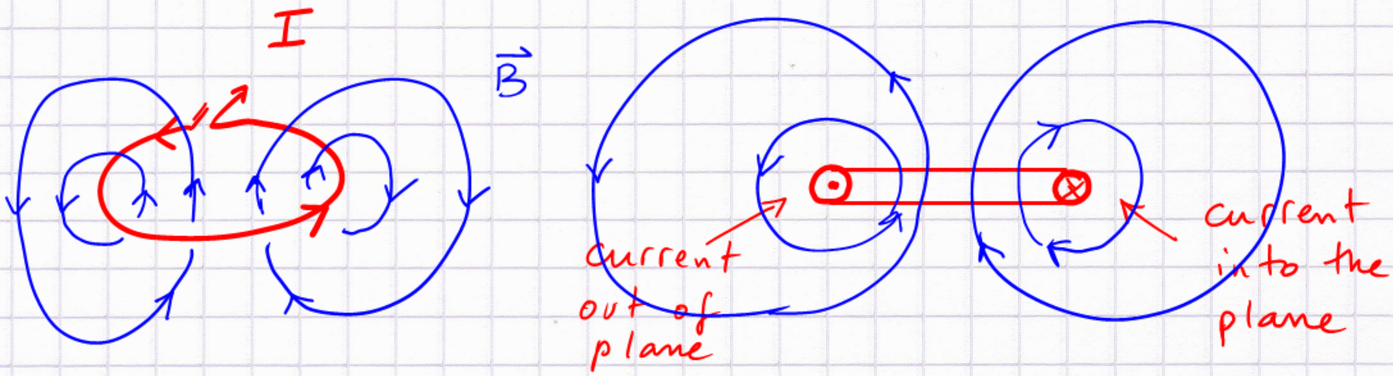
Magnetic Dipole: current loop or bar magnet

Biot-Savart allowed us to calculate from first principles:

- $\vec{B}$-field around long straight wire
- $\vec{B}$-field at centre of a current loop

For arbitrary positions in space the calculation is hard, and does not lead to a simple result.

$\therefore$ qualitative discussion:

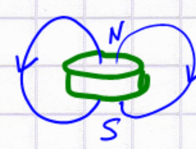


The $\vec{B}$ field is not uniform in space (distance between field lines doesn't remain constant)

The field lines remind us of the earth's $\vec{B}$ field (when drawn for the entire globe)

[origin of earth's $\vec{B}$: current loop in molten core]

Same $\vec{B}$ field is obtained for a short permanent magnet

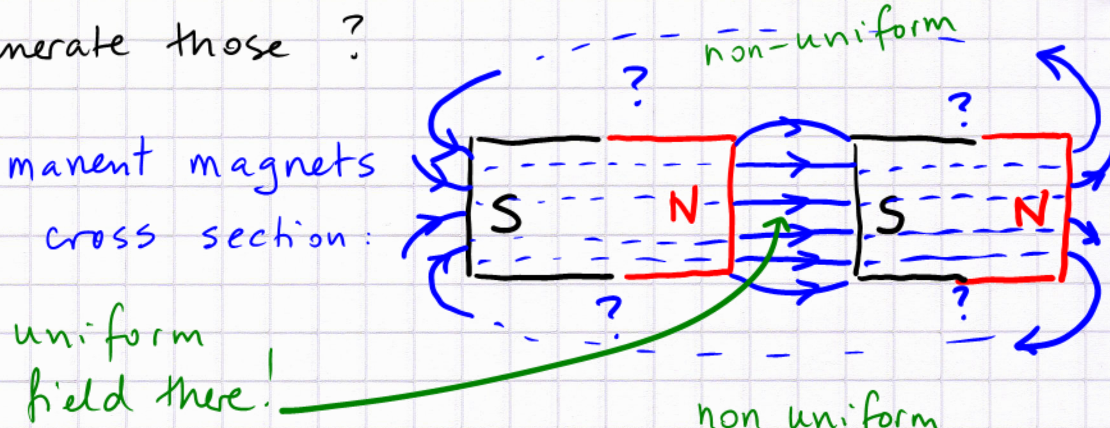


While we can't tell what's going on inside: we assume that the field lines are also closed loops in this case!

Q: We like homogeneous (uniform) fields.

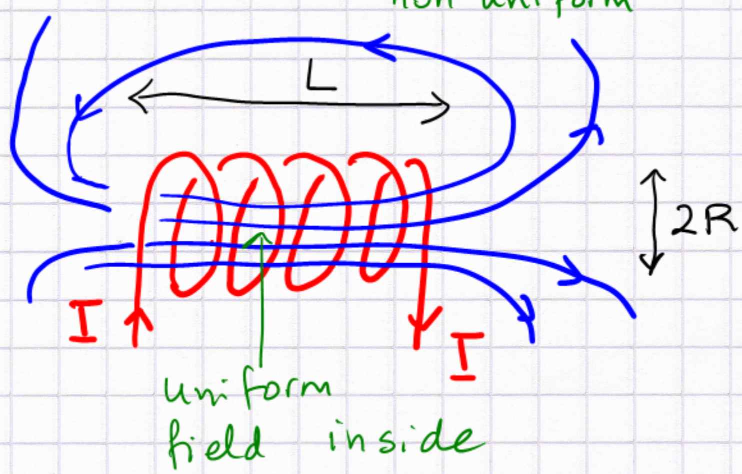
Can we generate those?

A: with permanent magnets of large cross section:



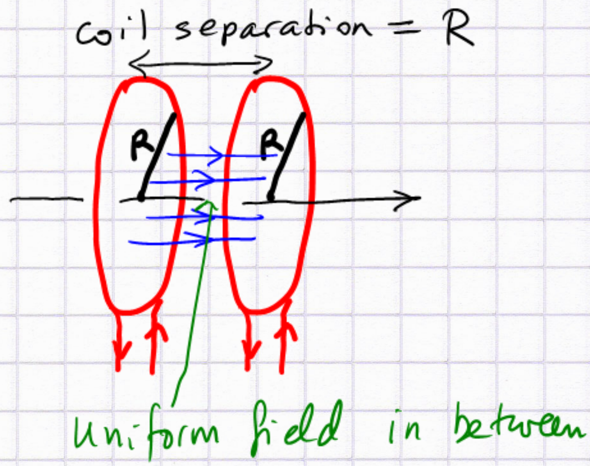
B: With electromagnets:

1) stacking current loops into a solenoid (not a coil): $L \gg R$



2) Helmholtz coil arrangement

large-R coils, many turns but length $L \ll R$



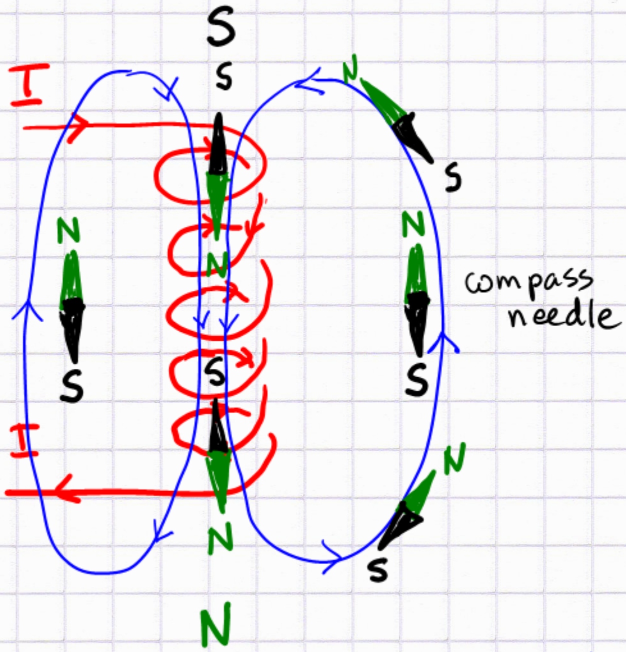
Q: How do we probe magnetic fields?

1) $\underbrace{\text{compass needle}}_{= \text{ magnetic dipole}}$ aligns to be tangential to $\vec{B}$

NB: the N-S orientation of the dipole aligns with the field direction

Q: so why does it appear to be opposite?

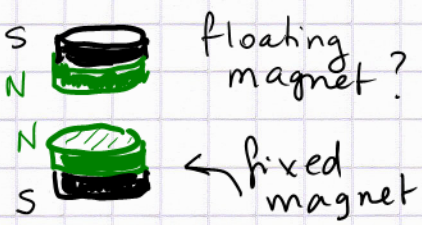
A: because we are usually observing it not inside the current loop, but outside!



A compass needle is a magnetic dipole.

In a magnetic field $\vec{B}$ it experiences a restoring torque which is zero when it is aligned.

When it is counteraligned, theoretically the torque is also zero, but this orientation is unstable!



Will a counter-aligned set-up remain stable? (floating magnet due to repulsion)

No: it will flip around and attract, unless it is prevented from doing so by a guide. (e.g., ring magnets stacked on a post)

Before we understand this in detail, i.e., magnet-magnet interactions, or current-current interactions, we need to investigate how moving charges respond to the presence of a magnetic field!

Magnetic force (Lorentz force)

Given a uniform (homogeneous) magnetic field $\vec{B}$.

A moving charge $(q, \vec{v})$ experiences a deflection at right angles to both $\vec{v}$ and $\vec{B}$:

$$\vec{F}_M = q\,(\vec{v} \times \vec{B})$$

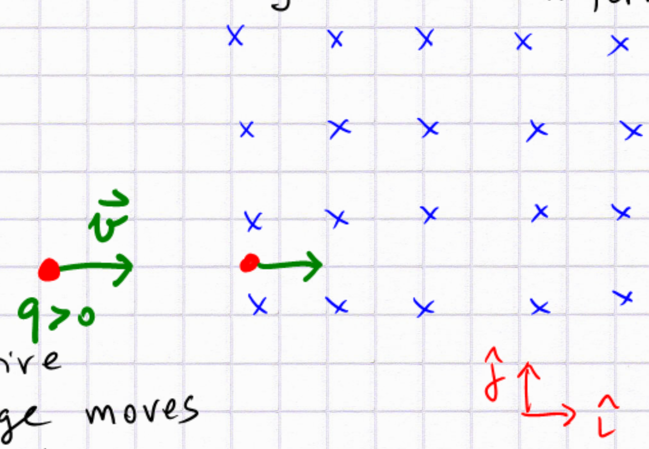
direction by full RH rule + charge sign

$$F_M = q\,|\vec{v}|\,|\vec{B}|\,\sin\vartheta \qquad \vartheta = \measuredangle\, \vec{v}, \vec{B}$$

can cause sign change, thus use RH rule and $|F_M| = |\,q\,v\,B\,\sin\vartheta\,|$

Example:

region with uniform $\vec{B}$ into the plane (tails of $\vec{B}$ arrows are indicated)



$\vec{B} = -B_0\,\hat{k}$

positive charge moves into the region

which way is the particle deflected?

$$\vec{v} = v_0\,\hat{i} \qquad \vec{B} = -B_0\,\hat{k}$$

$$\vec{F}_M = q\,v_0\,B_0\,\hat{j}$$

also via determinant: $q \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ v_0 & 0 & 0 \\ 0 & 0 & -B_0 \end{vmatrix} =$

RH rule:

thumb : points right

index : points into plane

middle = up!

$\sim \hat{j}$

$q>0 \rightarrow$ no change