TDGL Simulation on the Motion of Flux Lines in a Thin Superconducting Wire in a Transverse Magnetic Field

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1. Background
2. About my study
3. TDGL equation
4. Simulation model
5. E-J property
6. J_c-B property
7. conclusion

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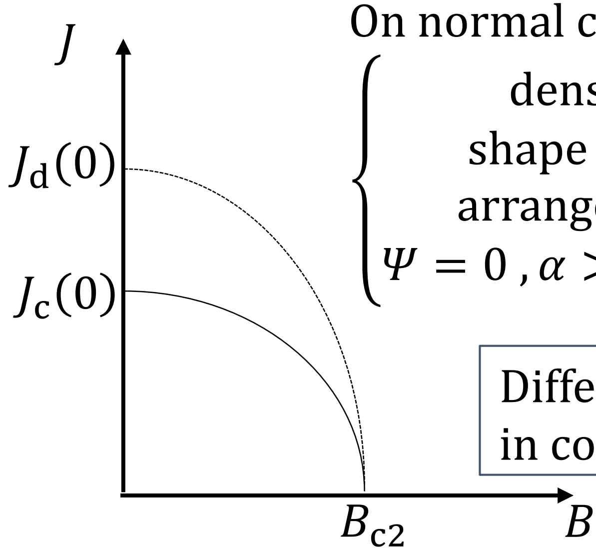
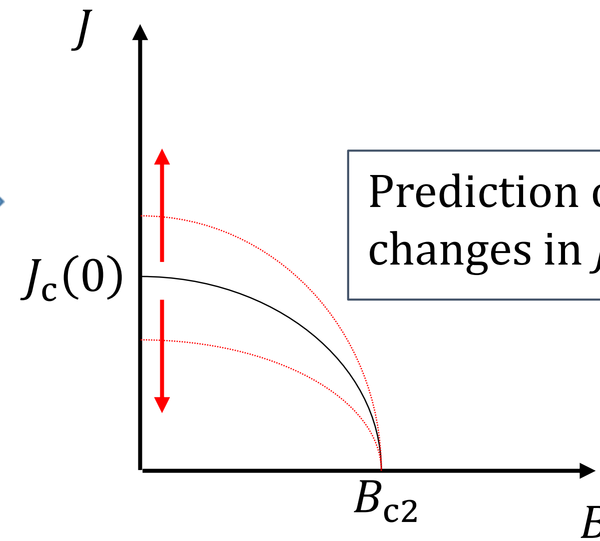
1. Background



On normal conductor…

- density
- shape / size
- arrangement
- $\Psi = 0\,,\alpha > 0\ \ \beta > 0$

Differences in conditions



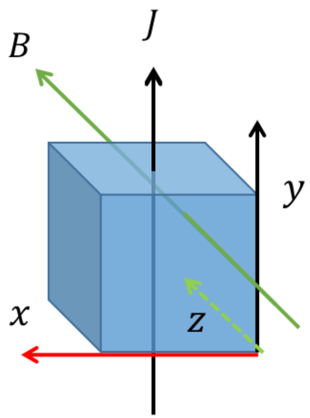
Prediction of changes in J_c

Difficult to confirm

Improvement of computer processing performance in recent years

Confirmation is realistically possible

2. About my study

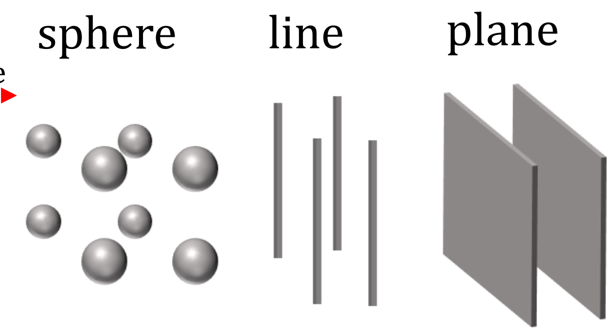


Transverse magnetic field

On normal conductor

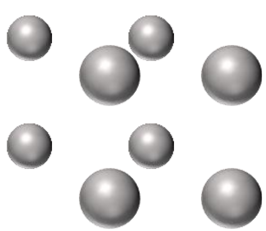
- density
- shape / size
- arrangement
- boundary condition

For example →



Pick up

sphere



$$\begin{cases} \Psi = 0 \\ \dfrac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi + \eta\Psi = 0 \,, \eta = \left(\dfrac{\xi}{\xi_\mathrm{n}}\right)^{\frac{1}{2}} \end{cases}$$

Investigate E-J and J_c-B properties.

3. TDGL equation

- Ginzburg-Landau(GL) equation
  - Phenomenological theory to explain superconductivity
  - Calculate order parameter Ψ
  - $|\Psi|^2$:Superconducting electron density

- Time Dependent GL(TDGL) equation
  - GL equations with time dependency

3. TDGL equation

- Equations

$$\begin{cases} \dfrac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi - \Psi + |\Psi|^2\Psi = 0 & (1) \\ \sigma\nabla^2 V = \dfrac{\mathrm{i}}{2}(\Psi^*\nabla^2\Psi - \Psi\nabla^2\Psi^*) - \nabla\cdot(|\Psi|^2\boldsymbol{A}) & (2) \\ \begin{cases} \Psi = 0 \\ \dfrac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi + \eta\Psi = 0\,, \eta = \left(\dfrac{\xi}{\xi_\mathrm{n}}\right)^{\frac{1}{2}} \end{cases} & (3) \end{cases}$$

$$\left(\boldsymbol{J}_\mathrm{s} = \frac{\mathrm{i}}{2}(\Psi^*\nabla\Psi - \Psi\nabla\Psi^*) - |\Psi|^2\boldsymbol{A}, \boldsymbol{J}_\mathrm{n} = -\sigma\nabla V\right)$$

ξ_n : Coherence length of normal region

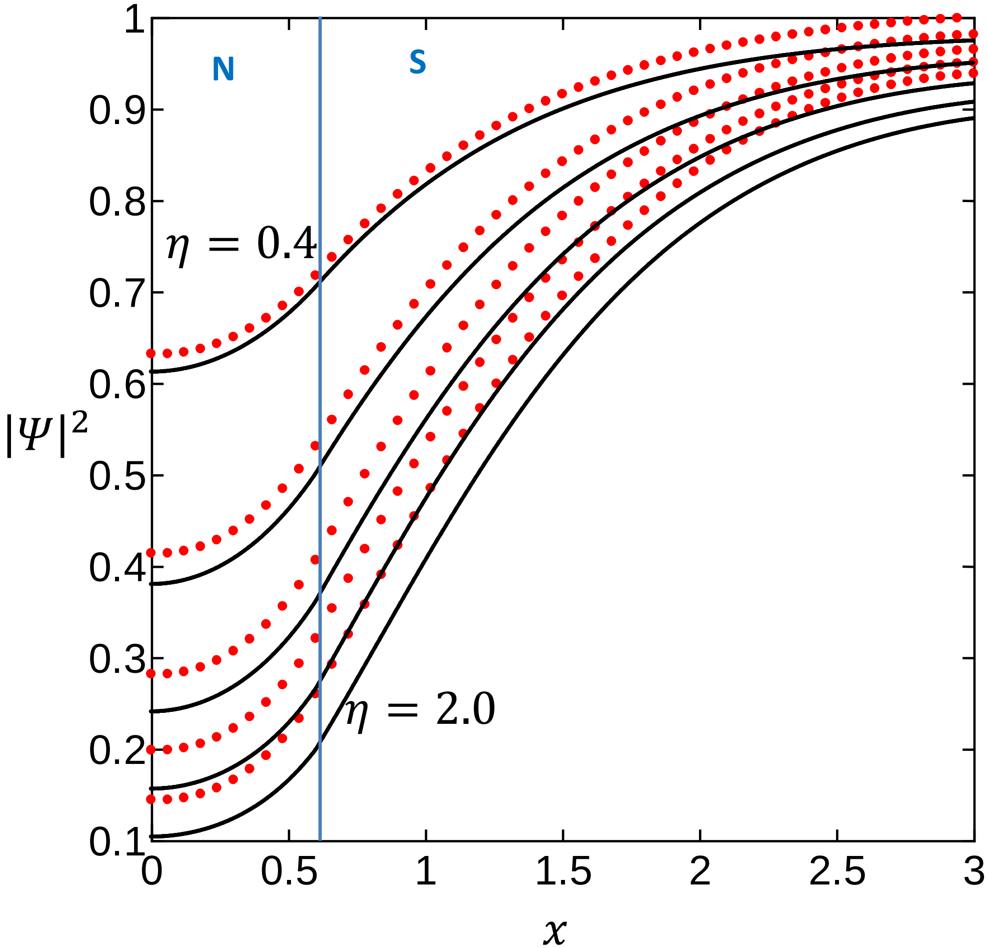
(1) Ψ in superconducting region

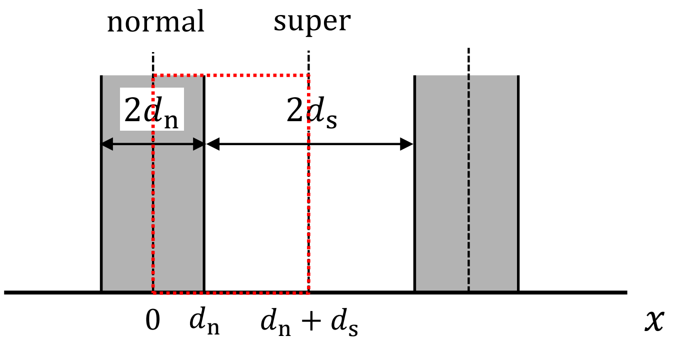
(2) Scalar potential V

(3) Ψ in normal region

3. TDGL equation

- Comparison with previous research without time evolution





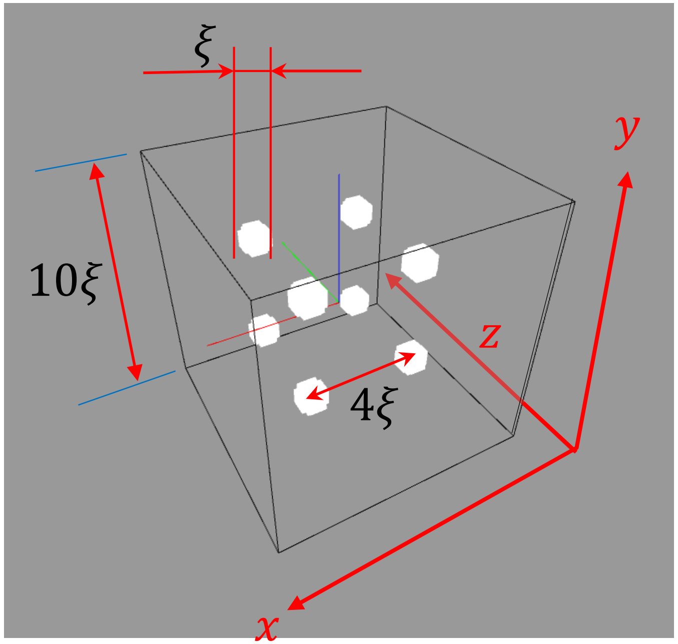
$$\frac{1}{\xi} x \to x,\ \eta = \left(\frac{\xi}{\xi_n}\right)^{\frac{1}{2}}$$

Solid line : Previous study*
Broken line : My calculation

$\eta = 0.4, 0.8, \cdots, 2.0$

(*)E.S. Otabe and T. Matsushita, Cryogenics (1993) 33 531-540

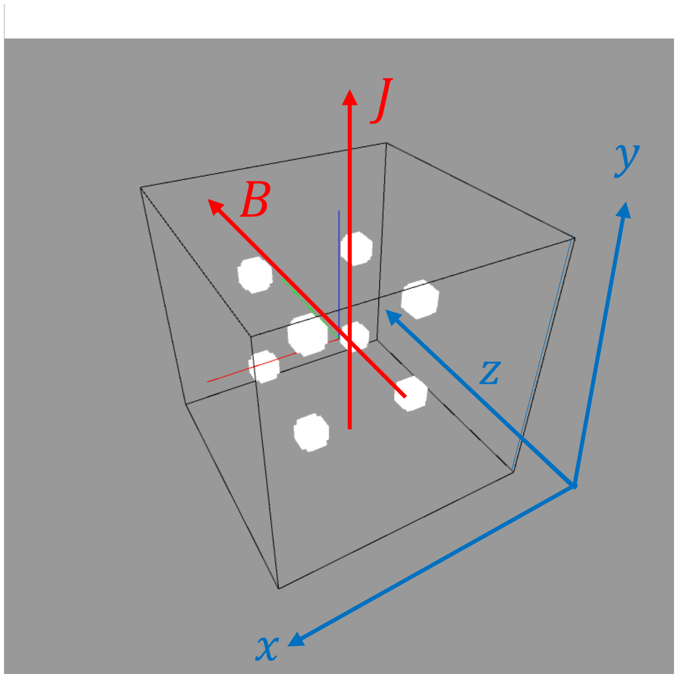
4. Simulation model



■Model

- Assuming in vacuum
- Consider a cube space(side length:10ξ)
- Spherical pin(diameter :ξ)
- The distance between adjacent pins : 4ξ

4. Simulation model



■Current density J, Magnetic flux density B

- $J = J_y \boldsymbol{i}_y, \quad B = B_z \boldsymbol{i}_z \quad (\because J \perp B)$

  ($\boldsymbol{i}_x, \boldsymbol{i}_y, \boldsymbol{i}_z$: Unit vector of each axis)

■ Initial condition

- $\Psi(t = 0) = \cos\theta + \mathrm{i}\sin\theta$
- $V(t = 0) = -Jy/\sigma$

■ Boundary conditions

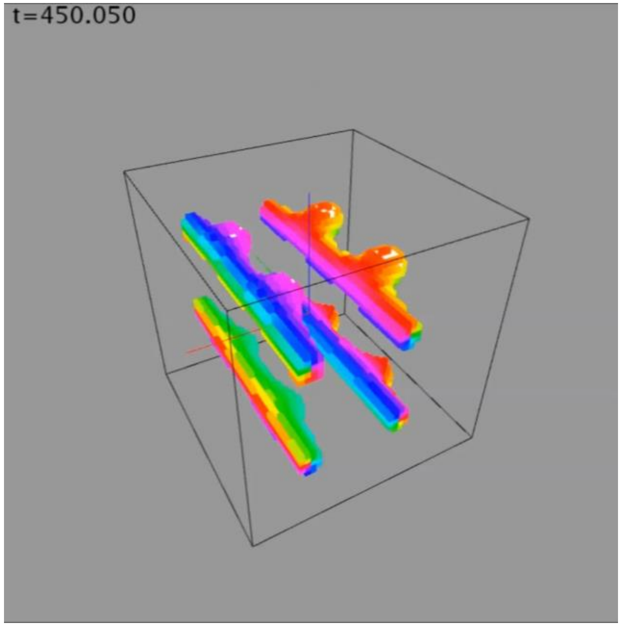
- $\boldsymbol{n} \cdot (\nabla\Psi + \mathrm{i}\boldsymbol{A}\Psi) = 0$
- $\nabla V = -\boldsymbol{J}/\sigma$

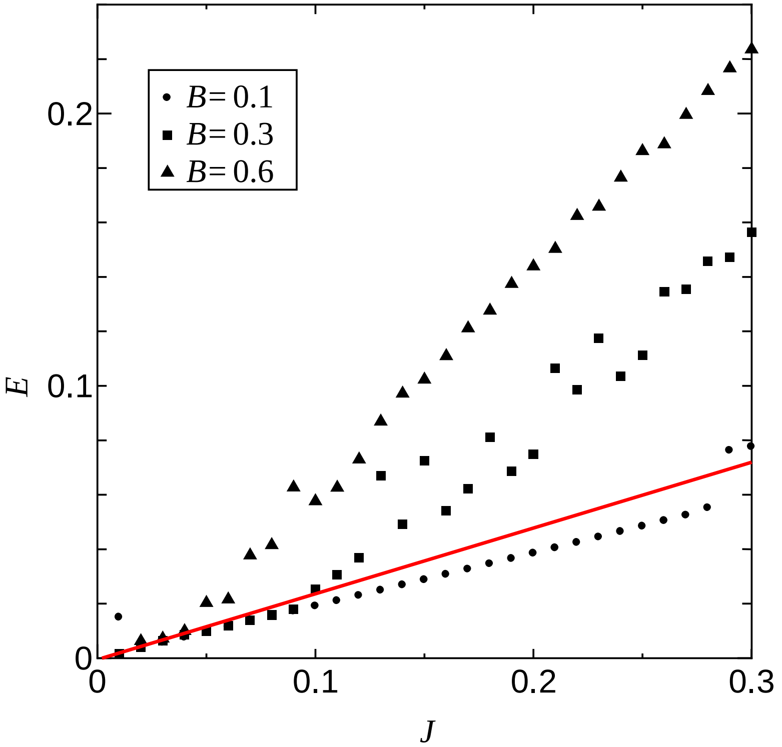
※$\boldsymbol{n}$: A unit vector perpendicular to the plane

5. E-J property

■ $\Psi = 0$

$$\boldsymbol{E} = -\boldsymbol{\nabla} V$$





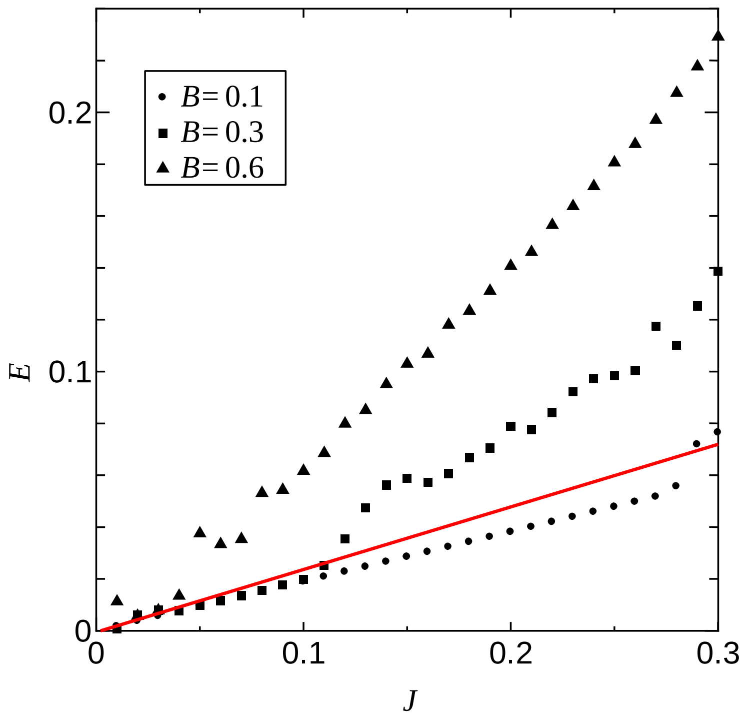
Super : $\frac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi - \Psi + |\Psi|^2\Psi = 0$

Normal : $\Psi = 0$

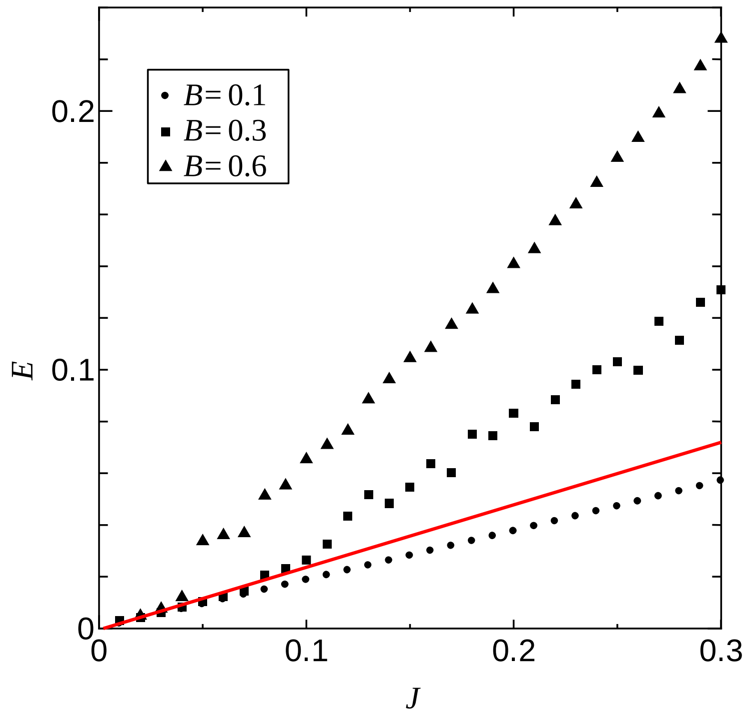
In each E-J properties, rising the electric field E can be confirmed.

5. E-J property

$$\frac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi + \eta\Psi = 0$$



$\eta = 0.4$



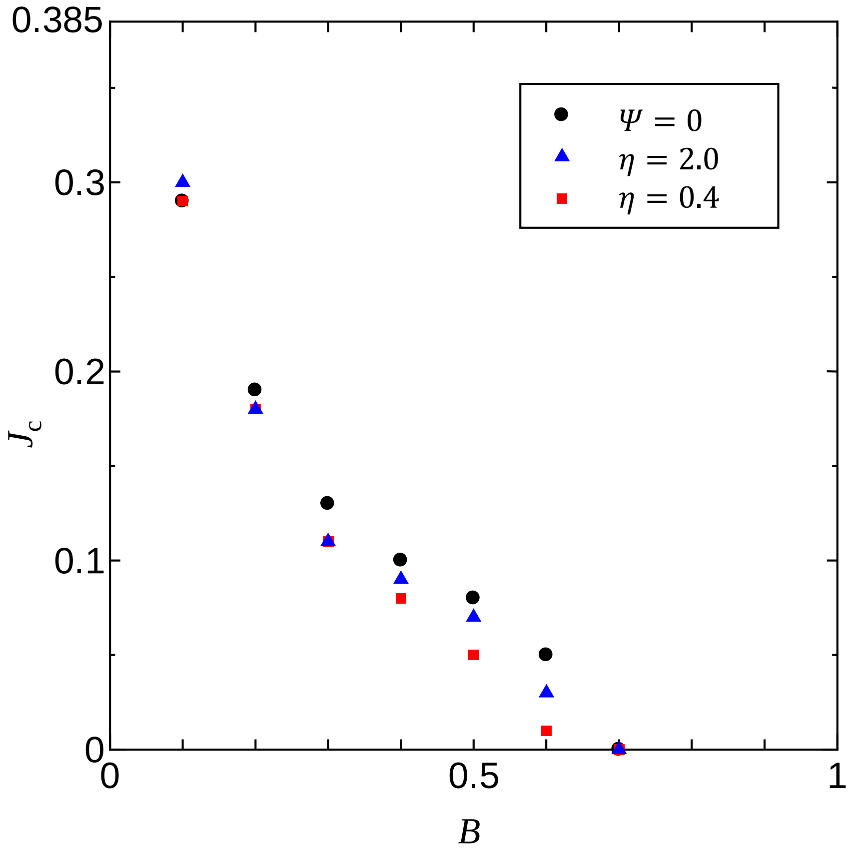
$\eta = 2.0$

Super : $\frac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi - \Psi + |\Psi|^2\Psi = 0$

Normal : $\frac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi + \eta\Psi = 0\ , \eta = \left(\frac{\xi}{\xi_{\mathrm{n}}}\right)^{\frac{1}{2}}$

In each E-J properties, rising the electric field E can be confirmed.

6. J_c-B property



- Each J_c-B property has a similar tendency
- J_c monotonously decreases as B increases
- The property is the best when $\Psi = 0$
- the property is better as the value of η is larger

$$\text{Super} \quad : \frac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi - \Psi + |\Psi|^2\Psi = 0$$

$$\text{Normal} : \frac{\partial \Psi}{\partial t} + \mathrm{i}V\Psi + (-\mathrm{i}\nabla - \boldsymbol{A})^2\Psi + \eta\Psi = 0\,,\, \eta = \left(\frac{\xi}{\xi_\mathrm{n}}\right)^{\frac{1}{2}}$$

7. Conclusion

- The J_c-B property was clarified by solving the simplified three - dimensional TDGL equation by simulation.

- The stronger the superconductivity of the pin is,
the weaker the effect as a pin to hold the magnetic flux line is.
Therefore it was confirmed that the J_c becomes lower.

- It is necessary to investigate the J_c-B property by changing the shape, size and arrangement of the pins.