Superconducting Nanowires for Classical and Quantum Logic

Cliff Sun

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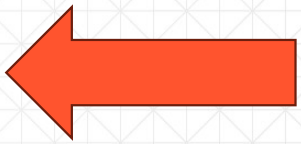
Introduction

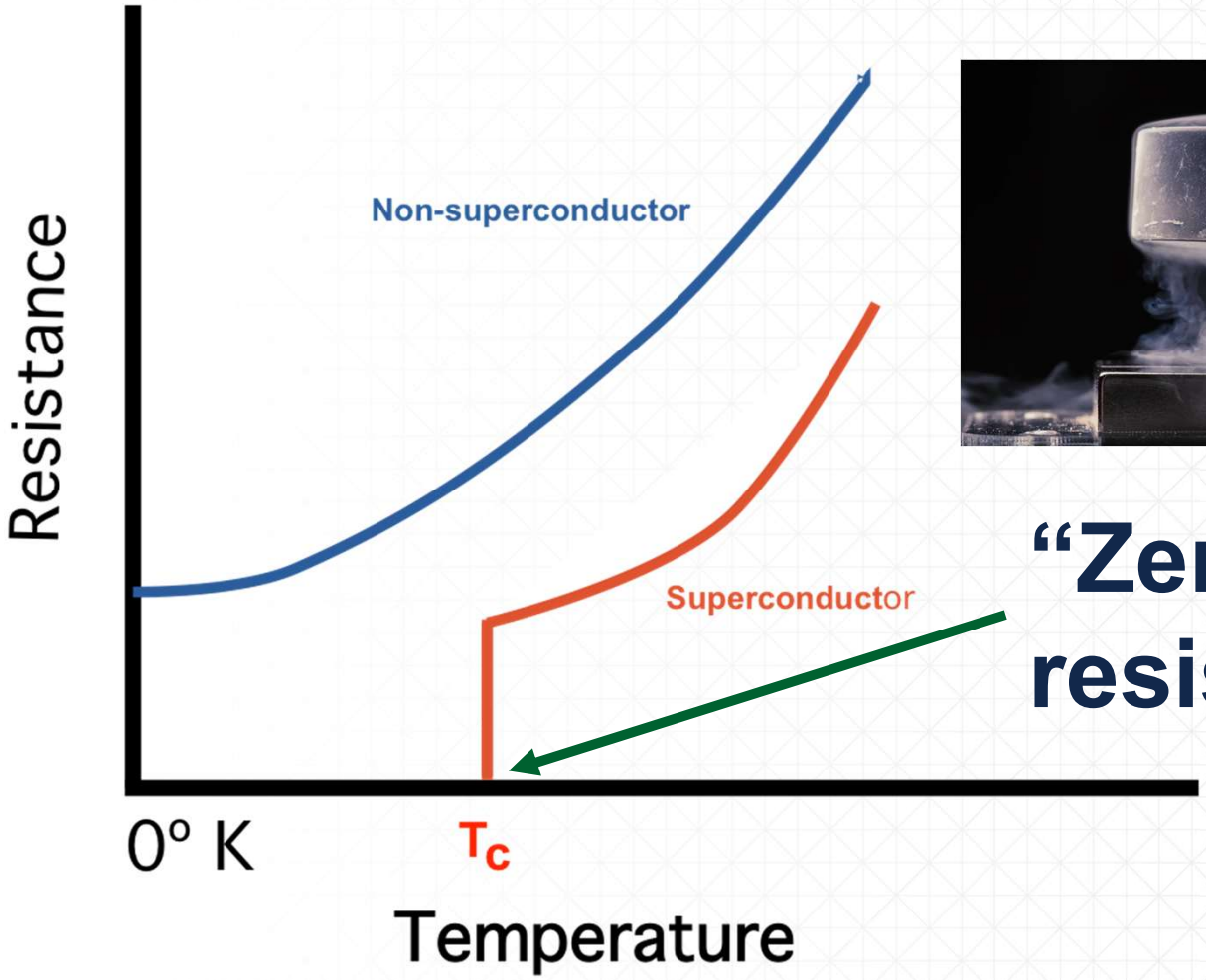
- **3rd year undergraduate in physics and math**
- **Fun fact:** I failed my first drivers test in 3 seconds
- **Fun fact:** I've eaten over 97 pieces of sushi in one sitting

Agenda

1. Intro to Superconducting Nanowires
2. Nanowires for Classical Logic
3. Nanowires for Quantum Logic

Agenda

1. **Intro to Superconducting Nanowires** 
2. Nanowires for Classical Logic
3. Nanowires for Quantum Logic



“Zero resistance”

Superconductors for Computing

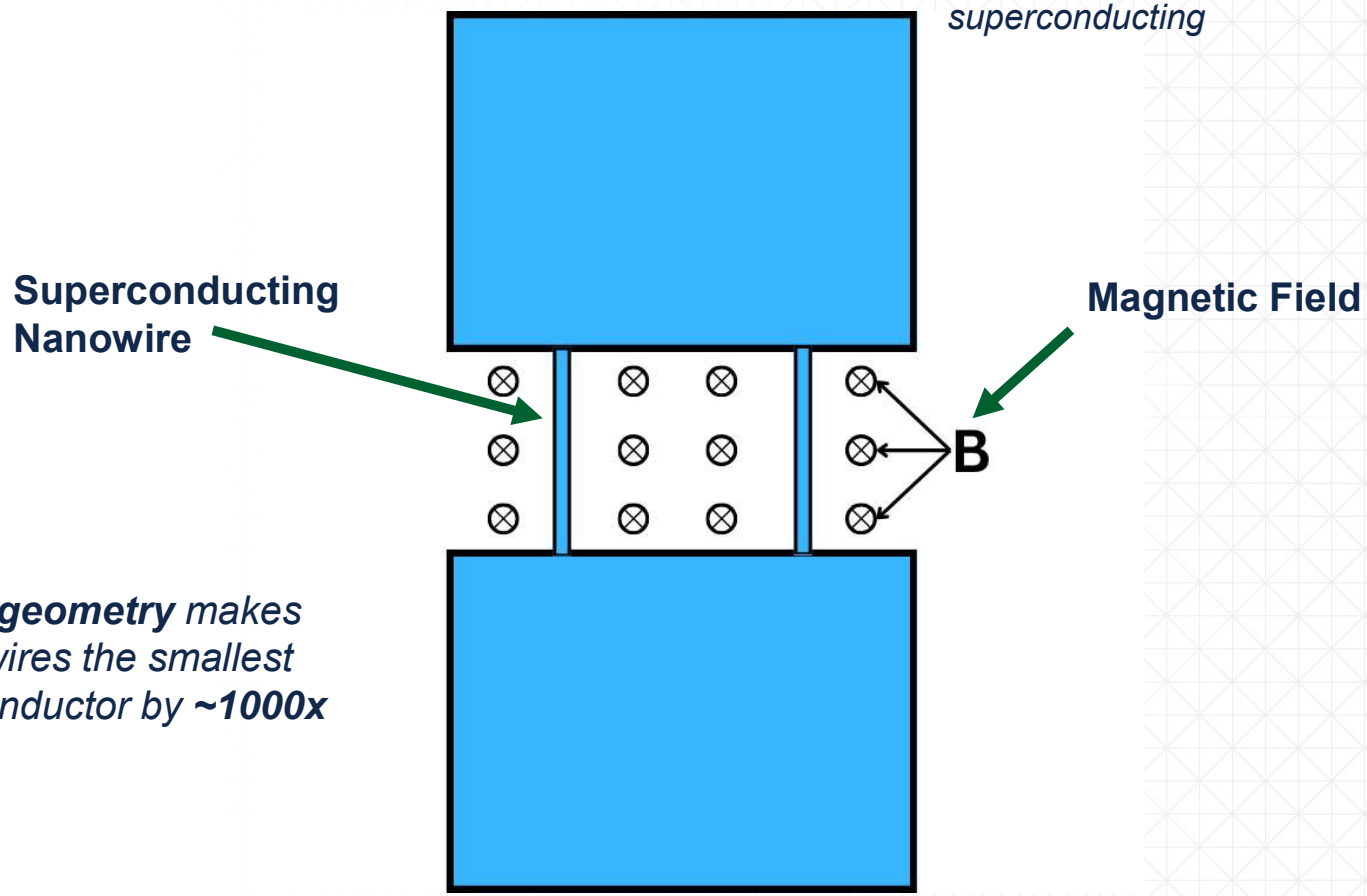
Zero Resistance → **Zero Power Dissipation** → **Perfectly Efficient Superconducting Computers**

Problem: Current superconducting computers are too big and fragile

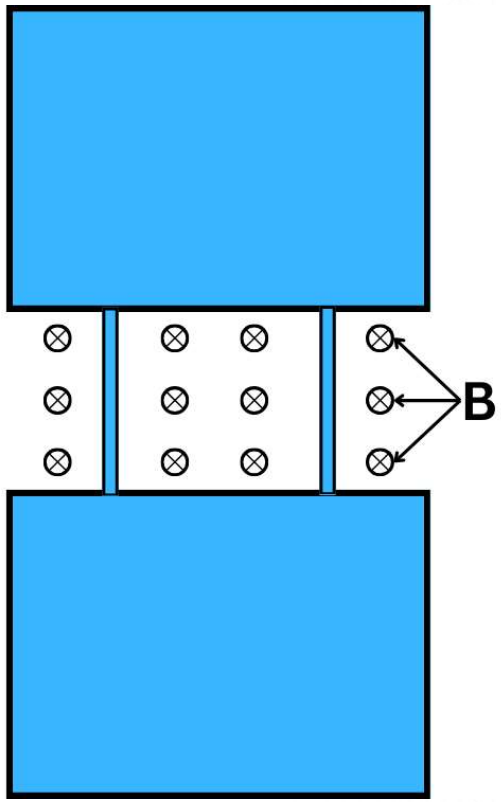
(!) Computers with superconducting nanowires

→ 1000x smaller and more robust (!)

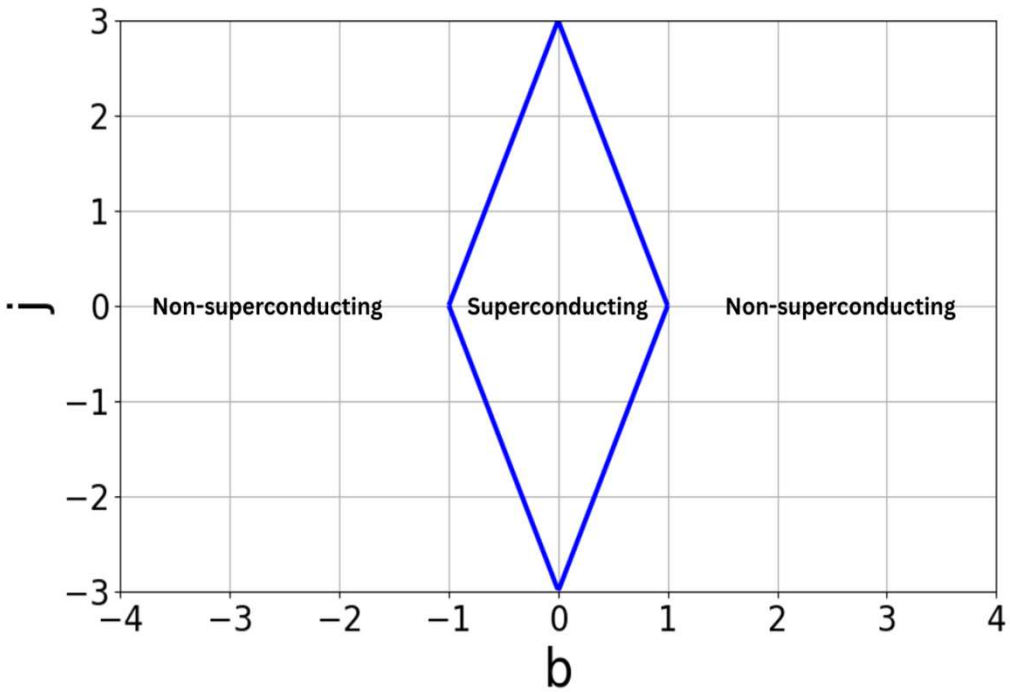
Everything in blue is superconducting



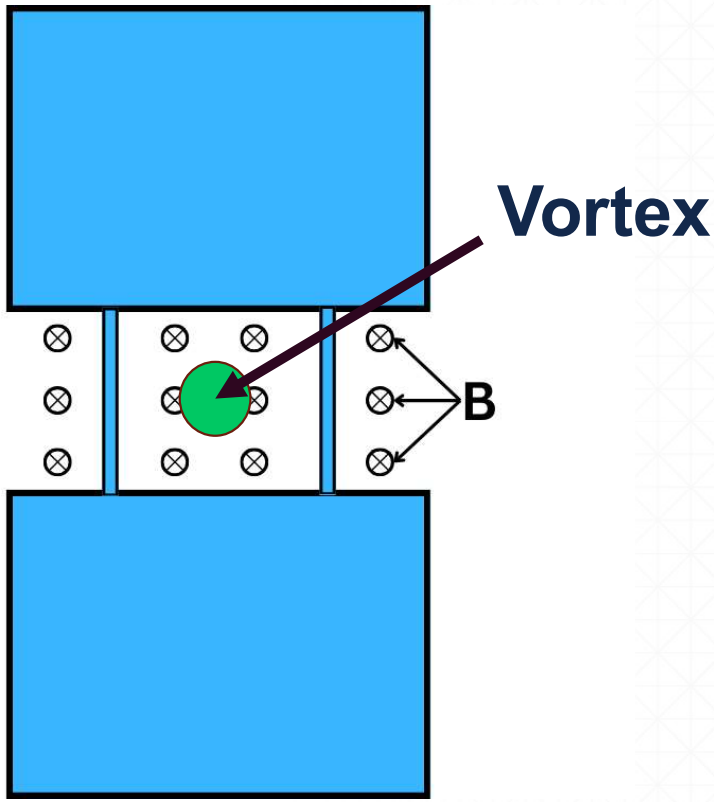
*"**1-D" geometry** makes nanowires the smallest superconductor by **~1000x***



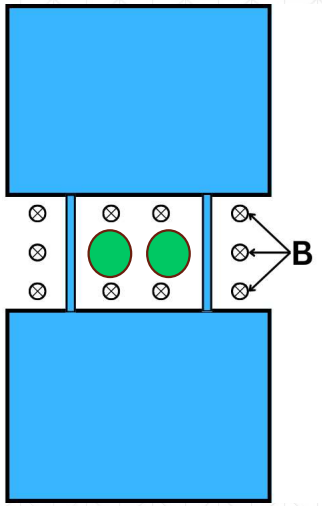
“Closed superconducting domains”



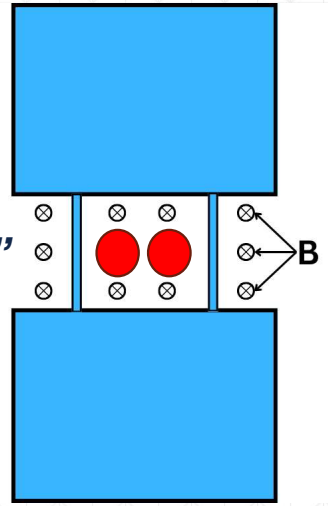
“VSR”



"2 Vortices"



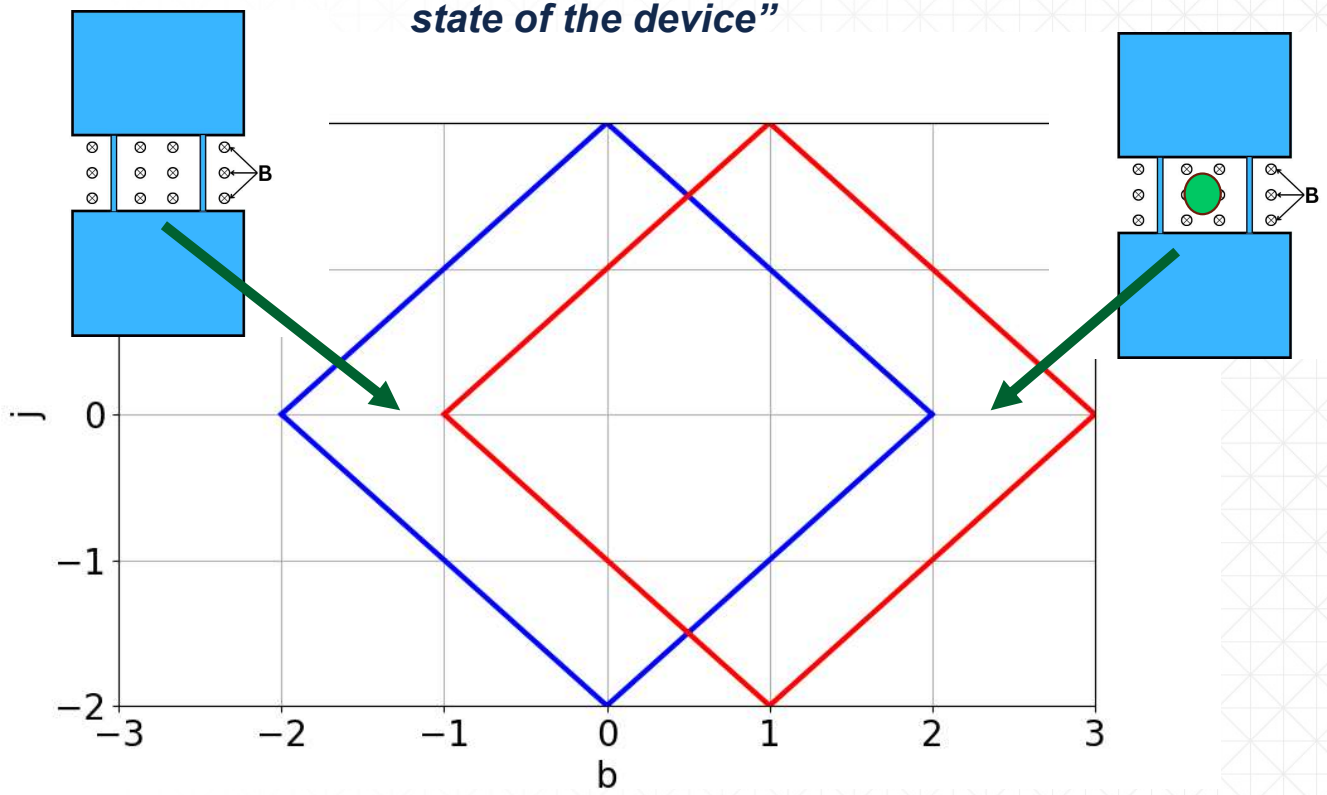
"2 Anti-Vortices"



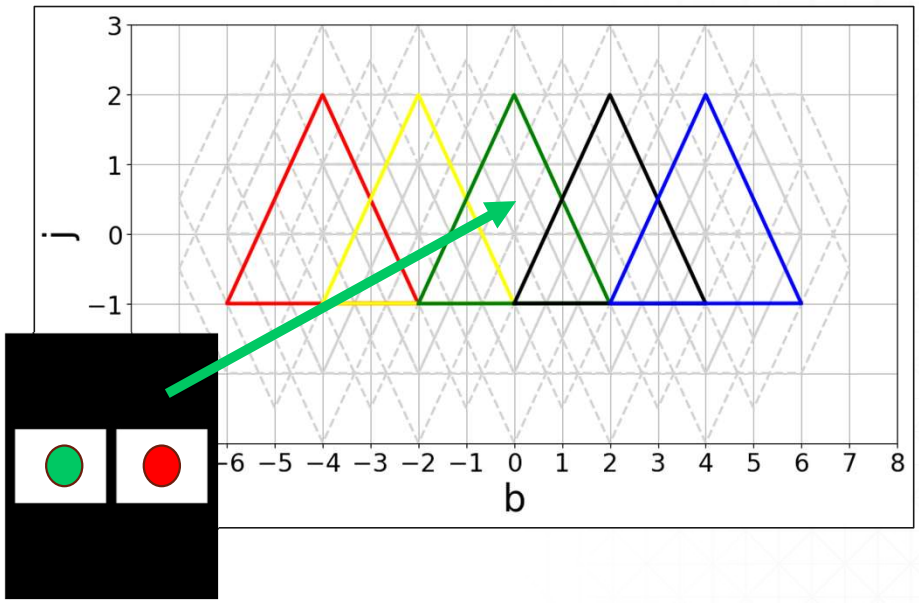
“v = 0”

“Adding vortices changes the state of the device”

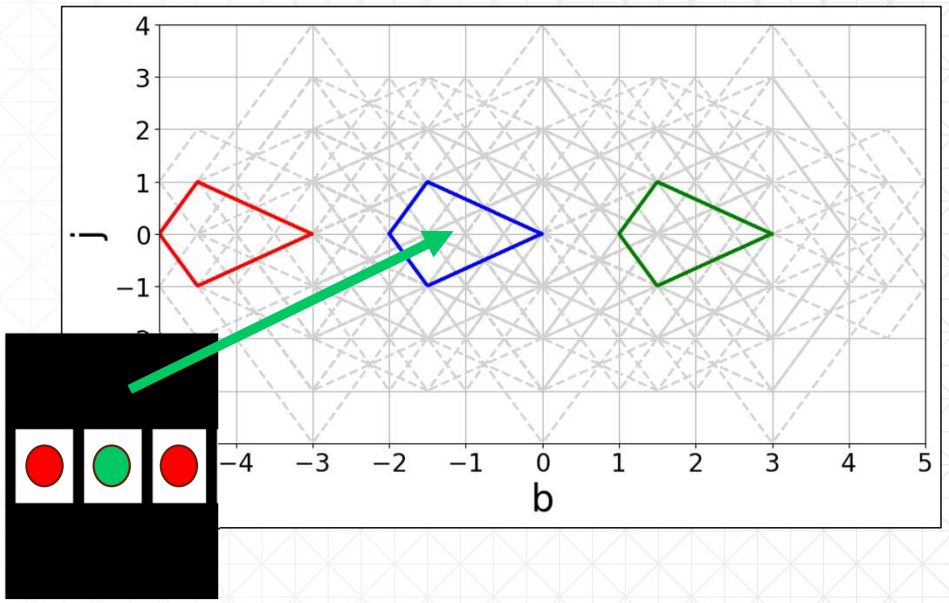
“v = 1”



"VSRs get complicated for many nanowire devices"

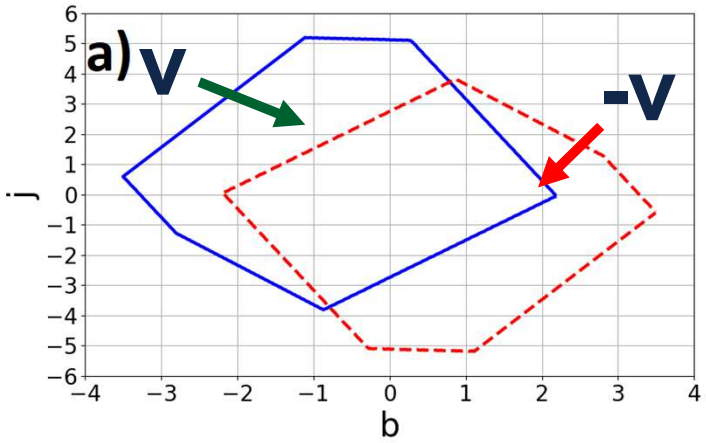


"v = [1, -1]"

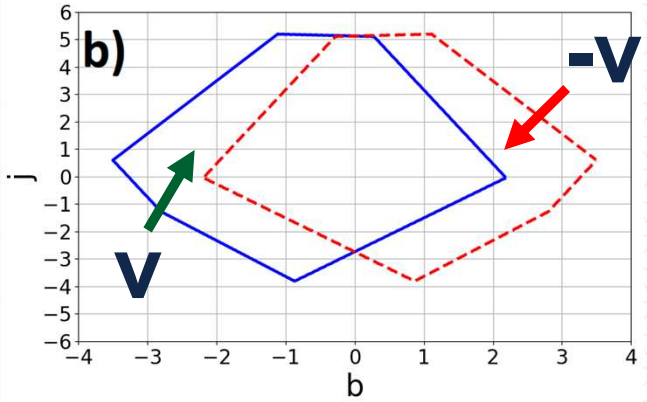


"v = [-1, 1, -1]"

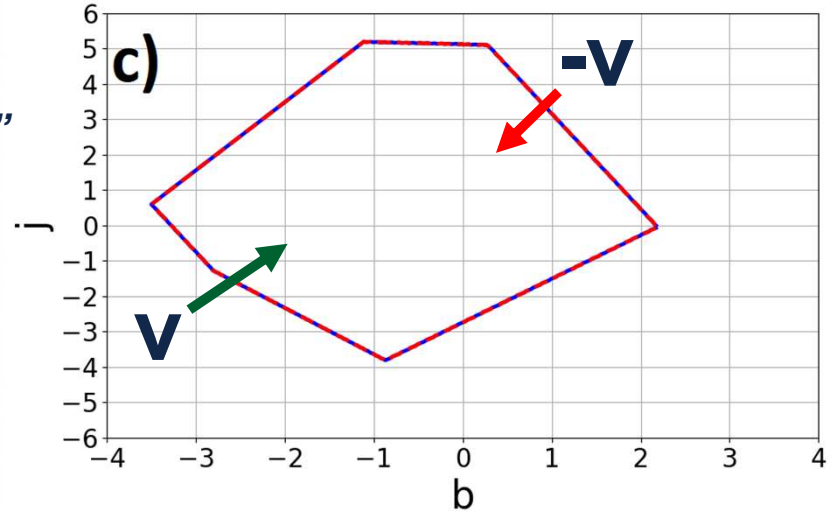
*Sun et al. Nano Ex. **6** 035014*



Current (I) Inversion



"All VSRs obey IBV Symmetry"



Magnetic Field (B) Inversion

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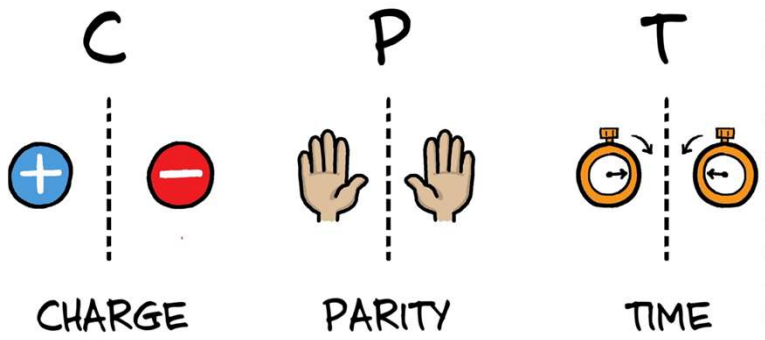
"Connecting superconductors to Particle Physics"

Mathematically Identical

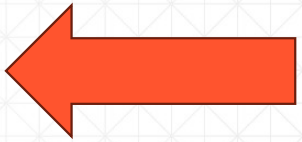
IBV Symmetry ≅ Charge-Parity-Time Symmetry in Particle Physics



Magnetic Field ⇔ Parity
Current ⇔ Charge
Vortex ⇔ Time

Sun et al. Nano Ex. ***6*** *035014*

Agenda

1. ~~Intro to Superconducting Nanowires~~
2. **Nanowires for Classical Logic** 
3. Nanowires for Quantum Logic

Superconductors for Computing

Perfectly Efficient Superconducting Computers

Small + Robust Computing Logic

"Many computer logic gates rely on diodes"

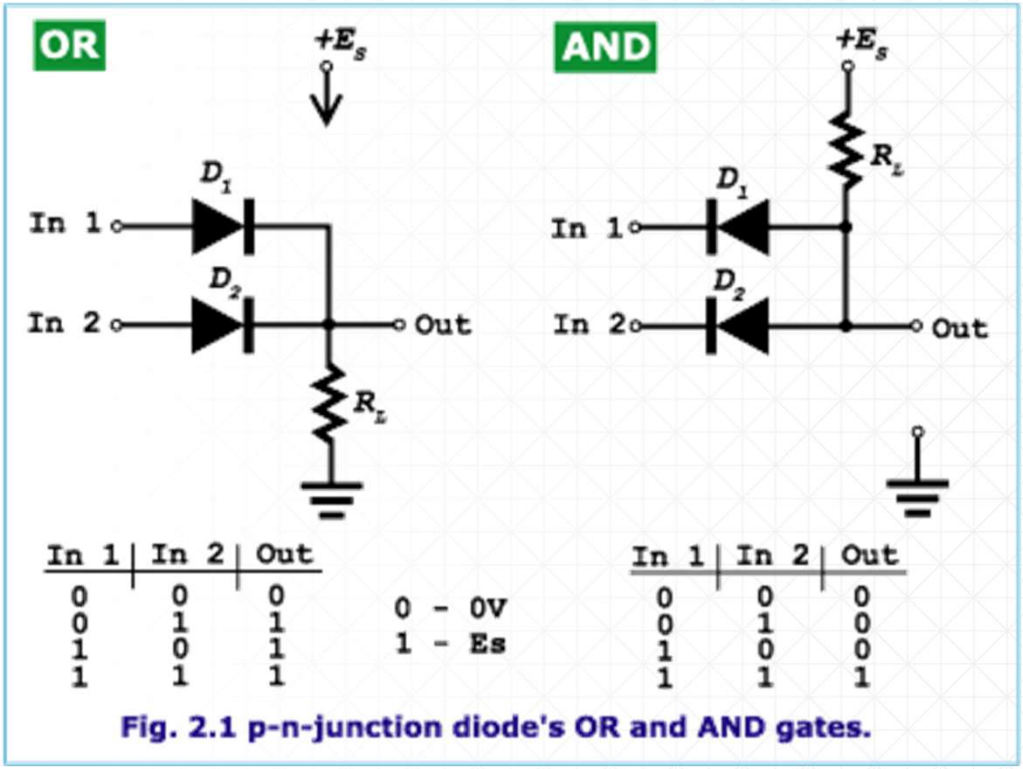
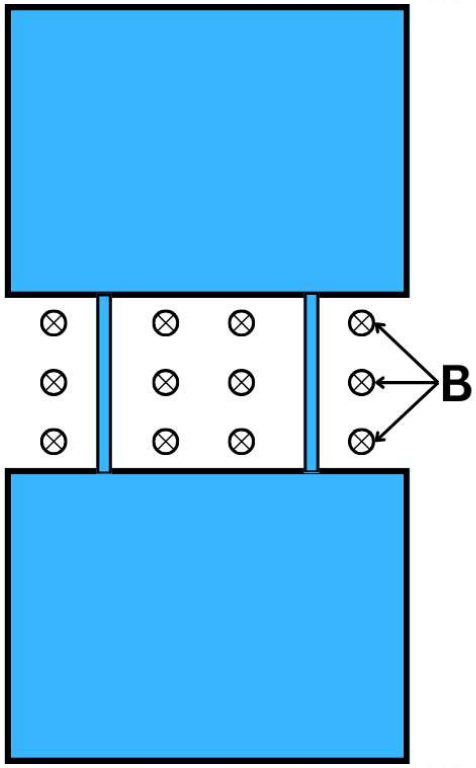


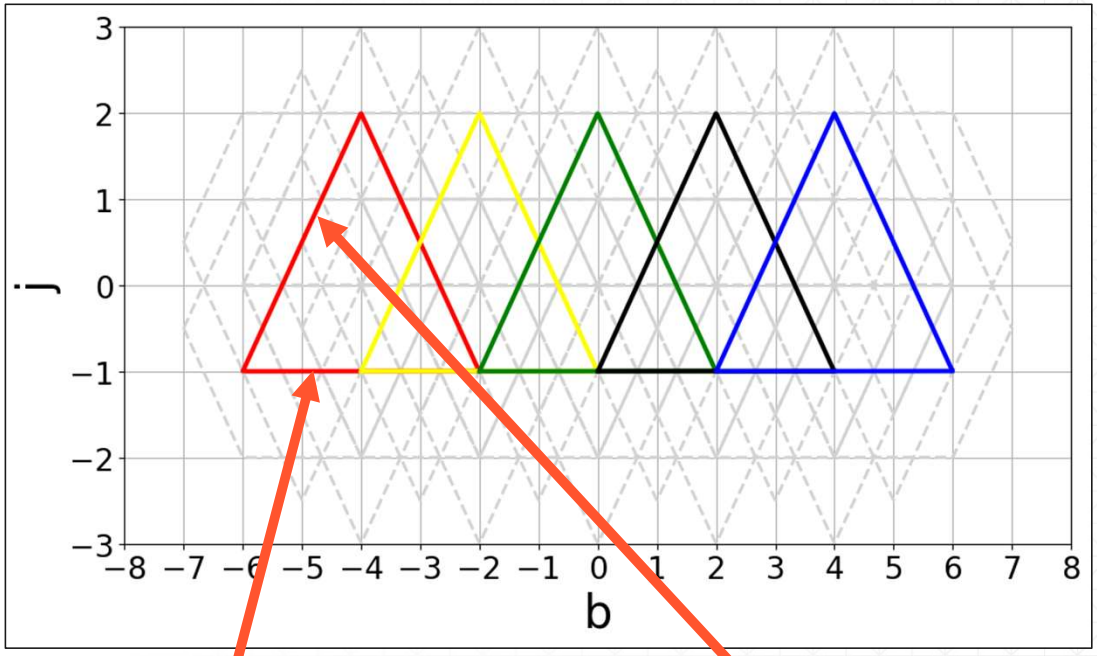
Fig. 2.1 p-n-junction diode's OR and AND gates.

Need a superconducting analogy…..



Diode is:

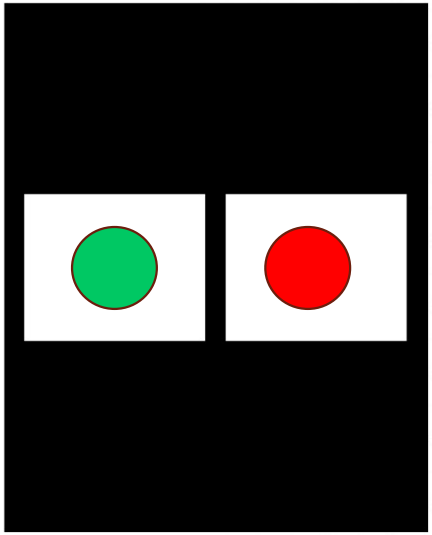
Current ≠ Current



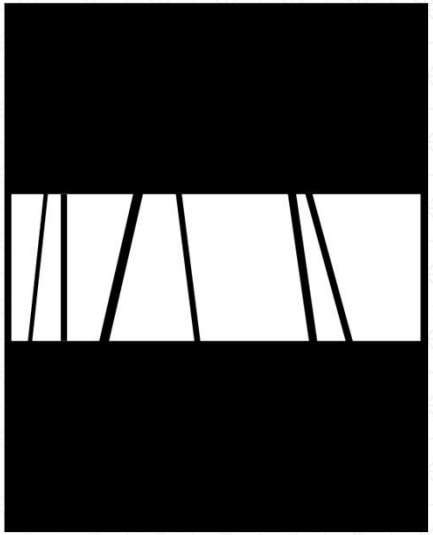
Current ≠ Current

A diode occurs if…

"Symmetry breaking"



Vortices are present



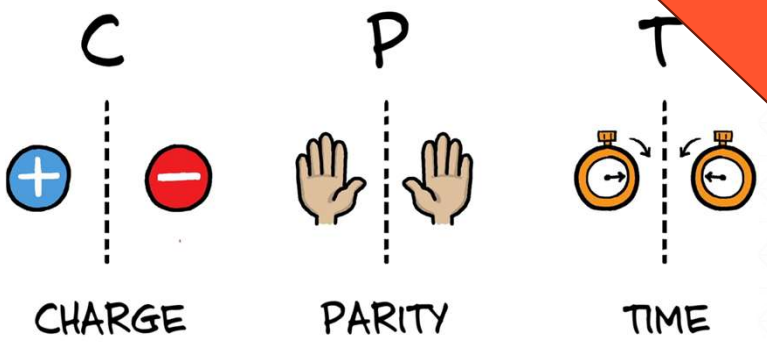
Device is asymmetric

Sun et al. Phys. Lett. A. ***563*** *131055*

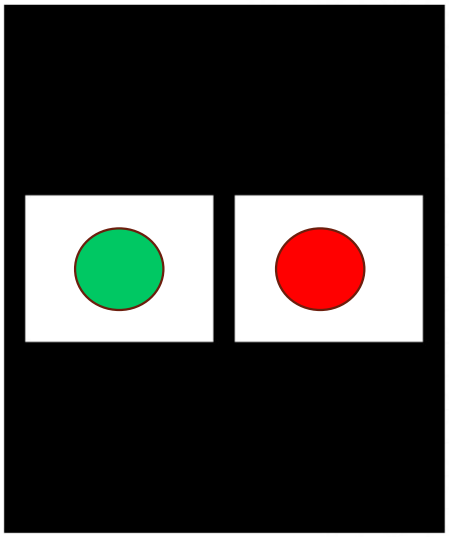
"IBV Symmetry arises from Particle Physics"

Mathematically Identical

IBV metry ≅ Charge-Parity-Time
Sy try in Particle Physics



Magnetic Field ⇔ Parity
Current ⇔ Charge
Vortex ⇔ Time



Vortices are present

$\Longleftrightarrow$

Broken Time Symmetry

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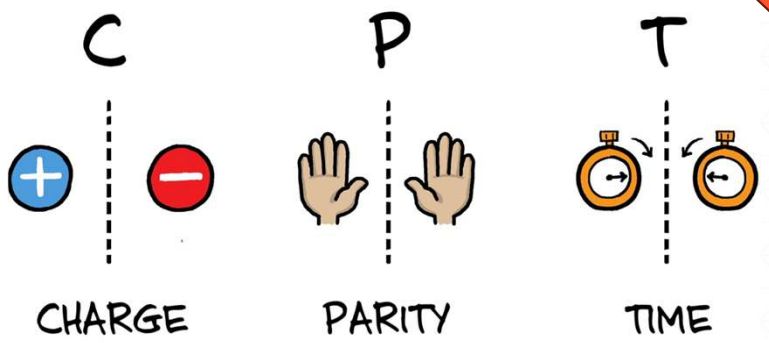
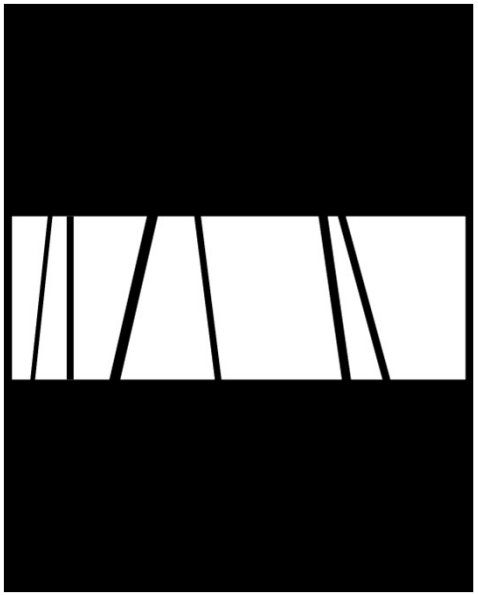
"IBV Symmetry arises from Particle Physics"

Mathematically Identical

IBV Sy try ≅ Charge-Parity-Time
Sym in Particle Physics



Magnetic Field ⇔ Parity
Current ⇔ Charge
Vortex ⇔ Time

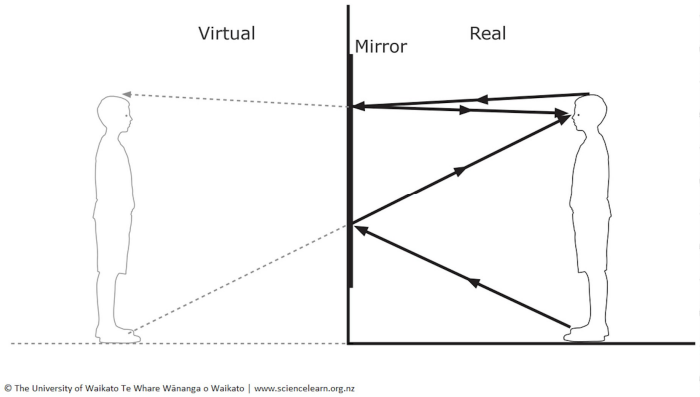


Device is asymmetric

$\Longleftrightarrow$

Uneven Magnetic Field Distribution

$\Longleftrightarrow$



Broken Parity Symmetry

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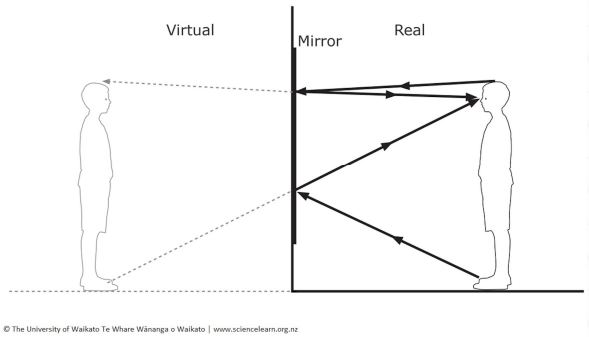
*Sun et al. Phys. Lett. A. **563** 131055*

A nanowire diode occurs if…

Time and Parity Symmetry are broken!



Agenda

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2. ~~Nanowires for Classical Logic~~
3. **Nanowires for Quantum Logic**

Quantum computers are cool!

Who cares about quantum?

$O(n)$

Random Search

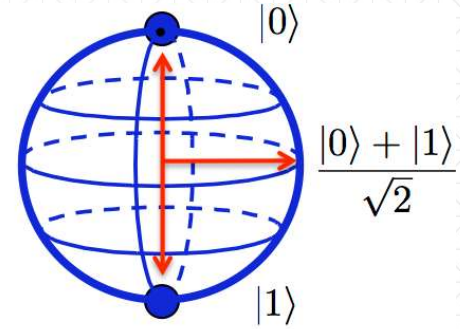
Quantumified

$O(\sqrt{n})$

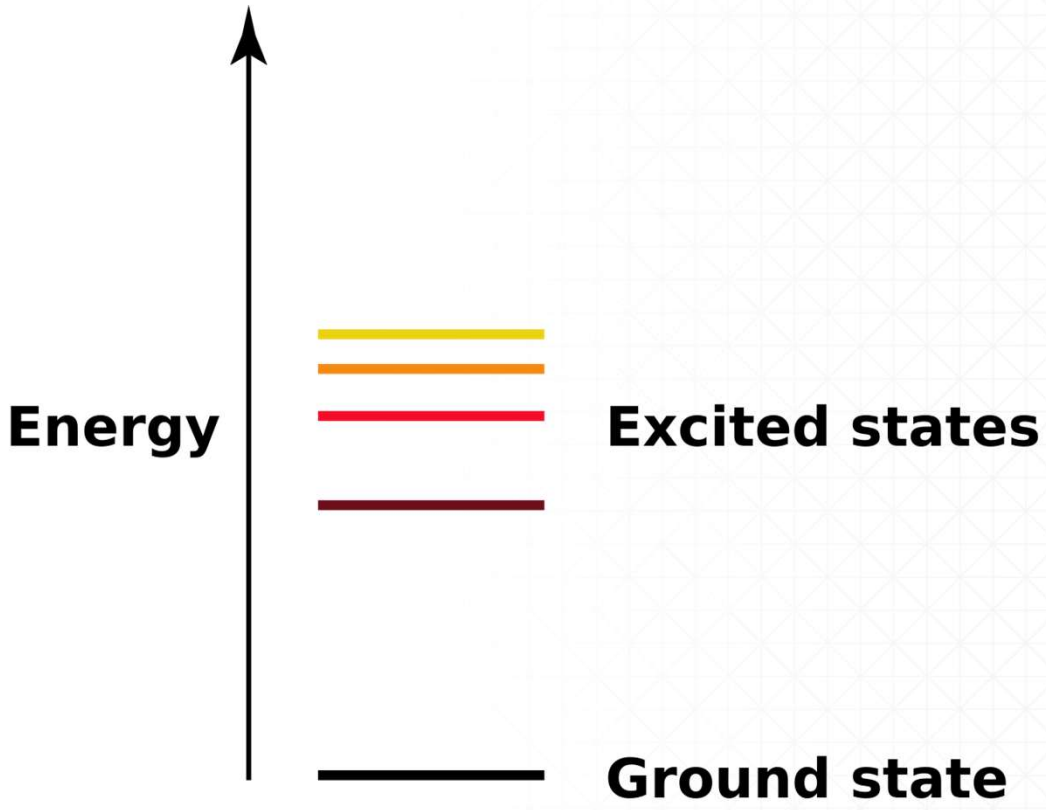
Quantum Random Search

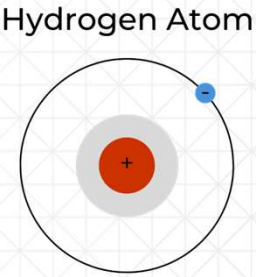
"Quantum computers speed up regular algorithms"

"Quantum computers run on quantum bits"



(!) Current superconducting qubits are large and fragile (!)





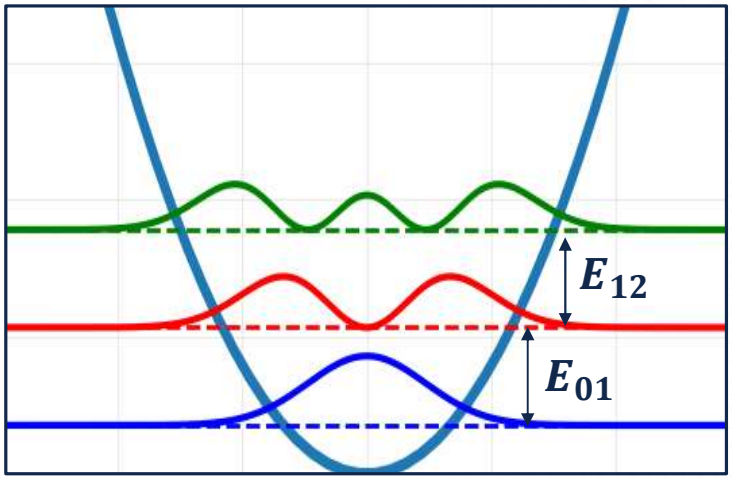
"Quantum systems have discrete* energy levels"

**Only applies to bounded systems*

"Uneven energy levels → superconducting quantum bits"

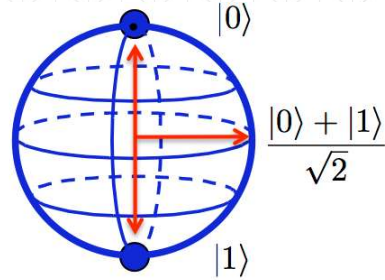
"Difference in energy levels"

$$\alpha_r \equiv \frac{E_{12} - E_{01}}{E_{01}} = 0\%$$

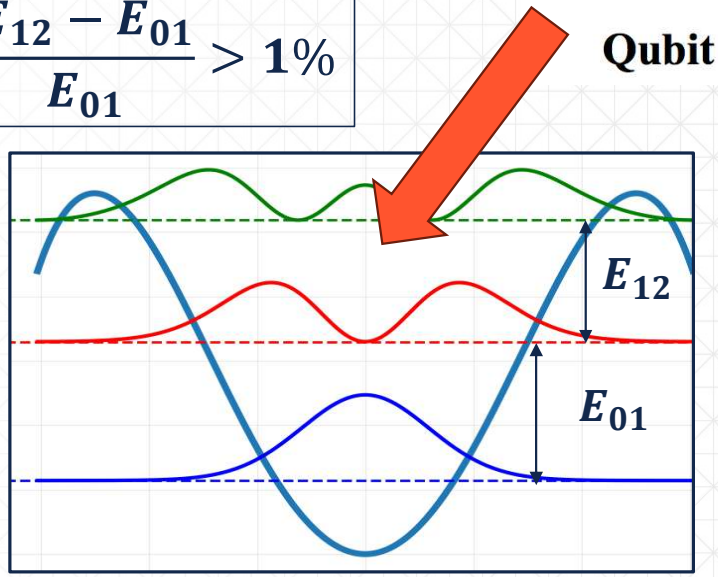


Evenly spaced energy levels

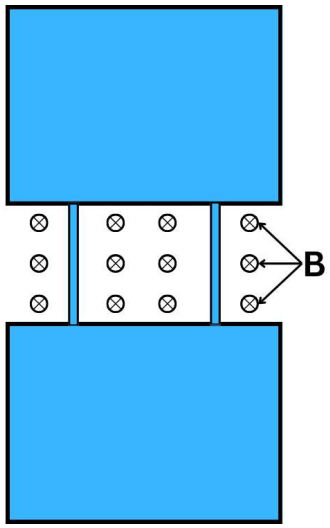
$$\alpha_r \equiv \frac{E_{12} - E_{01}}{E_{01}} > 1\%$$



Qubit



UNEvenly spaced energy levels



+ Magnetic Field

$$\alpha_r \equiv \frac{E_{12} - E_{01}}{E_{01}} > 1\%$$

+ 20-year problem solved!

"Parallel Nanowires + Magnetic Field →
1000x smaller & robust
superconducting quantum bits"

Sun et al. arXiv:2603.17214

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