GEOMAG™ Paradoxes

Silvia Defrancesco and *Fabrizio Logiurato,* Univ. of Trento Povo, Trento, Italy
Grzegorz Karwasz, Mesiano, Trento, Italy and Nicolaus Copernicus University, Toruń, Poland

As often happens, a lot of physics can come out of a toy. What we found interesting is the observation of the magnetic field produced by different configurations built with GEOMAG.TM [1] This toy provides small magnetic bars and steel spheres to play with. Amusing 3-D structures can be built; nevertheless, this possibility is not so obvious. Indeed, in order to build a solid figure it is necessary to join at least three bars to a sphere, and therefore at least two of the poles attached to the sphere present the same polarity, but opposite poles should attract and similar poles should repel. To understand what happens, it is helpful to consider simpler configurations.

Two Bars

The most obvious thing is to observe the magnetic field of a bar (a dipole) in the usual way, i.e., with the help of iron filings. We connected two bars with a sphere in between. It was very surprising for us to note that the bars can easily be joined not only when two opposite poles are facing each other, but even when like poles are facing each other. Therefore we were eager to check how the magnetic field turned out to be in both cases. Since the results were puzzling and interesting, we built various configurations, hereafter exposed.

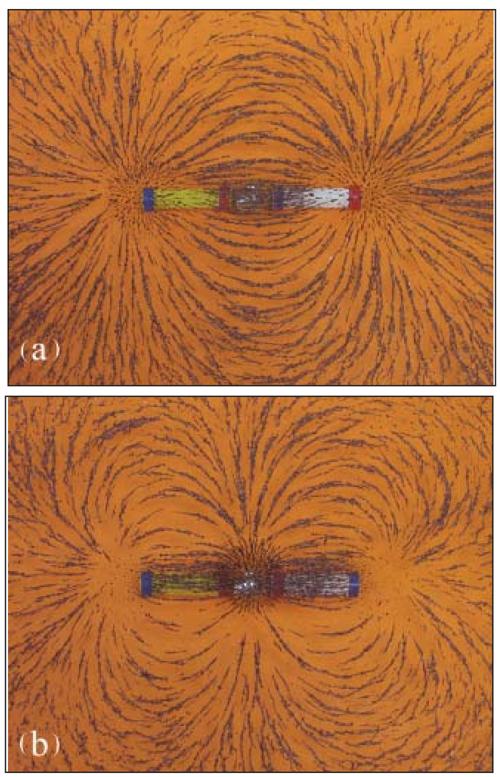

Fig. 1. (a) A dipole: two bars face the sphere with opposite poles, i.e., the sphere is situated between two opposite poles. (b) Two bars face with poles of the same polarity. The sphere is situated between two poles of the same polarity.

When opposite poles of magnetic bars are connected by means of the ferromagnetic sphere, the magnetic field is as expected: a dipole, as shown in Fig. 1(a).[2] The presence of the sphere practically does not change the configuration of a "normal" dipole. The sphere magnetizes showing two poles. On the contrary, when poles of the same polarity are connected to the sphere, something amazing occurs; the sphere magnetizes in an unexpected way [Fig. 1(b)].

Let's try to explain what's going on in both cases. To understand the configuration of Fig.1 (a), let's first consider the sphere and one magnet (magnet 1). Magnet 1 will induce the molecular magnetic dipoles of the ferromagnetic material to line up in the direction of the field. If the north pole faces the sphere, a north-south dipole will be induced in the sphere, with the

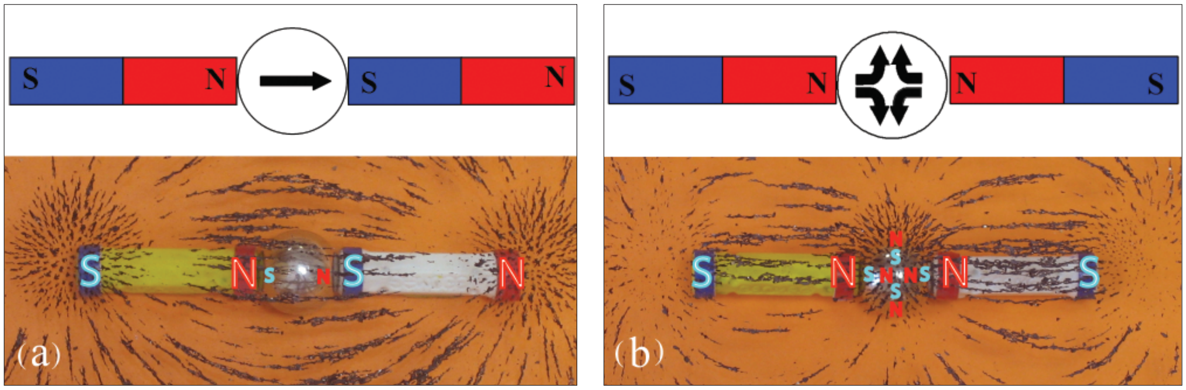

Fig. 2. (a) When the opposite poles of the two magnets face each other, they induce a magnetization in the same direction in the sphere; the resultant field of the sphere is similar to a dipole. Fig. 2(b) On the contrary, when the facing poles are similar, the induced magnetization in the sphere is similar to a quadrupole. The orientation of some elementary dipoles within the sphere is shown. In the upper figures the direction of the field lines inside the sphere is illustrated.

south pole facing the magnet. Thus, the two objects will be subjected to an attractive magnetic force, producing a resulting magnetic field similar to a dipole. Let's now draw the second magnet (magnet 2) close to the sphere. If the south pole faces the sphere, magnet 2 is attracted and the three objects produce a magnetic field similar to a dipole [Fig. 2(a)].

Let's now consider the configuration of Fig.1(b). Again, let's consider one sphere joined to magnet 1 and presenting the north pole in the free side. When the north pole of magnet 2 is drawn close to the sphere, a repulsion force is originated as expected. But drawing the magnet closer and closer, it will eventually stick to the sphere.

To understand this behavior, let's recall that magnetization increases by increasing the external magnetic field; on the other hand, the intensity of the magnetic field decreases with the distance. Magnet 2 tends to magnetize the sphere in an opposite way with respect to magnet 1.

When bar 2 is far away from the sphere, its influence on the sphere is weaker than the one produced by magnet 1; thus, the sphere is magnetized according to magnet 1 along the direction S-N and magnet 2 is pushed back.

On the contrary, when bar 2 is close to the opposite side of the sphere, its magnetic field can be intense enough to induce in the sphere a resulting internal field given by the sequence of poles S-N N-S along the direction of the magnets [Fig. 2(b)]. Magnet 2 is consequently subjected to an attractive force.

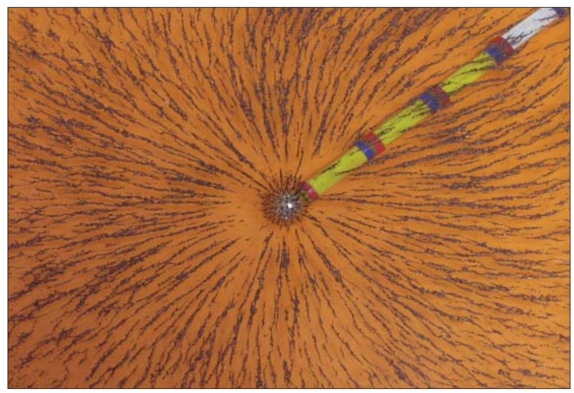

Fig. 3. Did we discover a magnetic monopole?

Figure 2(b) shows that the magnetic field in the sphere presents a configuration similar to the field of a quadrupole. With the help of a little compass it is possible to chart the configuration of the magnetic field around the sphere.

A Monopole?

Since the toy provides a large number of magnetic bars, it is possible to connect them and construct a very long stick (Fig. 3). The field lines show the behavior of a monopole. But where is the trick? Of course the dipole is there, but since the second, opposite pole is very far from the other one, the magnetic field in the neighborhoods of each pole looks like the field of a single electric charge with spherical symmetry.

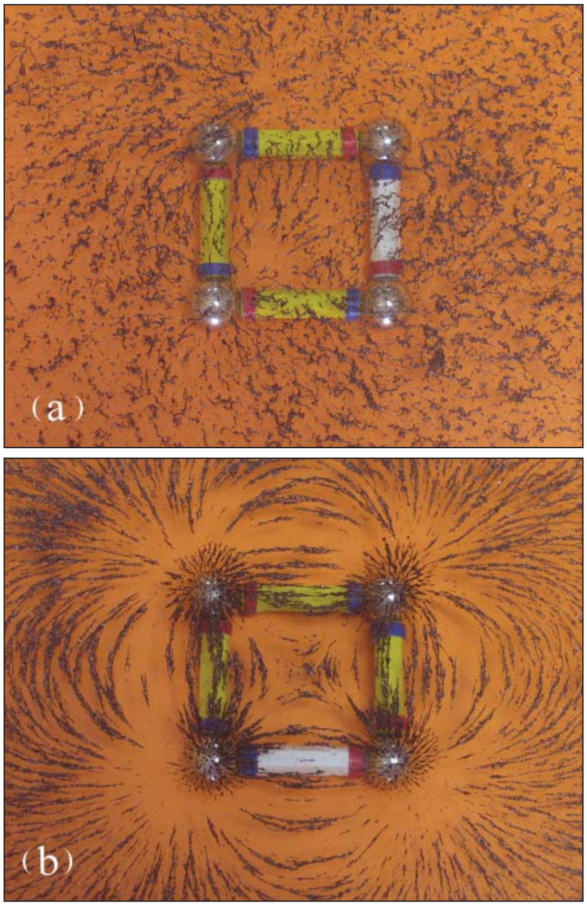

Fig. 4. (a) Each vertex presents opposite poles facing each other. (b) Each vertex presents like poles facing each other. The resulting external field is a quadrupole field.

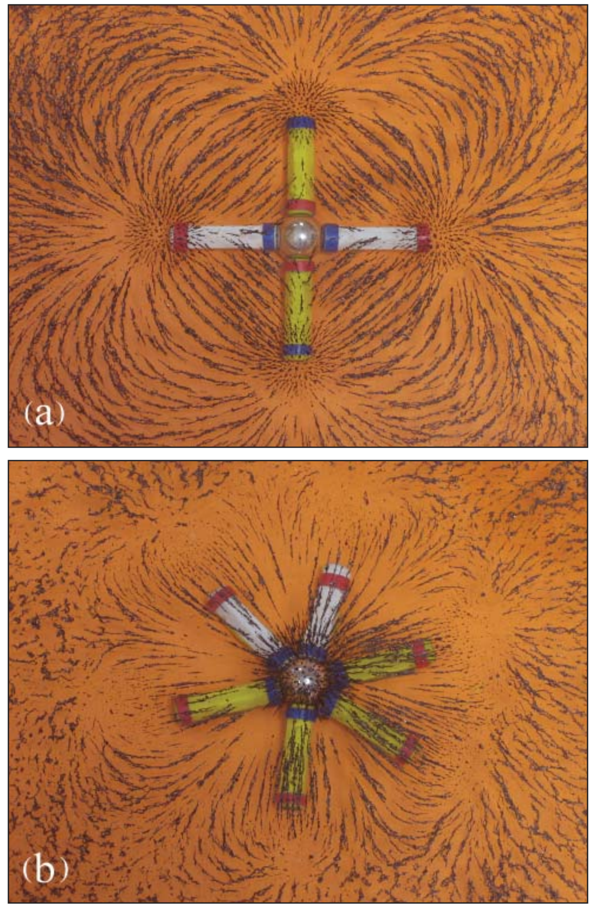

Fig. 5. (a) The poles joined to the sphere of each horizontal and vertical couple are of the same polarity. (b) Poles of the same polarity are joined to the sphere. The sphere shows a plane-like N pole, and two S poles, vertical to the plane of the picture.

Two Closed Loops

The presence of ferromagnetic objects determines the configuration of the field itself. The ferromagnetic object magnetizes strongly, thus creating an additional field that adds to the previous one. The resulting field lines are denser in the ferromagnetic material, while they are less dense in the external area, showing that the field is much weaker. The so-called magnetic shields are based on this principle.

Thanks to the spheres, it is very easy to build a square. Even if the geometrical pattern is the same, it is possible to construct two squares that are completely different from the point of view of their magnetic properties. Observe in Fig. 4 (a) that the bars are connected with opposite poles joined by the sphere. In this way, the field lines are closed in the loop; that is, the magnetic field is confined almost entirely to the ferromagnetic material.

In Fig. 4(b), the configuration is different; the bars are connected with like poles facing the sphere. In this case, again, a quadrupole must be generated in the spheres. An external magnetic field exists and the magnetic circuit[3] cannot be considered closed anymore.

And Much More…

We find it interesting to show the magnetic field lines using this toy, which is nowadays quite widespread. Besides, this toy allows us to make a few remarks that cannot be made using usual laboratory equipment. Of course, many other interesting configurations can be realized, following students' suggestions.

For example, in Fig. 5(a) two north poles facing the sphere form a vertical couple, and two south poles facing the sphere form a vertical couple. This arrangement results in a configuration of a quadrupole field, similar to the one on Fig. 4 (b) but rotated by a 45° angle. In Fig. 5 (b) all the magnets are connected to the sphere with similar poles. The field lines of the north poles are closed on the south poles of the sphere.

References

1. Many toy firms are now selling products similar to GEOMAG ™; http://www.geomagsa.com.
2. Each system of bars and spheres has been put underneath a glass, on the surface of which iron filings have been spread.
3. By "magnetic circuit" we mean a closed configuration of successive ferromagnetic elements in which the magnetic field is almost completely confined. Sometimes the circuit can be interrupted by small openings ("gaps"). The magnetic circuits are widely used in electrotechnics (for example, electromagnets and transformers).

PACS codes: Karl

Silvia Defrancesco *is a high school physics teacher. She is at present following a PhD program in communication of science at the Physics Department of the University of Trento, Italy.*

Fabrizio Logiurato *is a PhD student at the Physics Department of the University of Trento, Italy. His research field is history and foundations of quantum mechanics.*

Grzegorz Karwasz *worked in the Polish Academy of Science, got his PhD in atomic and molecular physics at Gdansk University in 1991, and worked until 2004 at the Istituto Nazionale per la Fisica della Materia, Trento University. Now he is associate professor of physics at Nicolaus Copernicus University in Torun.*