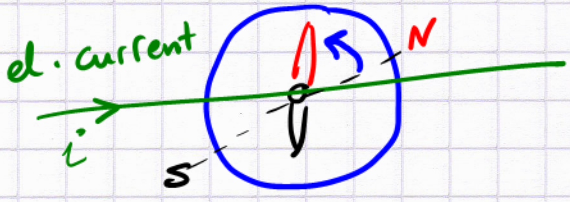
Magnetism

At first, we think of it as a separate phenomenon:

(A) compass needle, (B) animal compass → migratory birds
→ sea animals
→ insects

(C) earth, sun, galaxy have the ability to deflect incoming charged particles → permanent magnetism

Oersted's experiment:



compass needle deflects from (N-S) when a current passes over it.

→ birth of electromagnetism

→ understand permanent magnetism later!

Idea: current-carrying wires exert a force on each other

why? moving electric charge leads to phenomena "beyond Coulomb's law".

Introduce the idea of another field: magnetic, $\vec{B}$ field

Why? Compass needle is deflected by a current-carrying wire → some analogy to deflection by another compass needle.

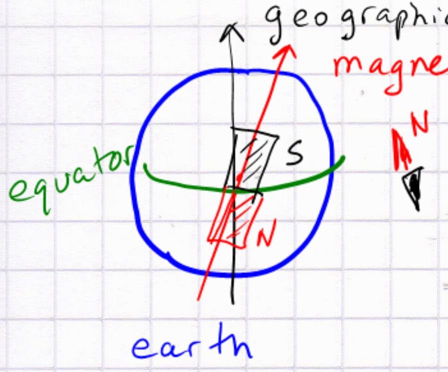
→ where do compass needles come from?

originally: pieces of rock that contain iron ore found on the surface of "old" mountains

today: steel needle magnetized by ↗ spending time inside solenoid
↘ brushed against strong magnet

Magnets come with two poles (N/S). Breaking them into half → two smaller (N/S) magnets.

NO MAGNETIC MONOPOLES EXIST!



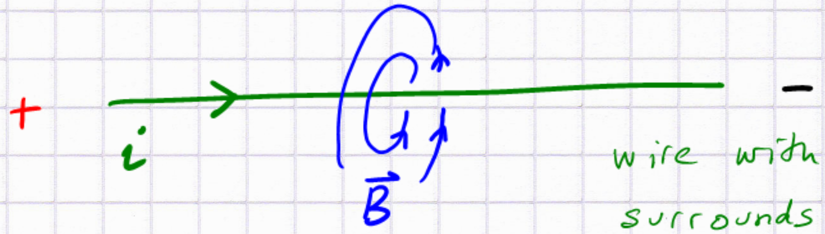
actually: NORTH POLE is a misnomer, the N-end of a compass needle points towards S (see Fig. 20.40 on p. 670)

Location of the magnetic pole (axis orientation) travels (Fig. 20.41) and (N-S) - (S-N) direction reversals happen on the 10^6 yr scale

The earths magnetic field is caused by an electric current loop inside its molten core. → currents can change
what causes the current? ⟶ geodynamo problem
⟶ solar magnetic field?

Field direction and $\vec{B}$ field lines.

1) $\vec{E}$ fields start @ + charge, end @ - charge
2) N/S has NOTHING to do with +/-, i.e., charge
3) $\vec{B}$ field lines never end, they always form loops.
4) Right hand rule gives their orientation



wire with current surrounds itself with $\vec{B}$

RH Thumb : current direction
curved hand (index/middle fingers) gives $\vec{B}$ orientation.

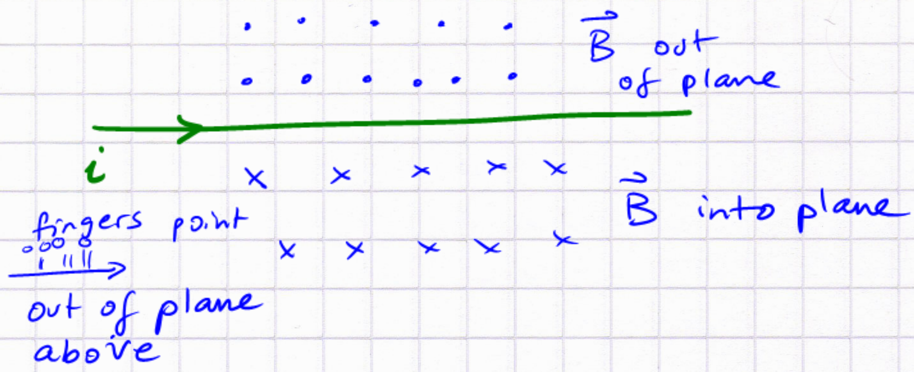
Magnetism is a little harder to understand than Coulomb's law.

→ spend time visualizing : iron filings surrounding current-carrying wires vs permanant magnets

Visualization

cross section

RH thumb

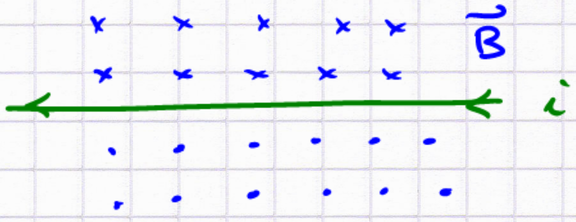


Q1: how does the field strength vary with distance from the wire?

Q2: is it proportional to the current i?

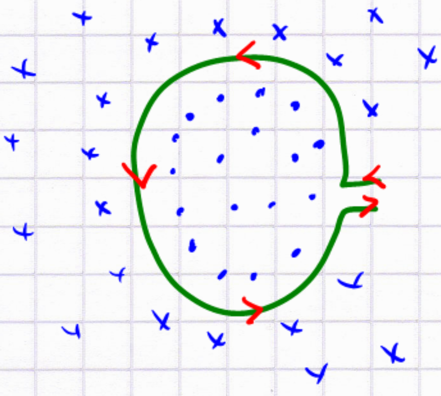
For a positive charge travelling right-to-left:

RH rule implies a direction reversal!



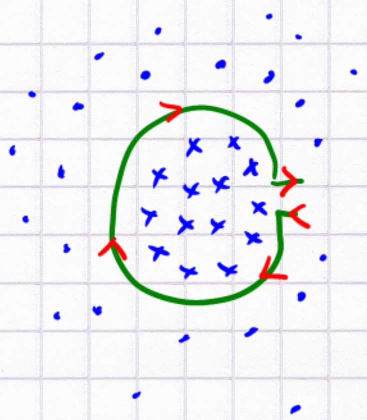
Current loop

The $\vec{B}$ field from a straight wire is usually weak. When forming a wire loop, one gets an additive effect inside the loop:



current loop with area A:

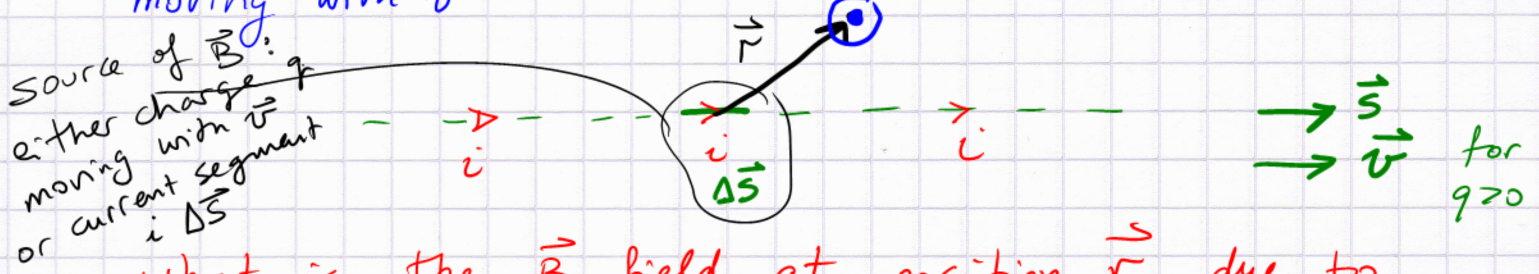
$\vec{B}$ fields from different segments add up!



Biot - Savart law (not in our textbook)

Coulomb's law (with its extension to Gauss' law) allowed to calculate the $\vec{E}$ field for a charge distribution

An analogous law can be formulated for the $\vec{B}$ field due to a short wire segment, or due to a charge q moving with $\vec{v}$



what is the $\vec{B}$ field at position $\vec{r}$ due to the segment $i\,d\vec{l}$?

$$\vec{B}(\vec{r}) = \boxed{\frac{\mu_0}{4\pi}}\, q\,\frac{\vec{v}\times\vec{r}}{r^3} = \frac{\mu_0}{4\pi}\, q\,\frac{\vec{v}\times\hat{r}}{r^2}$$

$$= \frac{\mu_0}{4\pi}\,\frac{i\,\Delta\vec{s}\times\hat{r}}{r^2}$$

μ_0 = permeability constant

why?

$i = \frac{\Delta q}{\Delta t}$

$\therefore\ i\,\Delta\vec{s} = \Delta q\,\frac{\Delta\vec{s}}{\Delta t} = \Delta q\,\vec{v}$

Δq = charge q smeared over $\Delta\vec{s}$

From this law one can calculate the $\vec{B}$ field due to:

a) a charge q travelling with $\vec{v}$

b) a current-carrying wire segment

To obtain the field from the entire wire at point $\vec{r}$ one has to sum (integrate) the contributions from all segments (2^{nd} year, PHYS2020).

In 20.7 we will learn a shortcut → Ampère's law.