Electricity and Magnetism
Magnetic Fields

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Nov 3, 2015

Overview

- magnets
- magnetic field
- Earth's magnetic field
- magnetic force on a charge

Magnets

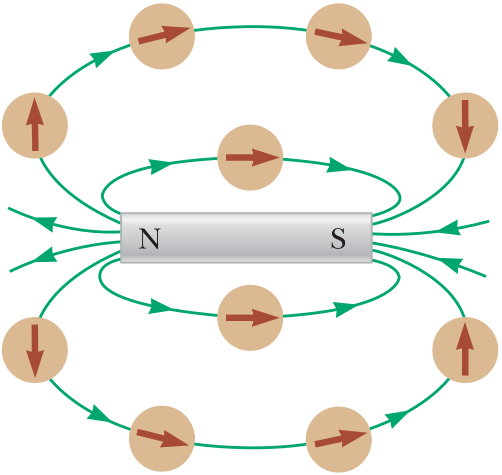
Like charges, magnets also interact at a distance.

They can either attract or repel.

Similarly to charges, they can also attract certain kinds of nearby material (*eg.* iron) by *magnetizing* it. (*cf.* polarization)

Magnets and Magnetic fields

Compass needles point along the direction of a magnetic field.

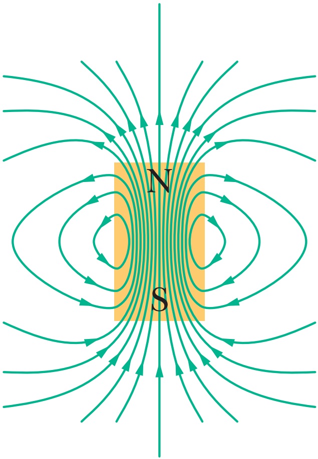


[1]Figure from Serway and Jewett, 9th ed.

Magnetic Field Lines

Draw magnetic field lines similarly to E-field line: lines emerge from North pole, enter South pole, denser lines means a stronger field.

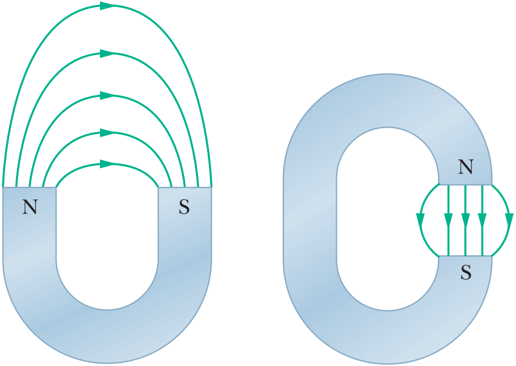
A bar magnet:



[1]Figure from Halliday, Resnick, Walker, 9th ed.

Magnetic Field Lines

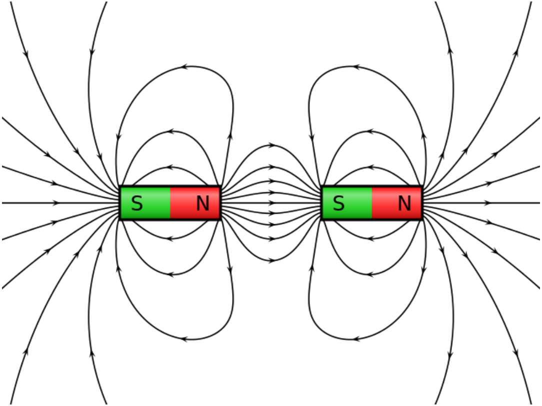
Magnetic fields for a horseshoe magnet and a C-shape magnet:



[1]Figure from Halliday, Resnick, Walker, 9th ed.

Magnetic Field Lines

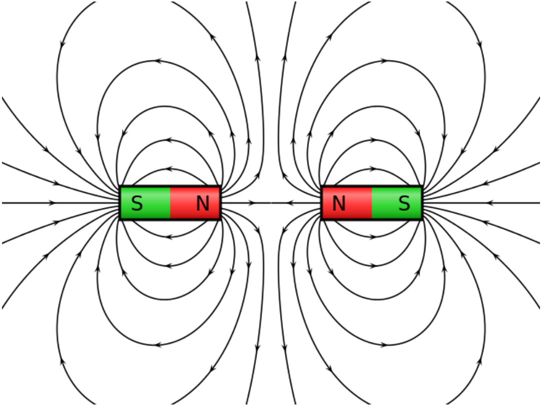
Opposite poles attract each other:



[1]Figure from Wikipedia.

Magnetic Field Lines

Like poles repel each other:



[1] Figure from Wikipedia.

Magnets vs. electrostatics

Magnets are different from charges, but there are some similarities.

For two magnetic poles in free space small enough to be modeled as points, the magnitude of the force between them is:

$$F = \frac{\mu_0}{4\pi} \frac{q_{m1} q_{m2}}{r^2}$$

where μ_0 is the magnetic permeability of free space, q_{m1} is a magnetic charge.

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This looks a lot like the Coulomb force:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

However, the equation for magnetic force is not in the textbook. Why?

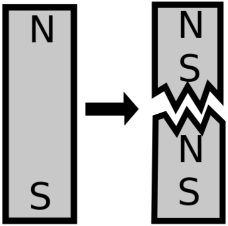
Magnets vs. electrostatics

Magnets also have an important difference from electric charges.

It is possible for a positive or negative electric charge to be found on its own: *eg.* electrons, protons.

Magnetic charges (q_m) are **never** found on their own.

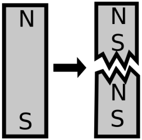
Magnets have a North pole and a South pole. If you break a magnet in two, new North and South poles form:



[1]Figure from Wikipedia.

Lack of Magnetic Monopoles

Breaking a magnet in two:



It is impossible to separate a North pole from a South pole.

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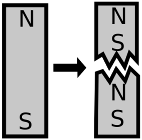

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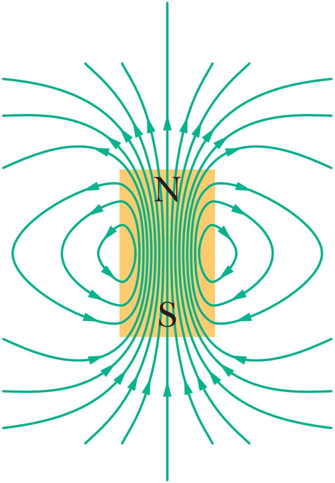
It is unclear at this time why magnetic monopoles do not exist, but they have **never been conclusively observed**.

Some (unconfirmed) theories predict them, and they may have existed in the early universe. Other theories attempt to explain why they do not exist. **EM theory assumes they do not exist.**

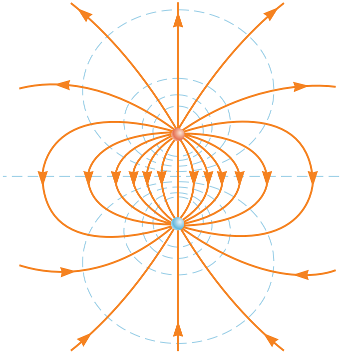
We can think of magnets as behaving similarly to electric dipoles.

Electric dipoles vs. bar magnets

Magnetic field around bar magnet:



Electric field around a dipole:



[1]Figures from Halliday, Resnick, Walker, and Serway and Jewett, 9th ed.

Magnetic Fields

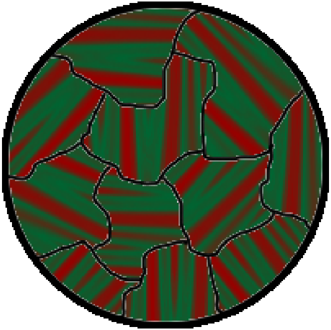
There are two (main) types of sources of magnetic fields:

- **permanent magnets** - some materials have their constituent particles aligned in such a way as to create an overall electric field; typical bar magnets
- **electromagnets** - currents (moving charges) also create magnetic fields

(Materials that interact with magnetic fields do also produce a magnetic field of their own during the interaction.)

Why do some objects have magnetic fields?

Microscopic view of ferrous metal:



The different red and green regions are magnetic domains.

Within each domain are atoms with their outermost electrons aligned (green) or oppositely aligned (red).

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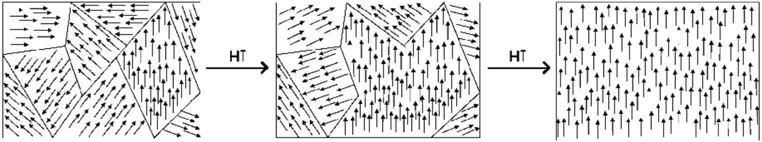
[1]Figure from Wikipedia, by Ra'ike.

Why do some objects have magnetic fields?

Diagram of atomic magnetic moments in ferrous metal:



In a strong external magnetic field regions that align with the field dominate and can remain after the field is removed.

The material then creates its own field!

[1]Figure from Wikipedia, by Jose Lloret and Alicia Forment.

Summary

- magnetic field

Homework Halliday, Resnick, Walker:

- Look ahead at Ch 28