Pinning Effects in Two-Band Superconductors

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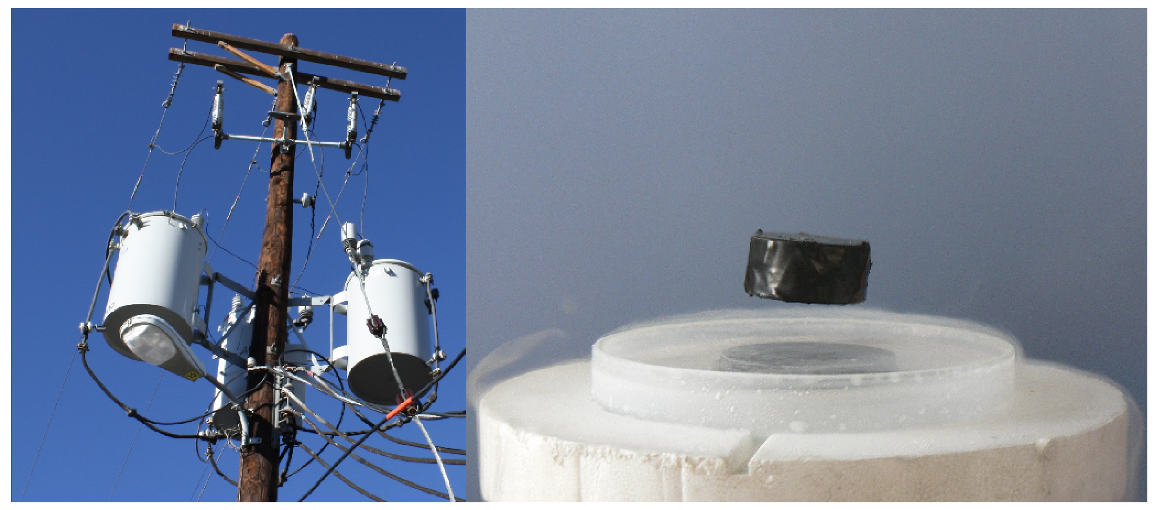
Objectives

- Numerically simulate the vortex dynamics in the superconducting material MgB_2.
- Devise a way to raise the maximum amount of current carried in the superconductor.
- Simulate how impurities raise the maximal current in MgB_2.

Introduction

Most are familiar with the waste heat produced by resistance in an electrical wire. This wasted energy can be avoided by using resistance free superconductors. However superconductors posses critical (maxiumum) values for their temperature, magnetic field, and current, only below which they operate as resistance free. Introducing impurities can raise the critical current by preventing flux flow. Practical superconducting devices could revolutionize technology but numerical simulations are needed to give insight.



MgB_2

- Magnesium Diboride (MgB_2) is a two band superconductor that can carry resistance free current under a temperature of 39K (-389.47 ° F).
- The bands act as pathways for electrons, each possessing their own properties seen in Table 1 .
- The bands interact to give composite direction and temperature dependent magnetic properties.

λ_1=47.8 nm	λ_2= 36.6 nm	ξ_1=13 nm	ξ_2=51 nm
κ_1=3.61	κ_2=0.658	$\nu = 2.757$	$\eta = -0.1701$

Table 1: The material parameters for MgB_2.

Flux Flow

- In the presence of a external magnetic field, normal materials are completely penetrated by the field. However superconductors such as MgB_2 are only penetrated by small magnetic flux vortices.
- The flux vortices interact with the applied current, **J** to produce a Lorentz force, **F**, perpendicular to **J**.
- The movement of the vortices, known as flux flow, induces an electric field, **E**, parallel to the applied current, creating an effective resistance.
- Figure 3 shows how the force moves the vortices (red) as time increases.

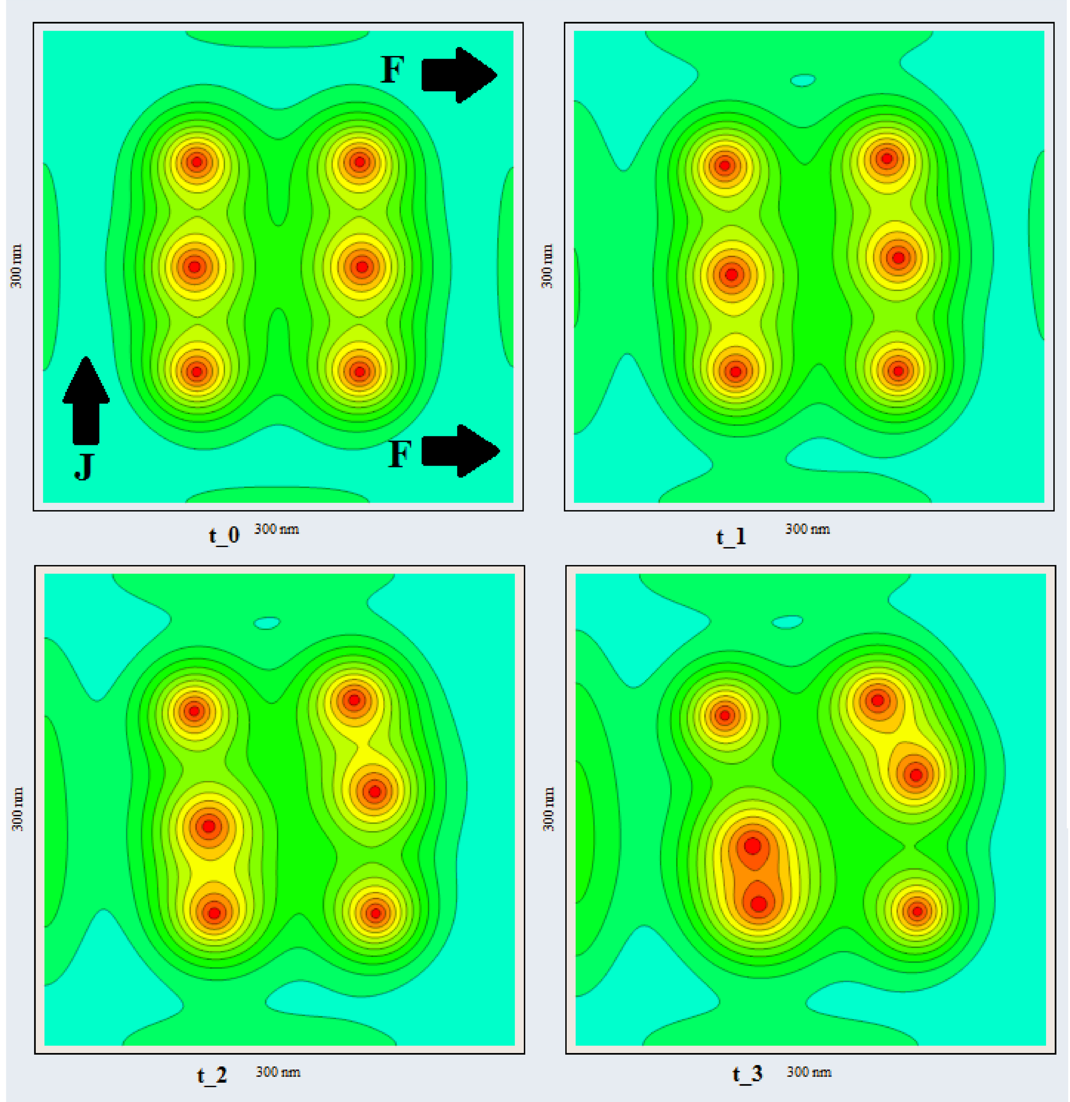


Figure 1: The vortices can be seen where ψ_1 is at is smallest (red). They are pushed to the right by the Lorentz force. At later times (t_3) the vortices rearrange themselves.

Mathematical Model

The Modified 2B-TDGL model describes superconductivity and contains ψ_1 and ψ_2, the density functions for the current carriers, the magnetic vector potential, **A**, and takes the parameters from Table 1 as input. The vortices can be seen where ψ_1 is at its smallest. Numerical simulations of vortex dynamics from the model are seen in Figures 1, 4

Methods

The finite element, Euler, and Newton methods were used together to solve the model equations. Supercomputers were used at F.S.U.'s R.C.C. for calculations.

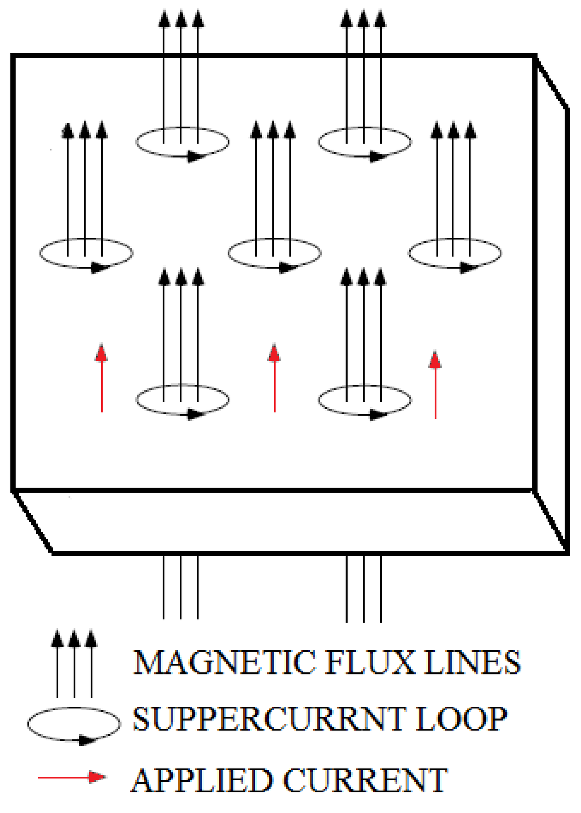


Figure 2: The set up for the numerical simulations. The magnetic field penetrates the sample as flux vortices and an applied current is transported across the sample.

Results

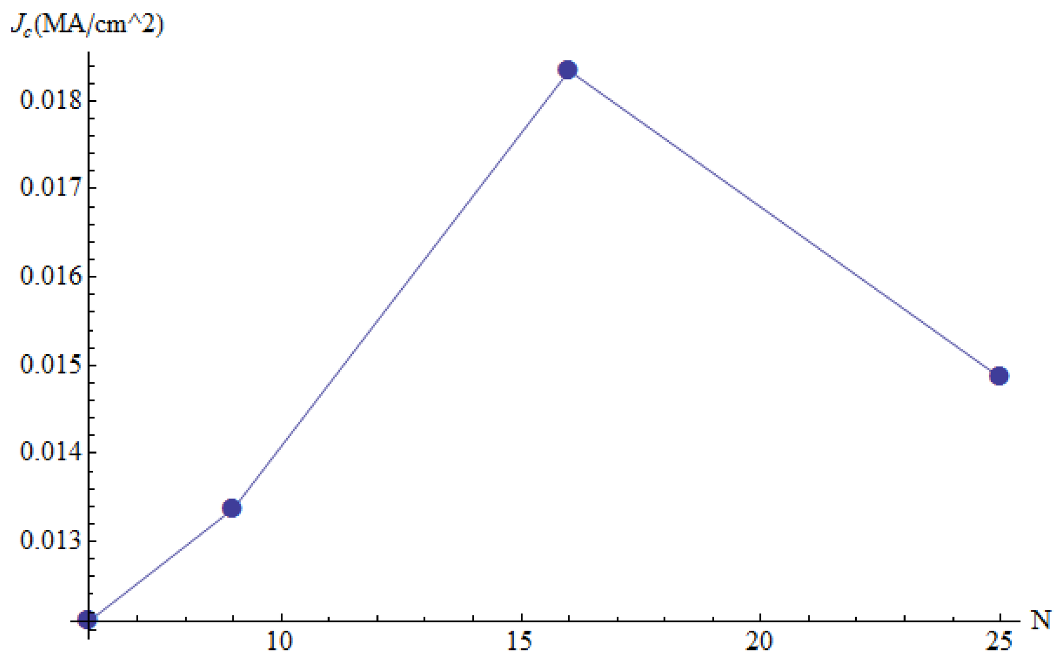


Figure 3: The critical current for different numbers of impurity sites. This under a temperature of 30 K and magnetic field of 0.106 Tesla.

Impurities were successfully modeled in the material. The pinning effects are shown in Figure 4. The impurity sites are outlined by the open black circles. A raise in the critical current J_c was found by increasing the normals N (Figure 3). However too many impurities degraded the superconducting material and lower J_c, as seen where N=25.

Conclusion

MgB_2 was successfully modeled using the simulation. Figure 5 shows directional dependence on the critical magnetic fields, comparable to experiments. An algorithm to model impurities in the sample was successful in raising the critical current.

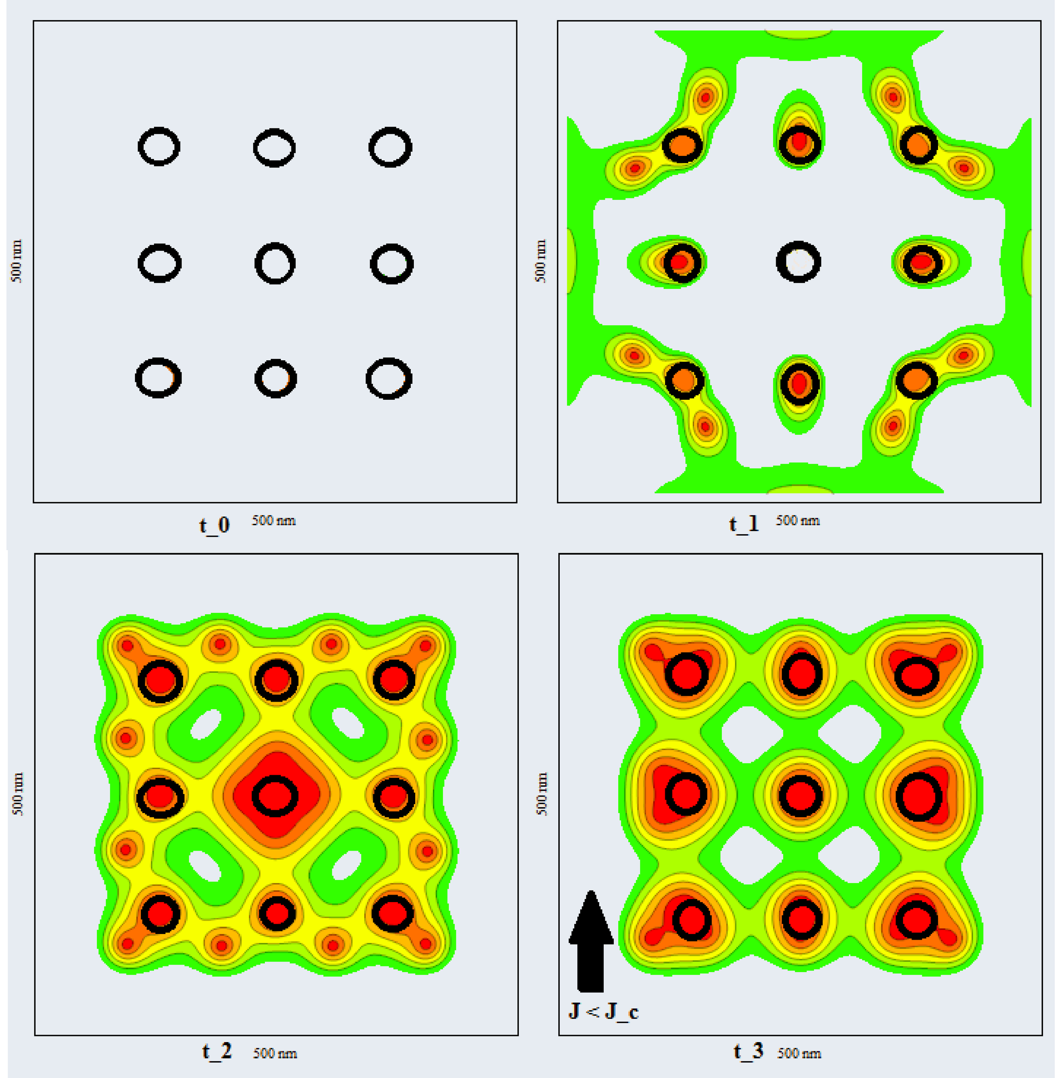


Figure 4: From top left to bottom right, vortices (red) are generated from a magnetic field. They become pinned to the normal site (black circles). When a current **J** is applied, the vortices remained pinned, unlike Figure 2.

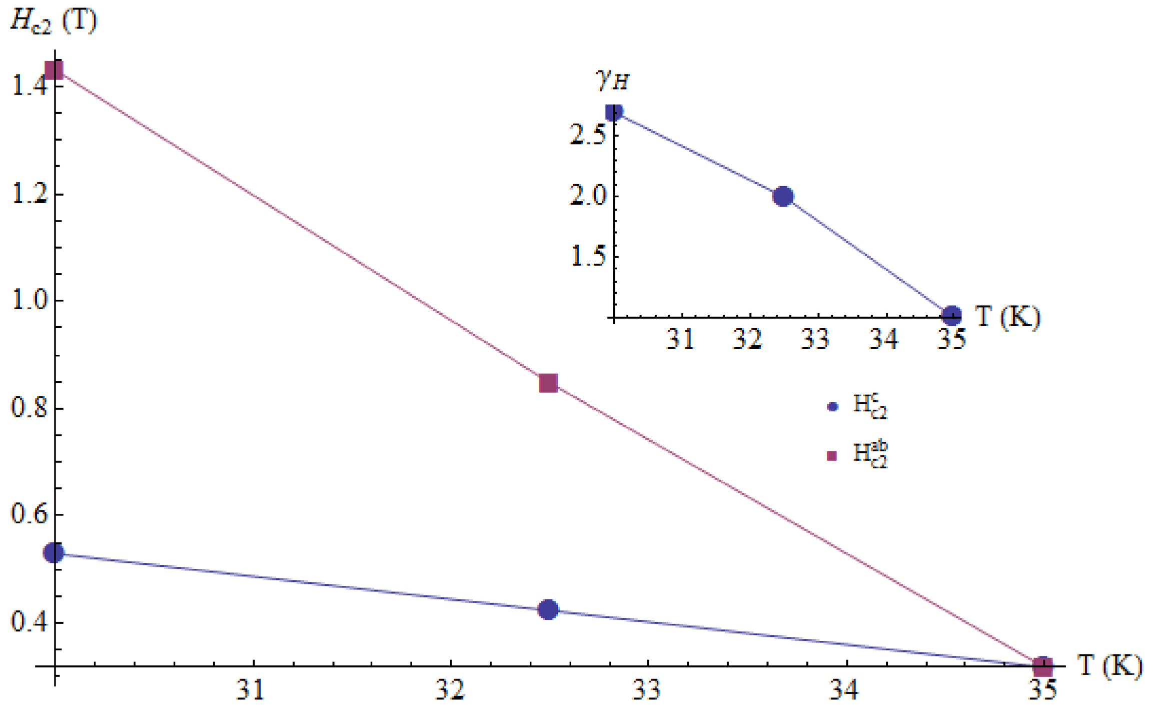


Figure 5: Magnetic properties comparable to experiment, $\gamma_H = H_{c2}^{ab}/H_{c2}^{c}$.

Acknowledgements: I would like to acknowledge and graciously thank The Center for Undergraduate Research and Academic Engagement at F.S.U. and their private donors for the M.R.C.E. award that supported this research.