Research Experience for Teachers
Year One

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General Goal

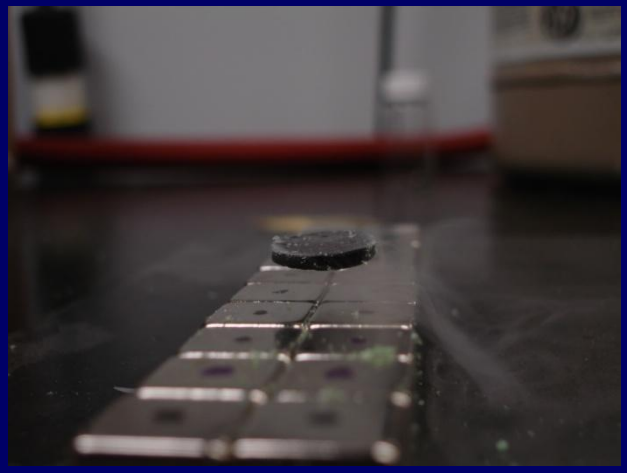
“The most beautiful experience we can have is the mysterious. It is the fundamental emotion which stands at the cradle of true art and true science.” --Albert Einstein

“The most exciting phrase to hear in science, the one that heralds the most discoveries, is not "Eureka!" (I found it!) but "That's funny..." ~Isaac Asimov

- Utilizing discrepant events and “magic” can intrigue and inspire even the most disengaged students.
- OUR GOAL: Build a discrepant event which can be used during outreach presentations at local schools to foster the “mysterious” and “that’s funny” moments.

Specific Goals

- Synthesize a high-temperature superconductor
- Create a magnetic track over which the superconductor can levitate and move with stability.
- Create a vehicle to house the superconductors and travel along the track.



Superconductors– The Basics

- A material that can conduct electricity with zero resistance.
- Occurs only at or below a “critical temperature” (T_c)
  - Above this temperature, the material exhibits typical resistance vs. temperature behavior.
- Our Superconductor: $YBa_2Cu_3O_{7-x}$
  - a.k.a. YBCO, Y-1,2,3
  - Considered a high temperature superconductor
    - T_c = 95 K

Meissner Effect

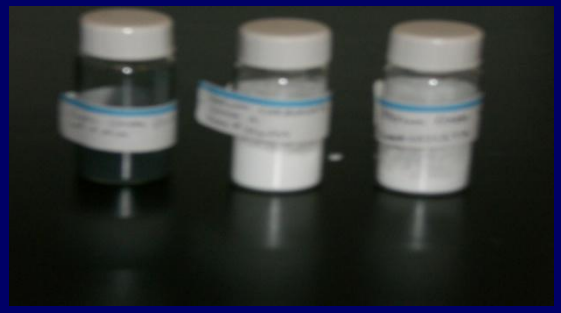
Discovered by Walther Meissner and Robert Oschenfeld in 1933

When cooled below a critical temperature, most superconductors become diamagnetic (exclude all magnetic fields).

Enabling Magnetic Levitation!!

Methods (Solid-State Synthesis)

$$1/2Y_2O_3 + 3CuO + 2BaCO_3 \rightarrow YBa_2Cu_3O_{7-x}$$



Yttrium Oxide, Barium Carbonate, Copper (II) Oxide

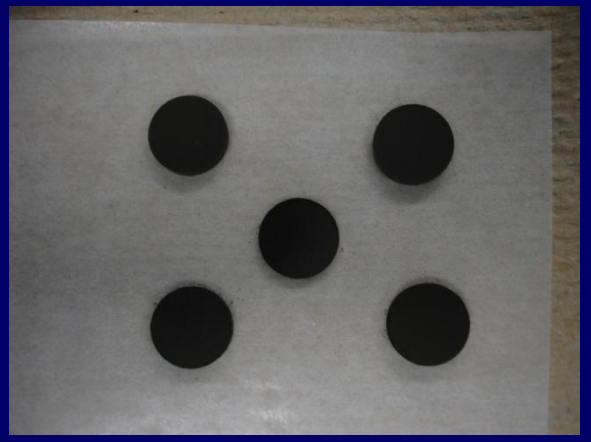
Measure and grind into a fine powder, carefully! ($600 agate mortar)

Combined with ethanol and ball-milled overnight

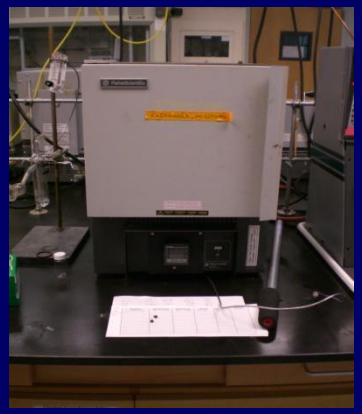
Poured powder into 13 mm die for pressing 1.0 g pellets

Methods (Solid-State Synthesis)

Pressed the die with approximately 3 metric tons of pressure (6,600 lbs!)



Powder is now a pellet!



Heated the pellets for 48 hours at 930° C in the furnace (not oven!)

Re-ground the pellets and re-pressed

Methods (Solid-State Synthesis)

- Post-anneal in oxygen environment

  (48 hrs @ 940°C)

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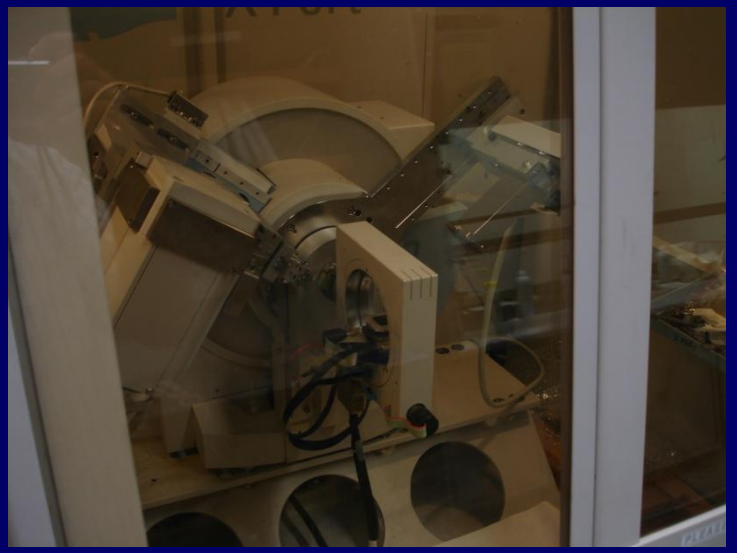
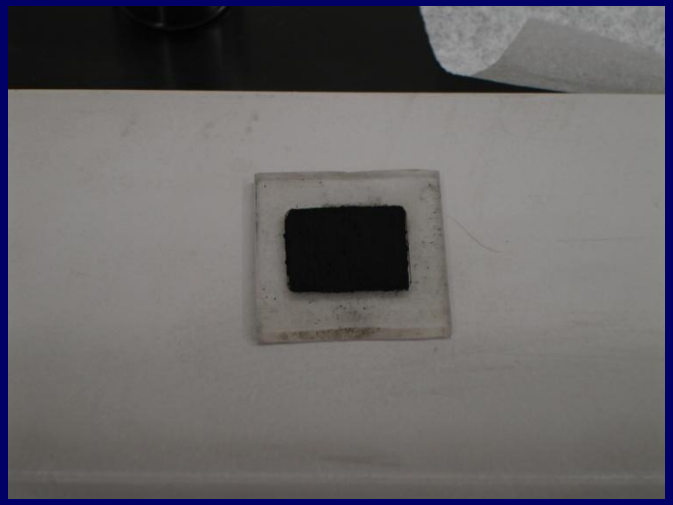
- Post-anneal in oxygen environment

  (48 hrs @ 940°C)

- X-Ray Diffraction





Methods (Solid-State Synthesis)

- Post-anneal in oxygen environment

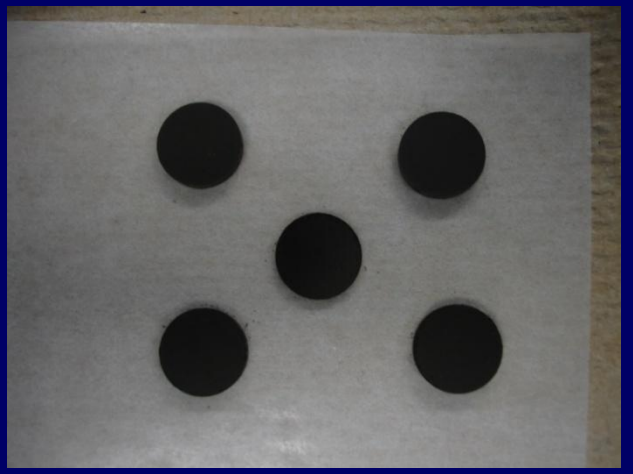
  (48 hrs @ 940°C)

- X-Ray Diffraction

- Re-grind and treat with poly-vinyl alcohol

Methods (Solid-State Synthesis)

- Press into ~1.0 g pellets

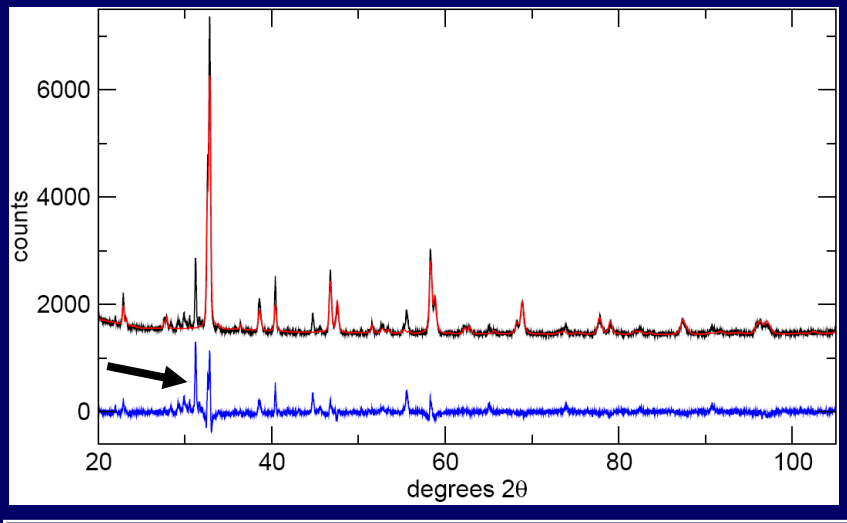


Methods (Solid-State Synthesis)

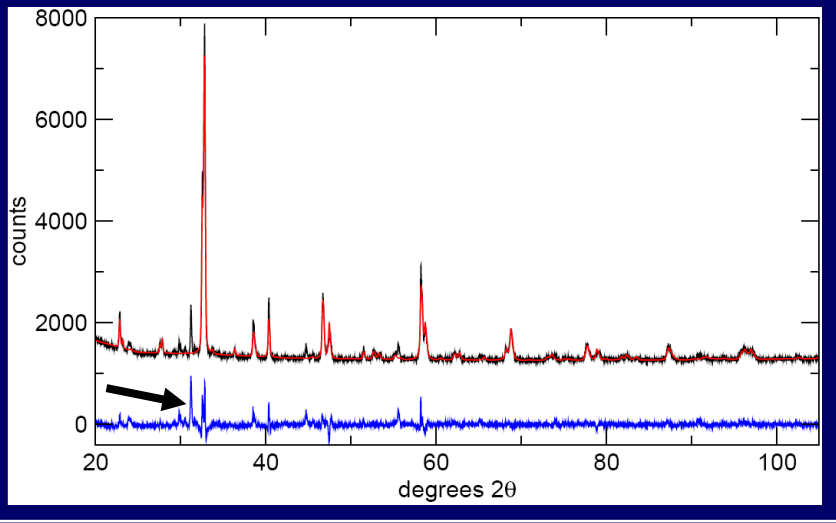
- Press into ~1.0 g pellets
- Post-anneal in oxygen environment
  - 48 hrs @ 940°C
  - Slow Cooling
    - 4 hrs @ 800°C
    - 10°C/min ramp down
- X-Ray Diffraction

X-Ray Diffraction Data Batch #1

48-hr annealing



88-hr annealing



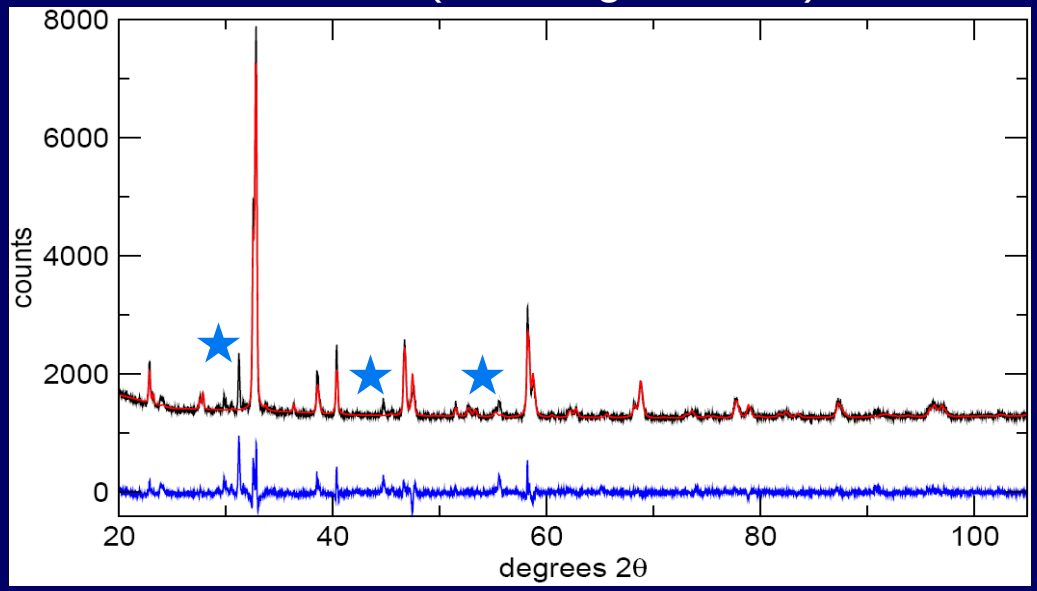
Black = Observed intensities Red = Calculated intensities Blue = Difference/Impurities

- 48 hr annealed pellets showed poor levitation capability.
- Re-annealed for an additional 40 hours, resulted in greater levitation time and height.
- Impurity phases have lower intensity after second annealing.
  - Cause of improved levitation likely due to higher oxygen content, rather than removed impurities.

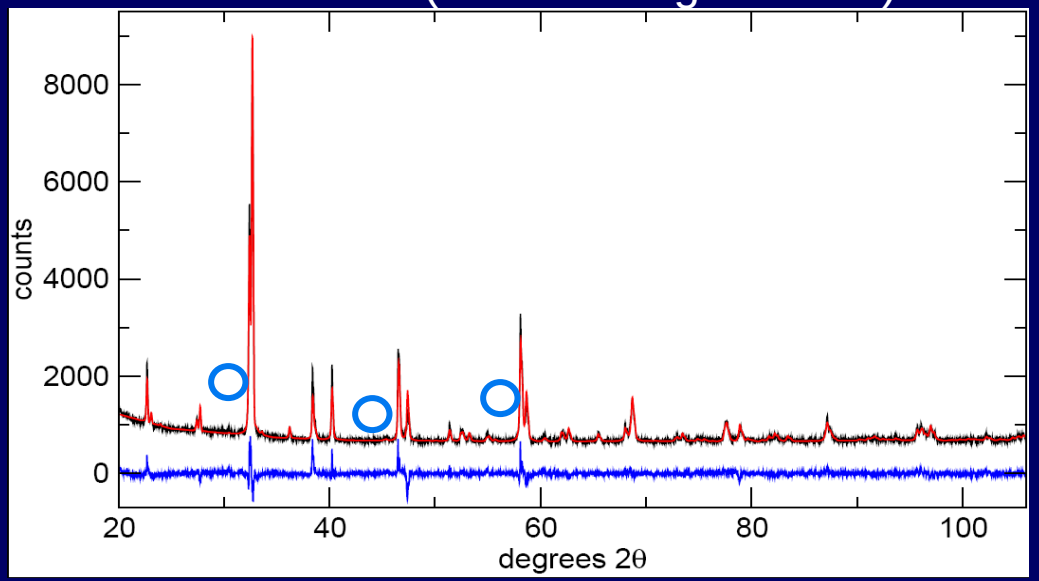
Diffraction Data

Comparing Batch #1 & Batch #2

Batch #1 (touching alumina)



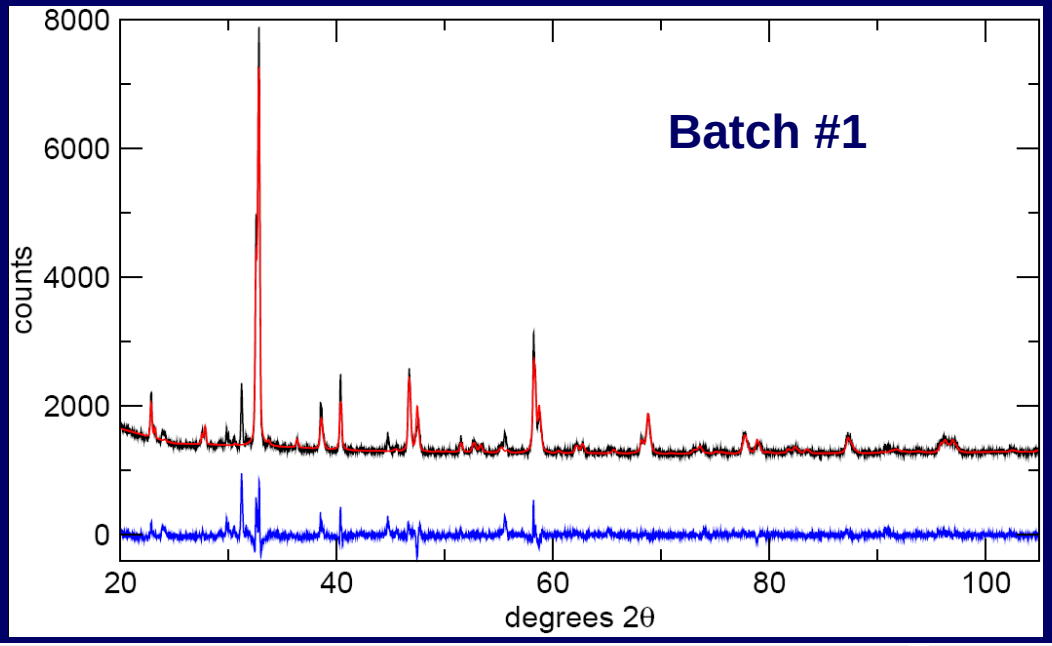
Batch #2 (not touching alumina)



- Non-modeled peaks from Batch #1 were not present in Batch #2.
  - Possible evidence of alumina contamination, leading to poorer levitation

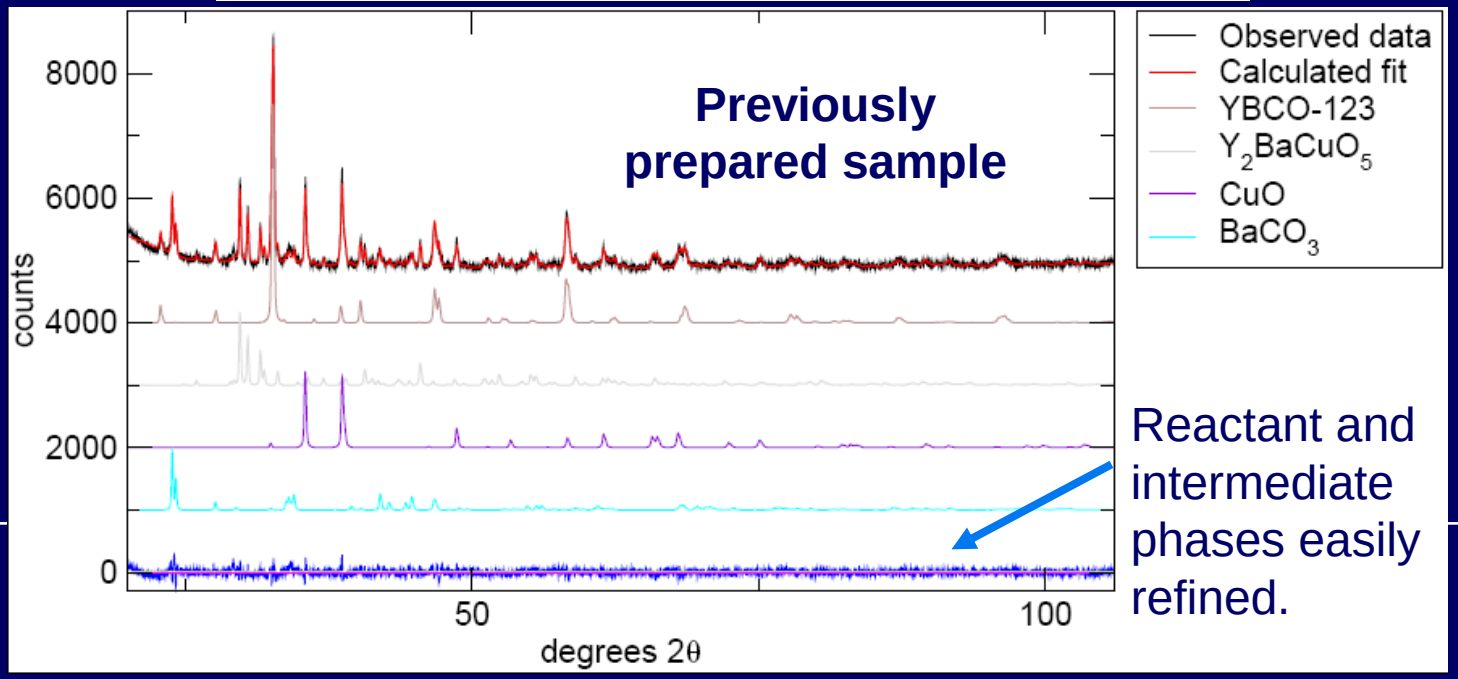
Comparing Diffraction Data

- Reactant and intermediate phases not well-refined.
- Suggests possible alumina contamination



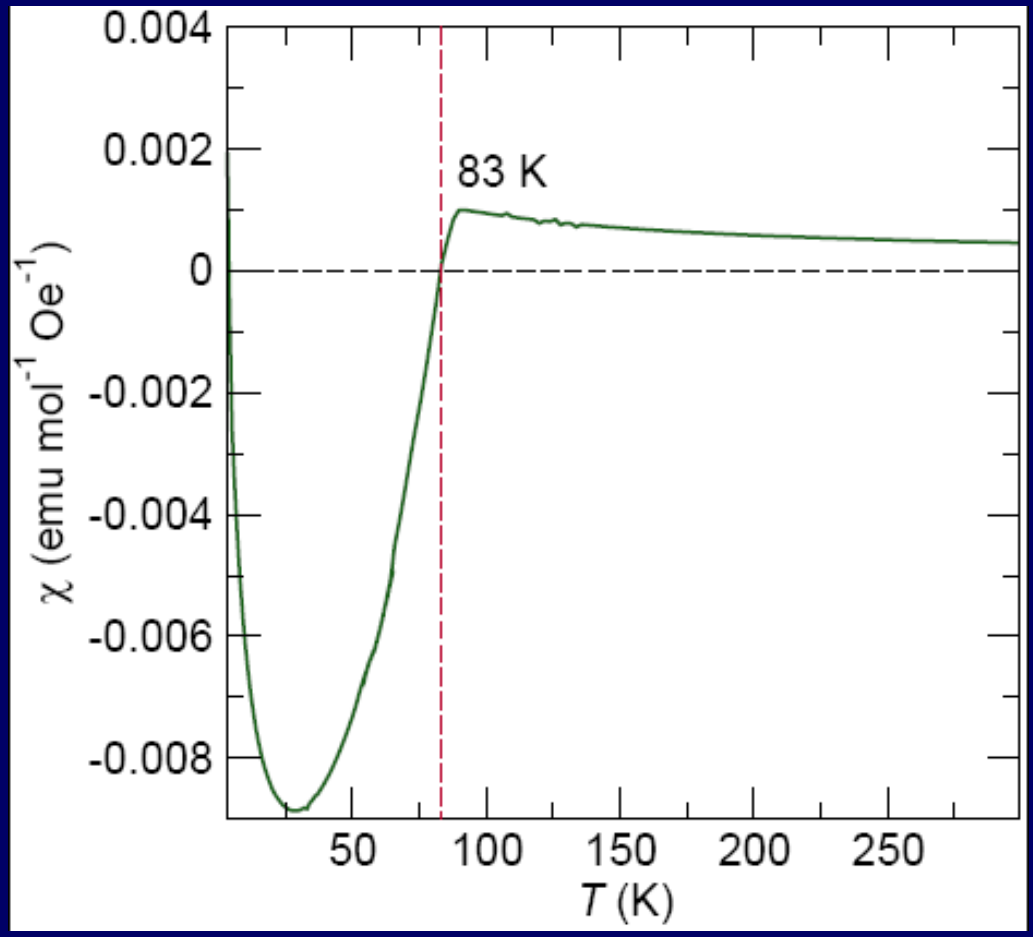
WEAK LEVITATION

NO LEVITATION



Magnetization vs. Temperature

- Above 83 K, substance is paramagnetic.
- Below 83 K substance becomes diamagnetic.
  - Formation of Cooper pairs results in superconductivity.
  - Disappearance of magnetism
- Upturn at ~25 K is likely impurity.

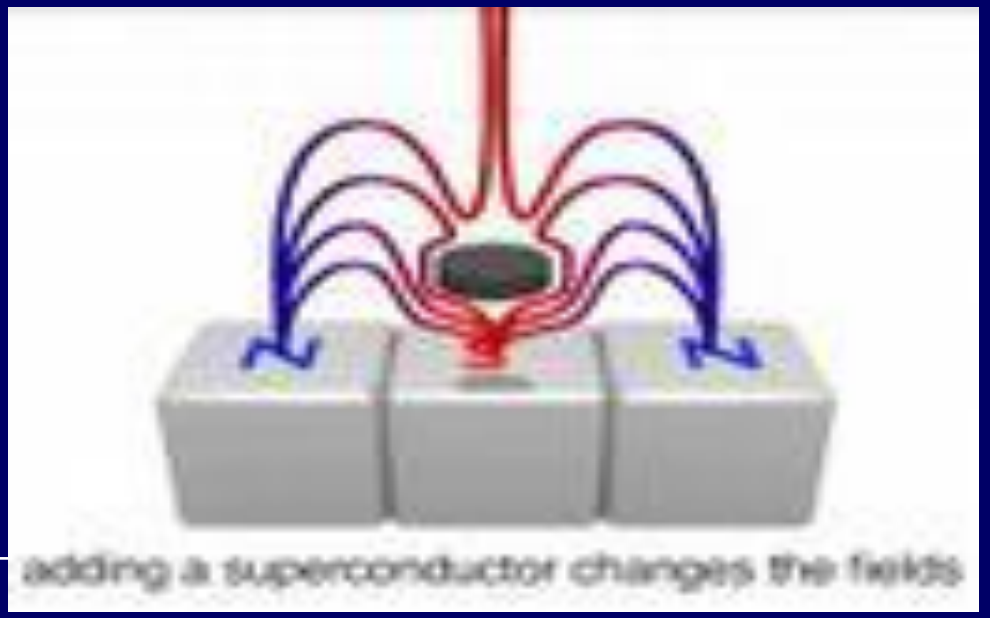


Due to instrumental problems, measurement conducted in 2.0 tesla field, resulting in lower critical temperature data point.

Track Construction

-Located the poles of each magnet with compass.

- Alternating the poles across the width of the track creates a tunnel that allows a superconductor to travel.



www.mcgill.ca/wowlab/train

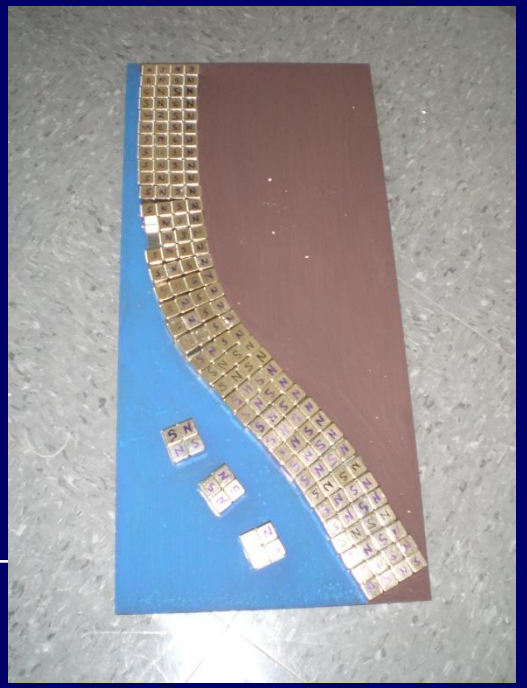
Track Results

-Track

158 Rare Earth Magnets (Nd-Fe-B)
extremely strong– 0.5 tesla
Dimensions of each magnet
0.5 inch w/l/h

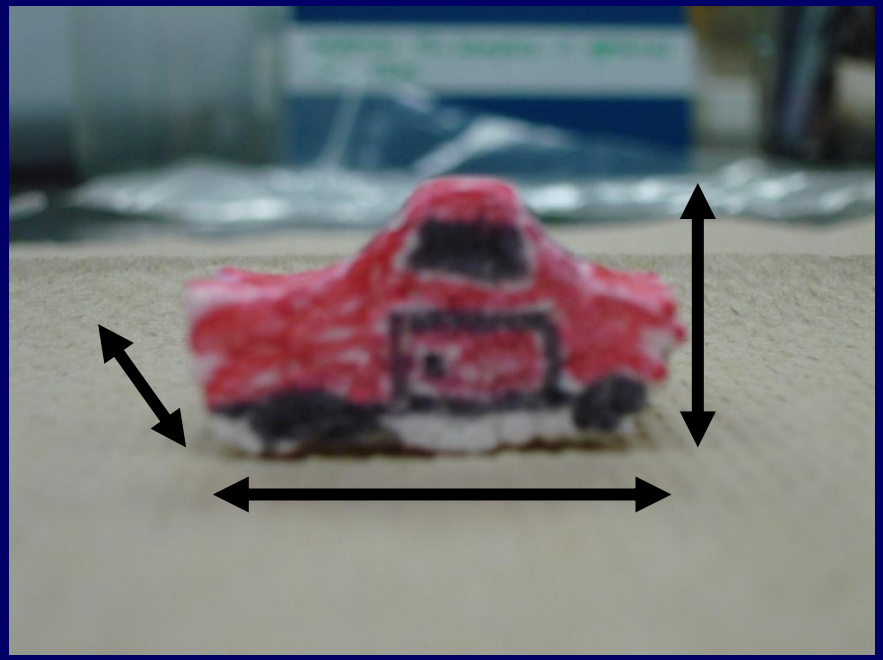
-Arrangement

4 vertical lines of similar poles
4 across (horizontal) with alternating poles
Distance between magnets on outer curve is 3 mm



Vehicle Construction

- Material: styrofoam
  - Sculpted from an old cooler
- Mass: 0.25 g
- Dimensions: (as pictured)
  - Length: 3.4 cm
  - Height: 1.8 cm
  - Depth: 2.5 cm



Vehicle Design

Solid Body

Channel carved from bottom

Five or six pellets fit in channel

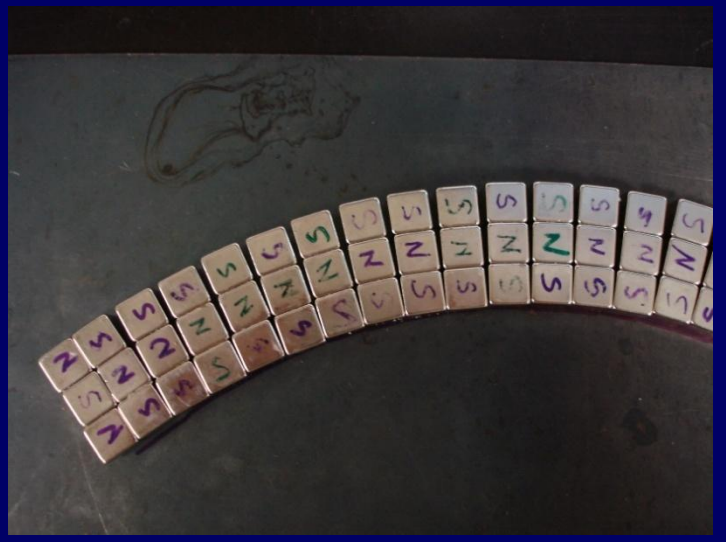
Stacked 3x2 or 3x3

Pellets secured with tape

Testing the Meissner Effect

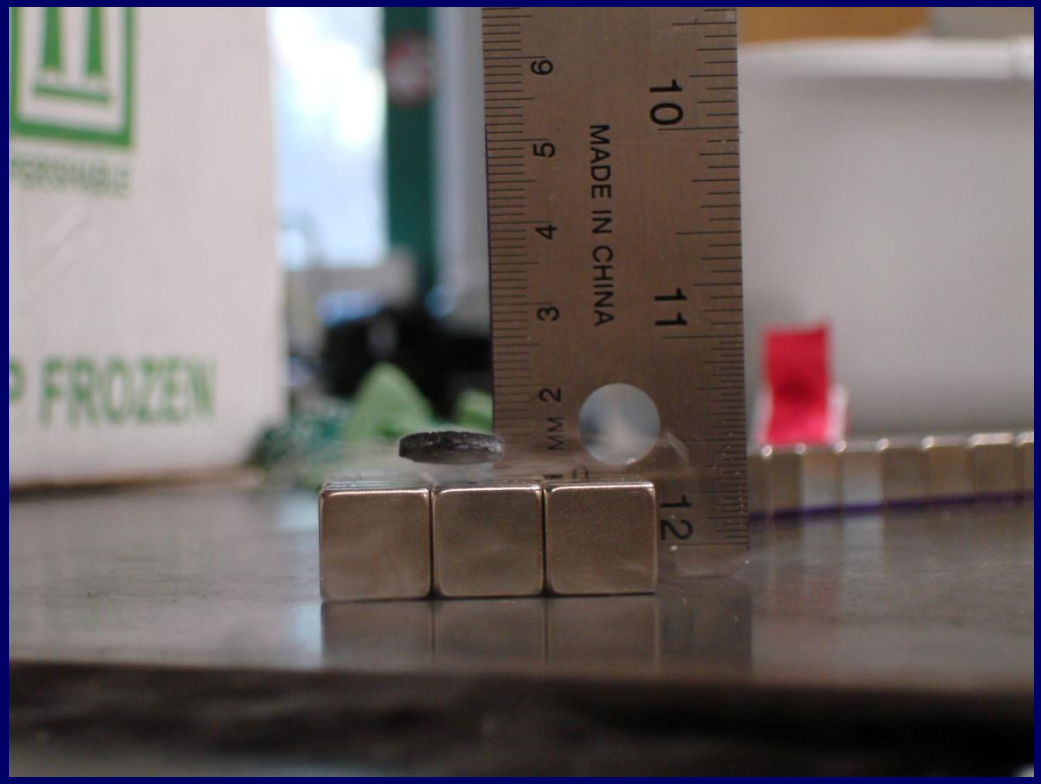
Tests 1 & 2: Track Manipulations

Parameters: Can the 5-pellet car move down the track with continuous motion?



Testing the Meissner Effect

Test 3: Levitation Height



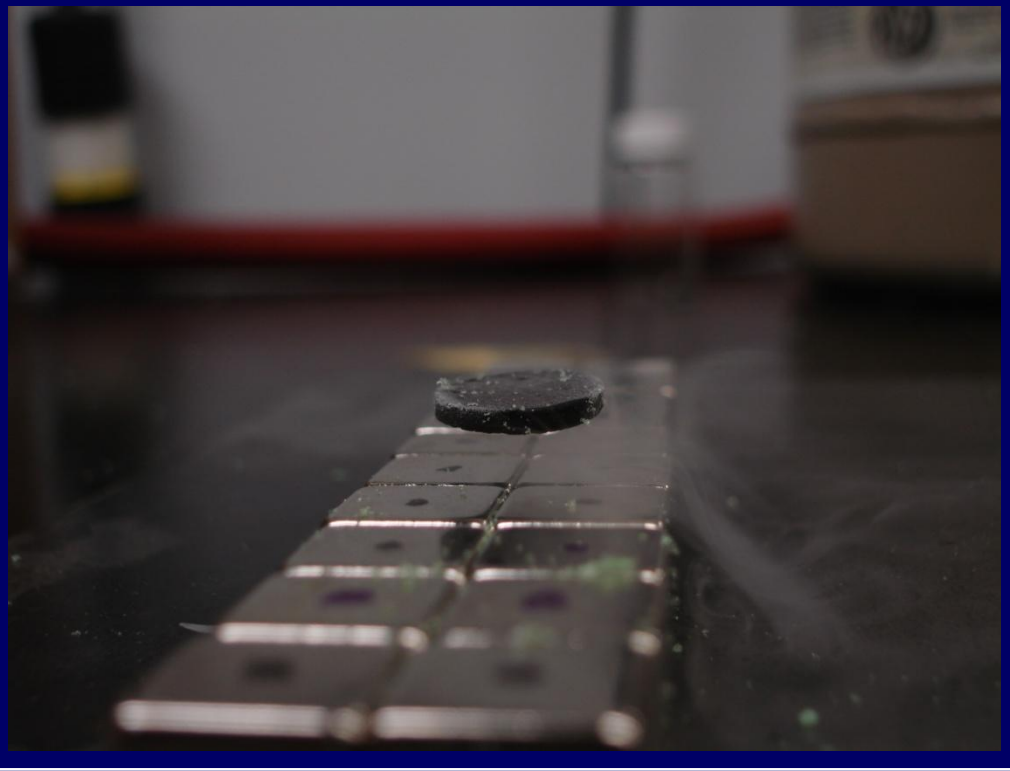
Test 4: Mass Levitating Power

Meissner Effect Data Summary

Test #	Measurement	Value
1	Maximum distance between magnets (straight track)	2.0 mm
2	Maximum distance between outer magnets (curved track)	3-4 mm
3	Average levitation height (individual pellets)	6.0 mm
4	Maximum mass levitated by five pellets	1.8 g

Data– Meissner Effect

- Test 5:
  - *Levitation Time*- How long could the pellet or group of pellets remain levitated before any part touched the magnets?



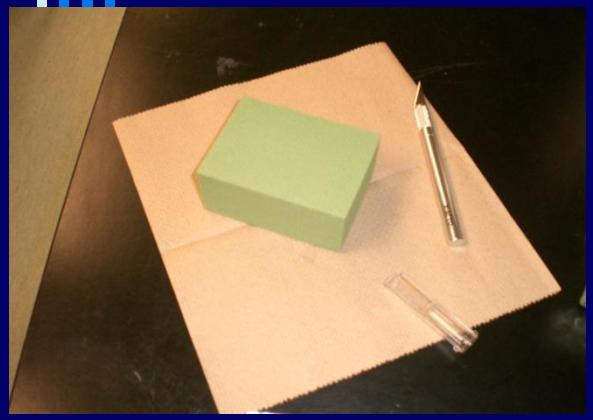
Data– Meissner Effect

- Test 5:
  - *Levitation Time*- How long could the pellet or group of pellets remain levitated before any part touched the magnets?

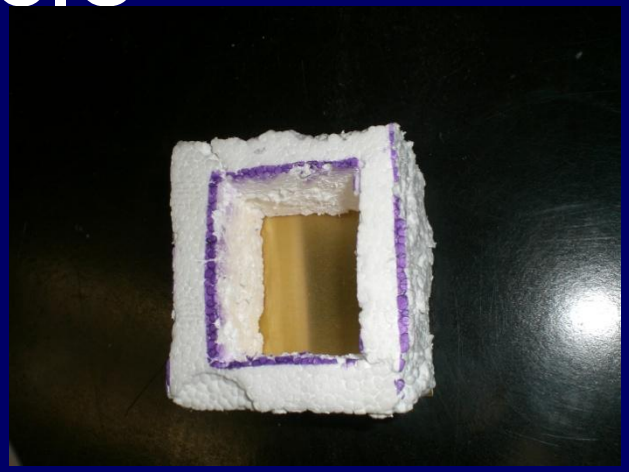
	Longest Levitation (s)	Shortest Levitation (s)	Average of All Trials (s)
Individual Pellets	17.06	7.31	10.52
Best Three-Pellet Car	45.63	38.61	41.07
Best Five-Pellet Car	63.85	52.68	60.50

Big Ideas!!

Evolution of Vehicle



Started with fine-grained styrofoam



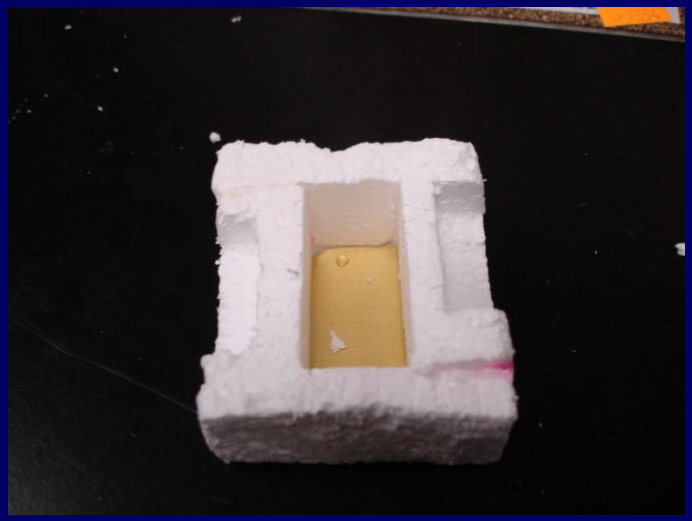
Moved to styrofoam that was more dense

Tried styrofoam glue!

Tried different glue!

Evolution of Vehicle

Tried Contact Cement



Attempted to make a liquid nitrogen bath for pellets to stay below T_c.

Carved out a channel for pellets

The journey is finished!

Vehicle

Beginning & Ending Specifications

Mass Adjustment

Beginning: 2.5 grams Ending: .25 grams

Adhesives

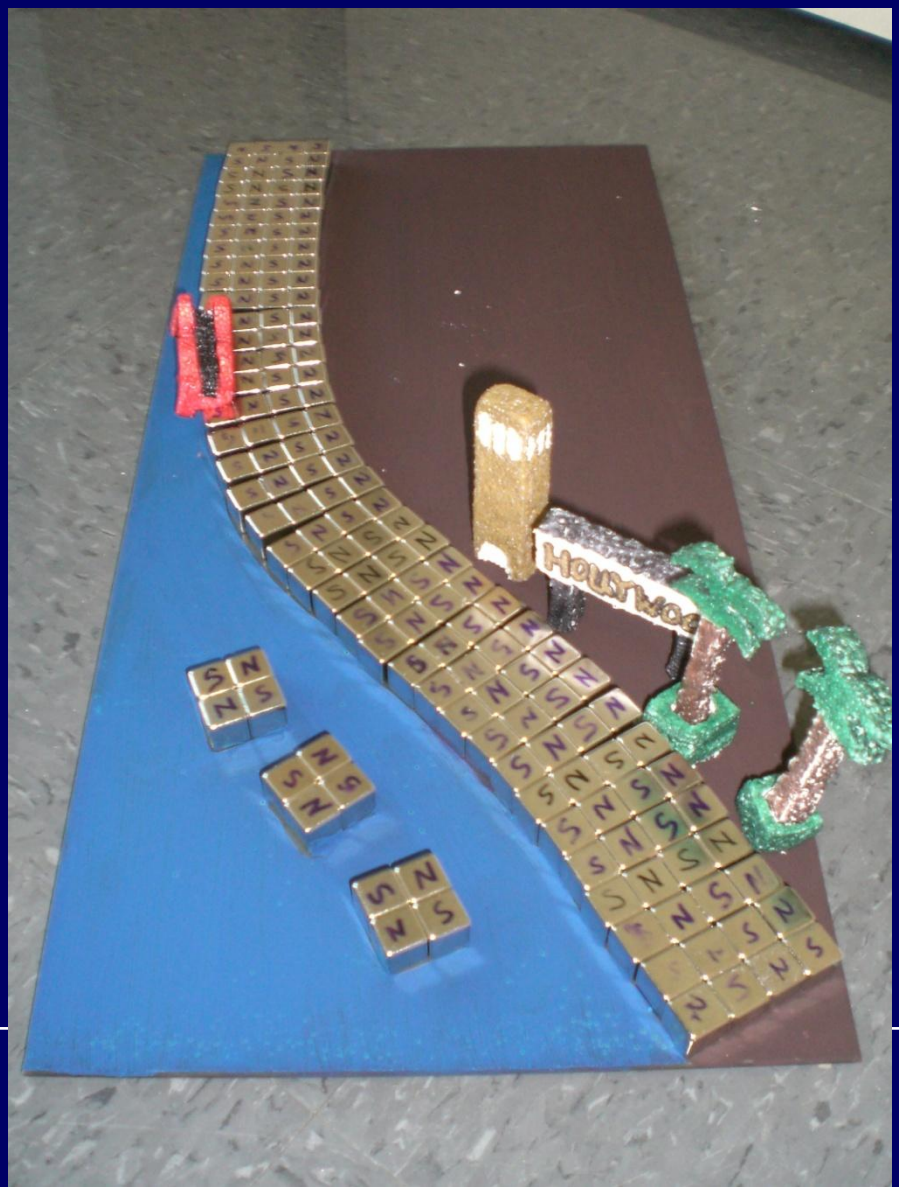
Beginning: glue, cement Ending: tape

Design for stable temperature

Beginning: liquid nitrogen reservoir Ending: insulating pellets

Project Evolution-- Track

How we got here!



Project Evolution-- Track

Random Arrangement

Dots to label levitating sides

Dots with arrows

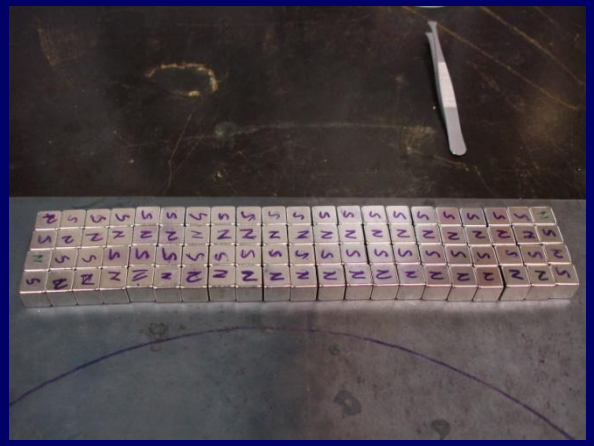
North-South

Breakthrough!

A “stop”

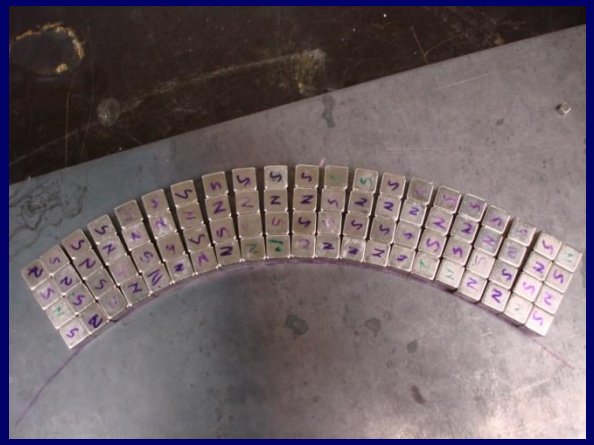
Project Evolution-- Track

Three-Wide



Four Wide

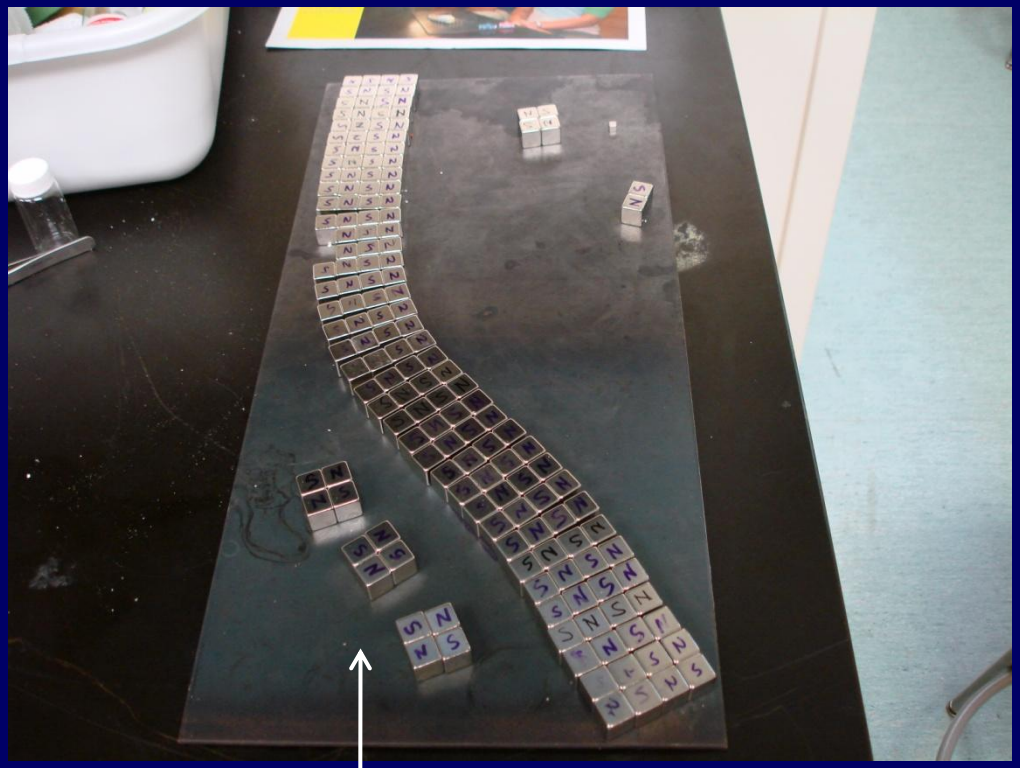
Three-Wide with curve



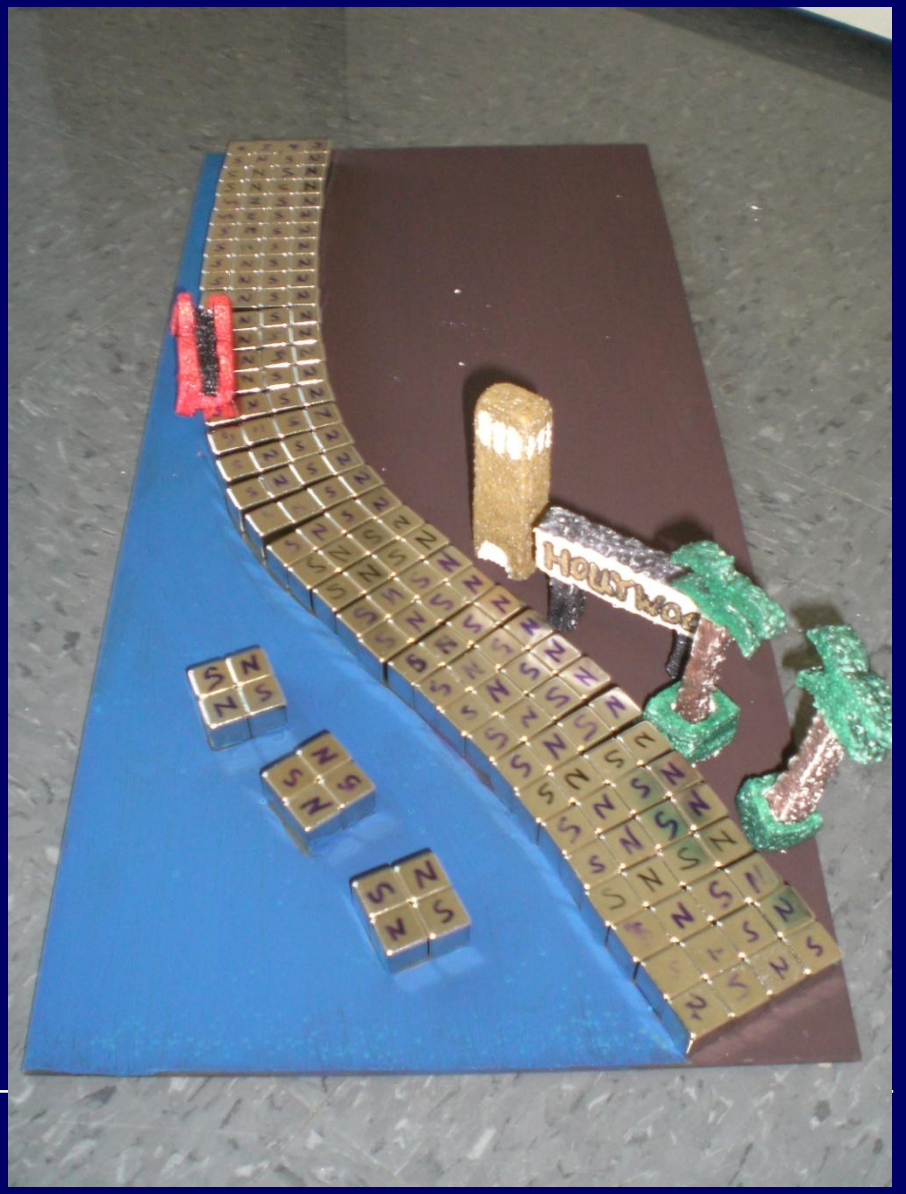
Four Wide with curve

Project Evolution-- Track

California!



The Channel Islands



Conclusions
Lessons Learned:

- **Scientifically**
- Superconductors, Meissner effect, x-ray diffraction, annealing, squid, solid-state chemistry, Y-123, ball-milling, paramagnetic, diamagnetic, cooper pairs, refinements, too much to list!
- Being able to work in a research lab has given me more confidence as a physical science teacher.

- **Personally**
- Intimidation should not stop you.
- Be excited about your work, it's contagious!
- Initial set-backs can be blessings in disguise.
- Ask questions, even if you think they are foolish!

Conclusion– Lessons Learned

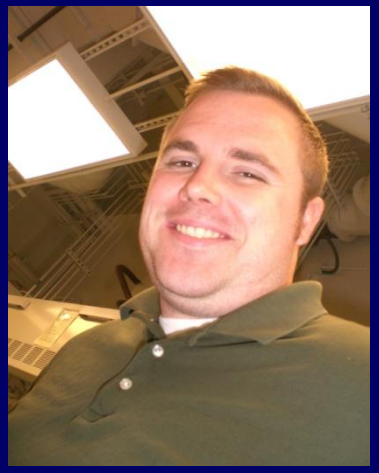
- Scientific:
  - Solid-state chemistry
  - Properties of superconductors
- Personal:
  - Finding the balance between when to be delicate and when to strong-arm lab equipment
  - One small mistake can undo weeks of work.
  - Periodic nature of research
  - Discrepant events can intrigue the most veteran scientist.

This process was chronicled at: http://gonzalezret.blogspot.com

Thank You!

Our Fearless Leader -Ram Seshadri

Josh Kurzman



Brent Melot

Thank you also:
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