MAGNETIC FIELDS

How should we define the magnetic field? When two objects attract each other gravitationally, their gravitational energy depends only on the distance between them, and it seems intuitively reasonable that we define the gravitational field arrows like a street sign that says “this way to lower gravitational energy.” The same idea works fine for the electric field. But what if two charged particles are interacting magnetically? Their interaction doesn't just depend on the distance, but also on their motions.

We need some way to pick out some direction in space, so we can say, “this is the direction of the magnetic field around here.” A natural and simple method is to define the magnetic field's direction according to the direction a compass points. Starting from this definition we can, for example, do experiments to show that the magnetic field of a current-carrying wire forms a circular pattern, o.

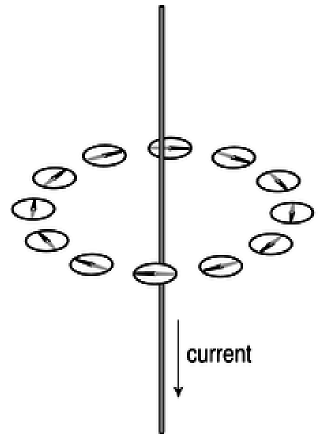

FIgure o: The magnetic field curls around the wire in circles. At each point in space, the magnetic compass shows the direction of the field.

But is this the right definition? Unlike the definitions of the gravitational and electric fields' directions, it involves a particular human-constructed tool. However, compare figure h with figure n. Note that both of these tools line themselves up along a line that's perpendicular to the wire. In fact, no matter how hard you try, you will never be able to invent any other electromagnetic device that will align itself with any other line. All you can do is make one that points in exactly the opposite direction, but along the same line. For instance, you could use paint to reverse the colors that label the ends of the magnetic compass needle, or you could build a weathervane just like figure n, but spinning like a left-handed screw instead of a right-handed one. The weathervane and the compass aren't even as different as they appear. Figure pshows their hidden similarities.

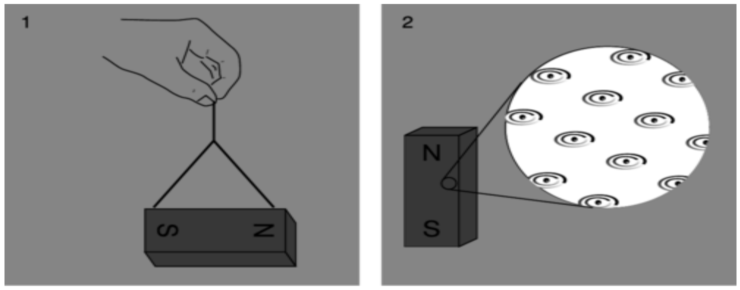

Figure p: 1. The needle of a magnetic compass is nothing more than a bar magnet that is free to rotate in response to the earth's magnetic field. 2. A cartoon of the bar magnet's structure at the atomic level. Each atom is very much like the weathervane of figure n.

Nature is trying to tell us something: there really is something special about the direction the compass points. Defining the direction of the magnetic field in terms of this particular device isn't as arbitrary as it seems. The only arbitrariness is that we could have built up a whole self-consistent set of definitions that started by defining the magnetic field as being in the opposite direction.

Example 2: Head-to-tail alignment of bar magnets

- If you let two bar magnets like the one in figure p interact, which way do they want to line up, head-to-head or head-to-tail?
- Each bar magnet contains a huge number of atoms, but that won't matter for our result; we can imagine this as an interaction between two individual atoms. For that matter, let's model the atoms as weathervanes like the one in figure n. Suppose we put two such weather vanes side by side, with their arrows both pointing away from us. From our point of view, they're both spinning clockwise.

As one of the charges in the left-hand weather vane comes down on the right side, one of the charges in the right-hand vane comes up on the left side. These two charges are close together, so their magnetic interaction is very strong at this moment. Their interaction is repulsive, so this is an unstable arrangement of the two weathervanes.

On the other hand, suppose the left-hand weathervane is pointing away from is, while its partner on the right is pointing toward us. From our point of view, we see the one on the right spinning counterclockwise. At the moment when their charges come as close as possible, they're both on the way up. Their interaction is attractive, so this is a stable arrangement.

Translating back from our model to the original question about bar magnets, we find that bar magnets will tend to align themselves head-to-tail. This is easily verified by experiment.

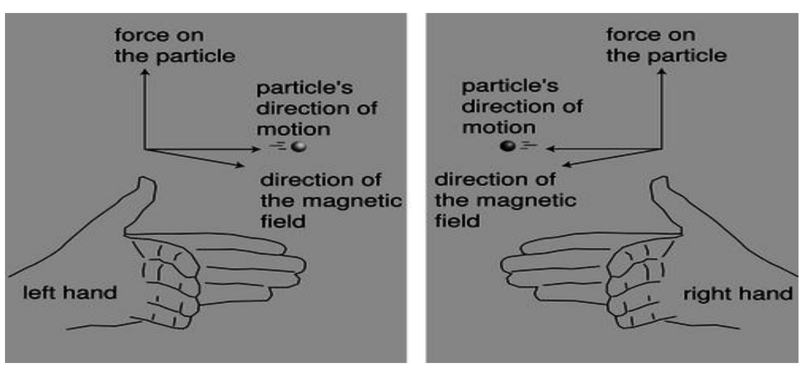

Figure q: The force on a charged particle moving through a magnetic field is perpendicular to both the field and its direction of motion. The relationship is right-handed for one type of charge, and left-handed for the other type.

If you go back and apply this definition to all the examples we've encountered so far, you'll find that there's a general rule: the force on a charged particle moving through a magnetic field is perpendicular to both the field and its direction of motion. A force perpendicular to the direction of motion is exactly what is required for circular motion, so we find that a charged particle in a vacuum will go in a circle around the magnetic field arrows (or perhaps a corkscrew pattern, if it also has some motion along the direction of the field). That means that magnetic fields tend to trap charged particles.

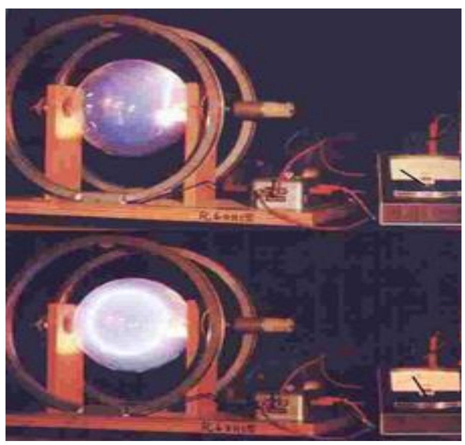

Figure r: A beam of electrons circles around the magnetic field arrows.

Figure r shows this principle in action. A beam of electrons is created in a vacuum tube, in which a small amount of hydrogen gas has been left. A few of the electrons strike hydrogen molecules, creating light and letting us see the path of the beam. A magnetic field is produced by passing a current (meter) through the circular coils of wire in front of and behind the tube.

In the bottom figure, with the magnetic field turned on, the force perpendicular to the electrons' direction of motion causes them to move in a circle.

Example 3: Sunspots

Sunspots, like the one aove, are places where the sun's magnetic field is unusually strong. Charged particles are trapped there for months at a time. This is enough time for the sunspot to cool down significantly, and it does not get heated back up because the hotter surrounding material is kept out by the same magnetic forces.

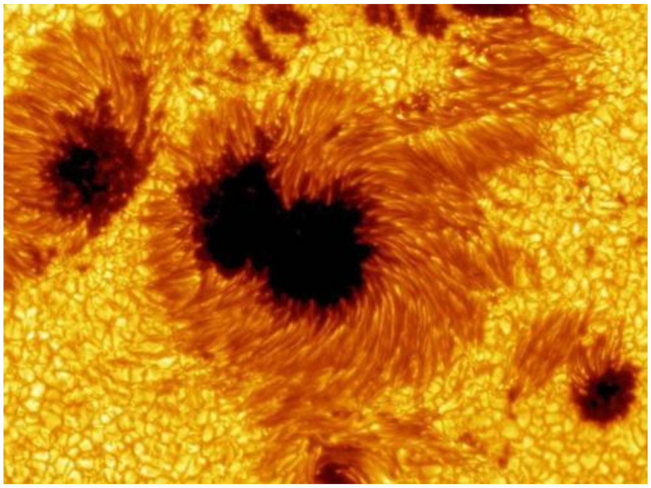

Figure: This sunspot is a product of the sun's magnetic fields. The darkest region in the center is about the size of our planet.

Example 4: The aurora and life on earth's surface

A strong magnetic field seems to be one of the prerequisites for the existence of life on the surface of a planet.

Energetic charged particles from the sun are trapped by our planet's magnetic field, and harmlessly spiral down to the earth's surface at the poles. In addition to protecting us, this creates the aurora, or “northern lights.”

The astronauts who went to the moon were outside of the earth's protective field for about a week, and suffered significant doses of radiation during that time. The problem would be much more serious for astronauts on a voyage to Mars, which would take at least a couple of years. They would be subjected to intense radiation while in interplanetary space, and also while on Mars's surface, since Mars lacks a strong magnetic field.

Features in one Martian rock have been interpreted by some scientists as fossilized bacteria. If single-celled life evolved on Mars, it has presumably been forced to stay below the surface. (Life on Earth probably evolved deep in the oceans, and most of the Earth's biomass consists of single-celled organisms in the oceans and deep underground.)

Source:
http://physwiki.ucdavis.edu/Electricity_and_Magnetism/Fields/Electromagnetism