Superconductivity

Work with liquid nitrogen and explore the properties of superconductors.

Lab Activities

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1. Tubes, magnets & gravity.

Task

Drop the two metallic balls (separately) into the three different tubes made of: **Copper**, **Plexiglas**, **Aluminium-alloy (Al Mg Si)**.

Observation

Fill in your worksheet.

2. A superconducting tube.

Prediction

Think first! Fill in your worksheet.

Explanation

Fill in your worksheet.

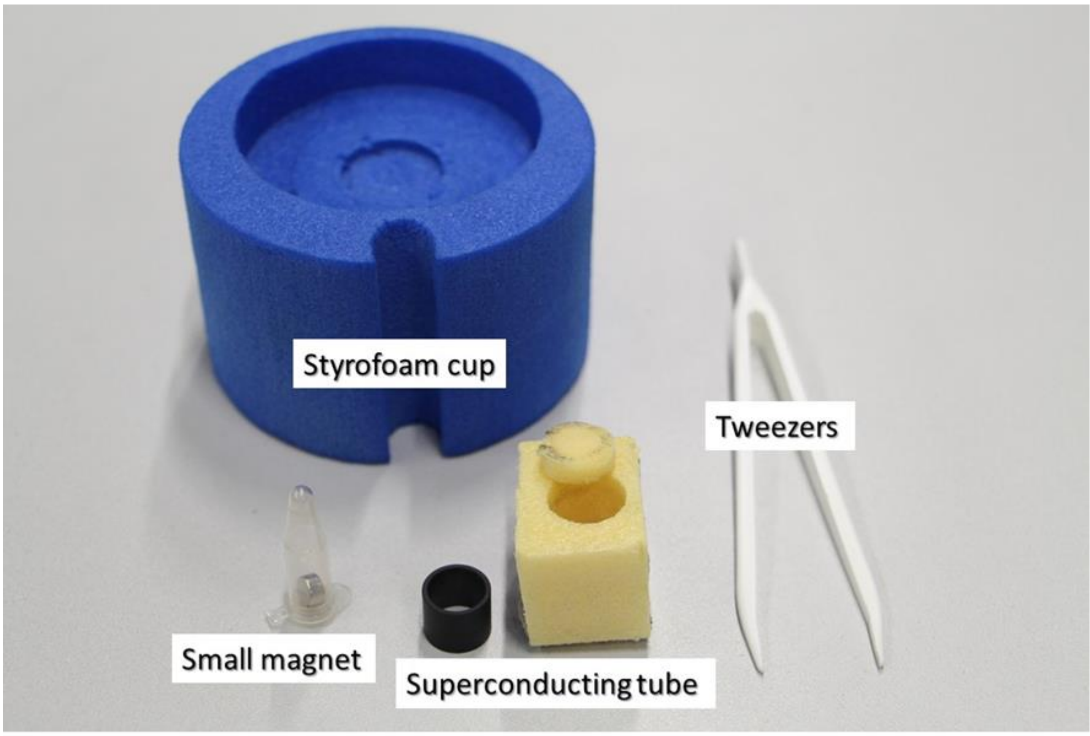
Task

Now try it out!

DANGER

The superconductor is very fragile, expensive and will break if you drop it!
Let the cold components (superconductor, magnet) warm up in the sides of the experimentation box. Wait for liquid nitrogen to boil away before starting the next experiment.

- Put the blue Styrofoam cup on the table with the **deeper indentation** of the two sides **facing upwards**.
- Place the small black tube (that's the superconductor) in the center of the cup using tweezers.
- Ask your guide to fill the blue cup with liquid nitrogen.
- Wait for the superconductor to cool down (approx. 1 min).
- Use the tweezers to drop a magnet in to the cold tube.

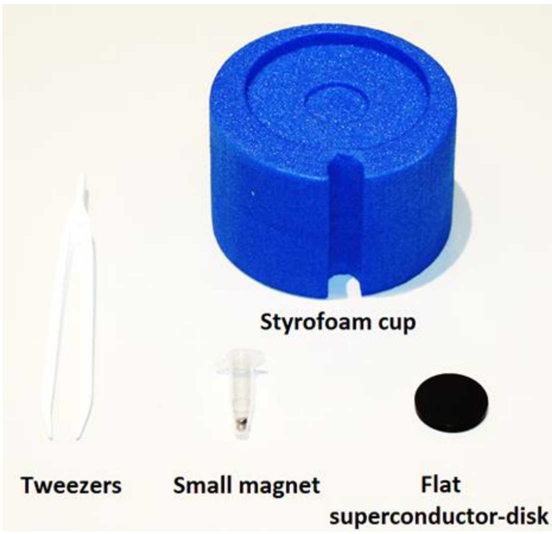


3. A superconducting disc.

Task

You will repeat the previous experiment with a superconducting disc and test different hypotheses about this phenomenon.

- Place the thin black disc (that's the superconductor) in the center of the cup using tweezers.
- Place the magnet on the disc before adding liquid nitrogen.
- Ask your guide to fill the blue cup with liquid nitrogen. Wait for the superconductor to cool down.



- Optional: Let warm up, remove the magnet, cool down again. Then drop the magnet on top of the cold disc.

We asked three people at CERN to come up with ideas that could explain your observations:

1) **Maria** says that the superconductor disc becomes a permanent magnet with a South and North Pole when it cools down. Therefore, the small magnet is repelled and it levitates.
2) **Philippe** says that the magnet induces an electric current in the superconductor disc. The small magnet levitates because of the magnetic field of this electric current.
3) **Sascha** says that when your fill the Styrofoam cup with liquid nitrogen, it produces a lot of water vapour. The small magnets levitates above this vapour.

Can you reject 2 of these 3 hypotheses? Fill in your worksheet.

- Design the experiments with which you can test these hypotheses. Add a sketch to the description of the testing experiment.
- Before you do the experiments, write down the predictions: What will the outcome of the experiment be, if this hypothesis is valid?
- Do the experiments.
- Did the predictions match the outcome of the experiment?
- What does that say about the validity of the hypotheses? If the outcome of the experiment did not match the predictions, think about the assumptions you made that might have been wrong.

DANGER

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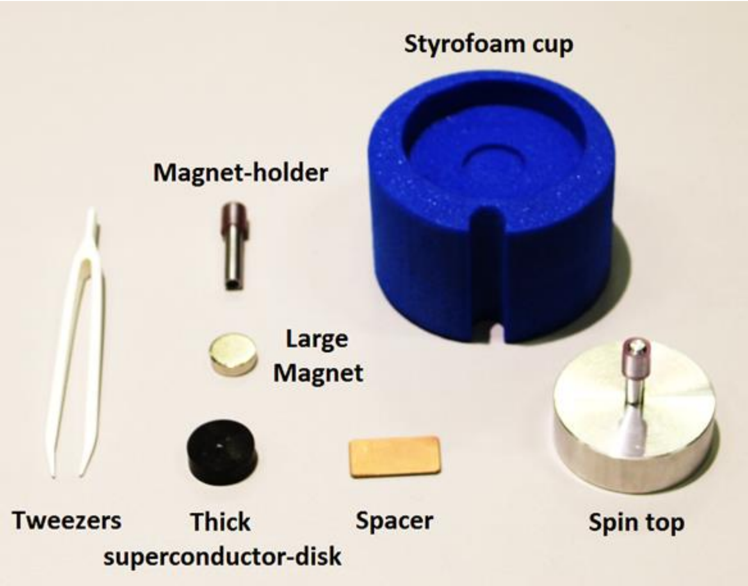
Let the cold components (superconductor, magnet) warm up in the sides of the experimentation box. Wait for liquid nitrogen to boil away before starting the next experiment.

4. The flux – pinning effect.

Task

- Put the blue Styrofoam cup on the table with the **deeper indentation** of the two sides **facing upwards**.
- Place the thick superconductor disk in its centre.
- Place the spacer on the disk.
- Place the large magnet disk on top.
- Ask a guide to add liquid nitrogen until the upper edge of the thick superconductor is only just covered.

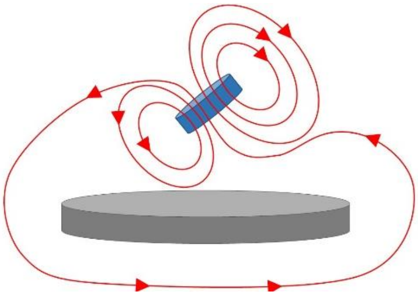


- Remove the spacer with the tweezers, when the liquid nitrogen stops to boil. Do not use your bare hands!
- Try to move and spin the magnet with the tweezers.
- Put the magnet-holder on the magnet and try to lift it.

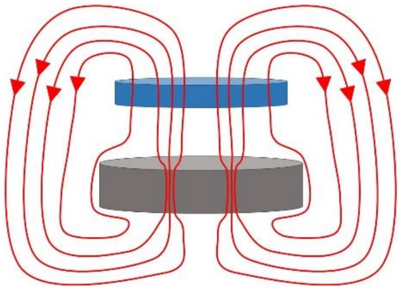
<u>Caution</u>: Move it only a few centimeters!

What happened? Answer the “observation” and “explanation” questions on your worksheet.

Meissner-Ochsenfeld effect



Flux – pinning effect



Bonus! Levitating train.

You will build a linear magnetic track for a superconducting magnetic levitation train. We need the following parts:

Orientation of the magnets

The poles of the small magnets are oriented as follows:

Prediction

Think first!
Fill in your worksheet.

Observation

- Now prepare a magnetic track according to your prediction on the bookend.

Task

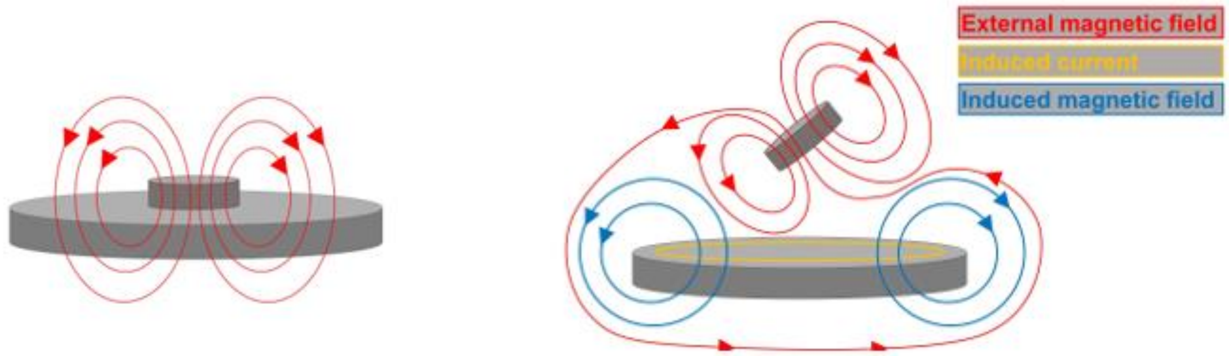
- Set the “train” with the spacer on your section and ask your guide for liquid nitrogen.
- When the superconductor is cold, you can remove the piece of cardboard and give the train a little push (e.g. with the Pole-Detector – not with your bare hands!).
- Optional: Analyse your magnet track with the Flux-Foil: This Flux foil makes magnetic fields visible. The foil turns dark in colour when the magnetic field is perpendicular to the foil and turns lighter when the magnetic field runs parallel to the foil.
- Compare different magnet configurations.
- Fill in your worksheet.

Which magnet configuration works? Why?

Explanation The Meissner - Ochsenfeld effect.

Why can we observe this effect?

The magnetic field of the small magnet induces eddy currents on the surface of every material. Typically, these eddy currents fade quickly due to the electrical resistance of the material and there is no visible effect. Therefore, the magnetic field of the magnet can penetrate the material of the WARM superconductor without problems. Have a look at the drawing on the left below.



$T > T_c$ Room temperature

$T < T_c$ Cooled down

Once the superconductor is cooled below its critical temperature T_c by the liquid nitrogen (in the case of our superconductor YBCO: T_c≈-180°C), it loses its electrical resistance and the induced eddy currents on the surface of the superconductor can flow freely and won't stop. The induced eddy currents flow as long as the superconductor stays cooled below its critical temperature.

These eddy currents produce a magnetic field, in the opposite direction of the external field. Therefore, it seems as if the superconductor is shielded against the external field of the magnet. Thus, the magnetic field of the magnet is repelled by the superconductor, the magnet starts to levitate. We visualise this using magnetic field lines that go around the superconductor (see picture above on the right). Superconductor and magnet will stay in this position until the superconductor gets warm again and the magnetic field of the magnet can penetrate it again.

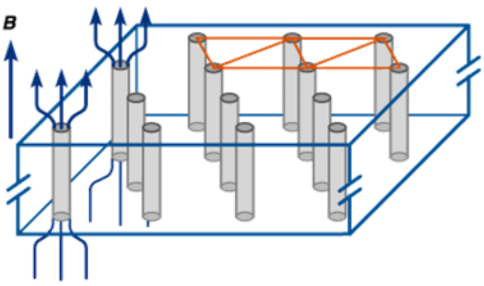
This effect is called the Meissner-Ochsenfeld effect.

Explanation The Flux-Pinning effect.

What is the difference between the Flux-Pinning-effect and the Meissner-effect?

The effect you observed is the so called “Flux-pinning effect”. This Flux-pinning-effect only occurs with so-called type-II superconductors. Both superconductor disks are made of YBCO, but the thicker disk has a different structure. While the first disc was sintered (i.e. pressed from powder and baked), the second disc has a crystalline structure.

Due to this symmetric crystalline structure certain directions of magnetic flux going through the superconductor are allowed. The tubes in which magnetic flux penetrates the superconductor are called "flux-tubes" and are a quantum-mechanical phenomenon. This is shown in the following sketch:



Due to the flux-tubes, the superconductor is now fixed relative to the magnet in its cool-down position. The magnetic flux is trapped in the cold superconductor. Therefore, it is also necessary to use a spacer when cooling the superconductor below its critical temperature T_c, since the magnet would be otherwise fixed directly on the superconductor and wouldn’t levitate.

Which movements are allowed?

As long as the strength and shape of the magnetic flux, which penetrates the superconductor in form of flux-tubes, remains constant, the superconductor is able to move. Therefore, movements such as horizontal rotations are allowed, but not lateral displacements.

Tip: This is also used in superconducting magnetic levitation train, which are topic of the bonus-experiment.