Magnetism

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Overview

- Variable Gap Magnet
  - Eddy currents based on the Geometry of Paddles
  - Effects of field strength on stopping paddles
- Paramagnetism vs. Diamagnetism
  - Behavior of rods in B-Field
  - Paramagnetic behavior of liquid oxygen
- Paperclip Demonstration
  - Magnetic effects overcoming gravity

Variable Gap

- Video shows Solid Paddle at several different gap sizes
  - Note the decreasing time of swing
  - At 1cm, the paddle is so constrained by eddy current forces that it does not complete a cycle

Solid Paddle, 5cm gap

Solid Paddle, 3cm gap

Solid Paddle, 1cm gap

Different Paddles

- All paddles shown at a gap of 1 cm
  - The open paddle takes significantly more time than the other two because of geometry..
  - The solid paddle takes less time than the slotted paddle to stop

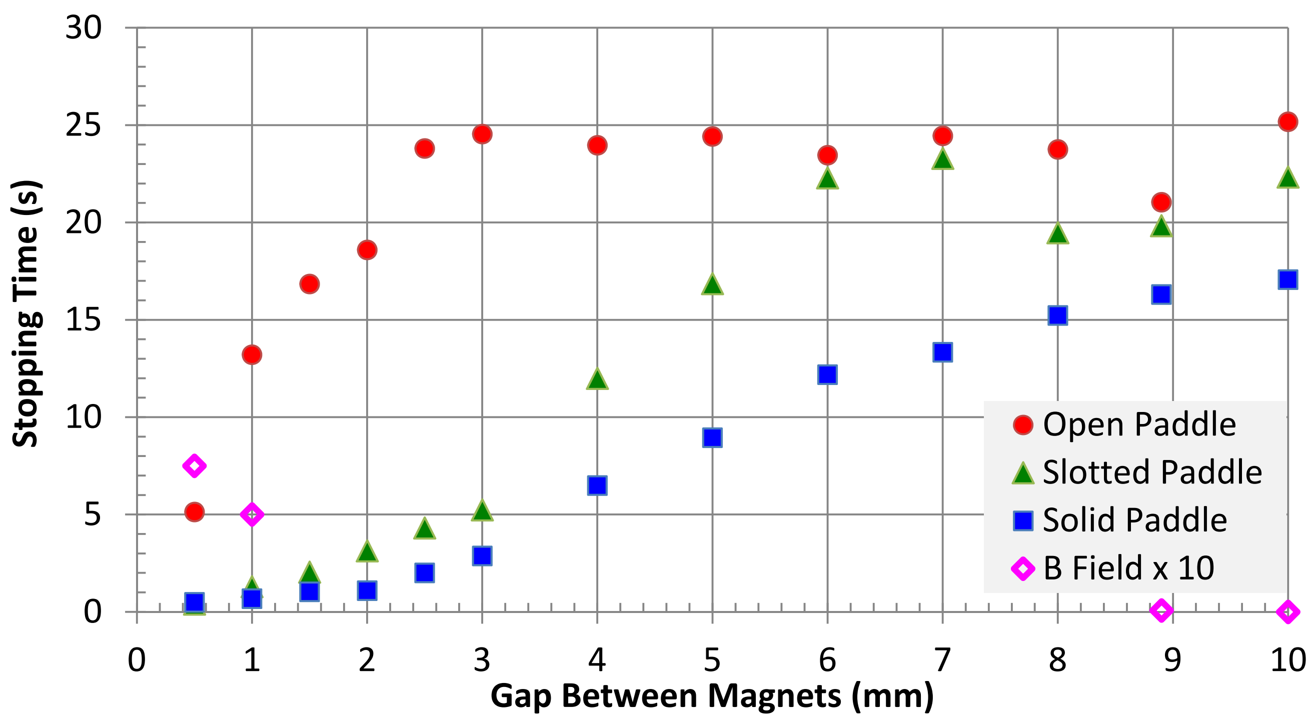

Open Paddle, 1cm gap


Slotted Paddle, 1cm gap


Solid Paddle, 1cm gap

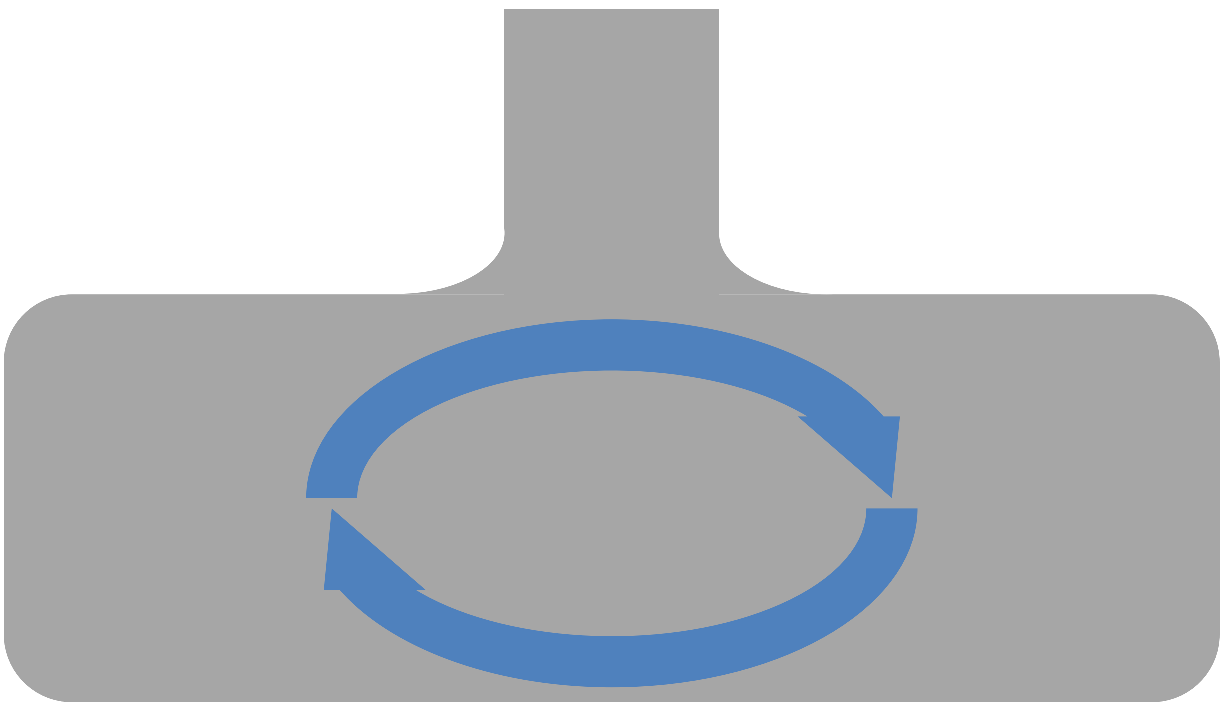
Stopping Time vs. Magnet Gap

- Each aluminum paddle was released from 90^{o} and then the time required for complete stop was measured
- The flat paddle yielded results at all distances, while the other paddles needed stronger fields to overcome friction
- The data suggests an exponential relationship between magnetic gap and time, which is negated at wider gaps due to friction



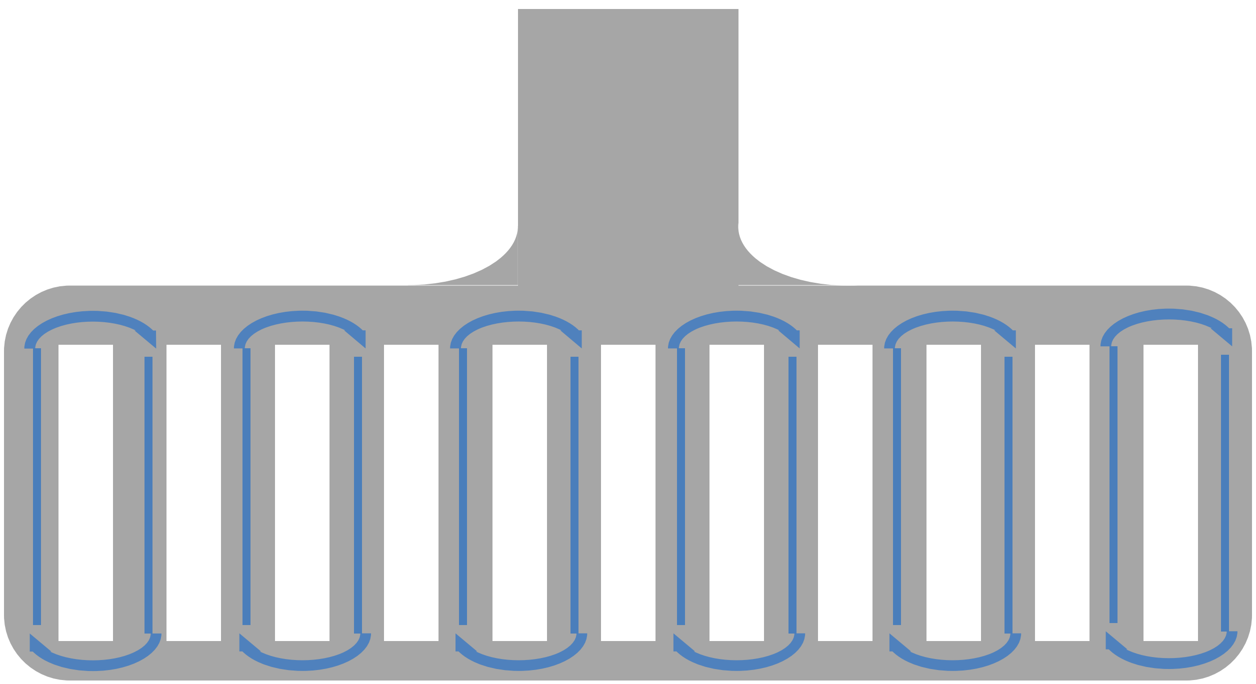
Solid Paddle

- Solid paddle has the strongest magnetic force on it.
- Small dipoles in the atoms of the Aluminum align to create a net magnetic moment in the paddle.
- Strongest because it has the most dipoles and because of geometry.



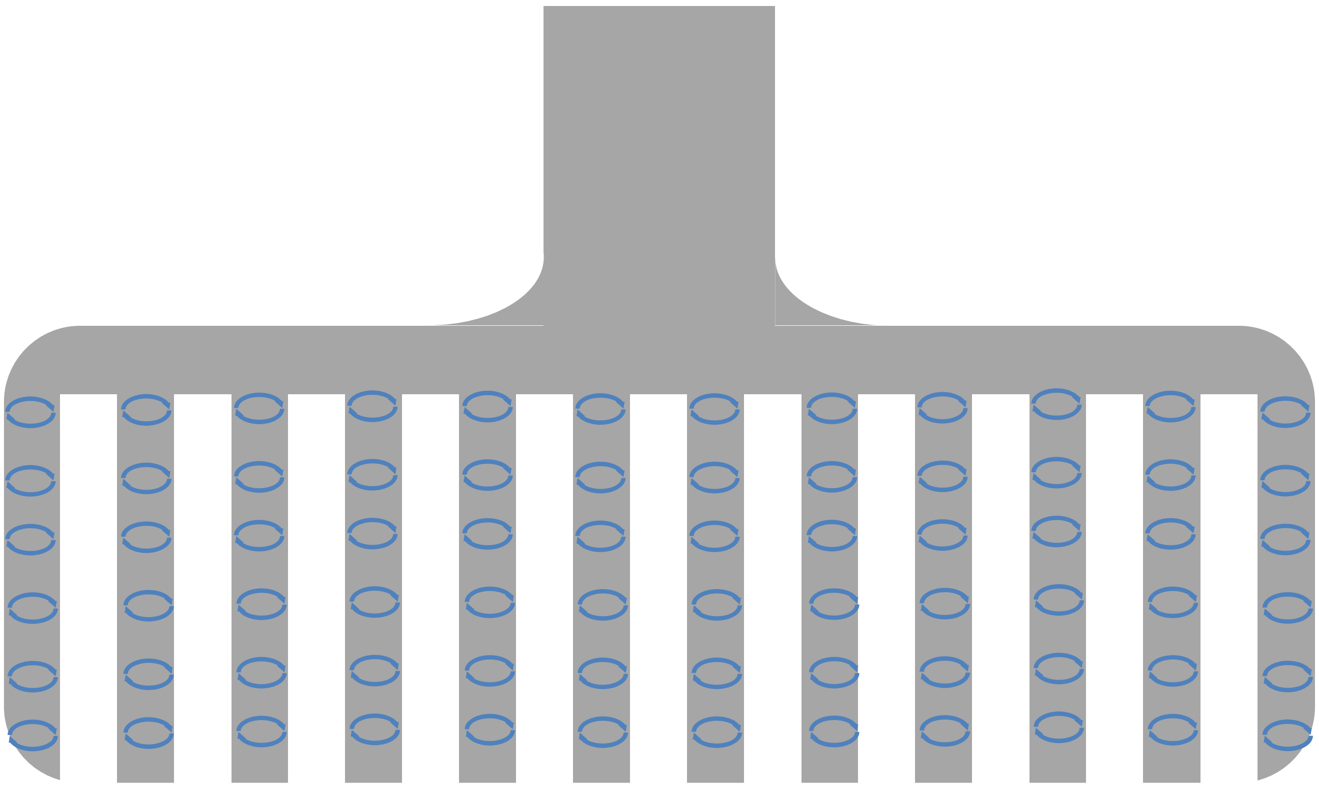
Slotted Paddle

- Slotted paddle has less force than solid paddle but effects are easily observed.
- With less mass than the solid paddle, there are less dipoles to contribute to the force.
- Geometry allows eddy currents to form, so there is still a strong effect.



Open Paddle

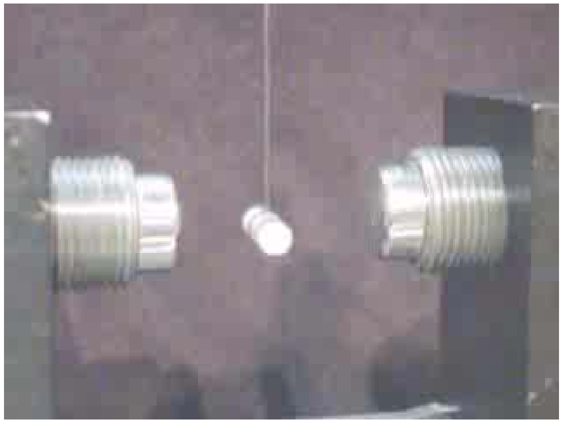
- Open paddle shows no effects except at very small gaps.
- Despite having comparable amounts of material as slotted paddle, geometry prevents eddy currents from slowing the paddle much.

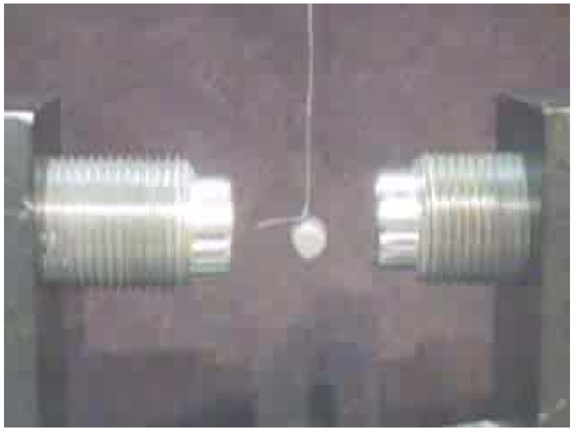


Paramagnetism vs. Diamagnetism

- Best way to test paramagnetic materials is to align the axis of the cylinder with the magnets and watch it follow the magnets as they are rotated. Aluminum cylinder will rotate about 180 degrees from the equilibrium position.
- To test a weak diamagnetic material (glass) put the magnets perpendicular to the axis of the rod and rotate the magnets to try to force the rod to align and it will be repelled.
- Graphite is a stronger diamagnetic than glass. Put the graphite rod perpendicular to the magnets and it will rotate with the magnets similarly to the paramagnetic, except perpendicular to the field.


Aluminum rod aligns with field


Glass rod forced into alignment


Graphite rod following perpendicular to field

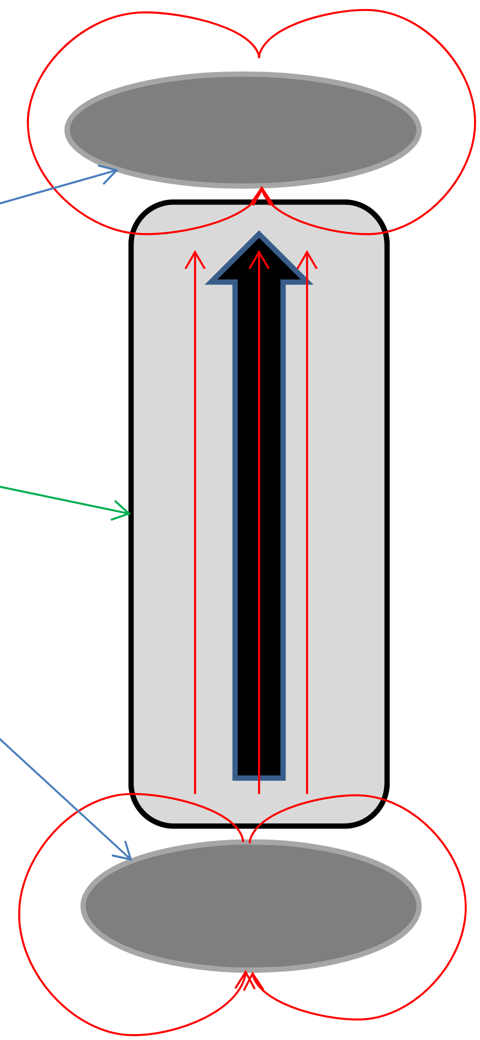
Paramagnetic vs. Diamagnetic Rod

- A dipole that is parallel to the field will be drawn into regions of high field strength
  - The ends of a paramagnetic cylinder will be attracted to the poles of the magnets
- A dipole that is antiparallel to the field will be expelled from regions of high field strength
  - The ends of a diamagnetic cylinder will be repelled by the poles of the magnets
- The behavior of the cylinders is the result of the nonuniform field between the poles of the magnets

Paramagnetic Rod

$$\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{B})$$

Magnets
Paramagnetic Rod
B
m



In a paramagnetic rod, m tends to be parallel to B along the axis of the rod. The field is nonuniform with the stronger field closer to the magnets, so $\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{B})$ is positive in the direction of the pole. If there is an angle θ between m and B, the torque is proportional to cos(θ) and is stronger the smaller the angle is.

Diamagnetic Rod

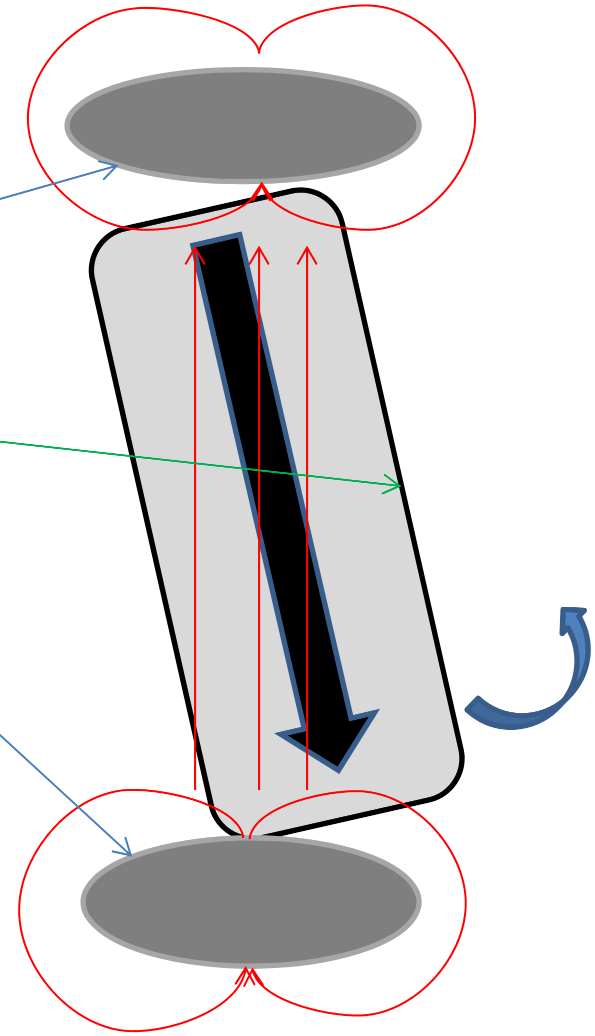
$$\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{B})$$

Magnets

Paramagnetic Rod

B

m

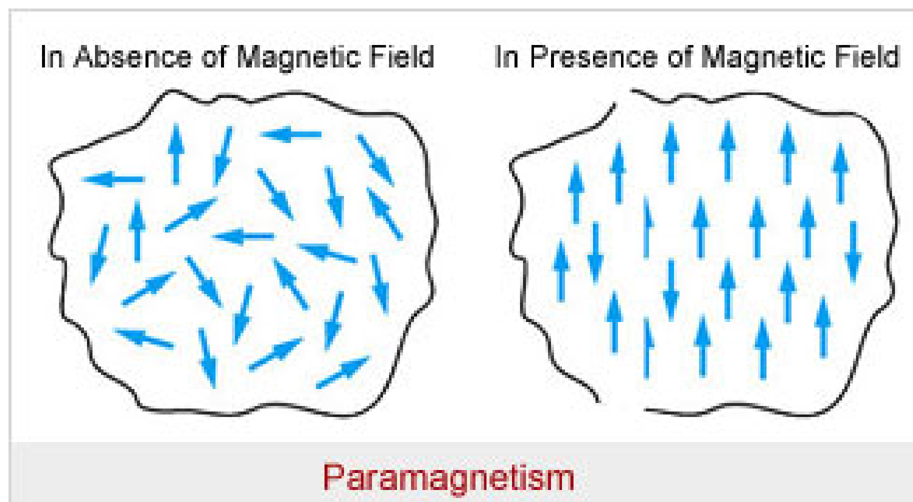


In a diamagnetic rod, m tends to be antiparallel to B along the axis of the rod. The field is nonuniform with the stronger field closer to the magnets, so $\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{B})$ is negative in the direction of the pole when B and m are pushed into alignment. If there is an angle θ between m and B, the torque is proportional to cos(θ) and is stronger the smaller the angle is. The rod is at equilibrium when the fields are perpendicular.

Paramagnetism

- Paramagnetic materials tend to align with the applied magnetic field.
- Before field is applied, it is as if the rod is made up of many magnets oriented randomly so that net magnetism is zero.
- After field is applied, dipoles line up along axis with the magnetic field.
- With the interaction of the dipoles, a net magnetic moment is formed in the direction of the magnetic field and the rod will line up with the magnetic field.
- Examples of paramagnetic materials include aluminum and liquid oxygen

Aluminum



Liquid Oxygen

- Exhibits paramagnetic behavior.
- Dripping Oxygen is caught by magnetic field before it can evaporate.

Oxygen getting caught in magnets

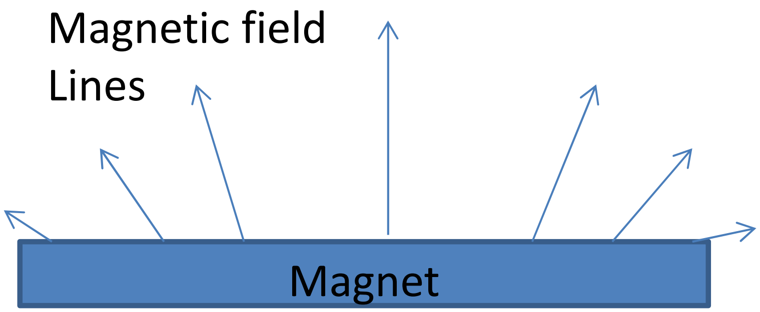
Oxygen disperses as magnets are separated.

Diamagnetism

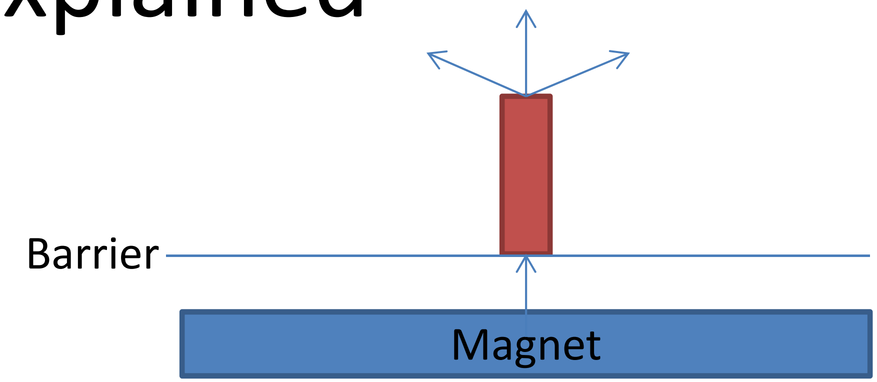
-Diamagnetic materials are repelled by the magnetic field.
-Quantum Mechanical effect in all materials, but not observed in everyday situations
-Much smaller than paramagnetic effects so not easily observed in paramagnetic materials.
-Materials are diamagnetic when magnetic susceptibility is less than 0
-Materials can be levitated using diamagnetic effects.

Diamagnetism can be used to levitate objects, like live frogs!

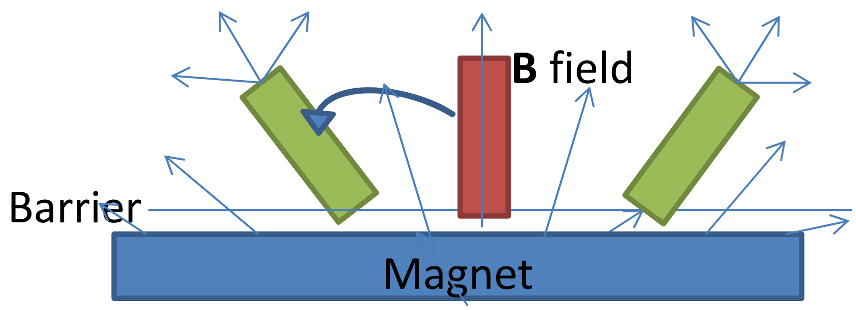
Dancing Paperclips Explained



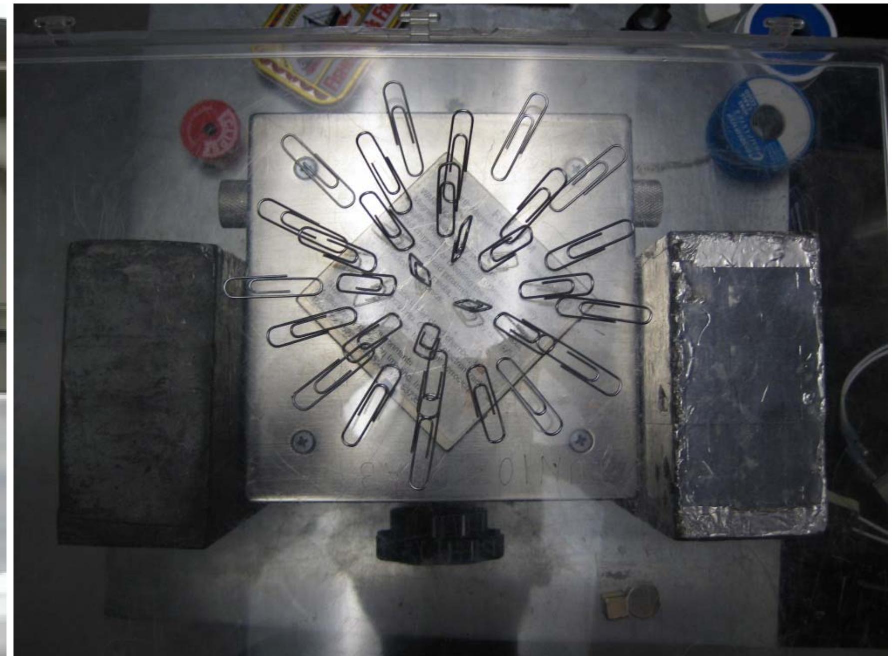
- The magnet produces a field in all directions

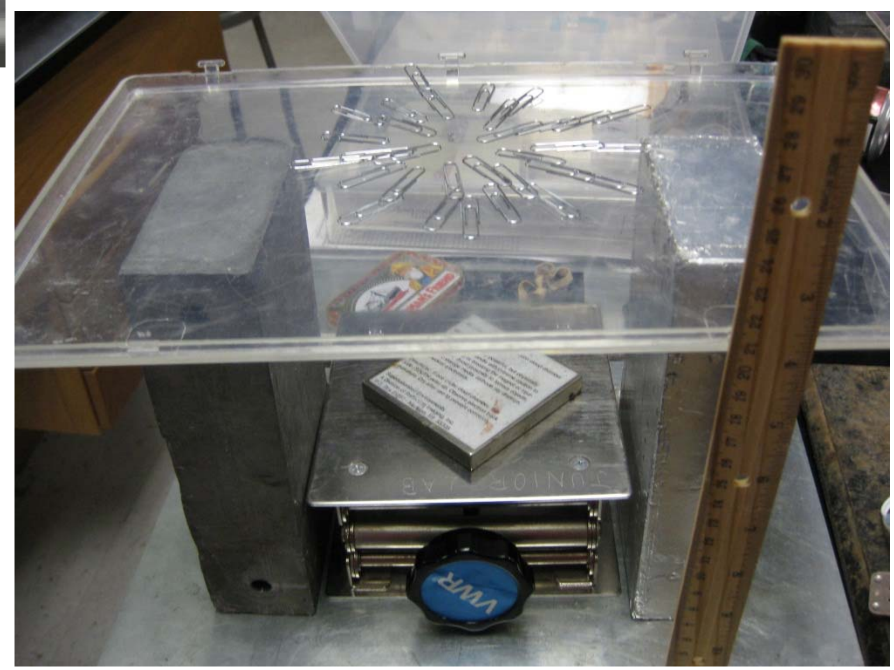


- When you put an object that is paramagnetic (paper clip), into the field, it aligns itself parallel to the field
- The object then produces its own field

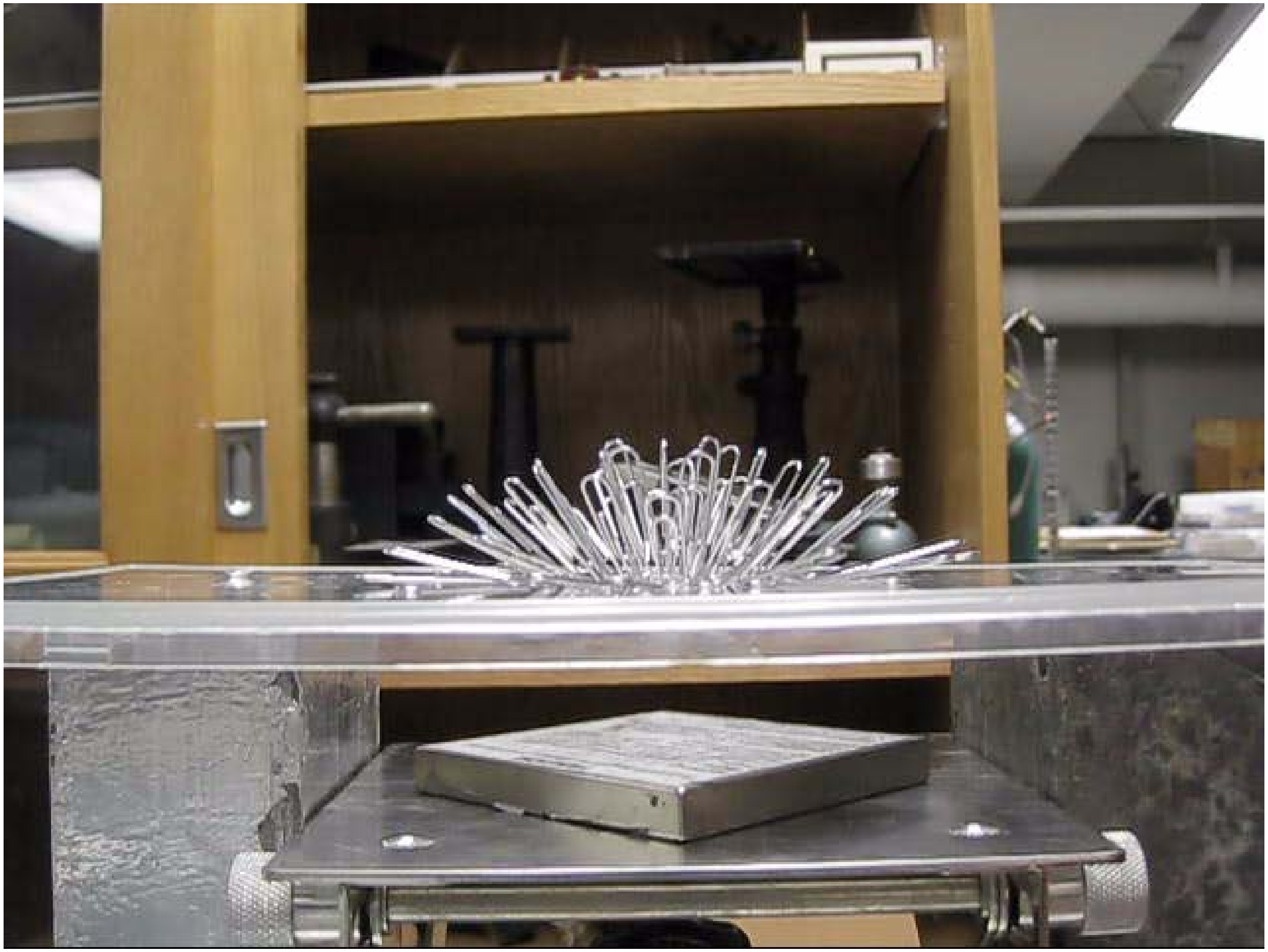


- When another object is introduced, it produces its own field that affects the original object which in turn affects it
- This system produces a very sensitive and complex magnetic field
- Paperclips “dance” only when they are farther from the magnet because the field close to the magnet it is parallel to the surface of the magnet and much stronger than those of the paperclips.
- When they are farther away the paperclips can produce fields stronger than that of the magnet and “dance”





- The video above illustrates how when a new paperclip enters the field it affects the other ones around it and forces them to follow different field lines. Created by the new paperclip.
- The two pictures to the right are the apparatus we used to change the strength of the field due to the magnet based on its distance from the paperclips



Paperclips rise and fall based on how close or how far the magnet and its field are to them.

Paperclips: Why?

- Field is approximately uniform, so $\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{B})$ is approximately 0, therefore diamagnetic and paramagnetic materials behave similarly
- $PE_{gravity} = \rho V g l(\cos\theta)$, where ρ= mass density of the paper clip, V = volume, l=length of paperclip
- $PE_{magnetic} = [(B_0^2 V\chi)/2\mu_0][(\cos2(\theta)/(1+n_x\chi)+\sin^2(\theta)/(1+n_y\chi)]$
- So, PE= $\cos(\theta)-C\chi[(2+\cos^2\theta)/(2+\chi)]$ where C is a constant that depends on the field and object.

Paperclips Illustrated

- You can see from this graph that depending on the strength of the field and the geometry of the paper clips, the most stable configurations for the paper clips are for them to be perpendicular to the field or to be parallel to it, where there are valleys in the graphs.