Magnetism & Magnetic Permeability

Unit: Magnetism & Electromagnetism

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 12.1.B, 12.1.B.1, 12.1.B.1.i, 12.1.B.1.ii, 12.1.B.1.iii, 12.1.B.1.iv, 12.1.B.2, 12.1.B.3, 12.1.B.3.i, 12.1.B.3.ii, 12.1.B.3.ii, 12.1.B.4, 12.1.C, 12.1.C.1, 12.1.C.2, 12.1.C.3

Mastery Objective(s): (Students will be able to…)

- List and explain properties of magnets.

Success Criteria:

- Explanations account for observed behavior.

Language Objectives:

- Explain why we call the ends of a magnet "north" and "south".

Tier 2 Vocabulary: magnet

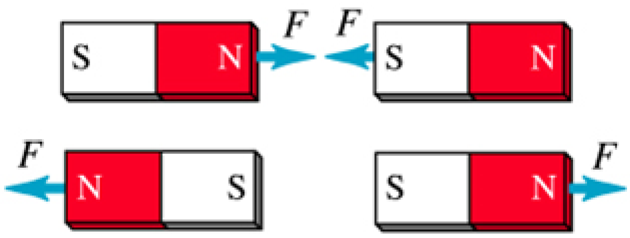
Labs, Activities & Demonstrations:

- neodymium magnets
- ring magnets repelling each other on a dowel
- magnets attracting each other across a gap

Notes:

magnet: a material with electrons that can align in a manner that attracts or repels other magnets.

A magnet is a dipole, meaning that it has two opposite ends or "poles", called "north" and "south". If a magnet is allowed to move freely, the end that points toward the north on Earth is called the north end of the magnet. The end that points toward the south on Earth is called the south end of the magnet. (The Earth's magnetic poles are near, but not in exactly the same place as its geographic poles.) All magnets have a north and south pole. As with charges, opposite magnetic poles attract, and like poles repel.



There is no such thing as a magnetic monopole (*i.e.,* a north or south pole by itself). If you were to cut a magnet in half, each piece would be a magnet with its own north and south pole:

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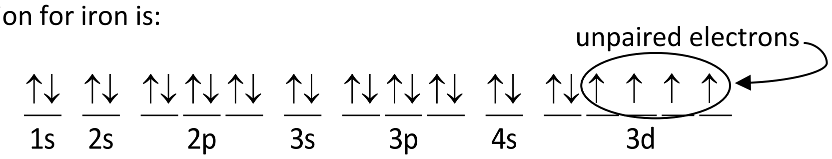
Electrons and Magnetism

Magnetism is caused by the alignment of unpaired electrons in atoms.

As you (should) recall from chemistry, electrons within atoms reside in energy regions called “orbitals”. Each orbital can hold up to two electrons.

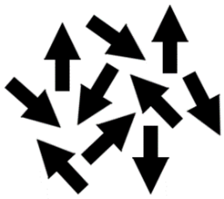
If two electrons share an orbital, they have opposite spins. (Note that the electrons are not actually spinning. “Spin” is the term for the intrinsic property of certain subatomic particles that is believed to be responsible for magnetism.) This means that if one electron aligns itself with a magnetic field, the other electron in the same orbital becomes aligned to oppose the magnetic field, and there is no net force.

However, if an orbital has only one electron, that electron is free to align with the magnetic field, which causes an attractive force between the magnet and the magnetic material. For example, as you learned in chemistry, the electron configuration for iron is:

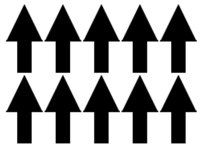


The inner electrons are paired up, but four of the electrons in the 3d sublevel are unpaired and are free to align with an external magnetic field.

When the electrons in a substance are aligned randomly, the substance is not magnetic and is not attracted to a magnet.



When the electrons in a substance are aligned, the substance is magnetic and will be attracted to a magnet.



diamagnetic: a material whose electrons are unable to align with a magnetic field. These substances will weakly repel a magnet.

paramagnetic: a material that has electrons that can move to align with a magnetic field. These materials are attracted to a magnet but are not themselves magnets.

ferromagnetic: a material with crystals that have permanently aligned electrons, resulting in a permanent magnet. Some naturally occurring materials that exhibit ferromagnetism include iron, cobalt, nickel, gadolinium, dysprosium, and magnetite (Fe_3O_4).

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Curie temperature (or Curie point): the temperature above which a ferromagnetic material becomes paramagnetic.

The Curie temperature is named after the French physicist Pierre Curie, who discovered this effect.

If a paramagnetic material is heated above its Curie temperature, placed in a magnetic field (to force the electrons to align), and then cooled (while still in the magnetic field), the material becomes ferromagnetic. This is how permanent magnets are made.

Substance	**Curie temperature (°C)**	**Substance**	**Curie temperature (°C)**
iron	770	cobalt	1130
iron(III) oxide	675	nickel	354
magnetite (iron (II,III) oxide)	585	dysprosium	−185.2

Magnetic Permeability

Magnetic measurements and calculations involve fields that act over 3-dimensional space and change continuously with position. This means that most calculations relating to magnetic fields need to be represented using multivariable calculus, which is beyond the scope of this course.

magnetic permeability (magnetic permittivity): the ability of a material to support the formation of a magnetic field. Magnetic permeability is represented by the variable μ. The magnetic permeability of empty space is defined to be $\mu_0 = 4\pi \times 10^{-7}\ \frac{\text{N}}{\text{A}^2}$.

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magnetic susceptibility (χ): a measure of the degree to which a material will become magnetized when it is placed in a magnetic field.

Diamagnetic materials have negative magnetic susceptibilities.

Paramagnetic materials have positive magnetic susceptibilities.

Ferromagnetic materials do not have well-defined magnetic susceptibilities, because these substances create their own magnetic fields, which interact with the external magnetic field.