Critical Exponents for Mott-Anderson Transition

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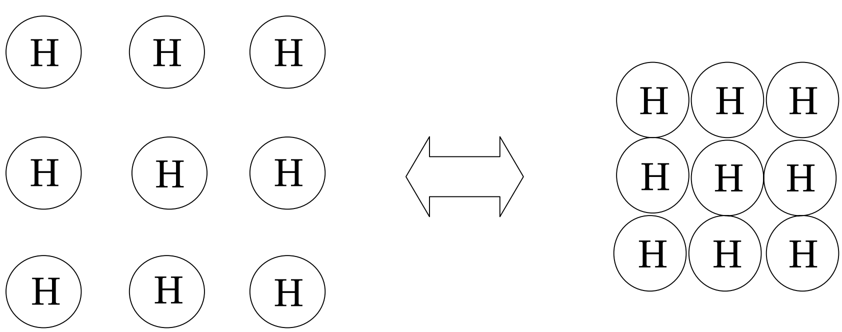
Mott Transition

Neutral hydrogen in a simple squared lattice at T= 0K

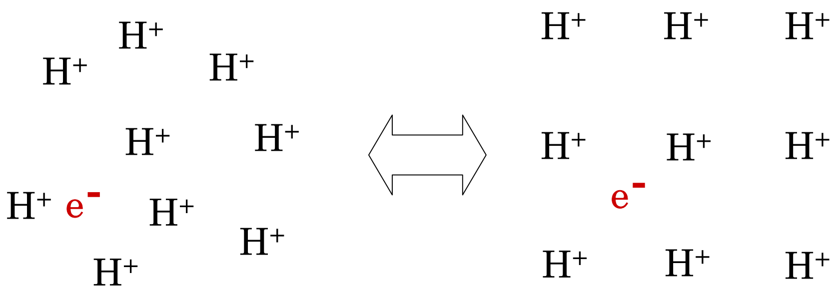


Insulator $N<N_C$ Metal $N>N_C$

electron-electron interaction

Anderson Transition

One electron in ordered and disordered potential at T= 0K



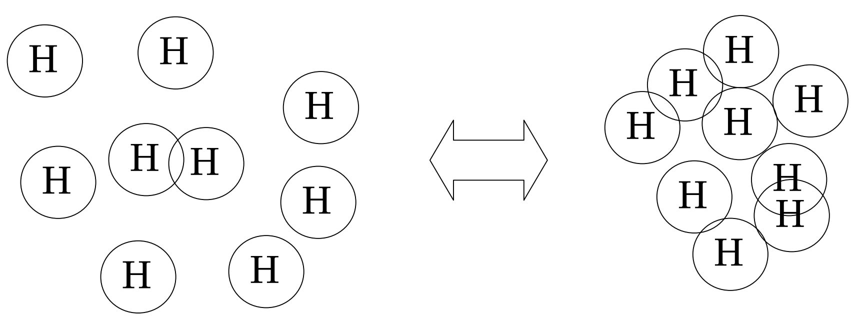
Insulator (disordered)

Metal (ordered)

disorder

Mott-Anderson Transition

Neutral hydrogen in the random state at T= 0K



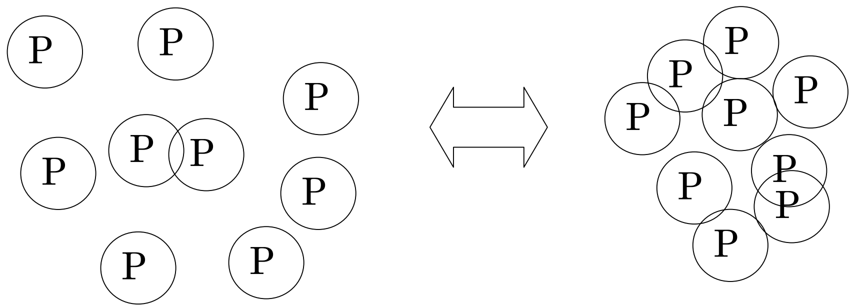
Insulator $N<N_C$

Metal $N>N_C$

electron-electron interaction and disorder

Mott-Anderson Transition in uncompensated Si:P

Neutral donors in semiconductors in
the random state at T= 0K

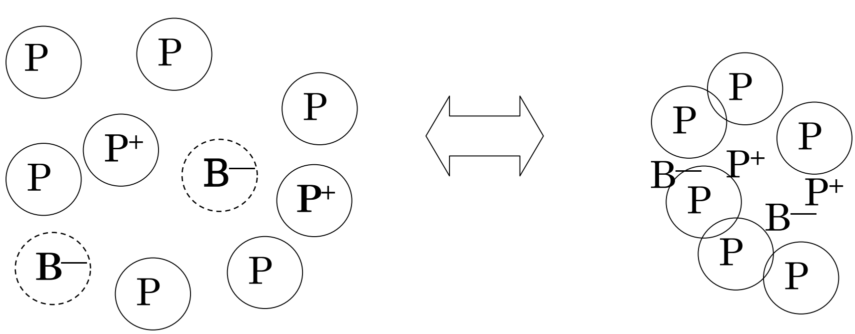


Insulator $N<N_C$ Metal $N>N_C$

electron-electron interaction and disorder

Mott-Anderson Transition in compensated Si:P

Neutral and ionized donors in semiconductors in
the random state at T= 0K



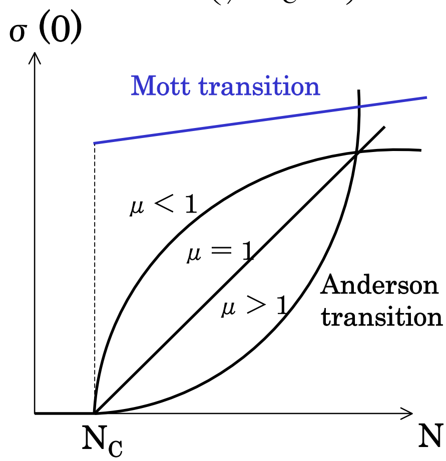
Insulator $N<N_C$ Metal $N>N_C$

electron-electron interaction and stronger disorder for larger $K \equiv \frac{[B]}{[P]}$

Critical exponents

Conductivity (experiment)

$$\sigma(0) \propto \left(N / N_C - 1 \right)^{\mu}$$



correlation length (theory)

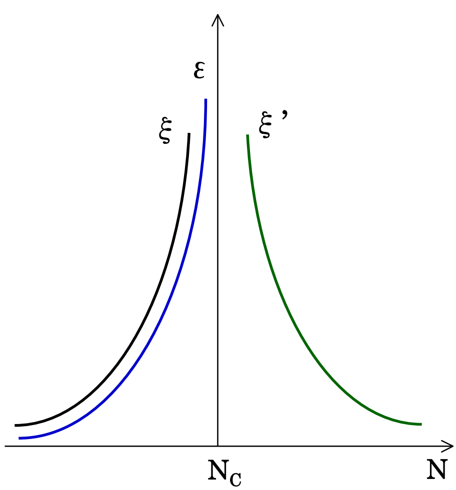
$$\xi' \propto \left(N / N_C - 1 \right)^{-\nu}$$

$$\begin{cases} \nu \approx 1.5 & \text{for pure-Anderson} \\ \nu > \dfrac{2}{3} & \text{Chayes's relation for Mott-Anderson} \end{cases}$$

Compare theory and experiment assuming Wegner's relation for 3-dimension (d=3)

$$\mu = (d-2)\nu = \nu$$

Critical exponents



Metallic side ($N>N_C$)

Correlation length (theory)

$$\xi' \propto \left(N / N_C - 1 \right)^{-\nu}$$

Insulating side ($N<N_C$)

Dielectric constant

$$\varepsilon(N) = \varepsilon_h + \chi_{imp}(N)$$

$$\chi_{imp}(N) = \chi_0 \left(N_C / N - 1 \right)^{-\zeta}$$

Localization length

$$\xi(N) = \xi_0 \left(1 - N / N_C \right)^{-\nu}$$

Experimentally reported μ for nominally uncompensated doped semiconductors

System	μ
Si:P	0.5, 1.0, 1.2
Si:As	0.5, 1.0
Si:B	0.65, 1.6
Ge:As	0.5, 1.2
Ge:Sb	0.9
Ge:Ga	0.5, 1.2

For compensated semiconductors **μ~1**

Fabrication of homogeneously doped sample by neutron transmutation doping (NTD)

^{70}Ge 20.5% + n → ^{71}Ge → ^{71}Ga acceptor
^{72}Ge 27.4% + n → ^{73}Ge
^{73}Ge 7.8% + n → ^{74}Ge
^{74}Ge 36.5% + n → ^{75}Ge → ^{75}As donor
^{76}Ge 7.8% + n → ^{76}Ge → ^{76}Se double donor

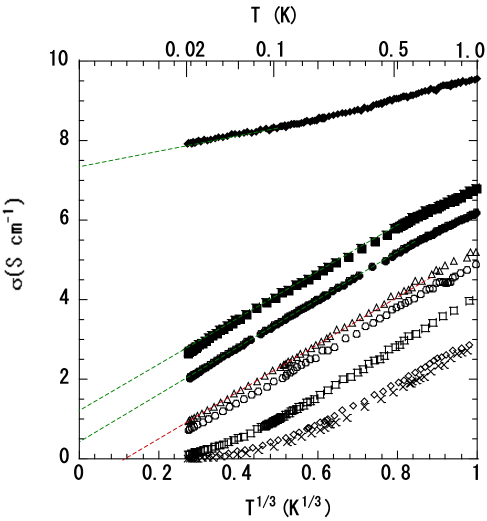
1. Nominally uncompensated series K~0

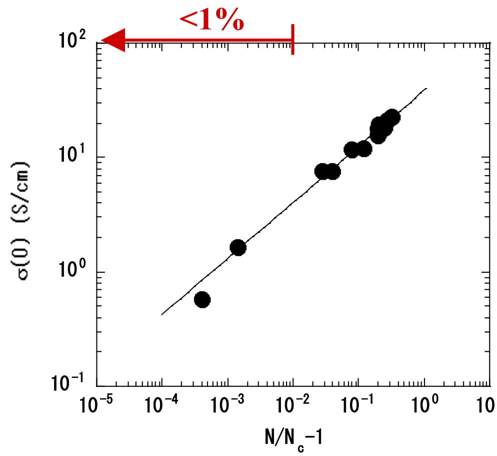
   NTD of ^{70}Ge (96.3%)+^{72}Ge (3.7%) single crystal

2. Compensated series K~0.32

   NTD of ^{nat}Ge

Nominally uncompensated series (K~0)





$$\sigma(0) \propto \left(N / N_C - 1 \right)^{\mu=0.55}$$

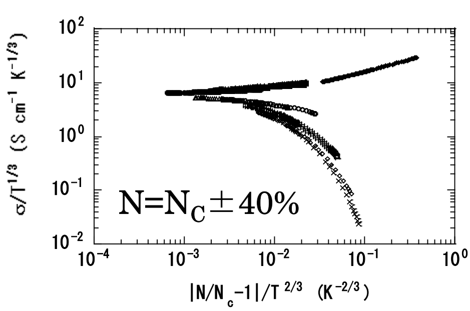
Nominally uncompensated series (K~0)

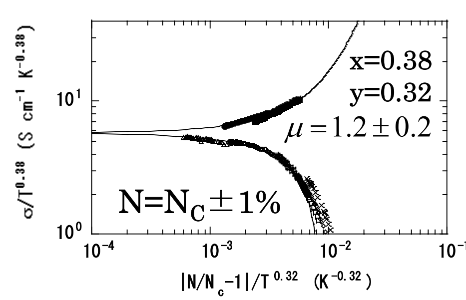
Finite temperature scaling

$$\sigma(N,T) \propto T^x f\left(\frac{N / N_C - 1}{T^y} \right)$$

$$\frac{\sigma(N,T)}{T^x} \propto f\left(\frac{N / N_C - 1}{T^y} \right)$$

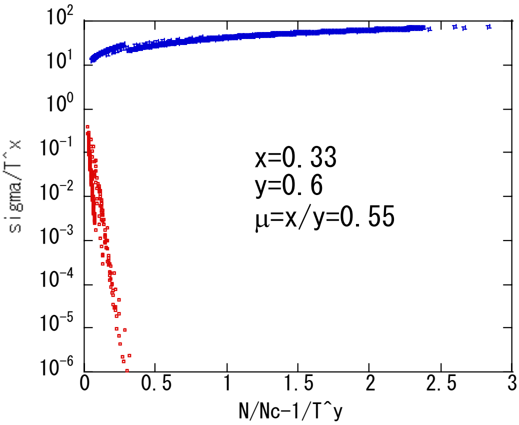
$$\mu = x / y$$

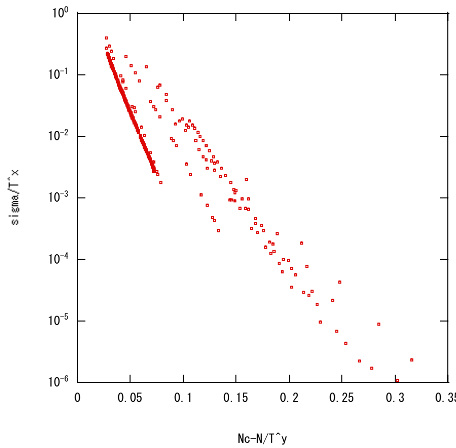




Nominally uncompensated series (K~0)

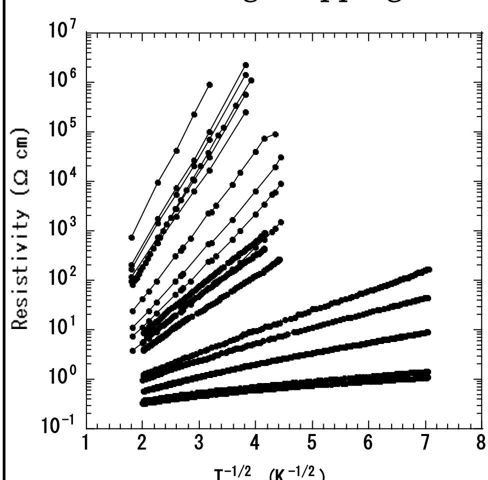
Finite temperature scaling without $N=N_C \pm 1\%$





Nominally uncompensated series (K~0)

Variable range hopping conduction in insulating samples



$$\rho(N,T) \propto \rho_0 T^{-1/3} \exp\left(\frac{T_0}{T}\right)^{1/2}$$

Dielectric constant

$$\varepsilon(N) = \varepsilon_h + \chi_{imp}(N)$$

$$\chi_{imp}(N) = \chi_0 \left({N_C}/{N} - 1 \right)^{-\zeta}$$

Localization length

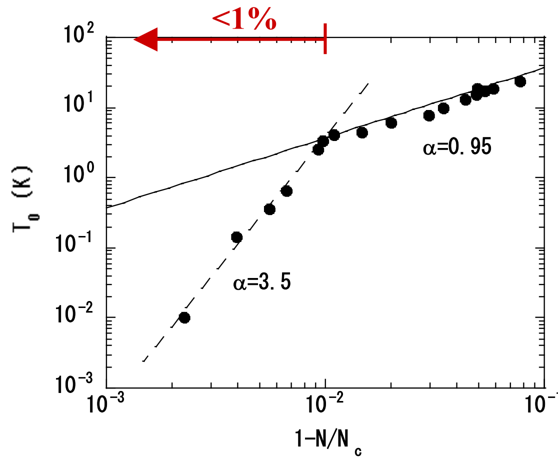
$$\xi(N) = \xi_0 \left(1 - {N}/{N_C} \right)^{-\nu}$$

$$k_B T_0 \propto \frac{1}{4\pi\varepsilon_0} \frac{2.8e^2}{\varepsilon(N)\xi(N)} = \frac{2.8e^2}{4\pi\varepsilon_0 \chi_0 \xi_0} \left(1 - {N}/{N_C} \right)^{\alpha=\nu+\zeta}$$

Nominally uncompensated series (K~0)

Variable range hopping conduction in insulating samples

$$k_B T_0 \propto \frac{1}{4\pi\varepsilon_0}\frac{2.8e^2}{\varepsilon(N)\xi(N)} = \frac{2.8e^2}{4\pi\varepsilon_0\chi_0\xi_0}\left(1-\frac{N}{N_C}\right)^{\alpha=\nu+\zeta}$$



Nominally uncompensated series (K~0)

Scaling of the dielectric constant and localization length in insulators

Wegner's law

$$\mu = (d-2)\nu = \nu$$

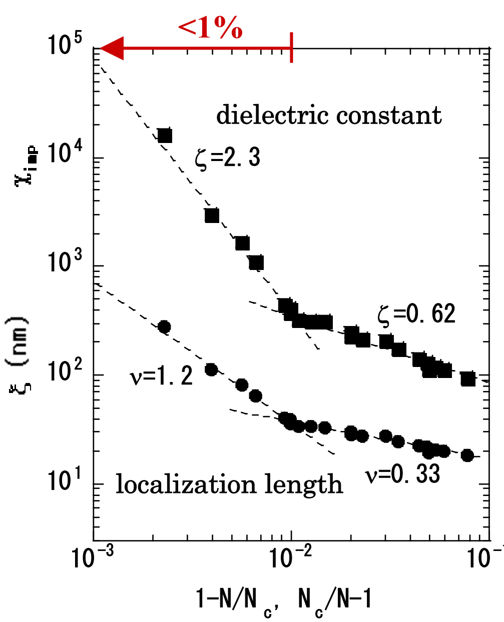
$\mu = \nu = 1.2$ within 1%

$\mu = 0.55 \neq \nu = 0.33$ for >1%

Dynamical scaling exponents

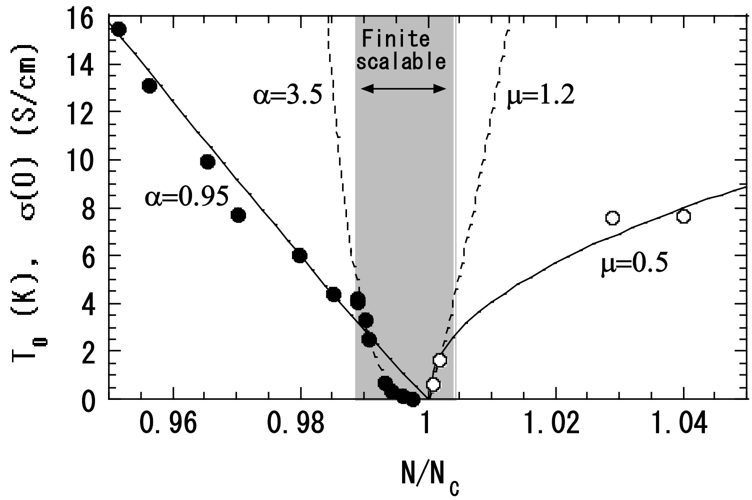
$$z = \frac{1}{y\nu} \approx 3 \quad \text{within } 1\%$$

$$\approx 5 \quad \text{for} > 1\%$$



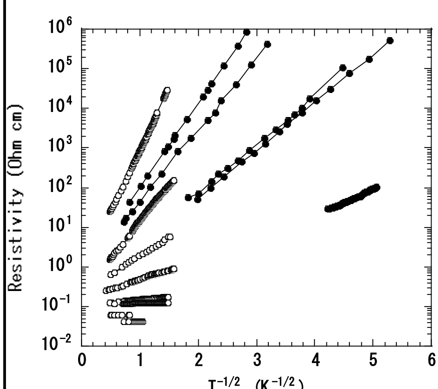
Nominally uncompensated series (K~0)

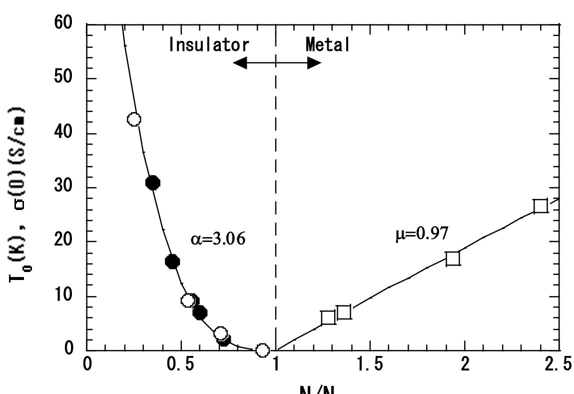
Variable range hopping conduction in insulating samples



Intentionally compensated series (K~0.32)

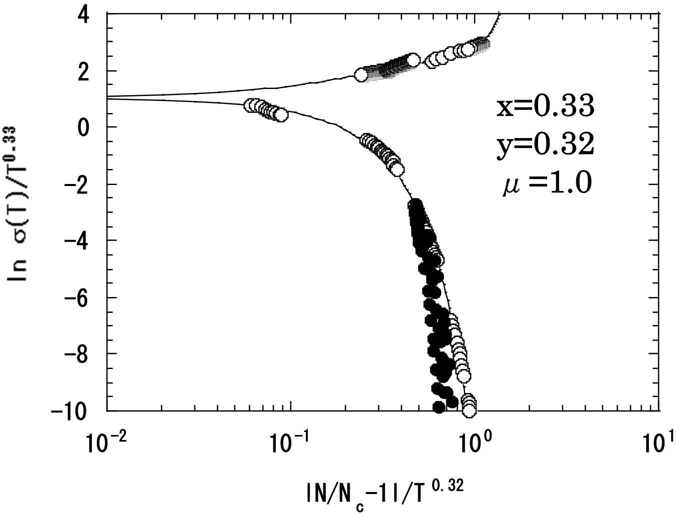
Variable range hopping conduction in insulating samples





Intentionally compensated series (K~0.32)

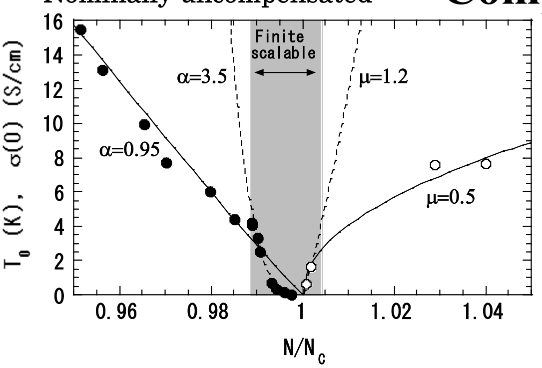
Finite temperature analysis for $N=N_C\pm 80\%$



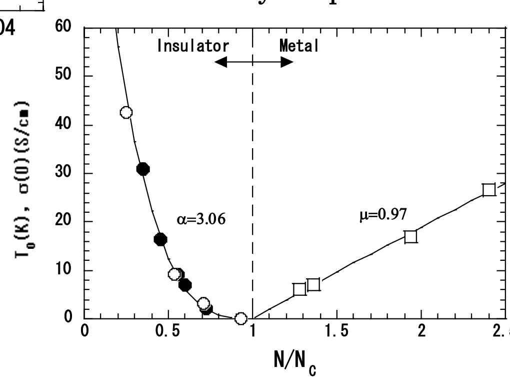
$$z = \frac{1}{y\nu} \approx 3$$

Comparison

Nominally uncompensated

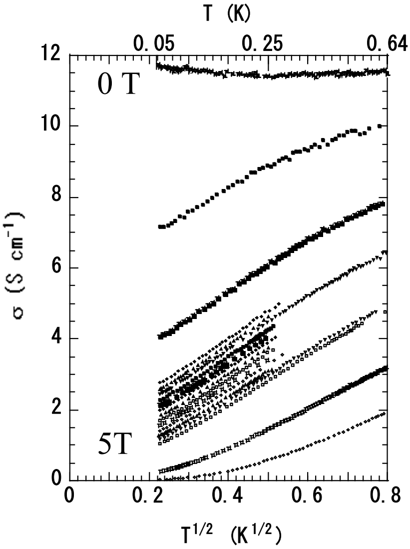


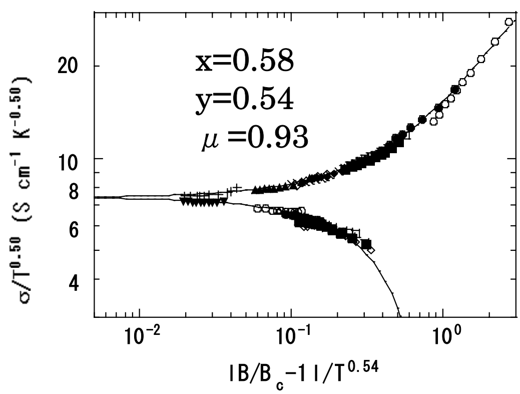
intentionally compensated



Nominally uncompensated series (K~0)

Magnetic field induced transition

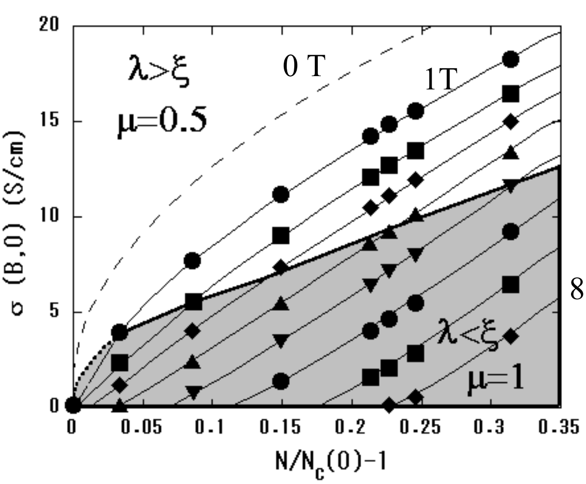




$$z = \frac{1}{y\nu} \approx 2$$

Nominally uncompensated series (K~0)

Effect of externally apply constant magnetic field



Magnetic length

$$\lambda = \sqrt{\frac{\hbar}{eB}}$$

$$z = \frac{1}{y\nu}$$

Summary

exponents	Compensation K~0, B=0		K=0.32, B=0	K~0, B>0
	up to 50%	within 1%	up to 80%	
Conductivity μ from σ(N, T=0)	0.55	----	0.97	1
Conductivity μ from σ(N,T)	0.55 ?	1.2±0.2	1.0	0.93
To of hopping α	0.95	3.5±0.5	3.1	---
Localization and correlation ν	0.33	1.2	~1 (Katsumoto)	---
Dielectric const. ς	0.62	2.3	~2 (Katsumoto)	---
Dynamical z	5 ?	3	3	2
Wegner's law	μ ≠ ν	μ = ν	μ = ν	---