Quantum Levitation

Amount of time Demo takes: 5 minutes

Don't try this at home!

Lesson's Big Idea

- Magnetic Fields can be used to create levitation and therefore eliminate sliding friction between two surfaces.
- The superconductor must be supercooled to take on magnetic properties (but it is not actually a magnet! (Meissner Effect))
- The superconductor and track oppose one another magnetically - much like trying to put the north ends of two magnets together.
- **Magnetic Levitation:** The track is a larger version of the ring magnets. The fact that the magnetic flux does not change along the track allows the superconductor to move around freely.
- **Suspension:** Moving around in circles is possible due to the circular symmetry of the magnetic field. In all other directions, the superconductor is locked in levitation. The levitation can, thus, be easily transformed into suspension.
- **Double Suspension:** The superconductors are not magnetic (at least not substantially). If there were magnetic, they would have affected each other. This experiment proves that the levitation is not (mainly) due to the Meissner effect. In the Meissner state the superconductor acts as a perfect diamagnet, having a magnetization of equal magnitude and opposite direction to the external field.

Materials

- Quantum Levitation Kit - Quantum Levitation
- LN2 (Liquid Nitrogen)
- LN2 safety Supplies (including gloves and safety glasses)
- Foam bowl to chill levitators and hold liquid nitrogen
- Plastic Tweezers
    a. 3D Printed Version found here: https://www.thingiverse.com/thing:1727040
- Aluminum foil

SAFETY!

- Tape a line on the ground 3 ft. from the table to use a barrier for students to be behind when you are working with Liquid Nitrogen.
- The handheld magnet **must** be kept a safe distance away from the magnet track. If not, they **will** get stuck to each other.
- Goggles and protective gloves **must** be worn at all times while handling the liquid nitrogen, because liquid nitrogen is -321 °F, it can cause frostbite if it touches skin. Use caution when pouring it and follow appropriate LN2 SOP procedures. Make sure the participants stay back far enough not to be hit by splashing liquid nitrogen**.** Don't be afraid to tell the kids to step back when pouring. Take extra care to ensure no droplets get into your glove, to avoid serious injury if this happens, remove the glove IMMEDIATELY. We don't want to cause injury to yourself or the public.
- This experiment contains extremely strong neodymium magnets. If not handled properly, they can cause serious injury. Keep the magnets away from magnetic materials and far from sensitive electronics.
- Safety glasses and gloves must be worn

Background Information

- Meissner Effect - the expulsion of a magnetic field from the interior of a material that is in the process of becoming a superconductor, that is, losing its resistance to the flow of electrical currents when cooled below a certain temperature, called the transition temperature, usually close to absolute zero.

Setup Instructions

- Assemble the track. There are two wooden pieces that slide together in the center of each piece. The track is then set on top of the stand.
- Set the handheld model out on the table (Small block with two rings on one side and six magnets on the other side)
- **Keep the handheld model away from the magnet track!**
- Wrap each superconductor with a **single** layer of aluminum foil. This is to hold the LN2 in and help insulate. Be careful with this step as

superconductors are fragile and expensive!
- Pour some LN2 into the foam bowl and place the superconductors into the bowl.

Instructional Procedures

There are a variety of demonstrations you can perform with this kit. You should set them all out on the table and go through each of them.
For any experiment that you are doing, you should use tweezers to get the superconductor out of the LN2, be careful not to jab into the superconductor with the tweezers. **DO NOT attempt to retrieve the superconductor with your gloves. They LN2 will soak through and burn you.**

Quantum Levitation Experiment

1. This section uses the small handheld model.
2. Quantum Locking
    a. Place the frozen levitator above the rectangle of 6 magnets.
    b. Show how the levitator is frozen in the vicinity of the magnets
    c. Using tweezers, gently try to move it in all directions and feel the resistance due to the pinning force.
    d. Flip the superconductor upside down to show that its orientation does not make a difference.
3. Frictionless Bearing
    a. Lock the levitator above the pair of ring magnets. It will rotate freely around the axis of the magnets but will be locked in any other direction.
    b. Shift the superconductor sideways to emphasize that it rotates around the magnet axis and not around its center.
    c. The superconductor will move freely as long as the magnetic field inside it (magnetic flux) stays the same.

Magnetic Levitation

1. Take out the circular Magnetic Levitation Track. Place the two wooden supports below it so it isn't sitting directly on the table.
2. Place the superconductor on the track top of the track

3. Show that it rotates freely along the track.
4. Show that the pinning force is stronger closer to the track but you can place the place the superconductor at different heights.

Suspension Train

1. Carefully place the superconductor above the rail.
2. Show how it moves around freely and follows the track.
3. You can try to place the superconductor below the track, but this can be quite difficult sometimes.

Double Levitation

1. Place one superconductor on the rail as high as possible. Try to fill it with a minimal amount of liquid nitrogen; this will allow a maximal levitation height.
2. Now place the second superconductor as low as possible. Notice that if it is too close to the magnets it will slow down more quickly; so be prepared to give it a boost more often.
    a. Another issue to pay attention to is the wrapping: if it is not wrapped neatly the aluminum might interfere with the other levitator.
3. Show how the two superconductors move without interfering with each other.
4. This can also be done with the handheld model, but it is more impressive if you get it to work on the track.

Tips & Tricks

- Wrap the aluminum foil around the superconductor in a neat and balanced way. If the foil is messed up your experiments will not work as well.
- The handheld model experiments typically work best and the participants really enjoy watching as you flip it upside-down.
- Pay attention to where LN2 is falling as you flip the superconductors. You do not want to get it on your skin.

Assessment Questions

1. Why doesn't the levitator (superconductor) leave the track/magnets?
    a. Pinning force - repulsive and attractive forces keeping the superconductor in place.
2. What is a superconductor?
    a. Materials that conduct electricity with zero resistance below a certain temperature.

Careers & Real-World Applications

- Liquid nitrogen is used for a variety of purposes such as storing samples in labs or even freezing off warts!
- LN2 is also used a coolant in computers!
- Levitation can be used in several applications such as trains and frictionless bearings. Although the use of LN2 is an expensive way to do this, the concept is still the same.

- **Careers:**
    - Medical Lab Scientist
    - Biologist
    - Genetic Scientist
    - Biomedical Engineer

Clean Up

- Note: The superconductor inside the quantum levitator is sensitive to moisture. If not handled properly, it will lose its superconducting properties. You should always let the levitator warm up and dry after usage. Store the levitor in a dry atmosphere, preferably inside a sealed container with silica gel.
- Wrap all parts of the track and quantum levitator board in bubble wrap.
- **The hand held model should be stored so its magnets are not facing toward the track or they will stick together and could break when trying to separate them!**
- Put levitators back in their boxes once warmed to room temperature and very dry.
- This demonstration is extremely valuable and fragile. Please be careful.

Related Next Generation Science Standards

- K-5
    - 3-PS2 Motion and Stability: Forces and Interactions
    - 4-PS3 Energy
- 6-8
    - MS-PS2 Motion and Stability: Forces and Interactions
    - MS-PS3 Energy
- 9-12
    - HS-PS2 Motion and Stability: Forces and Interactions
    - HS-PS3 Energy

Liquid Nitrogen (LN2)
Info & Safe Operating Procedure

Note: This document is *only* a suitable guide for low-pressure tanks and open-air dewars (containers for storing LN2). If after reading you have any questions, please contact Mind Trekkers Pro-Staff or E board for further direction.

Safety:

1. Safety Equipment:
    a. Must wear: safety glasses, insulated (cryo) gloves, long pants, closed-toe shoes, long hair pulled back
    b. Safety equipment must be worn to protect yourself as well as to be a positive role model for the public.
2. Pressure:
    a. LN2 should never be kept in a sealed container (soda bottle, water bottle, etc.) and heavy objects should not be stacked on top of dewars. LN2 boils at room temperature. The pressure buildup could cause a dangerous explosion once containers can no longer withstand the pressure of the gas. LN2 should always be kept in a well-ventilated area so the gas may disperse and not build up.
    b. The LN2 tanks Mind Trekkers orders are 22 psi. If you see the pressure gauge above 25 psi, alert a member of E board so they can vent to tank and reduce the pressure.
3. Contact:
    a. Never touch (or let others touch) LN2 with their bare skin. Even with gloves that are designed to withstand cold, LN2 is cold enough to cause severe damage to skin if submerged. People handling LN2 should avoid wearing jewelry on their hands/fingers/wrists. If LN2 becomes trapped between something and your skin, it will boil against you, promoting the chance of frost bite on that surface. If, your instance, a droplet enters you glove, remove it **immediately** as the glove my trap the droplet against the skin, causing damage.

4. Transport:
    a. Mind Trekkers will have LN2 delivered to the event sites by certified distributors. LN2 should only be transported in a dewar or other approved LN2 storage device. **LN2 is never to be transported via Mind Trekkers.** It is illegal and unsafe.

Chemistry:

Elemental nitrogen (N) naturally occurs as a gaseous molecule, meaning that when it is found in nature, it is rarely a single molecule of N, but twom (denoted N2). If you are interested in learning about diatomic molecules, please read the Wikipedia article titled, "Diatomic Molecule." This is the reason for the nickname LN2 (Liquid N2= LN2). The boiling point of LN2 is {77 K, -196℃, -321℉}, this means while it is exposed to our atmosphere, it's *boiling,* very much like a pot of water boils on the stove. If you don't have a reference to how cold this is, the coldest Houghton winter that we were able to find on record is {241 K, -32℃, -26℉}.

It is important that LN2 is treated with respect and kept in a safe operating regime. If you're uncertain about something, the best option is to ask someone who knows. If you would like more information, please read a MSDS (Manufacturer's Safety Data Sheet) about LN2, and it will have far more details than are listed or needed here.