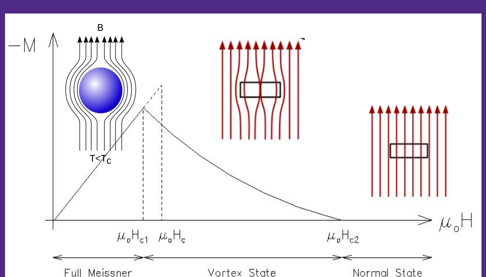
# The impact of the apex angle of isosceles triangle shaped holes drilled into type-II superconductors on the difference between their two critical currents

Jeffrey Lu

Working under Abdulwahab Al Luhaibi and Professor John B. Ketterson at Northwestern University

## Background

Superconductivity is a phase transition that causes certain materials to have the property of having zero electrical resistance, occurring at very low temperatures. All superconductors exhibit an effect called the Meissner Effect, which is the expulsion of a magnetic field. They can be divided into two classes according to their expression of the Meissner effect and how their superconductivity breaks down (a large magnetic field destroys superconductivity). Type-I superconductors have a critical magnetic field that, when reached, causes their superconductivity to break down. Type-II superconductors instead exhibit a vortex state after reaching the first critical magnetic field. These vortices penetrate the superconductor with quantized flux. Only when it reaches a second higher applied magnetic field does its superconductivity break down. A critical current is the minimum current required for a vortex to move and produce an electric field. In this manner, vortices act like small magnets. The holes drilled into these superconductors pin these vortices. Depending on the geometry of the hole, it may cause the superconductors to experience a diode-like effect where a material is superconducting in one direction and resistive in the other. This is because asymmetric holes can break the inversion symmetry present in the superconductors. Our system includes an isosceles triangle shaped hole drilled into a type-2 superconductor and applying a magnetic field orthogonal to the hole. A positive critical current means that the vortex depins from the apex of our triangle shaped hole, while a negative critical current means it depins from the base of the hole.

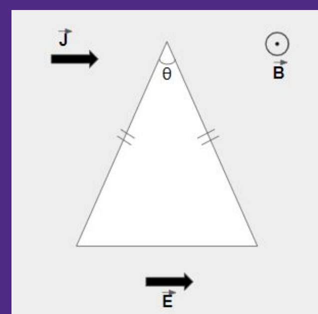



## Special Thanks

Special thanks to Professor John B. Ketterson, Mr. Erdmann, and Mrs. Pasquesi for offering me this amazing opportunity, as well as Abdulwahab Al Luhaibi for guiding me through the research.

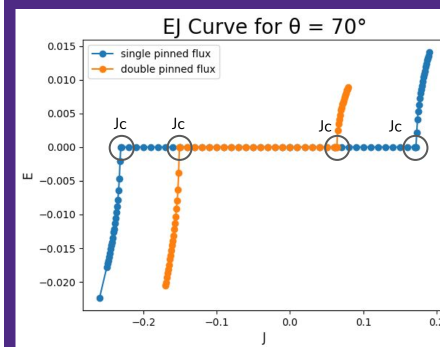
## Methodology

The simulation was run using Unix and presented and analyzed using Python. We first defined parameters to describe the situation at hand so that the computer will understand what it is simulating. We then run a bash script to actually allow the computer to run the parameters through a time-dependent Ginzburg-Landau simulator built by Sadovskyy et al. (2015)[1]. This simulation ran on the Northwestern QUEST cluster. We made sure that the area drilled out by each hole was the same to minimize changes in between trials. We then ran the same simulation but with two fluxons through a doubled applied B-field and graphed all results using the matplotlib library in Python.

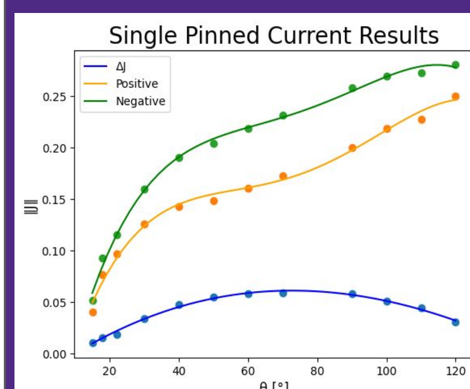


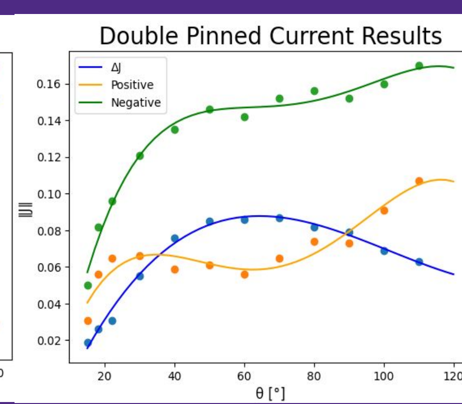

## Results

We obtained the Electric Field (E) vs Current Density (J) for several different θ and for single and double pinned vortices. We then graphed this relationship in the form of E-J curves. This image below shows the E-J curve for θ = 70°. Note the 2 critical currents (Jc) that can be seen in both graphs where voltage goes from 0 to a finite number, and there being one positive and one negative critical current. Also note that the double fluxon simulation had critical currents that were smaller in magnitude.




The two images below display how the positive and negative critical currents, as well as the difference in their magnitudes, changes with different values of θ for both the single pinned and the double pinned simulations..




## Discussion

The results show that the maximum ΔJ occurs when θ = 70° for both the single pinned and the double pinned vortex simulation. This means that a type-II superconductor with an isosceles triangle shaped hole drilled through that has an apex angle of 70° experiences the diode-like effect better than any other isosceles triangle shaped hole. Additionally, the magnitudes of the individual critical currents of the single pinned simulation are greater than those of the double pinned simulation, but the ΔJ of the single pinned simulation is less than the ΔJ of the double pinned simulation. Thus, if we were to pin more vortices, we would expect to have the magnitudes of both the positive and the negative critical currents to continually decrease, while the ΔJ will continue to increase. Thus, the more vortices pinned, the better the superconductor would experience the diode-like effect. These results have many applications in things such as a parametric amplifier, among other innovative technologies.

## Conclusion

These simulations can help scientists build better superconducting devices and non-dissipative circuits, as well as having many other applications such as parametric amplifiers and in cryogenics. An extension of this project would be to rerun these simulations with different shapes of holes to further narrow down the best exhibitor of the diode effect, and then to actually construct and test a prototype for physical use.

## References

[1] Sadovskyy, I. A., Koshelev, A. E., Phillips, C. L., Karpeyev, D. A., & Glatz, A. (2015). Stable large-scale solver for Ginzburg\textendashLandau equations for superconductors. Journal of Computational Physics, 294, 639–654. doi:10.1016/j.jcp.2015.04.002