How Torques on Current Loops Lead to Magnetic Materials

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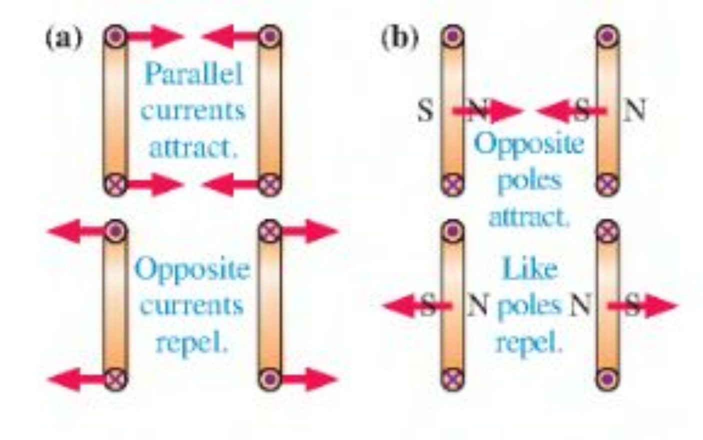
Current Loops

Forces



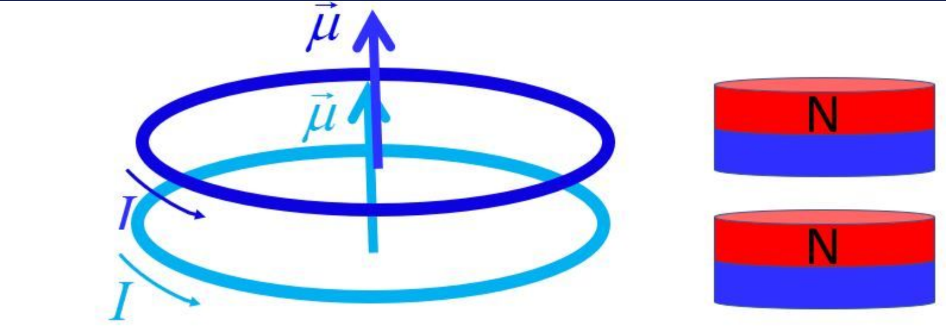
Straight wires: parallel currents attract, anti-parallel currents repel

Loops: just 4 straight wires, each section attracts/repels section in other loop→ same logic applies (take limit for non-square shapes)

More generally, clockwise currents attract clockwise currents because their dipole moments align

“Aligned dipole moments” is the most general form of lining up bar magnets SNSN

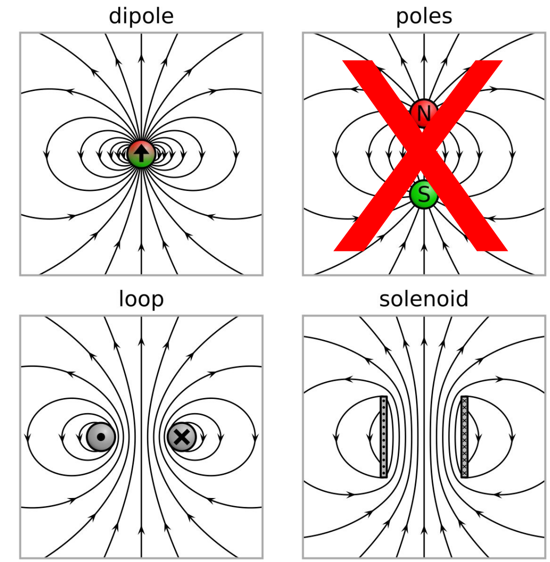
Dipole Moments, μ=IA
Bar magnets: points from S to N
Current loops/solenoids: points in direction of field through middle of loop

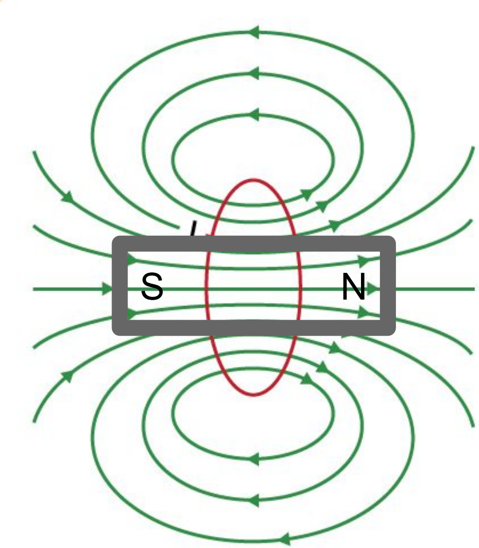


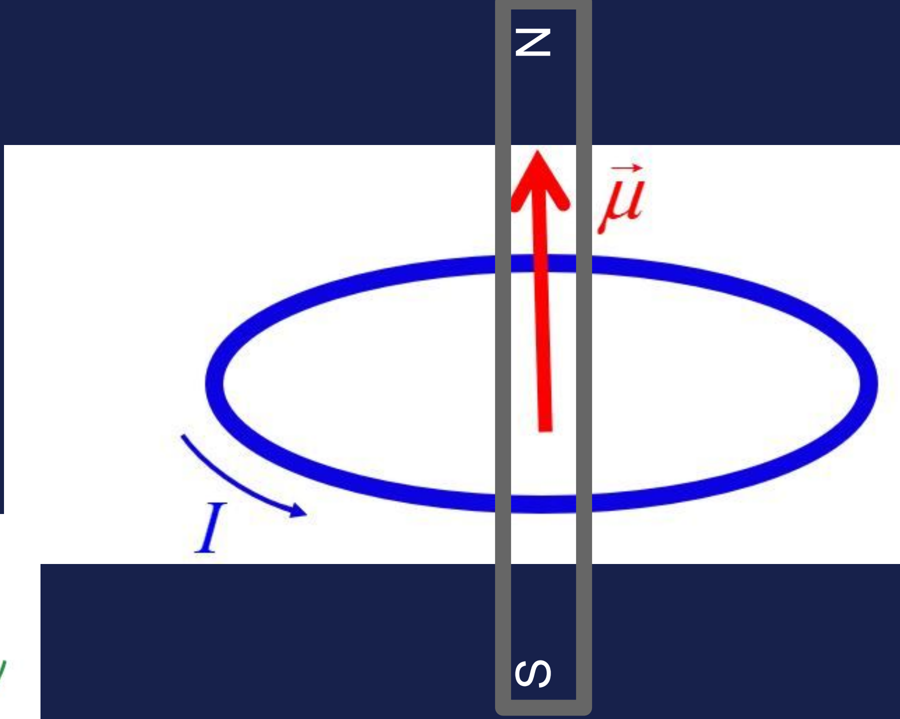
Everything is a Dipole!

Because magnetic monopoles (probably) don't exist, dipoles are basic building blocks of magnetism.

Besides a straight wire, all common current configurations can be reduced to dipoles:







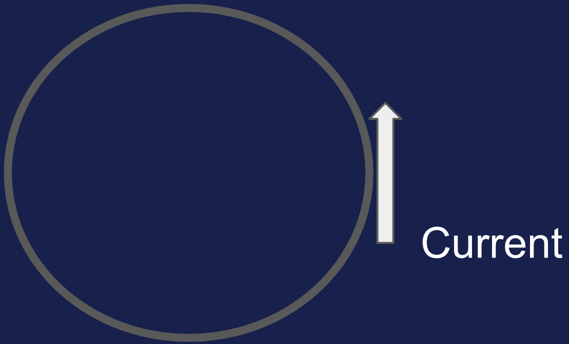
Bar Magnet→dipole!
Loop→dipole!
Solenoid→dipole!
Magnetar→dipole!
Problems with these objects are **magnetic dipole problems**

Dipole Problem 1

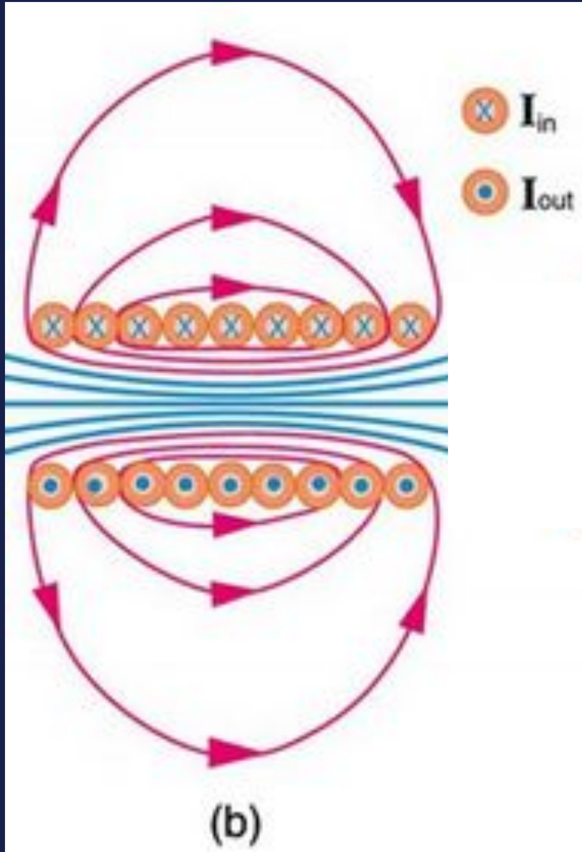
Recalling that dipole moment points S→N,or can be determined by the RHR, which direction is the dipole moment for the following dipoles?

A)

B)



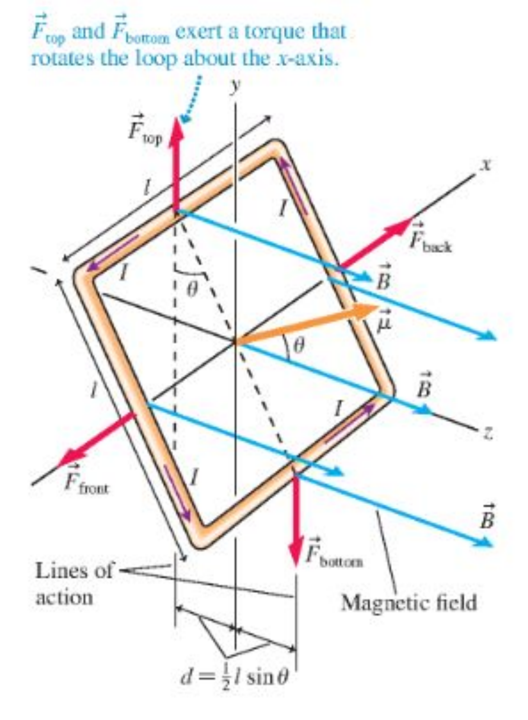
C)



Dipole Problem 2

Similar to electric dipoles in constant electric fields, there is no net force on magnetic dipoles in a magnetic field. But in both cases there is a torque.

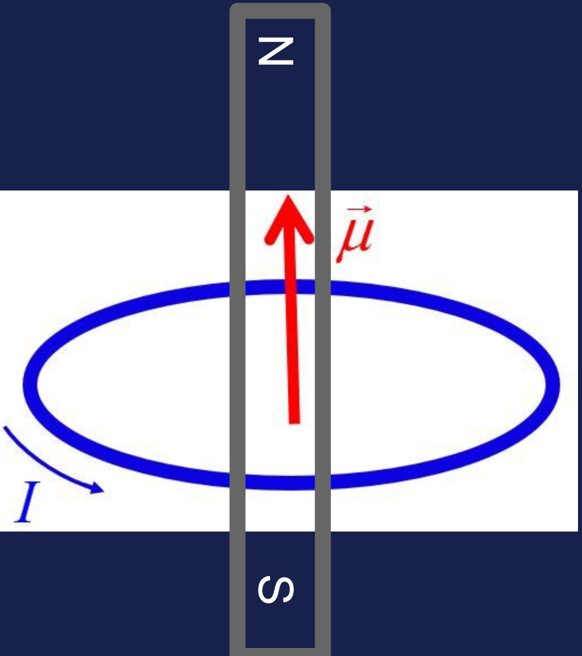
A wire loop with: current I, side length L, is immersed in a uniform field B, at an angle θ. What is the magnitude and direction of the torque on the loop?



θ is defined as the angle between the external field and the magnetic moment, NOT the angle between the field and plane of the loop!

Dipole Problem 2

In electrostatics, “(positively) charged particles feel a **force** which **pushes** them in the direction of the electric field”. In magnetostatics, “magnetic dipoles feel a **torque** which **rotates** them in the direction of the magnetic field”.



Generally, for any magnetic dipole: $\vec{\tau} = \vec{\mu} \times \vec{B}$

Just need dipole moment!
Magnitude: NIA (or given for bar magnets)
Direction of magnetic moment: S→N direction through middle of loop/solenoid/bar

Direction of torque: aligns magnetic moment with external field

Dipole Problem 3

One way to measure μ for a bar magnet is to place it in a known magnetic field and measure the initial force needed to rotate it.

A bar magnet of length L is allowed to align with an external field B. Then it is offset by θ<20 degrees (you have to start with the magnetic moment and external field misaligned a bit or the initial force needed is 0). Finally, you measure the initial force, F, it takes to rotate the bar magnet. Assume the pivot point is in the middle of the magnet.

A) Find an expression for the dipole moment of the bar magnet.
B) As you push the magnet, does it get harder or easier?
C) Is there a point (before 360 degrees around) where the torque felt by the magnet reaches 0?

Dipole Problem 4

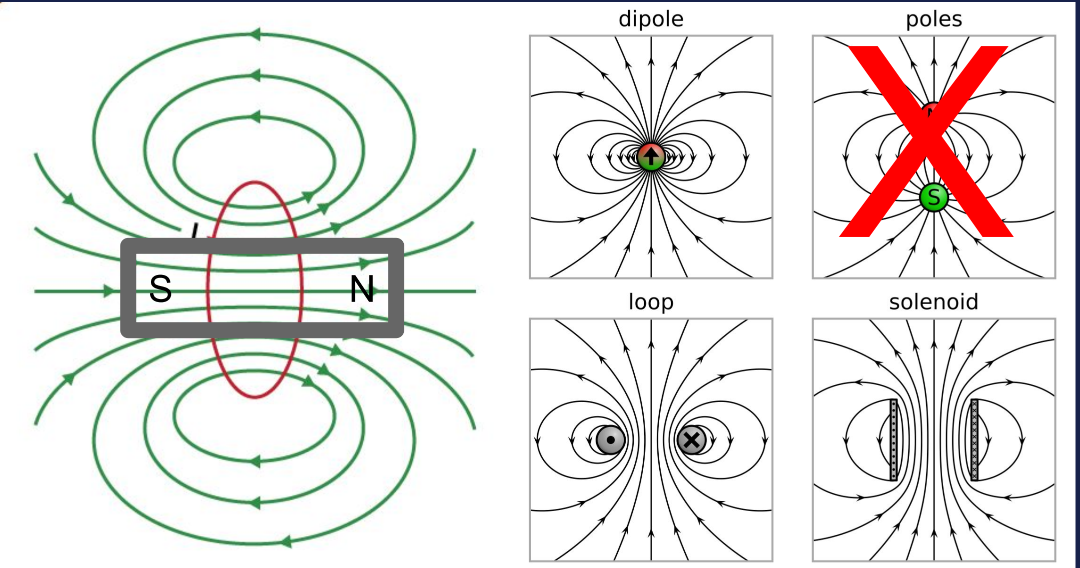
A smaller solenoid sits inside a much larger one. The smaller solenoid has m turns and the larger solenoid has N turns. Both have the same current, I. The magnetic moment of the solenoids is misaligned by θ degrees.

1) What is the torque felt by the smaller solenoid?
2) Does the larger solenoid feel any sort of torque?

Dipole Moment and Internal Fields

The magnetic dipole moment points from S→N. But field lines point N→S. Why is that?
The magnetic dipole moment actually DOES point in the direction of the stronger, INTERNAL field!

Compare, contrast different magnetic dipoles



What Causes "Regular" Magnetism?

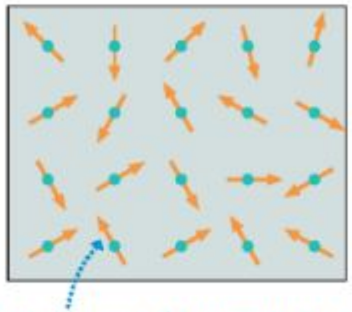
We used bar magnets as a stand-in for current loops, but actually current loops cause bar magnets!

1) Matter is made of atoms→atoms have electron orbitals→electrons going in circles=current loop!

2) Spinning spheres of charge create magnetic fields (each tiny part of the sphere is like a charged particle going in a loop), electrons are charged and have angular momentum→current loop!

3) Quantum mechanics

FIGURE 29.52 The random magnetic moments of the atoms in a typical solid.



What Causes “Regular” Magnetism?

We used bar magnets as a stand-in for current loops, but actually current loops cause bar magnets!

1) Matter is made of atoms→atoms have electron orbitals→electrons going in circles=current loop!

NO: electrons do not orbit in an orderly fashion like planets, this motion mostly cancels out

2) Spinning spheres of charge create magnetic fields (each tiny part of the sphere is like a charged particle going in a loop), electrons are charged and have angular momentum→current loop!

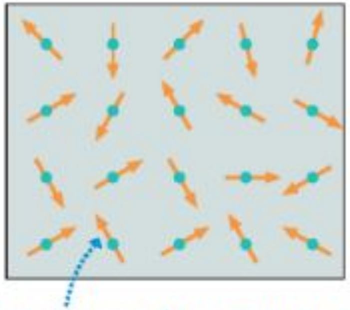
NO: Electrons do not have a radius→not spheres. Also not spinning

3) Quantum mechanics

YES: Although electrons do not spin, they “have spin”, or, “inherent” angular momentum and “inherent” magnetic moment. You cannot make electrons “spin” faster or slower, or alter the magnitude of their magnetic moment.

Some things “just have” mass; some things “just have” magnetic moment

FIGURE 29.52 The random magnetic moments of the atoms in a typical solid.



What Causes “Regular” Magnetism?

Any atom with unpaired electrons has magnetic moment. Atoms are randomly oriented, so macroscopic objects *still* don’t have magnetic fields!

In some materials, the atoms/molecules have special configurations which align the spins in chunks called “magnetic domains”.

Domains are randomly oriented, so macroscopic objects *still* don’t have magnetic fields!

Magnetization: Domains can be re-oriented by external fields! Domains can also change size and shape, so that the majority of the object has magnetic moments aligned with the external field. This is how magnets stick to non-magnetized metal (well, once this happens, the metal IS magnetized).

They did force arrows here, but arrows for magnetic moment AND internal magnetic field would both point right (S→N)

FIGURE 29.54 Magnetic domains in a ferromagnetic material. The net magnetic dipole is nearly zero.

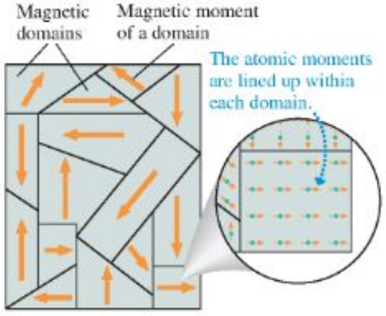
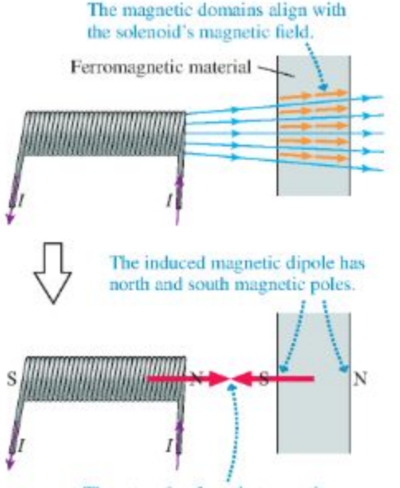


FIGURE 29.55 The magnetic field of the solenoid creates an induced magnetic dipole in the iron.



What Causes “Regular” Magnetism?

https://www.compadre.org/Physlets/electromagnetism/illustration27_5.cfm