Magnetic Fields

Unit: Magnetism & Electromagnetism

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS3-5

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

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

- Describe and draw magnetic fields.
- Calculate magnetic flux.

Success Criteria:

- Magnetic field lines connect north and south poles of the magnet.
- Arrows on field lines point from north to south.

Language Objectives:

- Explain how a compass works.

Tier 2 Vocabulary: field, north pole, south pole

Labs, Activities & Demonstrations:

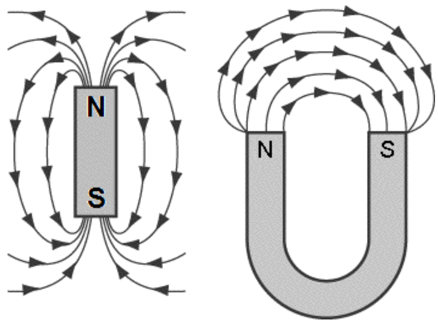
- magnetic field demonstrator plate
- placing various objects into the gap between two magnets
- ferrofluid
- representation of flux as dots on a balloon

Notes:

<u>magnetic field</u> ($\vec{B}$) : a force field (region in which a force acts on objects that have a certain property) in which magnetic attraction and repulsion are occurring.

Any object that is a magnetic dipole (*i.e.,* a magnet or something that behaves like one) creates its own magnetic field. If the object is allowed to move freely, the magnetic field will attract and repel the poles of the object so that it aligns with the magnetic field.

Similar to an electric field, we represent a magnetic field by drawing field lines. Magnetic field lines point from the north pole of a magnet toward the south pole, and they show the direction that the north end of a compass or magnet would be deflected if it was placed in the field:



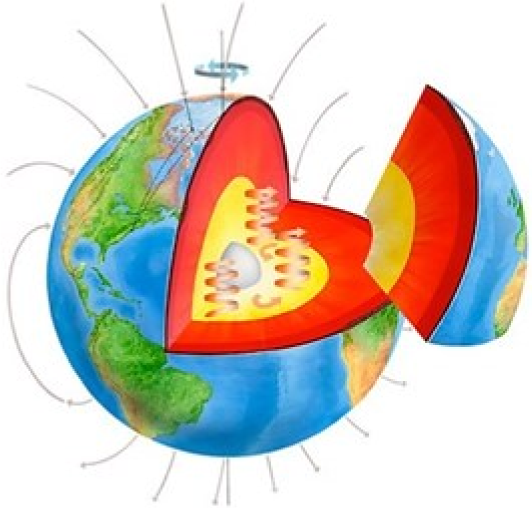
The strength of a magnetic field is measured in teslas (T), named after the physicist Nikola Tesla. One tesla is the magnetic field strength necessary to produce one newton of force when a particle that has a charge of one coulomb is moved through the magnetic field at a velocity of one meter per second. Because of the relationship between magnetism, forces, and electricity, one tesla can be expressed as many different combinations of units:

$$1\text{ T} \equiv 1\frac{\text{V}\cdot\text{s}}{\text{m}^2} \equiv 1\frac{\text{N}}{\text{A}\cdot\text{m}} \equiv 1\frac{\text{J}}{\text{A}\cdot\text{m}^2} \equiv 1\frac{\text{kg}}{\text{C}\cdot\text{s}} \equiv 1\frac{\text{N}\cdot\text{s}}{\text{C}\cdot\text{m}} \equiv 1\frac{\text{kg}}{\text{A}\cdot\text{s}^2}$$

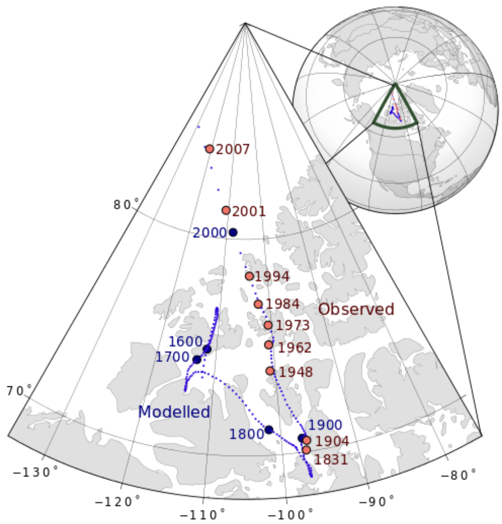
The Earth's Magnetic Field

The inner and outer core of the Earth are made of iron, which has a high magnetic susceptibility. The very high temperature of the inner core causes convection currents in the molten iron in the outer core.

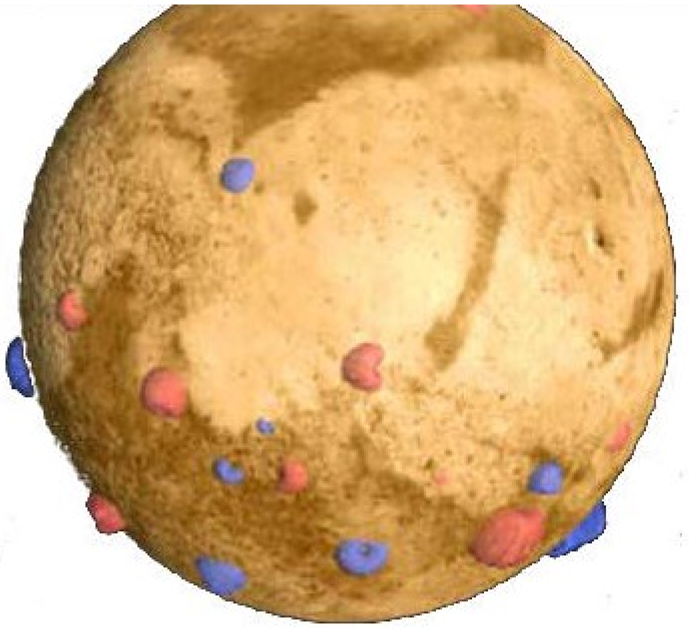
The rapid rotation of the Earth causes the molten iron in the outer core to swirl. The swirling iron causes a magnetic field over the entire planet.



Because the core of the Earth is in constant motion, the Earth's magnetic field is constantly changing. The exact location of the Earth's magnetic north and south poles varies by about 80 km over the course of each day because of the rotation of the Earth. Its average location (shown on the map of Northern Canada below) drifts by about 50 km each year:



Not all planets have a planetary magnetic field. Mars, for example, is believed to have once had a planetary magnetic field, but the planet cooled off enough to disrupt the processes that caused it. Instead, Mars has some very strong localized magnetic fields that were formed when minerals cooled down in the presence of the planetary magnetic field.



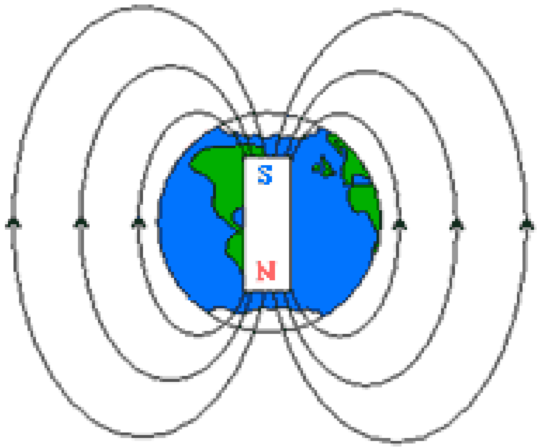
In this picture, the blue and red areas represent regions with strong localized magnetic fields. On Mars, a compass could not be used in the ways that we use a compass on Earth; if you took a compass to Mars, the needle would point either toward or away from each these regions.

Jupiter, on the other hand, has a planetary magnetic field twenty times as strong as that of Earth. This field may be caused by water with dissolved electrolytes or by liquid hydrogen.

Recall that the north pole of a magnet is the end that points toward the north on Earth. This must mean that if the Earth is a giant magnet, one of its magnetic poles must be near the geographic north pole, and the other magnetic pole must be near the geographic south pole.

For obvious reasons, the Earth's magnetic pole near the north pole is called the Earth's "north magnetic pole" or "magnetic north pole". Similarly, the Earth's magnetic pole near the south pole is called the Earth's "south magnetic pole" or "magnetic south pole".

However, because the north pole of a magnet points toward the north, the Earth's north magnetic pole (meaning its location) must therefore be the ***south*** pole of the giant magnet that is the Earth.



Similarly, because the south pole of a magnet points toward the south, the Earth's south magnetic pole (meaning its location) must therefore be the ***north*** pole of the giant Earth-magnet.

Unfortunately, the term "magnetic north pole," "north magnetic pole" or any other similar term almost always means the magnetic pole that is in the north part of the Earth. There is no universally-accepted way to name the poles of the Earth-magnet.