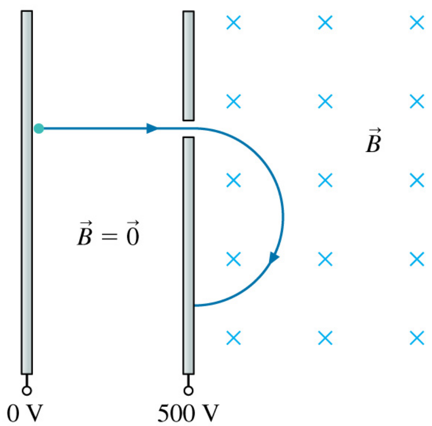
PHY294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **hand-in problem for next Wed: 32.80**
- Quizzes by iclicker (sometimes hand-written)
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

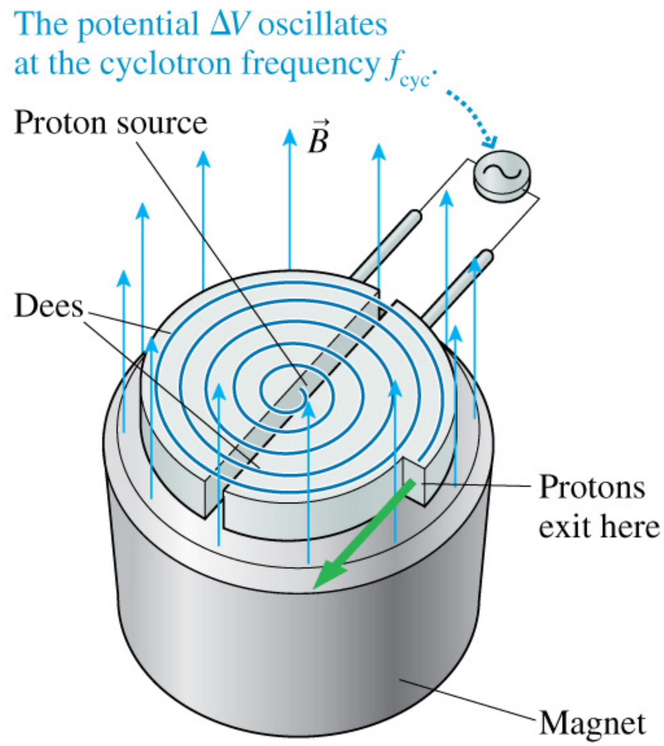
How a cyclotron works

- Suppose I accelerate a charged particle (a proton) through a potential difference of 500 V
- It then acquires a kinetic energy of KE=ΔU=qV=(1.6X10^{-19}C)(500V)=8X10^{-17} J
  - often easier to quote the energy gained as 500 eV (electron-volts)
- If it travels into a region of uniform magnetic field, it will travel a circular path of radius r



$$r = \frac{mv}{qB}$$

In a cyclotron, the potential oscillates in sign, so that when the protons emerge from the hollow conductors ("Dees"), they are accelerated towards the Dee on the opposite side. As p(=mv) increases, the radius r also increases (B is constant)



How a cyclotron works

- Suppose I have a 0.65 m cyclotron that uses a 500 V oscillating potential difference between the dees.
  - what is the maximum kinetic energy of a proton if the magnetic field strength is 0.75 T?
  - how many revolutions does the proton make before leaving the cyclotron?

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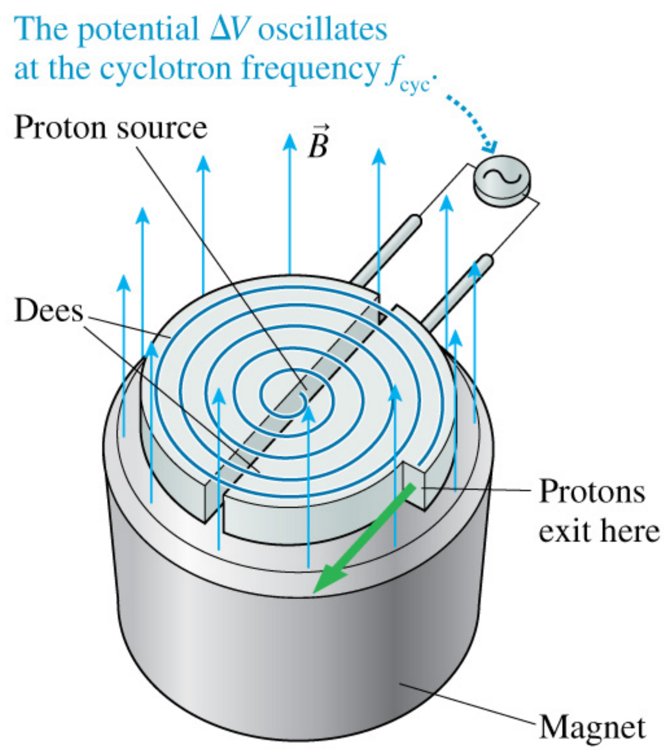
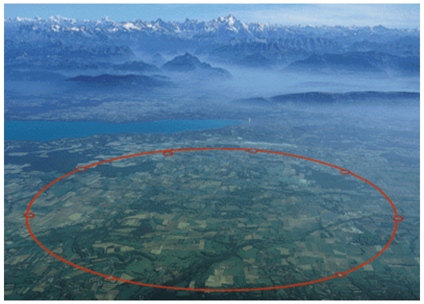
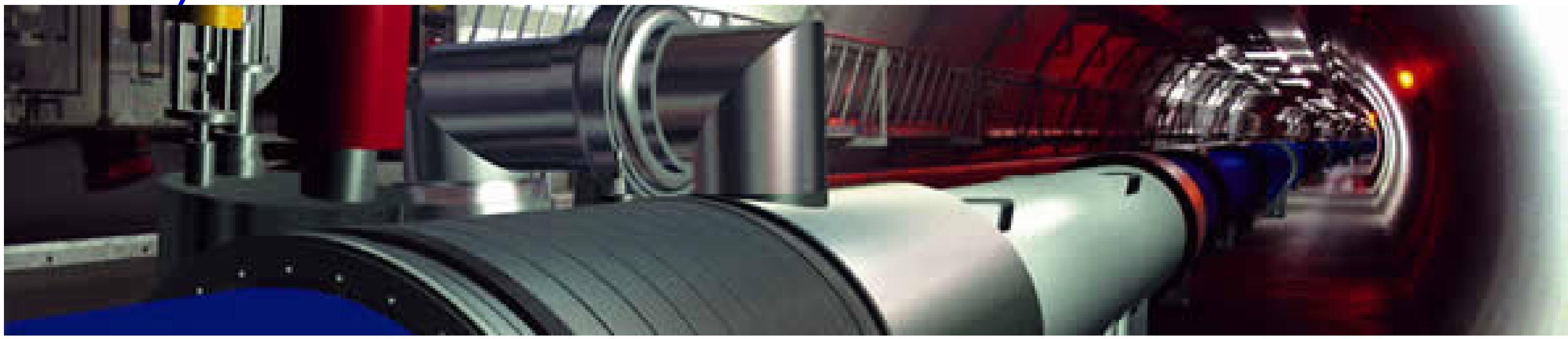


LHC

- The Large Hadron Collider at CERN is what is known as a proton synchrotron, 27 km in circumference with magnets that create a magnetic field of ~8 Tesla
- It accelerates protons to ~6.5 TeV (trillion electron-volts)



- Vertical B field in the dipole bends the beam round via the Lorentz force
- Need very strong magnets to get the high energy beam around the circle. Superconducting (1.9 K) dipoles producing a field of 8.3 T - current 11,850 A
- Bending magnets (dipoles): 14.3 metres long. Cost: ~ 0.5 million CHF each. Need 1232 of them
- Quads etc to keep beam focused and the motion stable
- Stored magnetic energy up to 1.29 GJ per sector. Total stored energy in magnets = 11GJ
- One dipole weighs around 35 tonnes.



Not to be confused with the other LHC

Do you remember what's unique about this picture?

Turns out I'm not completely right

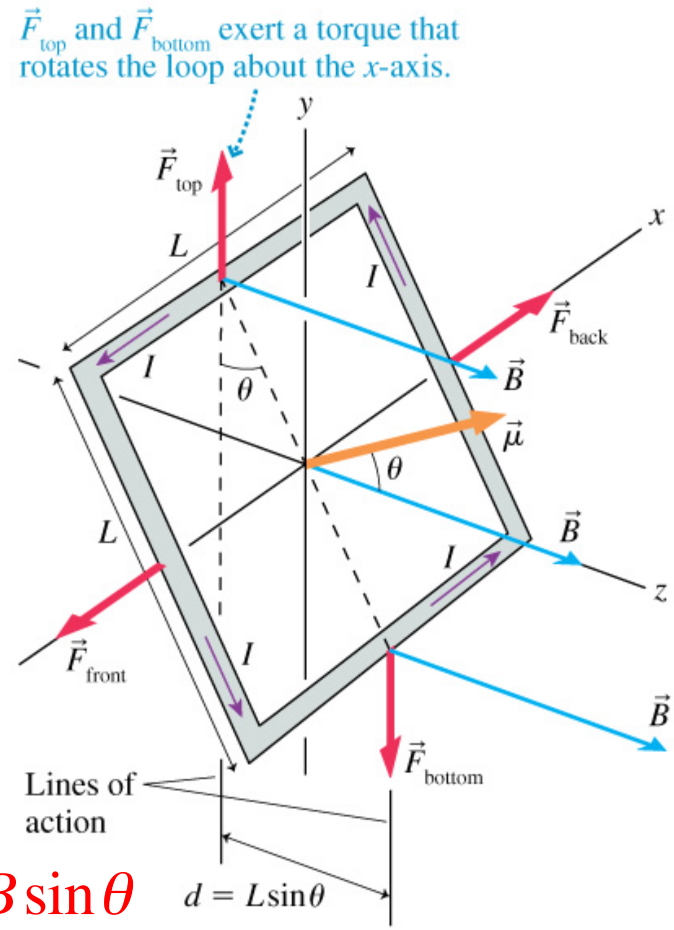
Later, Silvano was working on the photo on his computer – editing out the messy background so it could be used for the album cover – when **Tim Berners-Lee**, the inventor of the World Wide Web, walked into his office. When he saw the image, he told Silvano that he should make the Cernettes a website. "I hardly knew what the web was," Silvano says. At the time his work involved running software on servers at Cern. "I wasn't really working on it."

http://www.bbc.com/future/story/20160224-the-unlikely-photo-that-kickstarted-the-social-internet

Although this photo of the Cernettes is commonly called "the first photograph uploaded to the internet" that's not completely accurate. For starters, the internet existed before the web. And as the web was built for physicists to share data, that data often included scientific images. There were loads of images already on the web long before the Cernettes' photograph made its way there. But the photo of the four women is the first non-technical picture uploaded to the web. The first picture that was simply a photo for fun, not work. "It was the photo that opened the web to life," says Silvano.

Current loop in a uniform magnetic field

- Consider a current loop in a uniform magnetic field
- I have a force on each of the sides of the loop
- The forces on the left and right sides are of equal magnitude and cancel as do the forces on the top and bottom
- But the forces on the top and bottom do combine to exert a torque on the loop



$$\tau = Fd = (ILB)(L\sin\theta) = (IL^2)B\sin\theta = \mu B\sin\theta$$

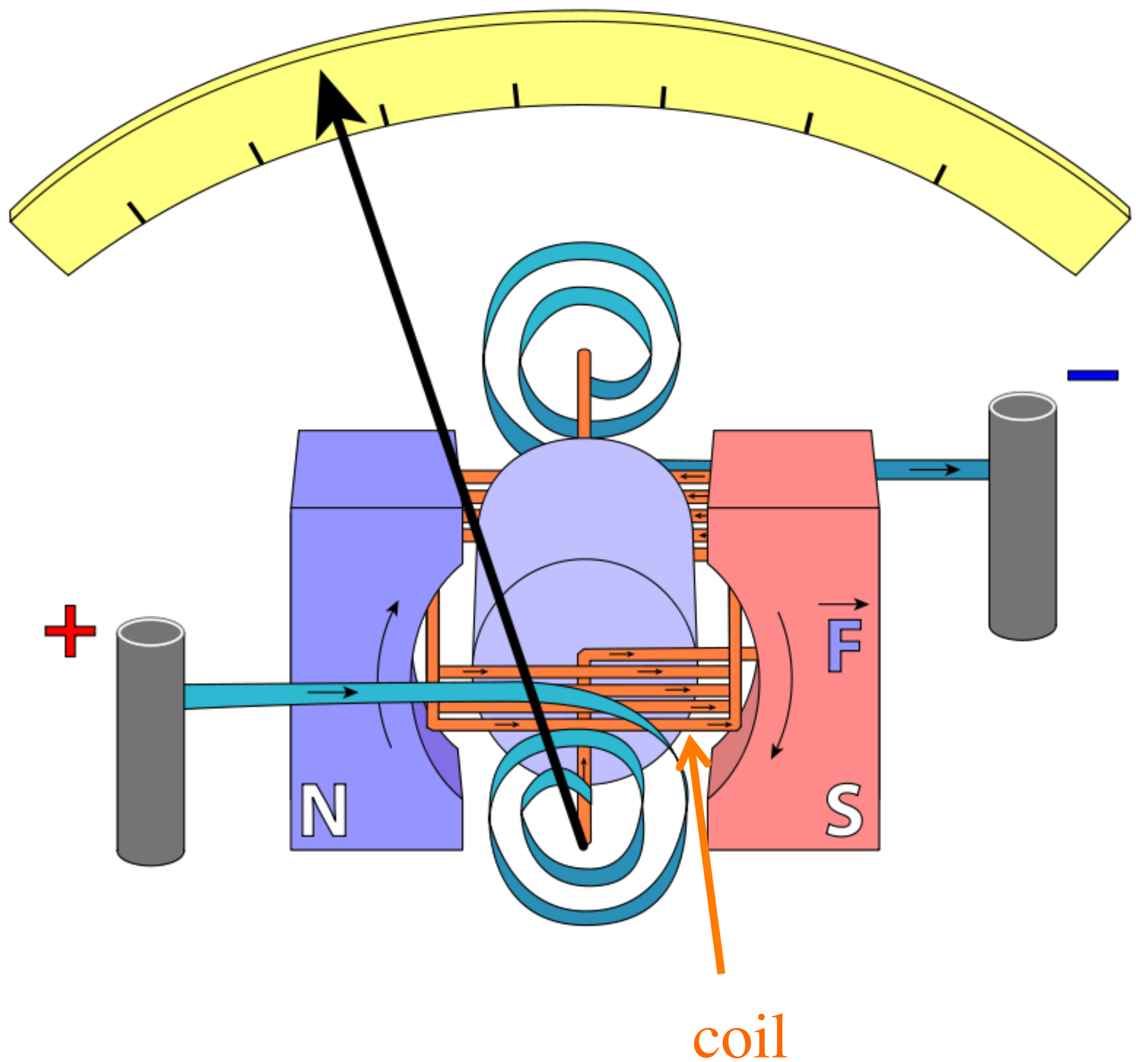
$$\mu = IL^2 = IA$$

$$\vec{\tau} = \vec{\mu} X \vec{B}$$

The torque tries to align the magnetic moment with the direction of the magnetic field.

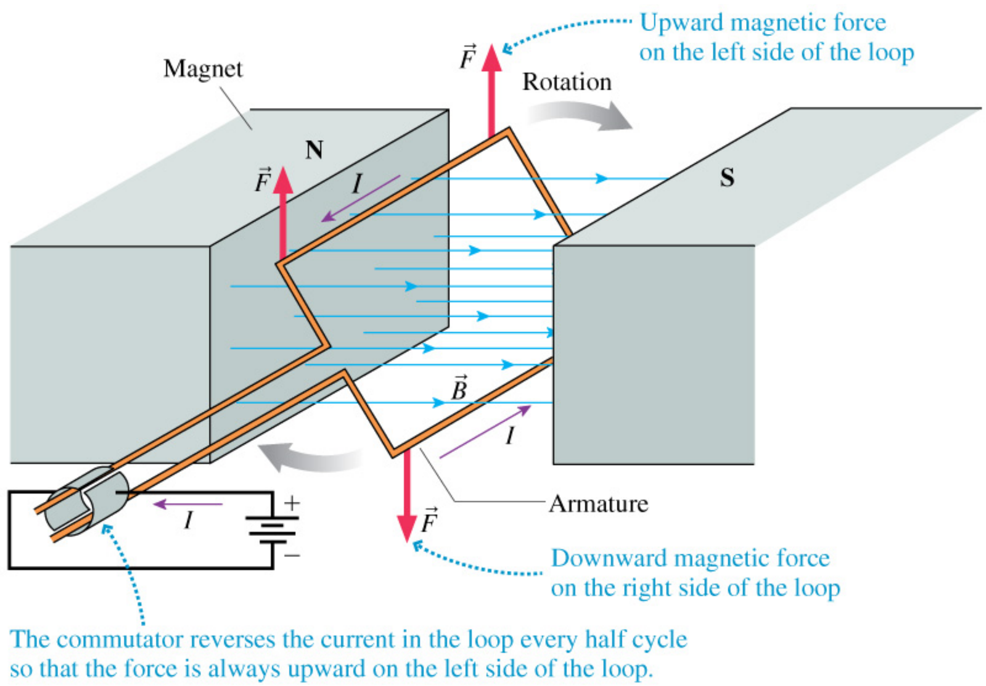
How does a galvonometer work?

- A DC electric current passes through a small coil, producing a magnetic field, and a magnetic moment
- There is a torque that tries to align the magnetic moment produced by the current in the coil with the external magnetic field
- But the torque is resisted by a spring
- The larger the current, the larger the deflection of the needle attached to the coil
- Everything has been calibrated such that the angle of deflection indicates the numerical value of the current flowing through



Motor

- Suppose I have a current running through a coil that's free to rotate in a magnetic field
- What's going to happen to the coil?
- It's going to experience a torque that will cause it to rotate so that its magnetic moment is pointing in the direction of the magnetic field
- If I use an alternating current, then the direction of the magnetic moment changes and the coil keeps rotating



iclicker question

If released from rest, the current loop will

A. Move upward.
B. Move downward.
C. Rotate clockwise.
D. Rotate counterclockwise.
E. Do something not listed here.

iclicker question

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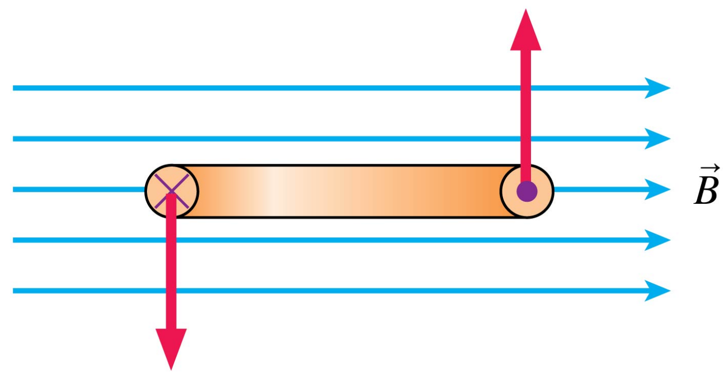
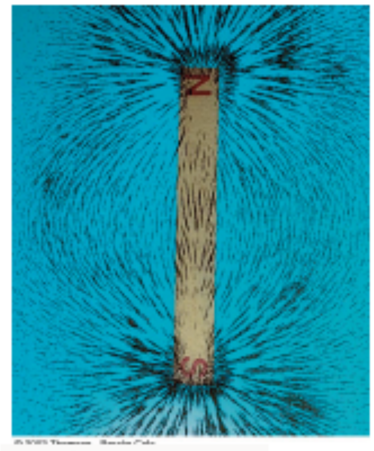
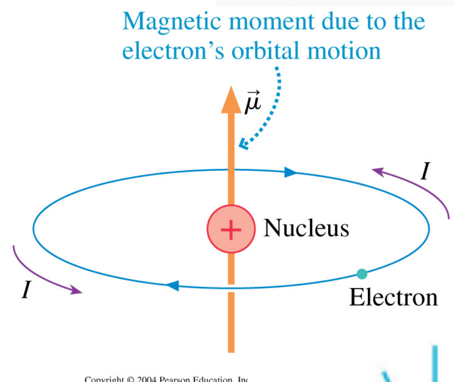


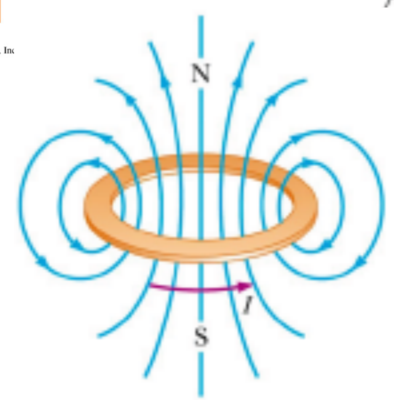
A. Move upward.
B. Move downward.
C. Rotate clockwise.
D. Rotate counterclockwise.
E. Do something not listed here.

Magnetism in materials

- What causes magnetism in materials?
- We said it has something to do with current loops
- Where do the current loops come from?
- Well the electrons are orbiting around the nucleus and each electron is spinning like a top
- Both of these actions produce current loops, which then produce magnetic moments

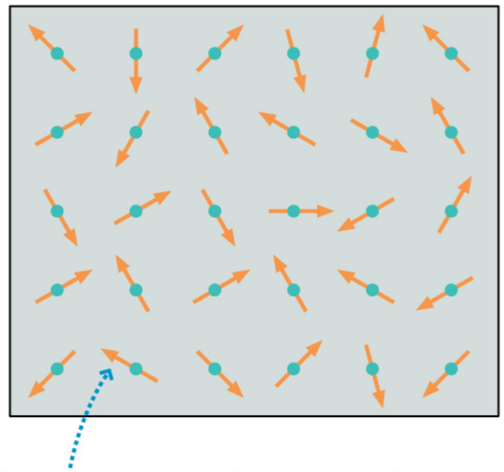




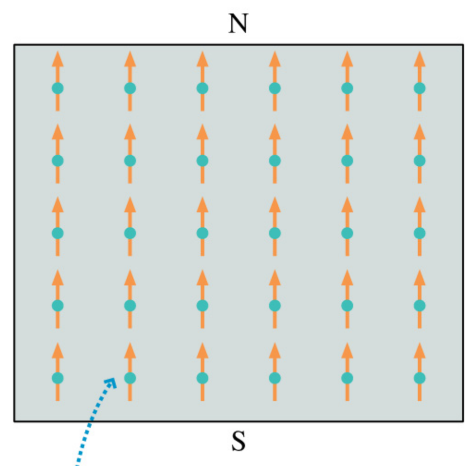


But that can’t work

- Because all materials have electrons and we know that all materials don’t have magnetic properties
- Electron magnetic moments oppose each other so that there is a cancellation for atoms with an even number of electrons
- With an odd number of electrons there is one electron whose magnetic moment is not cancelled, but each atom has a randomly oriented moment whose net effect is zero
- If I can get the moments of the atoms to line up ,then I do get a net magnetic dipole moment
  - a ferromagnetic material



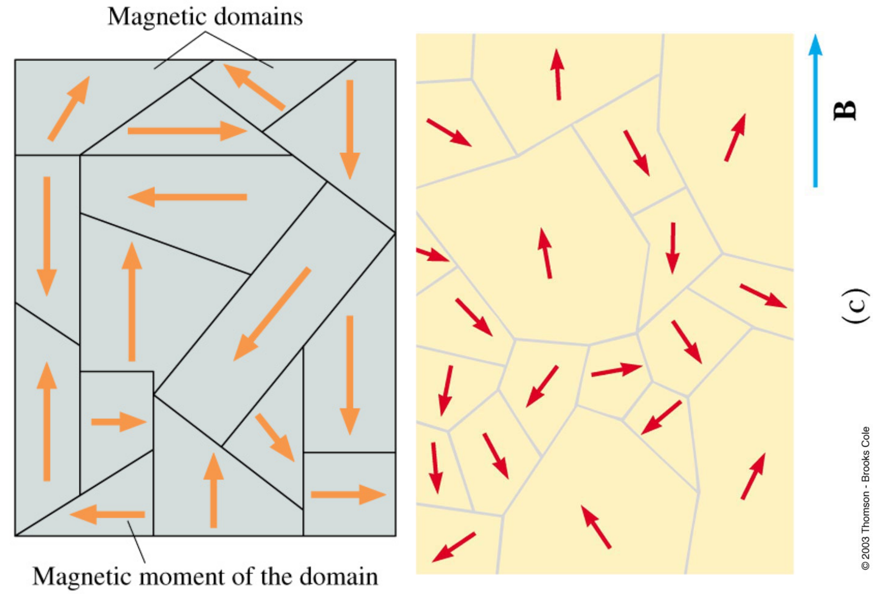
The atomic magnetic moments due to unpaired spins point in random directions. The sample has no net magnetic moment.

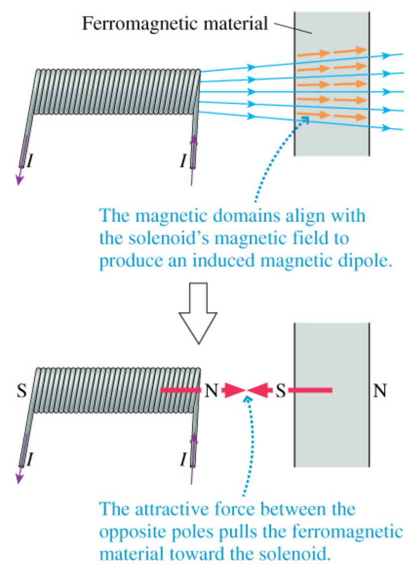


The atomic magnetic moments are aligned. The sample has a north and south magnetic pole.

Ferromagnetism

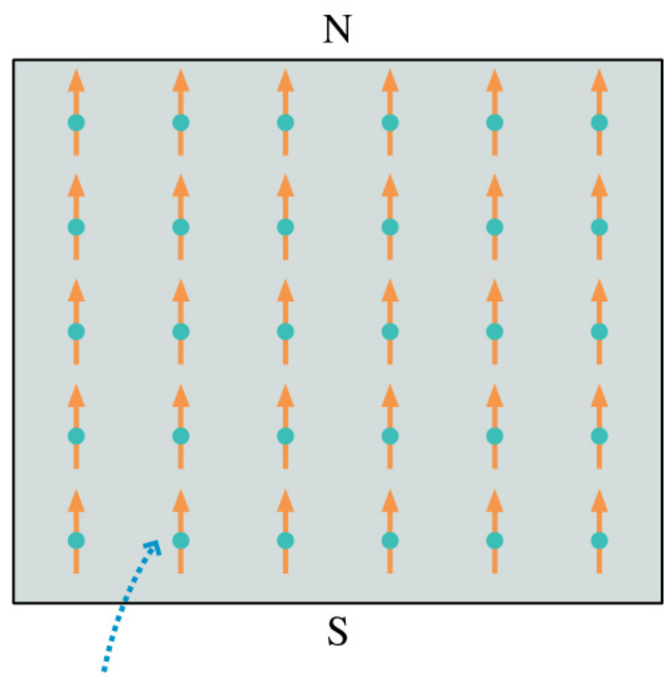
- In a ferromagnetic material like iron, all atoms in a domain (typical size 0.1 mm) have their moments pointed in the same direction
- However, all of the domains are random with respect to each other, unless there is an external magnetic field affecting the domain directions
    - the domains aligned with B tend to grow
- In that case, we see an attractive force between the magnet and the ferromagnetic material
- If I can randomize the directions of the domain magnetic moments, then I can eliminate the magnetic force
- I can do that by increasing the temperature which will increase the random motion of the atoms
- I can apply a varying magnetic field which randomizes the directions of the domains
- Or I can bang on it





Ferromagnetism

- What makes a permanent magnet?
- Depends on crystalline structure of material
- Pure iron does not make a good magnet because it's easy to get the domains to un-align themselves
- But an alloy of steel with 51% iron, 24% cobalt, 14% nickel, 8% aluminum and 3% copper has permanent magnetic properties and is used to make permanent magnets
- Most stainless steels, with chromium and nickel, have virtually no magnetic properties



The atomic magnetic moments are aligned. The sample has a north and south magnetic pole.

Other forms of magnetism

- **Paramagnetism** is a form of magnetism which occurs only in the presence of an externally applied magnetic field. Paramagnetic materials are attracted to magnetic fields. However, unlike ferromagnets which are also attracted to magnetic fields, paramagnets do not retain any magnetization in the absence of an externally applied magnetic field.

- The Curie point of a ferromagnetic material is the temperature above which it loses its characteristic ferromagnetic ability. At temperatures below the Curie point the magnetic moments are partially aligned within magnetic domains in ferromagnetic materials. As the temperature is increased from below the Curie point, thermal fluctuations increasingly destroy this alignment, until the net magnetization becomes zero at and above the Curie point. Above the Curie point, the material is purely paramagnetic.

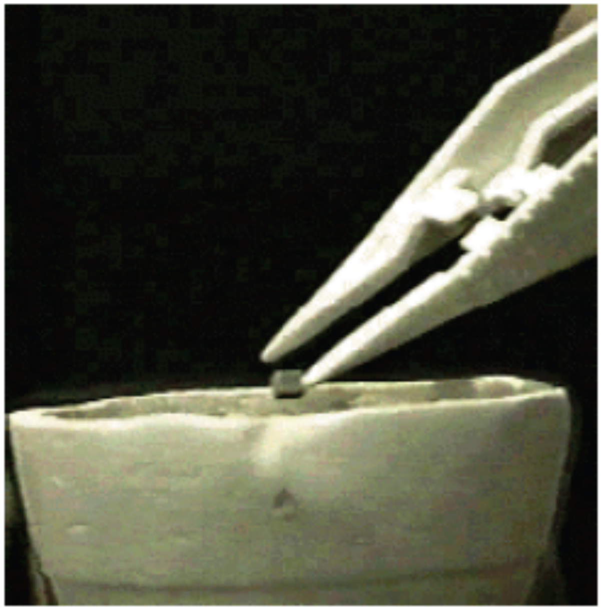
Curie temperature

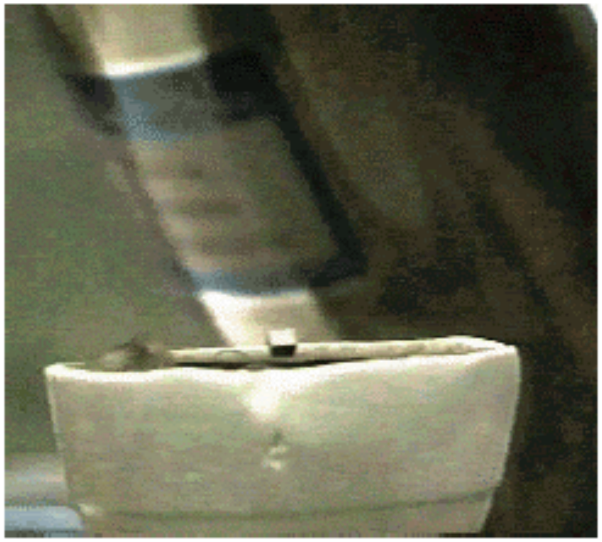
https://www.facebook.com/photo.phpv=10201511208436030&set=vb.119326601418561&type=2&theater

Material	Curie temperature (K)
Iron (Fe)	1043
Cobalt (Co)	1400
Nickel (Ni)	627
Gadolinium (Gd)	292
Dysprosium (Dy)	88
Mn Bi	630
MnSb	587
CrO_2	386
MnAs	318
EuO	69
Iron(III) oxide (Fe_2O_3)	948
Iron(II,III) oxide ($FeOFe_2O_3$)	858
$NiOFe_2O_3$	858
$CuOFe_2O_3$	728
$MgOFe_2O_3$	713
$MnOFe_2O_3$	573
$Y_3Fe_5O_{12}$	560
Neodymium magnets	583–673
Alnico	973–1133
Samarium–cobalt magnets	993–1073
Strontium ferrite	723

Diamagnetism

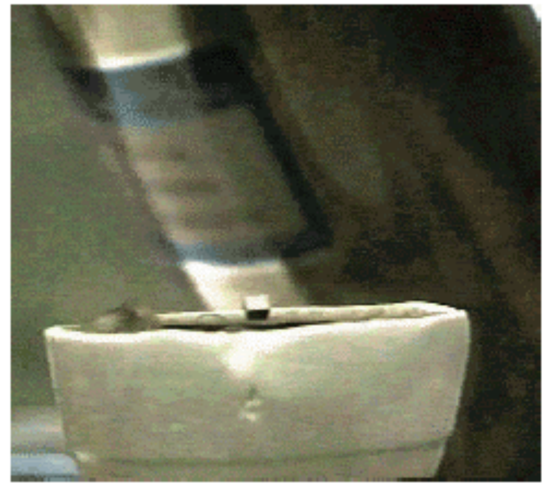
- **Diamagnetism** is a weak repulsion from a magnetic field. It is a form of magnetism that is only exhibited by a substance in the presence of an externally applied magnetic field. It results from changes in the orbital motion of electrons. Applying a magnetic field creates a magnetic force on a moving electron in the form of $\mathbf{F} = qvX\mathbf{B}$. This force changes the centripetal force on the electron, causing it to either speed up or slow down in its orbital motion. This changed electron speed modifies the magnetic moment of the orbital in a direction opposing the external field.

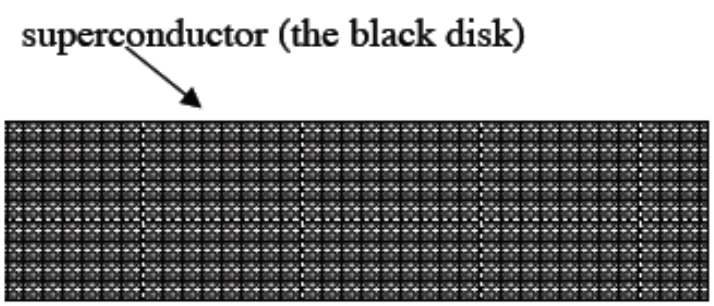




Diamagnetism in superconductors

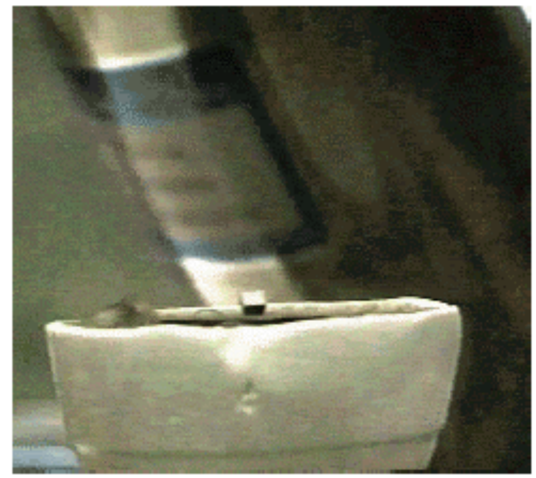
- How does this work?
  - superconductors hate magnetic fields
  - they want to push them away
  - you can push a magnet away by creating another magnetic field
  - a current loop produces a magnetic field
  - current loops can easily form in superconductors

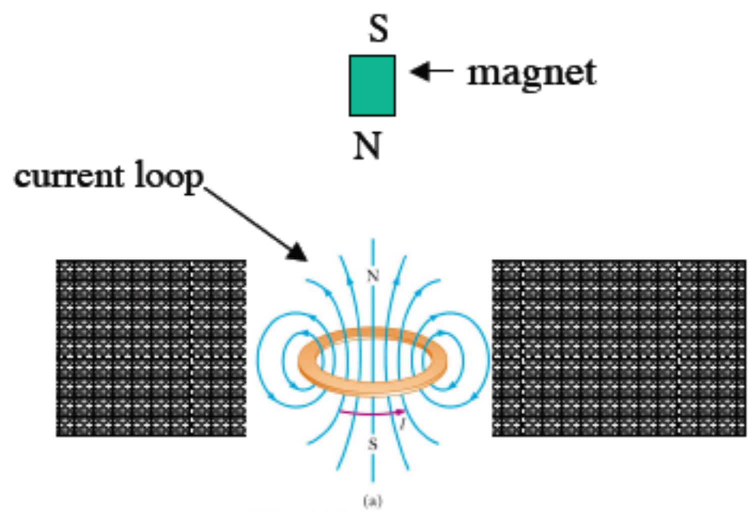




Diamagnetism

- How does this work?
  - superconductors hate magnetic fields
  - they want to push them away
  - you can push a magnet away by creating another magnetic field
  - a current loop produces a magnetic field
  - current loops can easily form in superconductors
  - voila, current loops form in superconductors when a magnet is nearby





Meissner effect

https://www.youtube.com/watch?v=lC-3li6ScUE