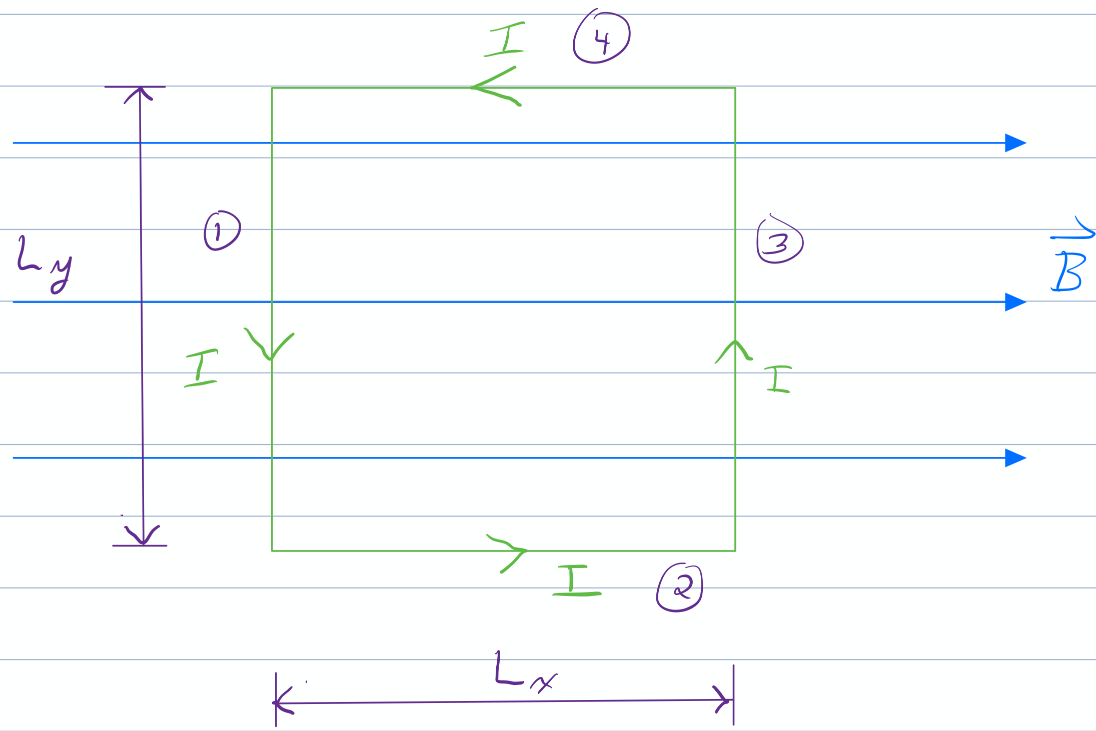
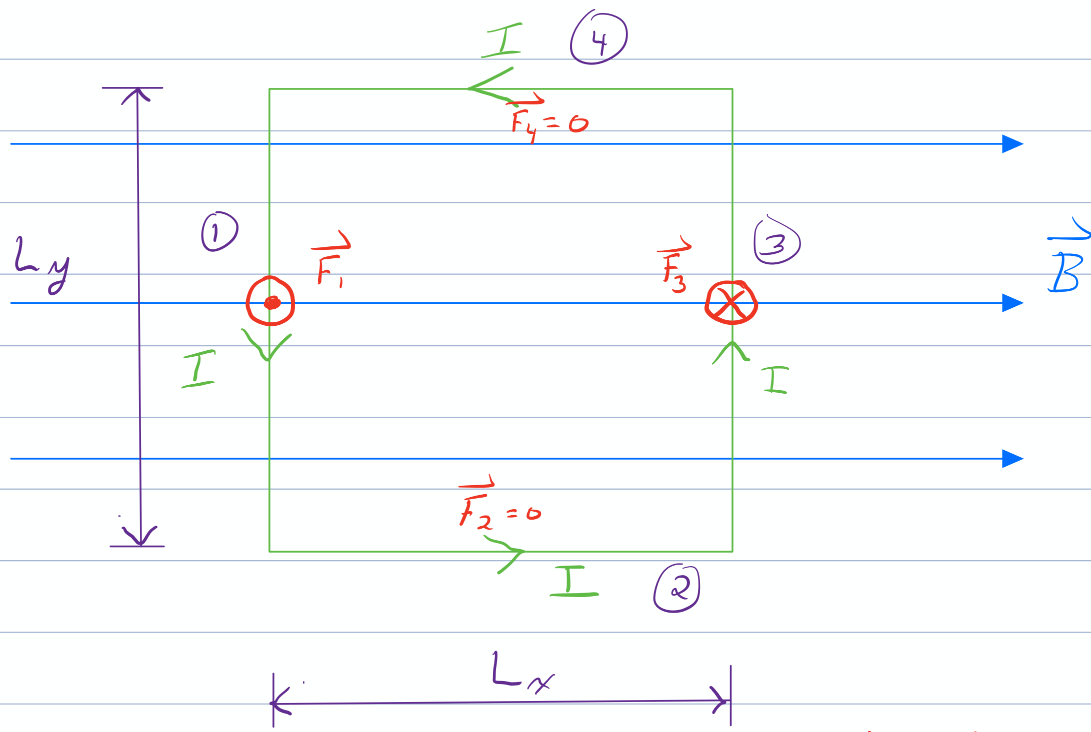
24.7: Magnetic Fields Exert Torques on Dipoles

Forces and Torque on a current loop in a uniform magnetic field.

Assume $\vec{B}$ = uniform and to the right. A rectangular current loop is in the x-y plane. What happens?



Poll: what are the magnitude and direction of the force on wire segment 1?



$|F_1| = I L_y B$ $|F_3| = I L_y B$

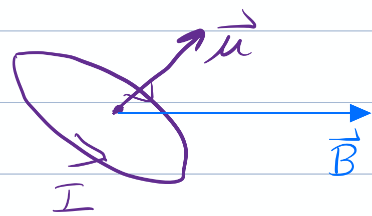
Net force = 0, but it does tend to rotate. There is a torque.

$$\tau = F_1\left(\frac{L_x}{2}\right) + F_2\left(\frac{L_x}{2}\right)$$

$$\tau = I \underbrace{L_x L_y}_{\text{area}} B$$

generalize: magnetic dipole moment

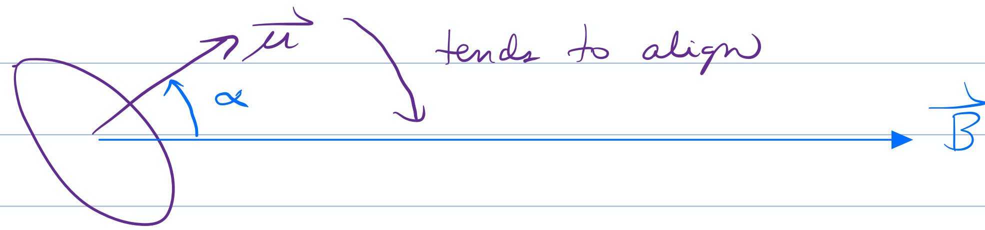
$\vec{\mu} \equiv I \cdot (\text{area})$, direction is perpendicular to the loop, parallel to the $\vec{B}$ that the loop tends to create.



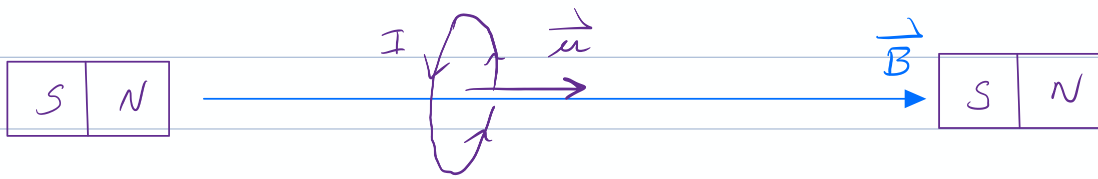
$|\tau| = \mu B \sin\alpha$

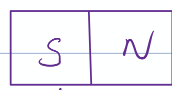
$\vec{B}$ (due to other sources not shown.)

Result: the external field $\vec{B}$ exerts a torque that tends to align $\vec{\mu}$ with the applied $\vec{B}$.



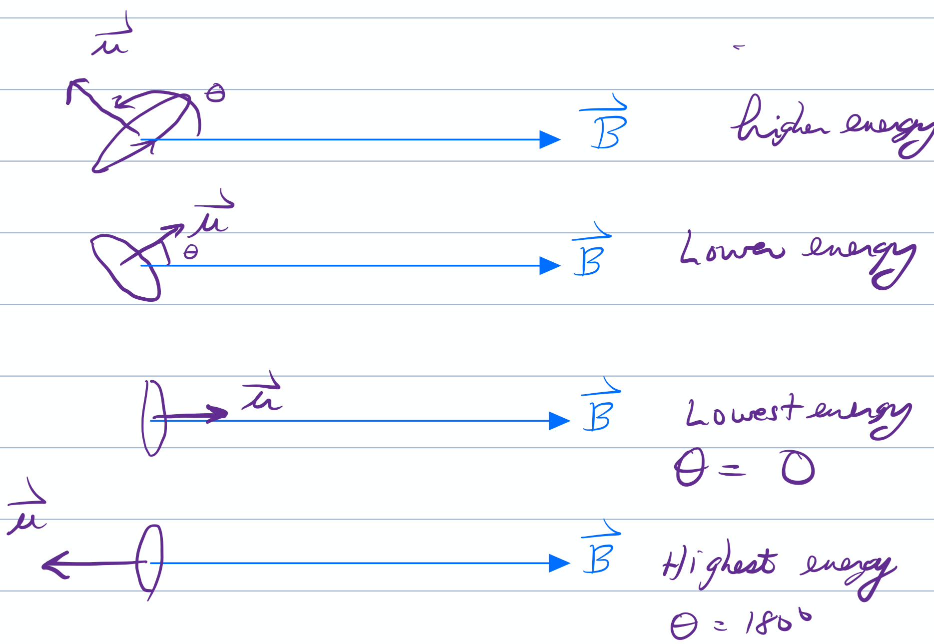
e.g.



$\vec{\mu}$ is a magnetic dipole. Just like a compass needle, 

it's north pole points along magnetic field lines.

ENERGY



Potential energy = $U = -\vec{\mu} \cdot \vec{B} = -\mu B \cos\theta$

$U_{min} = -\mu B$
$U_{max} = +\mu B$ } difference = $2\mu B$

Atomic example:

$\mu = \mu_B$ = "Bohr magneton" = typical scale of atomic magnetic moments.

$\mu_B = 9.27 \times 10^{-24}\ A \cdot m^2$

apply $B = 1.5\ T$ (big lab magnet)

Energy anti-aligned = $\mu_B B$ =

$U_{max} = (9.27 \times 10^{-24}\ A \cdot m^2)(1.5\ T) = 1.39 \times 10^{-23}\ J$

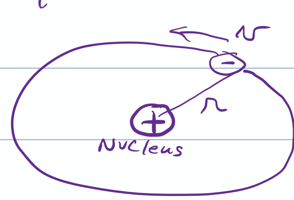
Energy aligned = $-\mu_B B$ = $-1.39 \times 10^{-23}\ J$

$$\Delta U = 2.78 \times 10^{-23}\ J \times \frac{1.602 \times 10^{-19}\ eV}{1\ J} =$$

$\Delta U = 0.00017\ eV.$

This is small but detectable — detecting such flips is at the heart of NMR/MRI techniques.

Atomic picture: (really cheating here!)



$$I = \frac{\text{charge}}{\text{Time}} = \frac{e}{T} = \frac{e}{2\pi r / v}$$

$$I = \frac{ev}{2\pi r}$$

Express in terms of angular momentum $L = mvr$

$$I = \frac{e(L/mr)}{2\pi r} = \frac{eL}{2\pi m r^2}$$

$$\mu = I \cdot \text{area} = I(\pi r^2) = \frac{eL}{2m}$$

Quantum Mechanics: Don't really have clear circular orbits, but we do have angular momentum.

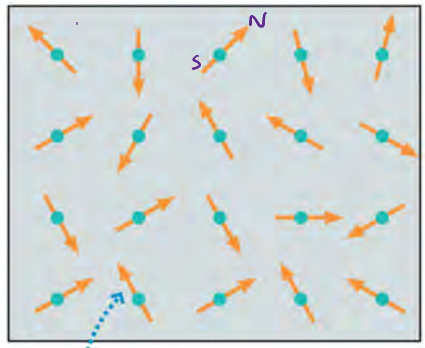
$$\mu_B = \frac{e\hbar}{2m_e} = \frac{(1.602\times10^{-19}C)(1.05\times10^{-34}kg\,m^2/s)}{2(9.11\times10^{-31}kg)}$$

$$\mu_B = 9.27\times10^{-24}A\cdot m^2.$$

24.8: Magnets and Magnetic Materials

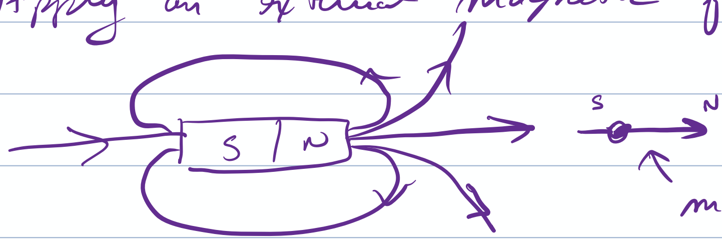
A rich and complex field. Focus on one application: Ferromagnetism. In some materials, the material has a permanent magnetic dipole moment. (Well, not permanent, but persistent under normal room temperature pressures and conditions.). These dipole moments tend to align with an applied magnetic field, and *also* produce their own magnetic field.

Disordered

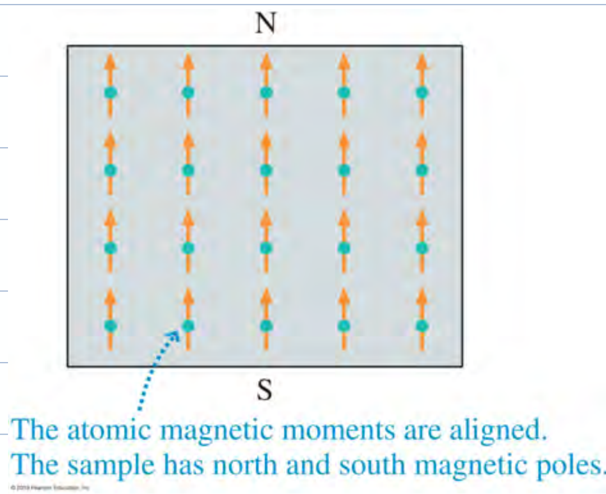


The atomic magnetic moments due to unpaired electrons point in random directions. The sample has no net magnetic moment.

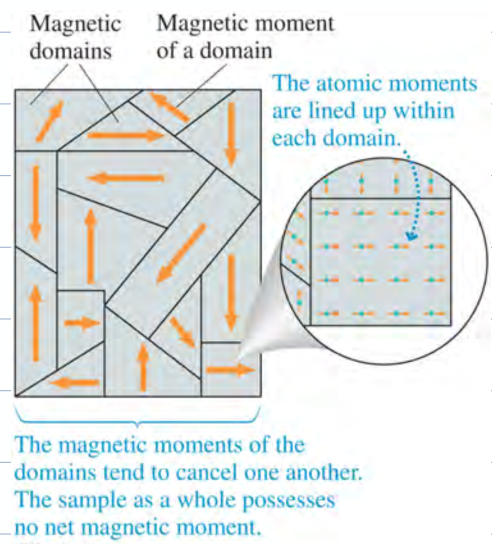
Apply an external magnetic field

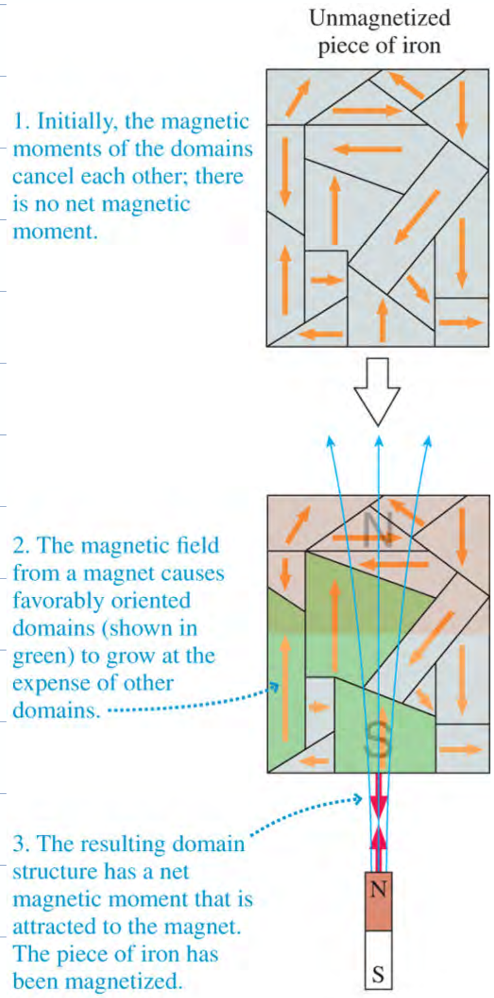


magnetic moment will tend to align.



Real materials are messier, and typically have to deal with domains.





The applied magnetic field induces magnetic dipoles that align so as to yield an attractive force.