Earth as Magnet

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A couple of years ago I gave some thought to what it meant for the earth to be considered a magnet. Recently an article in the magazine *BirdWatching* (p. 46 [1]) brought it all back. It is not my intention to denigrate the magazine, but a diagram from the article (Figure 1) provides an excellent example of a misunderstanding. Can you see what is wrong?

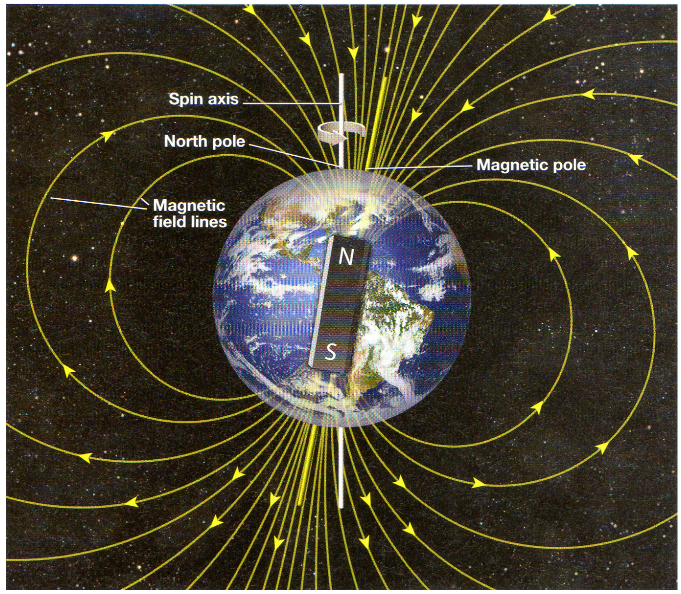

Figure 1 From "How Birds Migrate" in *BirdWatching*

A good place to begin is to state some definitions and conventions from physics. From my old physics book (p.359 [2]):

> If a bar magnet is suspended by a string or mounted on a pivot, it is found that the bar lines up roughly north and south, *the same end of the bar magnet always pointing north*. For this reason we shall call the pole that tends to seek the geographic north, the *north pole* (N), and the other, which tends to seek the geographic south, the *south pole* (S). In this way we may mark the ends of all bar magnets as north poles or south poles.

So far so good. But this definition won't work for the earth itself, since we cannot suspend the earth from itself and see which direction it points. So we will have to consider some properties of magnetism to see if we can derive a consistent answer for the earth.

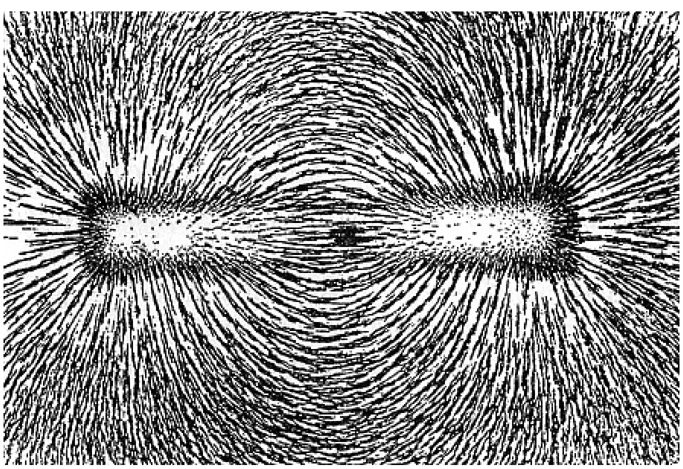

Figure 2 Iron filings over bar magnet

Let's consider the lines in Figure 1 designated "magnetic field lines." What might these be? Consider Figure 2 which shows the classic effect of scattering a lot of tiny iron filings on a piece of paper lying on top of a bar magnet ([3]). The tiny slivers of iron act like little compass needles that point towards one of the poles (see Figure 3).

The iron filing lines show no direction, however. We need to consider the properties of a bar magnet and its poles a bit further. To return to the physics text (p.359 [2]):

> By mounting bar magnets on pivots or suspensions so that they are free to move, we find that *the like poles of two magnets repel, whereas unlike poles attract each other*. By using long, slender, magnetized needles, the north and south poles of a magnet or magnets may be sufficiently separated from each other that the magnitude of the forces between individual, approximately isolated poles may be measured. This was first done by the French physicist Charles A. Coulomb (1736-1806) in 1785. … Coulomb found, first, that the force of

repulsion between two north poles was inversely proportional to the square of the distance between [them]. [He also found that the force was directly proportional to the magnetic "pole strength" m of each pole.]

There is a similar inverse square relationship for the attractive force between opposite poles, but with opposite direction from the repulsive force.

Thus we can imagine placing a north pole magnet probe at various points around a bar magnet and mapping out the resultant force on the probe. This provides the concept of a magnetostatic field about the bar magnet in which magnetic forces act, similar to an electrostatic field around an electric charge (Figure 4).

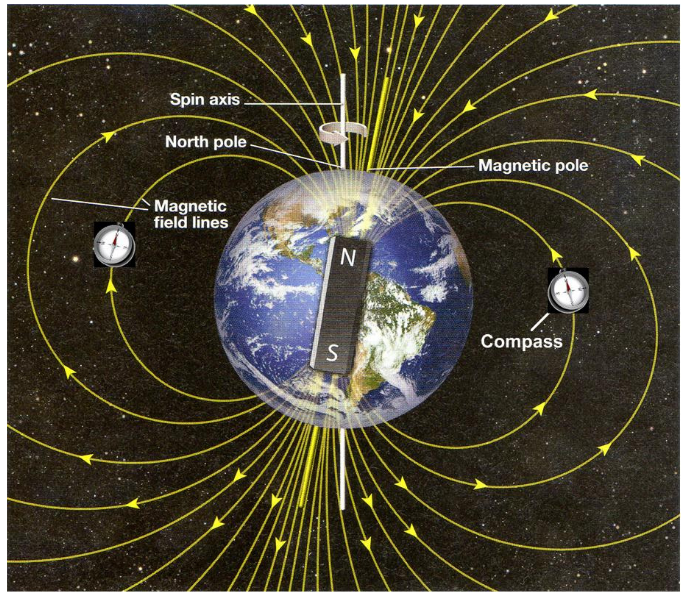

Figure 3 Compasses along magnetic field lines

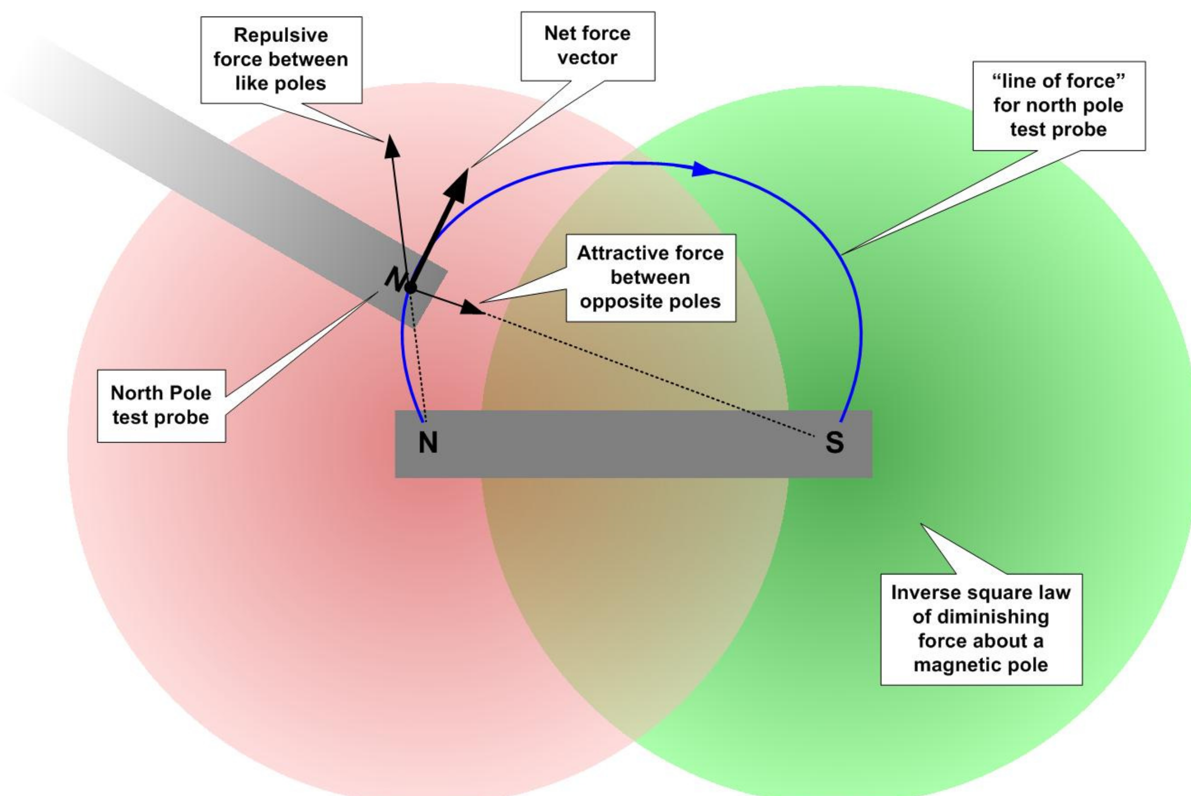

Figure 4 Measuring the force at various points of a magnetic field off the axis of a bar magnet.

Now we are ready to consider the behavior of a compass in terms of these notions.

From Figure 5 we can see what happens to a compass needle in the magnetic field. It lines up along the (north pole) line of force from the north pole of the bar magnet to its south pole. Thus we have the (surprising) answer to our original question: how can we think of the earth as a (bar)

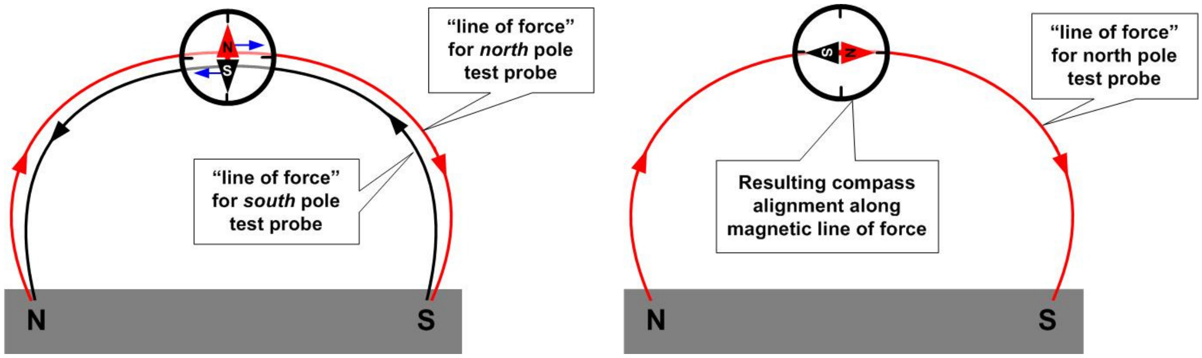

Figure 5   Effect of lines of force on compass

magnet? The answer is the counter-intuitive statement that it is a "magnet" with its north *magnetic* pole oriented toward the south *geographic* pole and its south *magnetic* pole oriented toward its north *geographic* pole. That is, **the N and S in Figure 1 and Figure 3 should be reversed!**

This result is such a pedagogical nightmare that most physics books (at least the ones I have seen over the years, including my old text (p.364 [2])) leave out the magnetic pole designations when showing the magnetic field about the earth. It is interesting that Wikipedia shows the correct labels in its article on the earth's magnetic field ([4]).

References.

[1] Greij, Eldon, "Amazing Birds: How Birds Navigate," in *BirdWatching*, Vol. 26, No.2, April 2012

[2] Ference, Jr., Michael, Harvey B. Lemon, and Reginald J. Stephenson, *Analytical Experimental Physics*, 2d revised edition, University of Chicago Press, 1956.

[3] Illustration (http://en.wikipedia.org/wiki/File:Magnet0873.png) from "Iron Filings" in *Wikipedia*, (http://en.wikipedia.org/wiki/Iron_filings), retrieved 3/22/2012.

[4] Diagram (http://en.wikipedia.org/wiki/File:Geomagnetisme.svg) in "Earth's Magnetic Field," in *Wikipedia*, (http://en.wikipedia.org/wiki/Earth%27s_magnetic_field), retrieved 3/22/2012.