2/8/13

- Based upon Oersted's expt., the seed of a new idea was born:

  → current-carrying wires exert a force on one another
  [this effect is 'beyond' Coulomb's Law]

  → motivates the introduction of a new field (the magnetic field, or $\bar{B}$)

<u>NOTE</u>: the word magnet derives from Greek for 'stone from Magnesia' (this was an area of Greece where rocks known as **loadstones** came from), these 'stones' were known to have highly unusual properties!!

- <u>$\bar{B}$ field lines and direction</u>

  1) $\bar{E}$ fields start at + charge and end at − charge

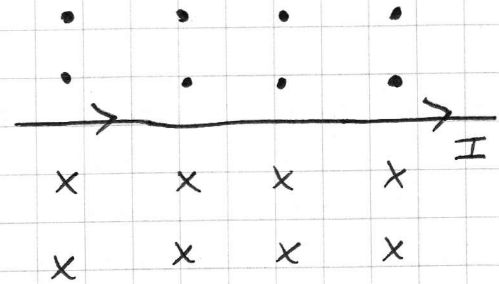
  2) N/S (the two 'poles' of a magnetic dipole) have nothing to do w/ + or − (i.e. charge)

  3) $\bar{B}$ field lines never end, they always form <u>**loops**</u>

  4) Right-hand rule (**RHR**) gives their orientation

  → see 2/7 notes for details along these lines as well as notes on visualization

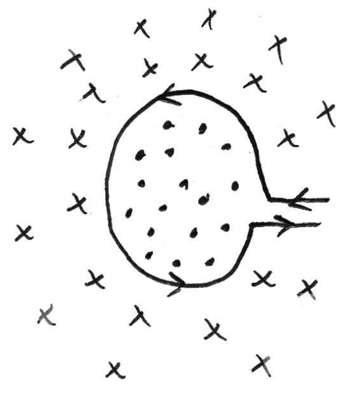
2/8/13



- Consider the current-carrying wire to the right and its magnetic field. Some questions arise at this point:

  - What sort of forces can this wire exert? And upon what sorts of objects?
  - How does the field strength vary w/ distance from the wire?
  - Is the field strength proportional to the current I?

- The $\bar{B}$ field from a straight wire is generally fairly weak. But consider the wire bent around itself into a loop:



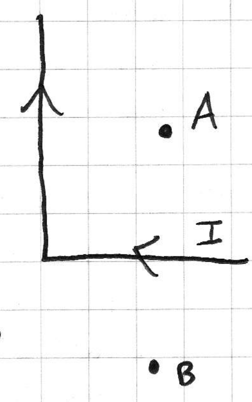
⤳ you get an additive effect as the $\bar{B}$ field from the different segments of the loop add up as you go around

<u>NOTE</u>: we don't know anything about the mag. of $\bar{B}$ yet!!

⟹ many 'strong' magnetic fields are obtained by using many loops (i.e. a **coil**) as then you get further additive effects (e.g. a solenoid, an MRI coil)

12/8/13

ex A wire carrying a current I has a 90° bend. What is the current at points A and B?



→ use RHR and consider as two semi-infinite wires (we can simply sum the two pieces) — though we need to be careful!

A - into the page

B - out of the page (?)

→ point B is a little less clear (i.e. we are not really sure what to do near the ends of a wire, just along it

□ Plan of attack at this point (a bit ~~out~~ of order relative to the book):

1) Determine a method to actually calculate the magnitude of $\bar{B}$ (Giordano ch. 20.7)

2) Examine the forces produced by $\bar{B}$ and the resulting consequences

□ To calculate $\bar{B}$, we will look back initially at how we approached determining $\bar{E}$ (the electric field):

A) Coulomb's Law let us determine $\bar{E}$ via a superposition of point charges (e.g. Giordano ch. 17.2 and 17.3)

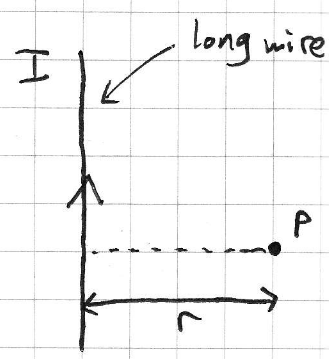
2/8/13

B) Gauss' Law, which while a bit more abstract, allowed us to exploit symmetries of **closed** surfaces to easily determine $\bar{E}$

→ determining $\bar{B}$ follows along similar lines:
- considering small contributions to $\bar{B}$ from lots of little pieces (this is known as the **Biot-Savart** Law and is fairly straight-forward but mathematically involved)

- make use of symmetry to more readily determine $\bar{B}$ for cases where the geometry is relatively simple (this is essentially a shortcut to the Biot-Savart Law and is known as **Ampére's Law**)
  → very similar in spirit to Gauss' Law !!

Ampère's Law



[discovered in 1826 by the same guy who has the units for current named after him!]

▫ Based upon extensive observations the magnetic field at point P was determined to have the following properties:

- direction is into the page (we already knew that)
- $|\bar{B}| \propto I$ (more current, proportionally stronger field)
- $|\bar{B}| \propto 1/r$ (field strength falls off as $1/r$)

→ further expt. determined $\underset{(\text{at } P)}{|B|} = \frac{\mu_0}{2\pi}\frac{I}{r}$

2/8/13

where $\mu_0 = 4\pi \times 10^{-7}\ T \cdot m/A$
(this quantity is known of the **permeability** of free space)

NOTE: we have introduced a new SI unit, tesla (T)

$$1 \text{ testla} = 1\,T = 1\,\frac{N}{A \cdot m} = 1\,\frac{kg}{C \cdot s} = 1\,\frac{V \cdot s}{m^2}$$

Some typical magnetic field strengths:

- surface of earth: $\sim 5 \times 10^{-5}\ T$
- refridgerator magnet: $\sim 5 \times 10^{-3}\ T$
- lab magnet: ~ 0.1 to $1\ T$
- superconducting magnet: $\sim 10\,T$
(this is what is used for MRI)

□ Now back to our question at hand: How to come up with a general rule/law to determine $\bar{B}$

→ this is precisely what Ampère did; how it was deduced is slightly beyond the scope of 1410, but we can go ahead and use the principle result:

it comes from the Biot-Savart Law

$$\sum_{\substack{\text{closed} \\ \text{path}}} B_{\parallel}\, \Delta L = \mu_0 I_{\text{enclosed}}$$

(Giordano's Version of Ampère's Law)

here we consider a closed path around our wire

component of $\bar{B}$ along our path that is parallel to our steps ΔL

little segments around our closed path (see Giordano fig. 20.30)

total current passing through the surface enclosed by our closed path