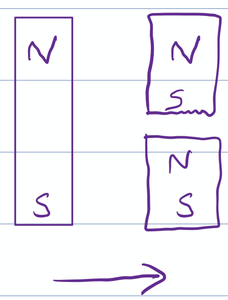
24.1: Magnetism: Read. The prelecture videos also offer a good introduction

Observations:

- Magnetic poles come in two types: Label them "North" and "South". ("North" is also sometimes labeled as "+", and "South" is also sometimes labeled as "-")
- Like poles repel
- Opposite poles attract
- Poles always come in N/S pairs. There are no isolated poles. Thus the simplest magnet is a dipole, with both a "North" and "South" pole.
- The magnetic force is long-range.



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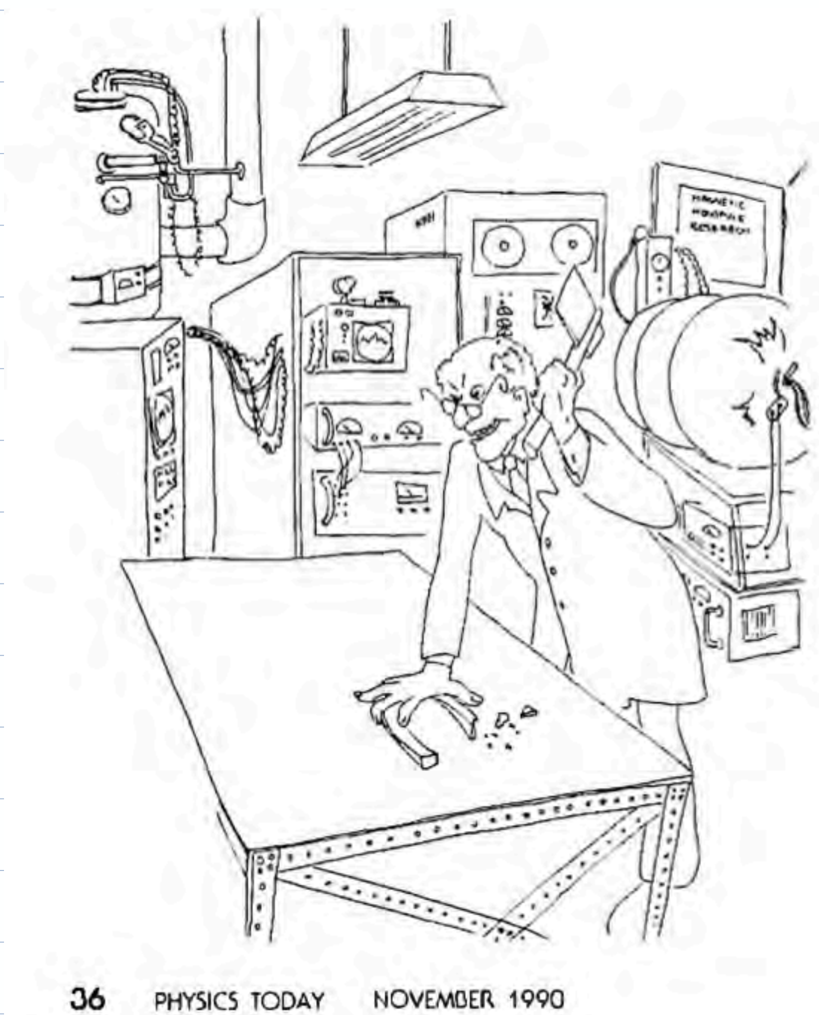
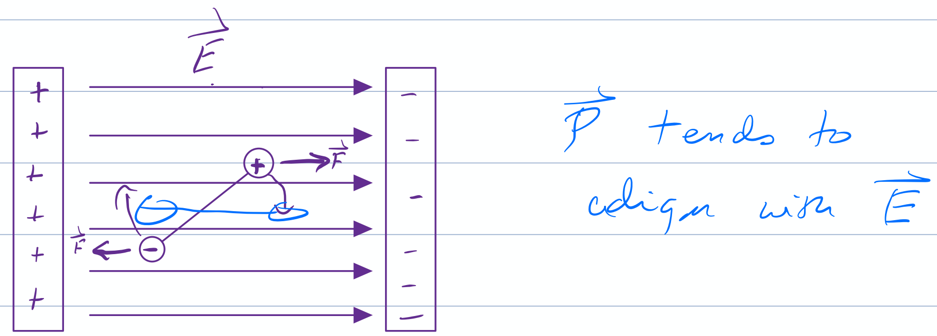


24.2. The Magnetic Field.

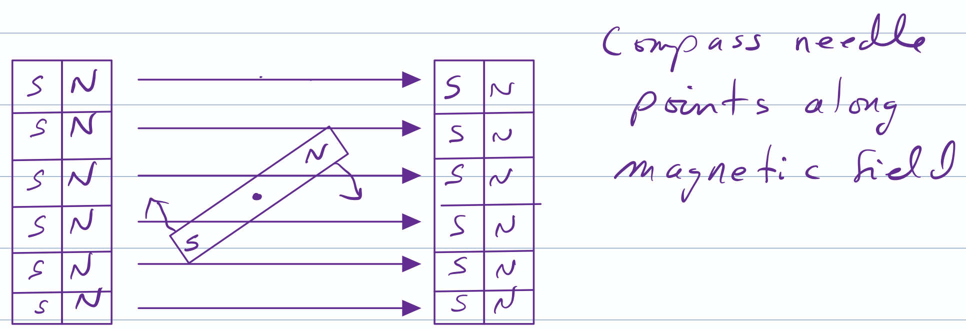
As was the case for the electric force, we find it convenient to think of the force interaction as resulting from a "source", which sets up a magnetic field, and a "test particle" that responds to the magnetic field.   We will see that electric currents act as the sources for a magnetic field, and moving charges experience a magnetic force when exposed to a magnetic field. We will deal with each of these phenomena in turn.

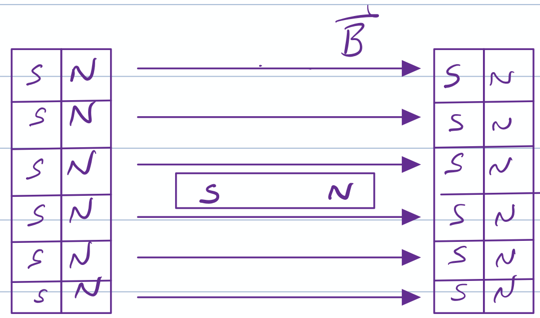
Magnetic field lines:

Recall that electric dipoles tended to align with an external electric field:



Similarly, magnetic dipoles (such as a compass needle) tend to align with an external magnetic field.



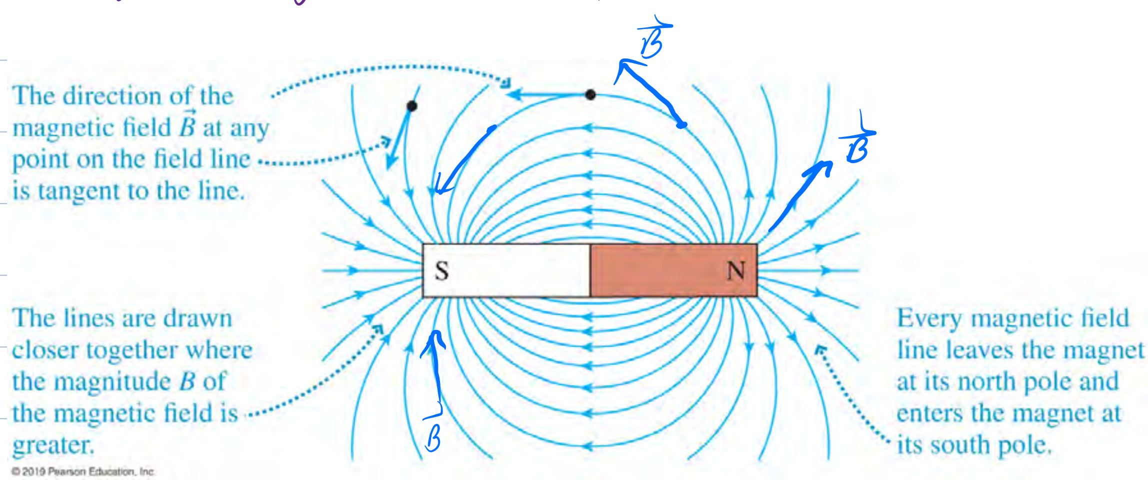


Use $\vec{B}$ for magnetic field strength. $\vec{B}$ points from Ⓝ to Ⓢ. Measure direction with a compass needle, or magnetic dipole.

Units $[B]$ = "Tesla" $T := \frac{Vs}{m^2}$

(more later in 24.4).

Magnetic field of a dipole:



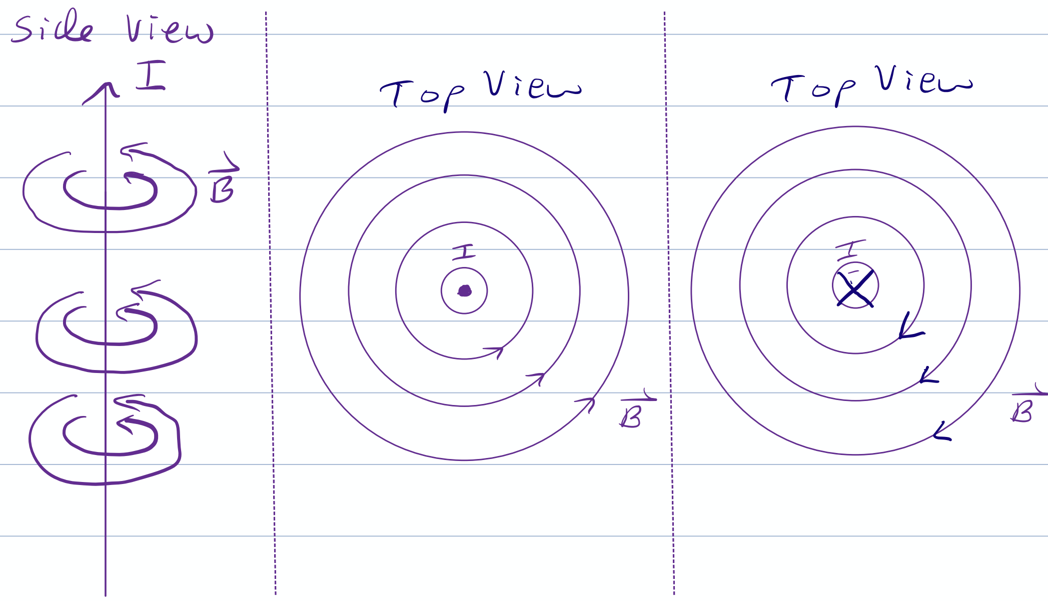
Key: Lines form <u>closed loops</u>.

Typical Scales

Earth's field near surface	$\sim 50 \mu T$
small bar magnet	$\sim 0.01\ T$
very strong bar magnet	$\sim 0.1\ T$
MRI	$\sim 1\ T$
Big lab magnet	$\sim 1\ T$
Neutron star surface	$\sim 10^{8}\ T$

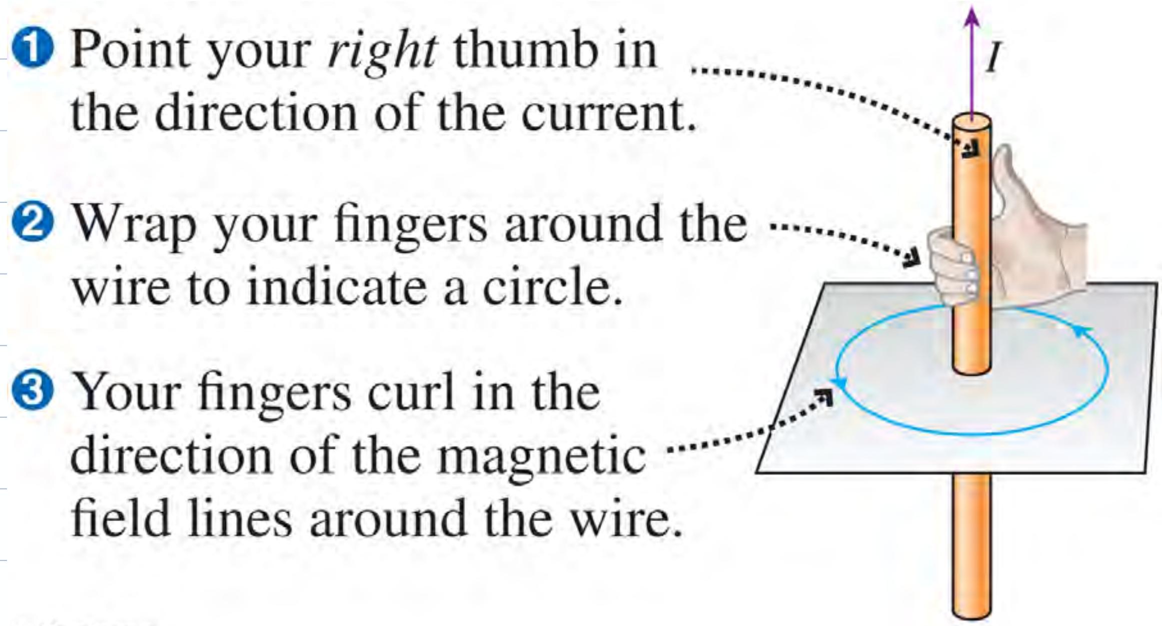
$B_{earth} \simeq 5 \times 10^{-5}\ T$

1) Long straight current-carrying wire
$\vec{B}$ goes in circles around the wire.



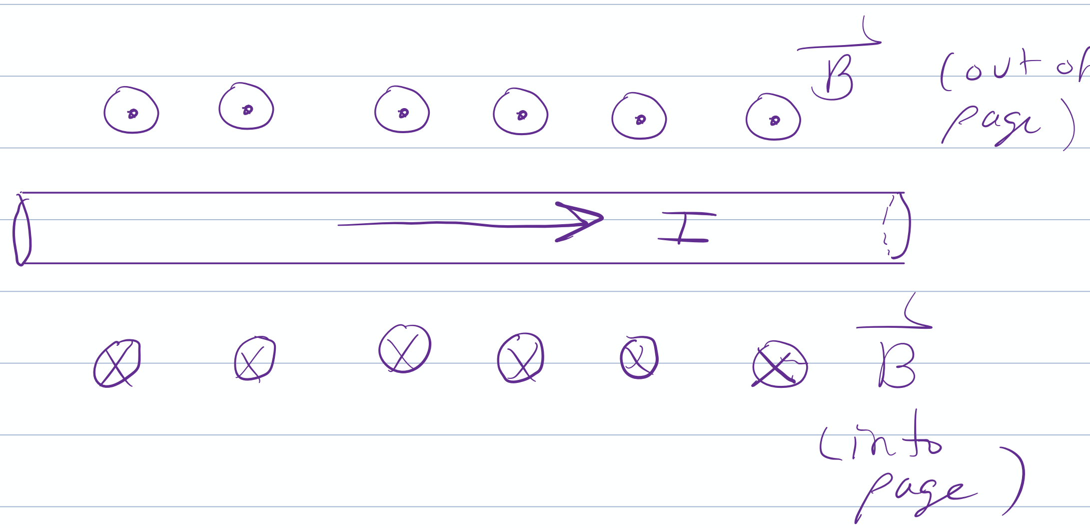
Convention: ⊙ = vector coming out of page at you
⊗ = vector going into the page, away from you.

Direction: Right Hand Rule
Thumb along current
fingers curl in the direction of $\vec{B}$



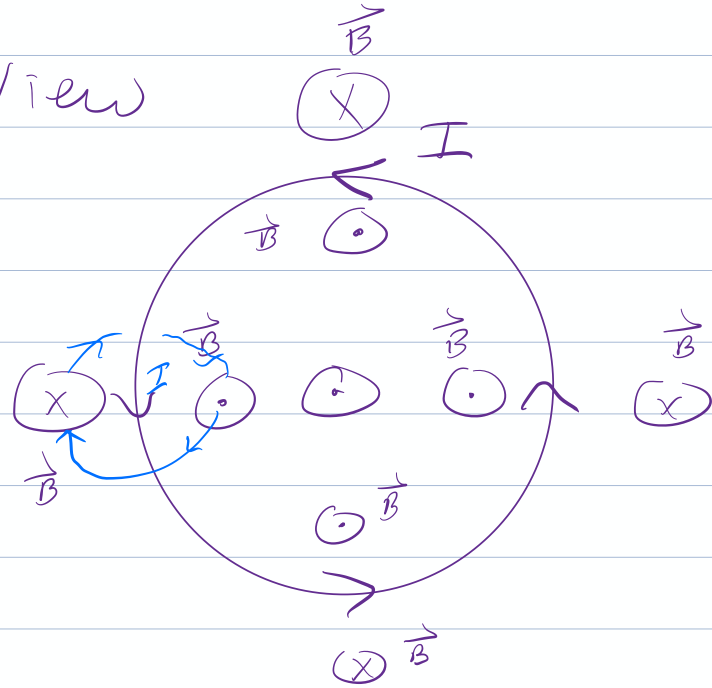
(see demonstration video)

Side view



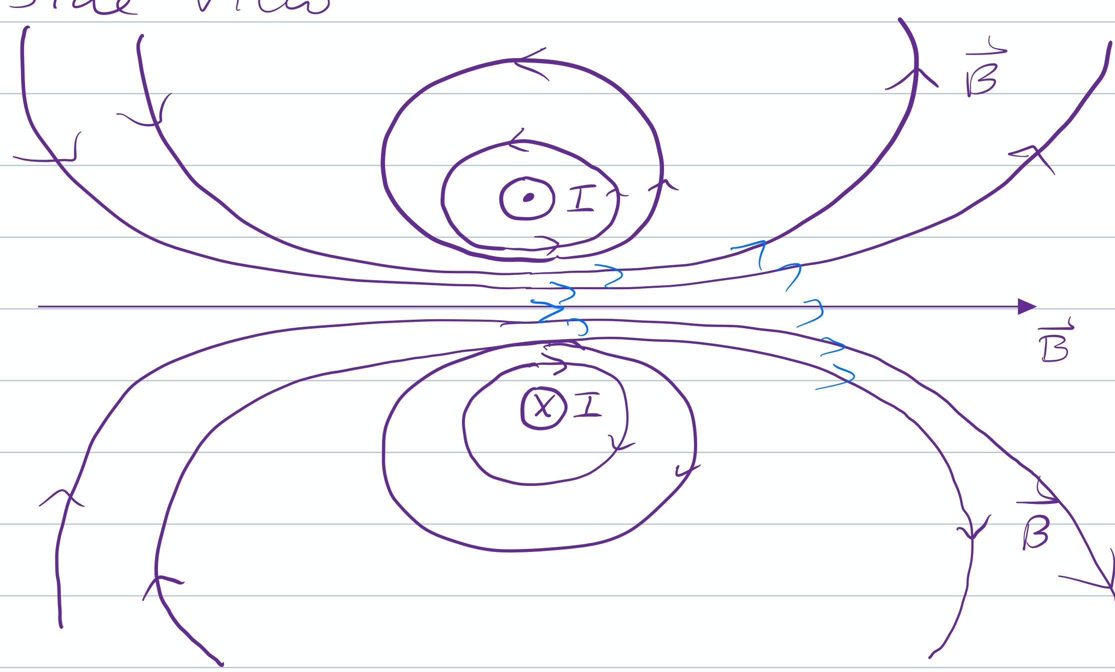
2) Current loop

Top View



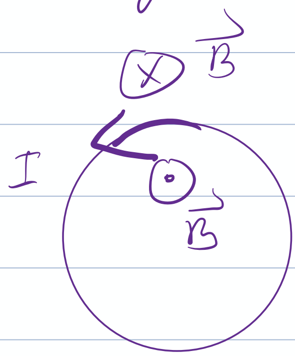
$\vec{B}$ comes out of page inside ccw loop.

Side View

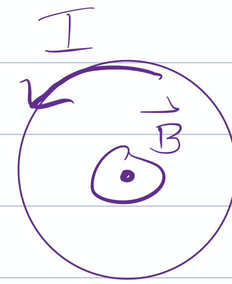


$\vec{B}$ lines go in closed loops. (see demonstration video.)

It is the same right hand rule, but you can express it 2 ways.

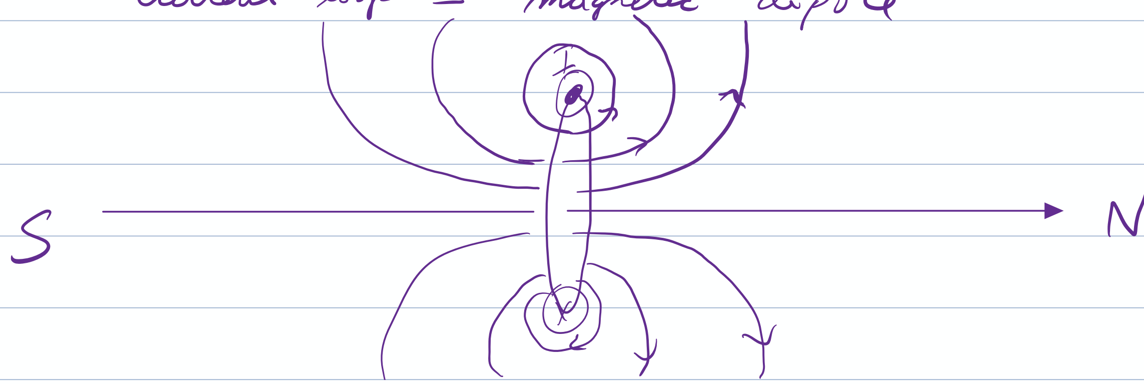


Put thumb along current, fingers curl in the direction of $\vec{B}$.

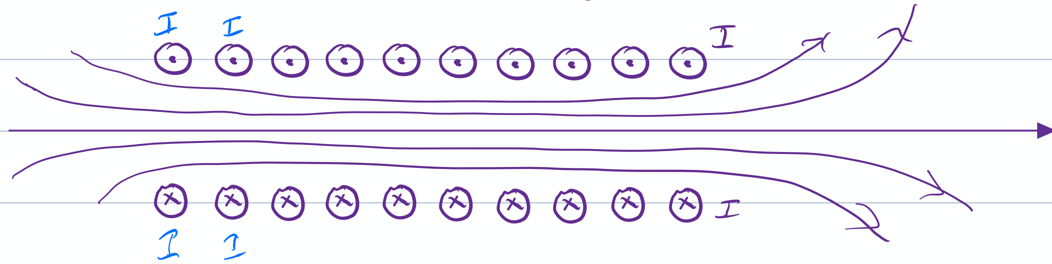


Curl fingers along I. Thumb points in the direction of $\vec{B}$ in the center of the loop.

Current loop = magnetic dipole



3) Solenoid – a stack of current loops



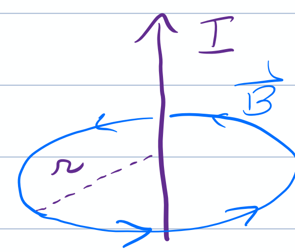
Inside: B ≈ uniform and parallel to the axis

Outside: B = quite weak

24.4: Calculating the Magnetic Field Due to a Current

1) Long Straight Wire

$\vec{B}$ goes in circles around wire



$$B = \frac{\mu_0 I}{2\pi r}$$

r = ⊥ distance from wire

$\mu_0 \equiv 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A} \approx 1.26 \times 10^{-6}\ \mathrm{T\,m/A}$

= "permeability of free space"

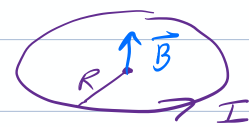
or "Vacuum permeability"

(Since 2018, it is no longer defined as exactly 4π, but is measured to be

$4\pi \times (1.000\,000\,000\,55(15)) \times 10^{-7}\ \mathrm{T \cdot m/A}$)

2) Circular current loop, at center.

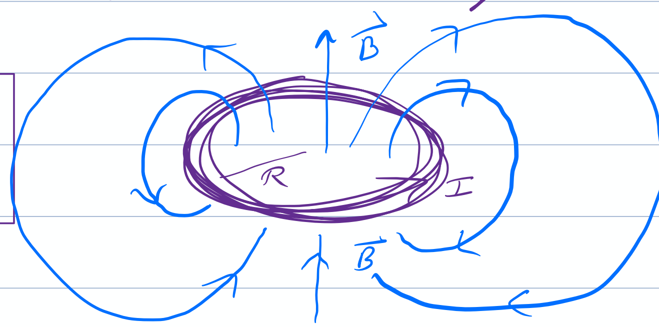
Current loop, radius R, carrying current I



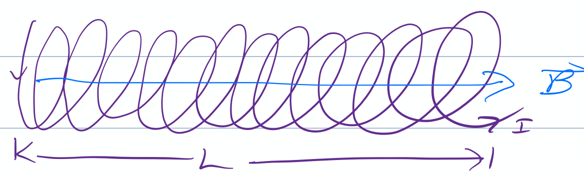
at center:
$$B = \frac{\mu_0 I}{2R}$$

2a) loop with N turns or windings

$$\boxed{B = \frac{\mu_0 N I}{2R}}$$



3) Solenoid



N windings, length L, current I

B (inside, away from edges) = $\mu_0 \frac{N}{L} I$.

$$B = \mu_0 \left(\frac{N}{L}\right) I$$

Examples: Ch24-long-wires-1 and Ch24-long-wires-2.