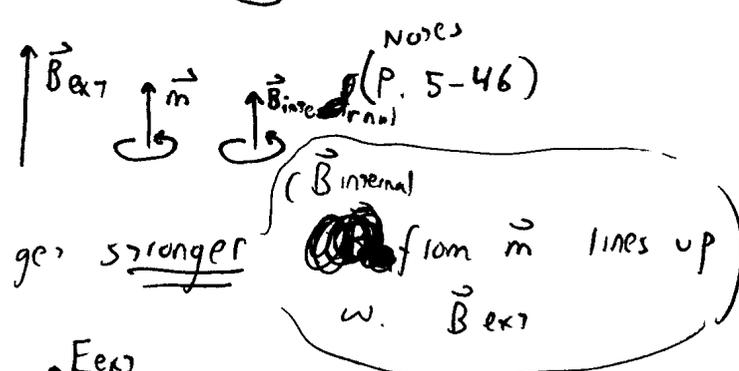


(Note - I covered Griffith's 6.1.1, 6.1.2, + 6.1.4 already.)

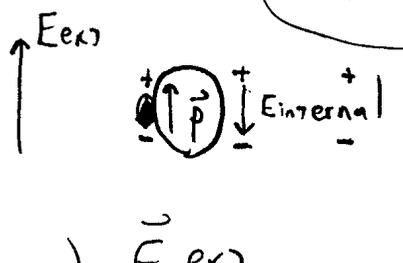
Magnetic fields affect matter, in 2 ways, one simple + obvious, the other ... less so! (eg. from electron's spin)

① If the matter has little dipoles in it  $\vec{m}$  we saw in ch. 5

that they will tend to line up. Thus, the B field in matter tends to get stronger from  $\vec{m}$  lines up w.  $\vec{B}_{ext}$



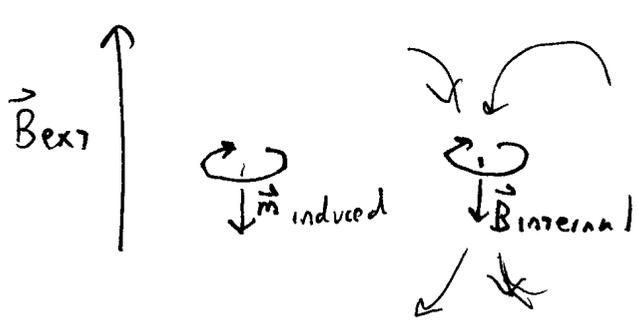
This is different from  $\vec{E}$ , where  $\vec{P}$  also lines up, but that makes an internal  $\vec{E}$  field opposing (weakening)  $\vec{E}_{ext}$



→ This effect is called paramagnetism - the  $\vec{B}_{int}$  is parallel to  $\vec{B}_{ext}$

② Here's the other thing that can happen. The  $\vec{B}_{int}$  can point the other way, diametrically opposed to  $\vec{B}_{ext}$ .

This is DIAMAGNETISM



- Typically weaker than paramag
- It observed only if paramagnetism is absent, e.g. no little dipole moments ~~or~~ even # of electrons which tend to "anti-align" from QM.

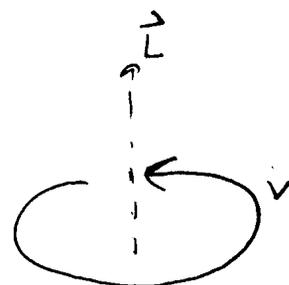
6-2.

Where does diamagnetism come from?

Real answer is Q.M. (!) Classical explanation is a cheat, but helps "make sense". So consider it a way to help visualize, without taking it too literally.

Consider  $e^-$  in orbit:  $v \cdot T = d = 2\pi R$

$$\text{so } I = \frac{\text{charge}}{\text{time}} = \frac{e}{T} = \frac{ev}{2\pi R}$$



Meanwhile magnetic dipole moment  $m = I \text{ Area} = \frac{ev}{2\pi R} \cdot \pi R^2 = \frac{e v R}{2}$

And Angular momentum  $L = m_e v R$  ( $m_e = \text{mass of electron}$   
 $m = \text{mag moment}$ )

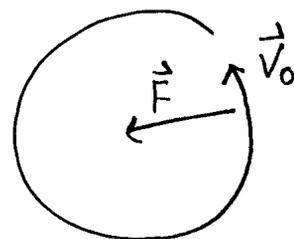
Note: because of  $-$  charge,  $\vec{m} = -\frac{e}{2m_e} \vec{L}$  (opp. direction)

So orbital ang momentum contributes to  $\vec{m}$  of an electron

(There's also  $m$  from "spin")

If  $e^-$  is in orbit,  $\vec{F} = m_e \vec{a}$

$$\frac{e^2}{4\pi\epsilon_0 R^2} = m_e \frac{v_0^2}{R}$$



Now slap on B field in  $\hat{z}$  direction

$$\text{new } \vec{F} = \frac{e^2}{4\pi\epsilon_0 R^2} + ev'B$$

- $R$  stays same (! see next p.)
- $v$  changes to  $v'$

6-3

As  $B$  turns on,  $dB/dt \neq 0$ , so there is an induced  $E$  field (Faraday's Law) running in circles. It changes KE of electron, + turns out to be "just so" that  $R$  is unchanged, but  $V$  changes

$$\left. \begin{aligned} \frac{e^2}{4\pi\epsilon_0 R^2} + eV'B &= \frac{m_e v'^2}{R} \\ &= \frac{m v_0^2}{R} \end{aligned} \right\}$$

$$\text{so } \frac{m_e}{R}(v'^2 - v_0^2) = eV'B$$

If  $B$  isn't huge,

$$v'^2 - v_0^2 = (v' - v_0)(v' + v_0)$$

$$\approx \delta v \cdot \frac{v}{2} \approx \delta v \frac{v'}{2}$$

$$\text{so } \delta v \approx \frac{eBR}{2m_e}$$

$$\text{But remember, } m = \frac{eVR}{2}, \text{ so } \delta m = \frac{eR}{2} \cdot \frac{eBR}{2m_e} = \frac{e^2 R^2}{4m_e} B$$

If  $\vec{B}$  was in  $+z$ ,  $\Rightarrow$  speeds up,  $\Rightarrow m$  is bigger but recall in opposite direction due to  $-g$ , so

$$\delta \vec{m} = -\frac{e^2 R^2}{4m_e} \vec{B}$$

[This is diamagnetism, add  $\vec{B}$  + get  $\vec{m}$  changing in opposite way.]

(If  $\vec{B}$  was in  $-z \Rightarrow$  slows down  $\Rightarrow |m|$  gets smaller,  $\delta \vec{m}$  is up, still in  $-\vec{B}$  direction)

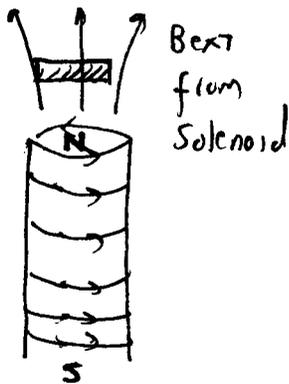
Bottom line:

If material has permanent dipole moments  
(e.g. odd # of electrons, though other mechanisms are possible)  
then paramagnetism dominates.

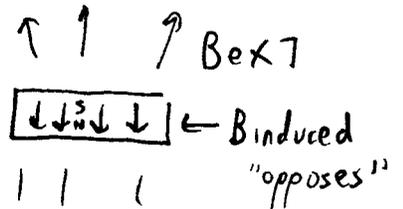
If  $\vec{m}_{atoms} = 0$ , likely to be diamagnetic.

If material is magnetized,  $M = \frac{\text{mag dipole moment}}{\text{Volume}} \neq 0$

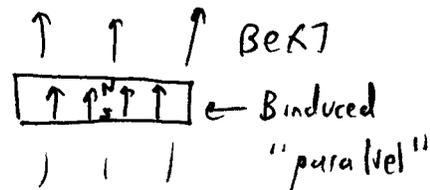
Might happen spontaneously, or because of  $\vec{B}_{ext}$  ...



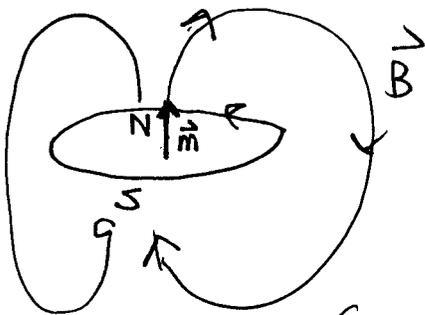
If material is  
diamagnet then  
It repels from  $B_{ext}$ .



If material is  
paramagnet  
It attracts into  $B_{ext}$



Remember



Both effects are very small, this  
is not "Kitchen magnet" kind of story,  
that's Ferro magnetism!

(Also, recall ++++ Dielectric is attracted!)