PhyzGuide: The Files on Magnetism*

FILE 1: IS IT REALLY ANOTHER PRETTY FORCE?

Our experience with magnets reveals that they are capable of exerting attractive and repulsive forces. But we've seen such forces before; why do we need to have a new force called magnetism? What makes magnetism distinct from gravity and electrostatic force?

Magnetic forces cannot be attributed to gravitational interactions for several reasons. Gravitational forces act between any objects with mass. Magnetic forces do not; magnets act only between objects made of certain materials. More importantly, gravitational forces are always attractive, magnetic forces are not. Magnets can exert repulsive forces.

But so can electric charges. What distinguishes magnetic forces from electrostatic forces? Electrostatic force exists between any two objects with electric charge. Magnets are nearly always electrically neutral yet exert attractive and repulsive forces nonetheless. Also, electrically charged objects do not exert magnetic forces on magnets.

Magnetic interaction is clearly distinct from that of gravity and static electricity. Magnetism is no farce.

FILE 2: DIPOLES FOREVER

Permanent magnets have north poles and south poles. Opposite poles (N & S) attract; like poles (N & N, S & S) repel. A bar magnet can be characterized as a **magnetic dipole** since its ends represent opposite poles. (Recall that an object with opposite electric charge on either end is an electric dipole.) If an electric dipole is bisected, the result is two electric monopoles: one positively charged half and one negatively charged half. However, if a magnetic dipole is bisected, the result is two smaller magnetic dipoles. Further divisions produce the same results. The existence of magnetic monopoles is hotly debated among physicists, and a great deal of research is currently devoted to their detection. The model of magnetism we will adopt in this course suggests that magnetic monopoles cannot exist.

FILE 3: MIRACLES FROM MAGNESIA

Permanent magnets were originally found in 6th-century BC Magnesia (now Turkey). Rocks of iron ore that displayed magnetic characteristics were called *lodestone* (this ore is now referred to as *magnetite*). When pieces of lodestone were suspended from threads or floated in water, they would always orient themselves the same way. This characteristic of lodestone led to the invention of the navigation compass.

FILE 4: GEOMAGNETIC MAYHEM

A compass is a small magnet mounted on a low-friction pivot-point. The north-seeking end of the compass needle is labeled "north," the south-seeking end is labeled "south." Compasses work because the earth itself has a magnetic field. The earth's field is like one that would be created by a permanent bar magnet thrust through the earth. Since opposite poles attract, the end of a compass needle that points toward geographic north must do so due to attraction from an opposite pole. The magnetic pole in the northern hemisphere is therefore a south magnetic pole! To make matters worse, the Earth's magnetic field is not in perfect alignment with the earth's axis of rotation. We say that compass needles are attracted to "magnetic north," which is in a different location from "true north." True north is the north pole of the earth; the location of the earth's axis of rotation. Magnetic north is currently located in Hudson Bay in Canada. The angular difference between true north and magnetic north is called magnetic declination. In California, magnetic north lies 18° east of true north. To recount: there is no magnetic pole at the north pole of the earth, the magnetic pole in the northern hemisphere, whose location is referred to as magnetic north, is actually a south magnetic pole (since it attracts the north pole of compass needles). To this day, the mechanism responsible for the earth's magnetic field is not well understood.

FILE 5: THE DANISH DISCOVERY

In 1820, Danish high school physics teacher Hans Christian Ørsted (pronounced UR–sted) discovered that the flow of electric charge creates magnetic fields. A magnetic field exists around any current-carrying wire or any stream of charged particles. Ørsted's discovery was the first step toward understanding the fundamental principle underlying magnetism: **all magnetic fields arise from moving electric charges.**

FILE 6: MAGNETIC FIELD DIRECTION, SYMBOL, AND UNITS

The direction of a magnetic field is defined as the direction a compass would point if placed in that field (the direction a compass points is taken as the direction that the north pole points). In other words: away from north magnetic poles and toward south magnetic poles. The earth's magnetic field is directed from geographic south to north (from magnetic north to south). The symbol for the magnetic field is $\mathbf{B}$ (scalar: B). The units of magnetic field strength are *teslas* (T), named after the Sacramento-based rock group. Coincidentally, there was an ingenious physicist by the name of Nikola Tesla who worked with electricity and magnetism in the late 19th century.

FILE 7: LARGEST AND SMALLEST MAGNETS ON EARTH

The biggest magnet in the world is the world itself (see file 4 above). The smallest magnet in the world is the electron. Recall from file 5 that all magnetic fields arise from moving electric charge. Electrons have charge and typically move in two ways. They rotate on an axis and they translate in orbit around a nucleus. Usually, electrons are paired so that they spin in opposite directions and the resulting magnetic fields cancel. In iron and a few other materials, some electrons are not "spin-paired." Each iron atom is therefore a tiny magnet.

A region of a piece of iron where adjacent atoms are magnetically aligned is called a **domain**. Unmagnetized iron consists of many tiny, disparate domains; a permanent magnet has more aligned atoms and may have one domain the size of the magnet itself.

Rare earth magnets such as samarium, gadolinium, and neodymium owe their magnetism to the orbital motion of electrons. When the magnetism related to this translational motion goes uncanceled, the resulting field can be very strong. Rare earth magnets are typically much stronger than iron-based magnets.