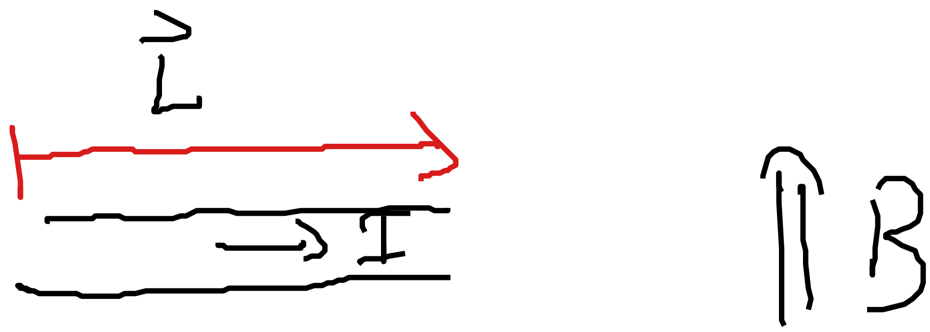
Magnetic Fields create a force on currents



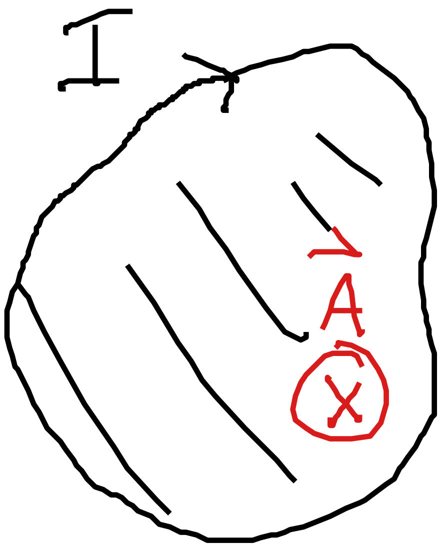
$\vec{L}$: points in direction of current

$|\vec{L}|$ = length of wire

$$\vec{F} = I\vec{L} \times \vec{B}$$

Loops of Current

Aside: bivectors



Define $\vec{A}$

$|\vec{A}|$ = area of loop

$\vec{A}$ is $\perp$ to loop

RHR: fingers: I
thumb: $\vec{A}$

loop feels a torque in $\vec{B}$
($\vec{F}_{net} = 0$ in a uniform field)
so that $\vec{A}$ aligns with $\vec{B}$.

$$\vec{\tau} = I\vec{A} \times \vec{B}$$

Define <u>magnetic dipole moment</u>

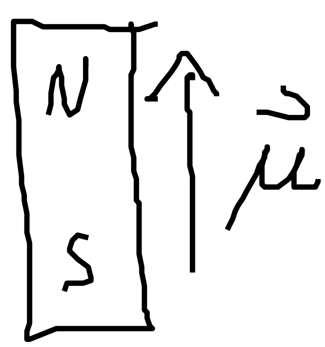
$$\vec{\mu} = I\vec{A}$$

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

$\vec{\mu}$ will tend to align with $\vec{B}$

We can define the magnetic dipole moment of a bar magnet

$|\vec{\mu}|$ = strength of magnet

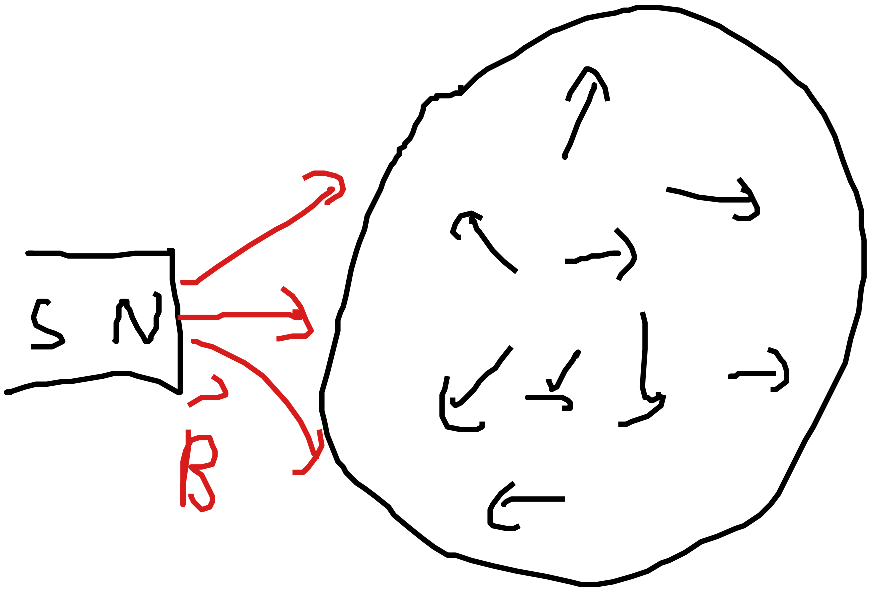


(eg $0.5\ \mathrm{A\,m^2}$)

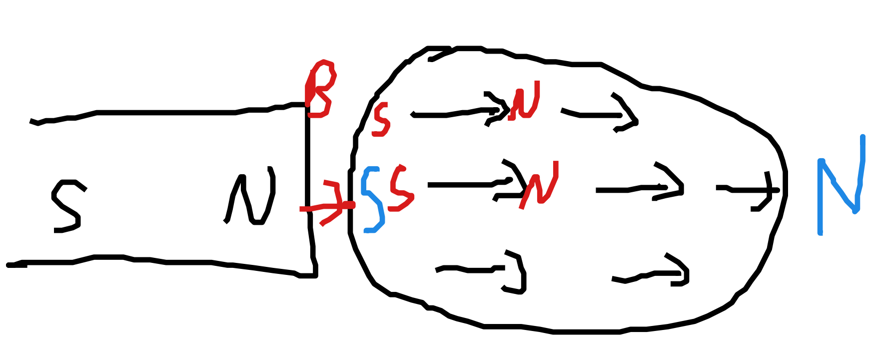
All materials contain magnetic dipoles.

- Electrons "orbiting" nuclei are like currents
- Electrons, protons, and neutrons all have a built-in magnetic dipole moment. "spin"

those $\vec{\mu}$ interact with magnetic fields



bring magnet close, then theoretically



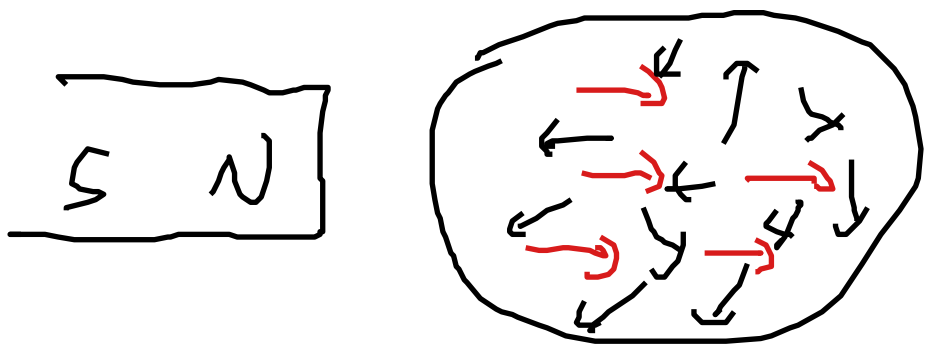
This doesn't actually happen like this

All materials, are either paramagnets, diamagnets, or ferromagnets

1) Paramagnets (Aluminum, Platinum)

behave sort of like we just showed

but dipoles are constantly bumped out of alignment due to thermal noise

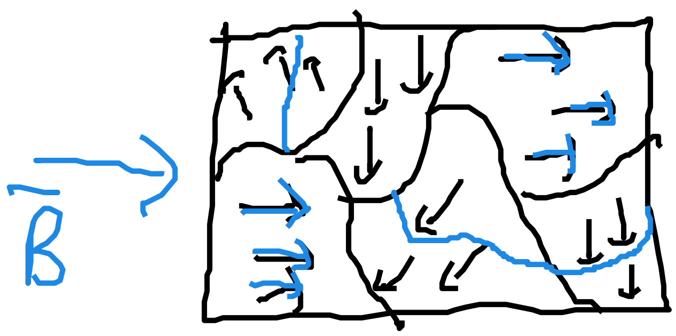


Paramagnets are weakly attracted to bar magnets.

2) Ferromagnets (Iron, Cobalt, Nickel, some steel)

- neighboring dipoles reinforce each other

"domains"



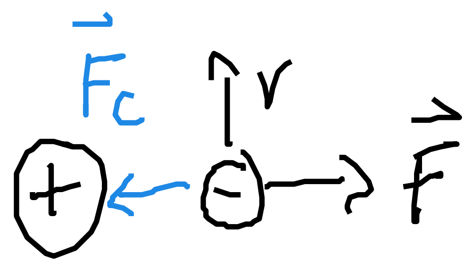
If you bring a magnet near, domains in the direction of $\vec{B}$ grow, at expense of others

material becomes strongly magnetized, can magnetize other objects

3) Diamagnets

- all electron spins ↑↓ pair up
- Only dipoles are current loops in atoms

Suppose $\vec{B}$ ⊗



Magnetic force reduces the centripetal force.

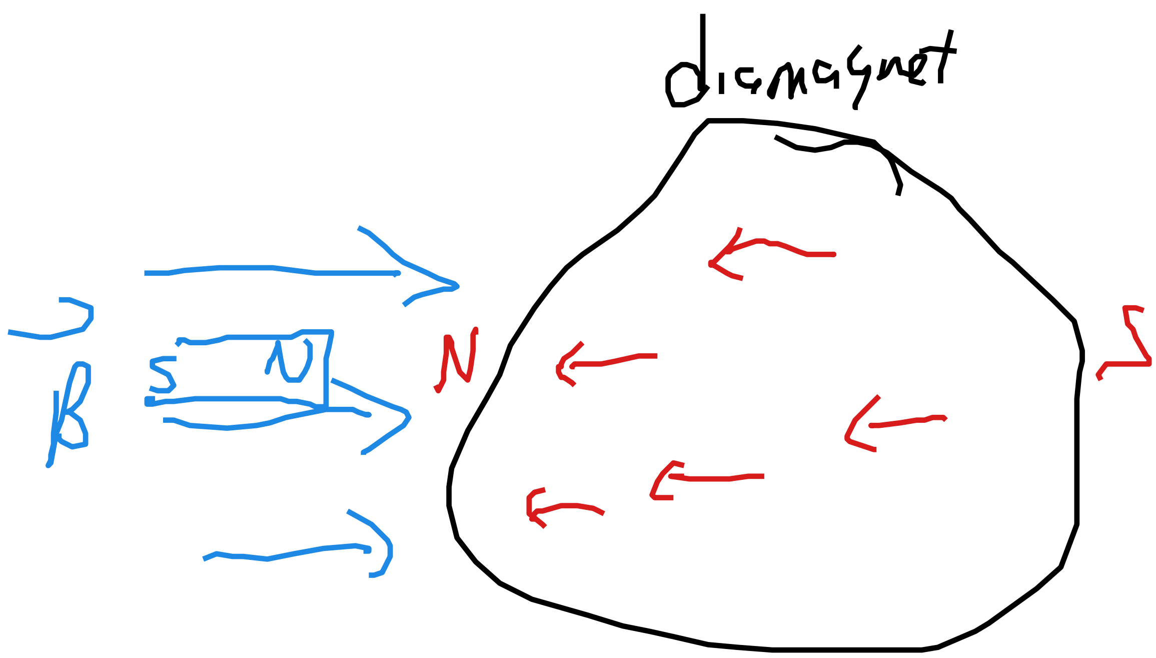
$$F_c = \frac{mv^2}{r}$$

but radius of electron orbital can't change (quantum mechanics)

less F_c → less v
→ less I → less $\vec{\mu}$

any dipole pointing in direction of $\vec{B}$ is weakened.

any dipole pointing in opposite direction is strengthened



diamagnets magnetize in opposite direction of $\vec{B}$ - repelled by magnets

Diamagnetic

Examples: copper, rubber, glass, water

usually a very weak effect

superconductors are strong diamagnets

- zero resistance
- maglev trains - superconductors "float" a little over magnets, reducing friction