GLASS
Δ
Δ_c
Δ_{co}
(b)
R
R_{xx}
R_{xy}
R^*_{xx}
VORTEX
GLASS
BOSE
INSULATOR
FERMI
INSULATOR
R^*_{xy}
B
B^c_{xx}
B^c_{xy}