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The Experimental Evidence on the Direct Measurements of Magnetic Monopoles in Magnetized Materials at Room Temperatures

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Abstract

A novel way to measure the isolated single magnetic poles was successfully achieved with simple equipment. A few magnetized pieces were tested and the results showing clearly the existence of separate magnetic charges on all the samples. The many similarities between the magnetic and electric charges were identified. The numerical values of the magnetic charges in our samples were also estimated. The existence of magnetic monopoles has far reaching implications for many other research areas other than magnetism itself, from quantum field theory to cosmology. The direct observation of magnetic charges and current would provide the strongest case for the finding of the magnetic monopoles. In addition, there are evidence that these opposite magnetic charges could be at a significant distance apart, some even greater than 10 meters. This has important implications for future applications of the magnetic materials.

Keywords: magnetic pole of single charges, magnetic monopoles, magnetic dipoles, quantized electric charges, Maxwell equations.

1. INTRODUCTION

There are many papers on the subject of the magnetic monopole (MM) in recent years. The subject matter is involved in many different fields of interests, such as particle physics, solid state, and quantum field theory, etc. However, there is no definite experimental evidence of its existence so far.

In a paper by Dirac in 1931 [1], he stated that in order that the electric charge to be quantized, there must be consistent with the existence of MM. Further development of particle physics, particularly in grand unified theories and quantum gravity also led to the conclusion that MM must exist. However in some theories, which predict that MMs are unlikely to be observed, because of their heavy mass to be created in modern particle accelerators and too rare in the universe to be detected as a particle with much probability [2]. In condensed matter, there are numerous reports since 2009 [3,4,5,6], that the quasi-particle MM were observed in so-called spin-ice at very low temperatures.

We note that Dirac's version [1] of MMs involves a string carrying magnetic flux, the ends of which act as north and south MMs. In this paper, we would like to report the observation of this analogous string and the separate locations of the North and South MMs in several magnetizing materials.

There are many similarities between the electric and magnetic charges. We will use this comparison as the basis for establishing the existence of MMs in magnetic systems. It is in fact very common to find the MMs in our daily environment. Most of the permanent magnets and magnetic materials should have them.

We are going to report the experimental results of MMs, such as the values of the magnetic charges involved, equipotential lines, Lorentz force (under external electric field) and the refractive effect between two different media which resulted a different locations for the MMs.

It is true in other magnetic system such as 'spin ice', which did provide some information about MMs and Dirac string. However, our system is much simpler to work with and to have an easy access directly to that of MMs.

It should be interesting to measure other relevant parameters of MMs in a magnetic system. And it can be studied in detail with other tools, such as neutron diffraction, heat capacity, ultrasound and many others in order to learn more about the characteristics of MMs and Dirac string.

2. METHODS

2.1. Sample preparation

All samples for the present experiment are prepared as described here. One piece of the sample was first magnetized with a small permanent magnet (about 0.1 T), either North or South facing one side of the sample only for about one minute. Then the permanent magnet is removed and the sample is ready for measurement.

2.2. Magnetic field directions and intensity measurement

With a small compass going around the sample, one can map out the magnetic field directions surrounding the sample. They are recorded with a pencil on a piece of paper for record keeping. A Gauss meter (Model 1, Alpha Lab Inc.) capable of measuring the field down to about 10^{-4} T was used to measure the magnetic field intensity of each point of interest. The Gauss meter has a small sensor tip which can put right on top or the side of the sample for readings. For a disk sample, the equipotential curve and flux lines were measured in this way. To measure the strings between the monopoles, take the readings on top of the sample as well. For example, the strings were measured along the rim of a ring sample. Since most of the samples are two-dimensional, to measure the three-dimensional features of the monopoles, one needs to make the sample standing upright so that the compass and Gauss meter can take the measurements sideway. When taking the small field readings, care must be taken not to be confused with the superposition of the earth magnetic field (which may have the similar values).

2.3. The electric field set up

In order to test whether the MM and the virtual poles (VP) will be effected by an external electric field due to Lorentz force, this was done in the following manner. An electric field was created between two parallel regular CDs which were wrapped with thin aluminum foil and mounted on an insulted stand. A DC power supply of 30 volts was used to produce an electric field between the four cm gap. The magnetized bar was then placed and moved from bottom to up position in the electric field and only the wide face was perpendicular to the field direction. To make sure only the upward movements were done, it was carefully moved out of the field when the wide face was parallel to the field. This is to make certain that the Lorentz force only affected the MMs and VPs when the movement is perpendicular to the field. (It was proved later that when the field direction is parallel to the bar movement there is practically no effect on MM and VP).

3. RESULTS AND DISCUSSION

3.1. A thin steel bar

A paper binder of about 30 cm long, 0.5 cm wide and 0.025 cm thick was first magnetized as described in Sec. 2.1. Then the magnetic field lines were measured.

The result of magnetic field directions is showing in Fig. 1. Two types of features were observed. One is the star shape point-like structure near each end, the other are focal points of field lines on each side of the bar. The center of star-shaped structures were identified as single magnetic poles (or monopoles, MM), they are concentrated sites of either North or South magnetic charges. The other types which are not MMs in their real locations were called virtual poles (VP). This new observation due mainly to the refraction effect of the field lines in the materials will be discussed in Sec. 3.3.

For an MM, a single magnetic charge should have the lines of forces as shown in Fig. 2; it looks the same as that of the single electric charges [7]. Thus we can estimate the magnetic charges with the Gauss law as follows: Using a Gaussian sphere surrounding the magnetic charges Q_m of radius r in:

$\nabla \cdot \overline{B} = \mu_0 Q_m$ where $\mu_0 = 4\pi \times 10^{-7}$ N/A^2, the magnetic permeability in vacuum, one can calculate the value of Q_m. Using B= 5 x 10^{-4} T,

r= 5x10^{-3}m, and we get Q_m= 2.5 A-m. This agrees well with the Q_m calculated from the equation of Coulomb-type law; $\overline{B} = (\mu_0/4\pi)(Q_m/r^2)\,\overline{r}$.

In order to test whether the MM and the VP will be affected by an external electric field due to Lorentz force, this bar was put in an electric field up to 30 volts as described in Sec. 2.3.

The resulting effect of this electric field exposure to the magnetized bar is very interesting. There is a slight movement of the MM, but that of the VP is very different. The distances between the bar and the PVs have changed. Sometimes it becomes unsymmetrical with respect to the bar.

Due to the small amount of movement from the Lorentz force on MMs, it is difficult to estimate any meaningful numbers from the data. A higher electric field would provide better data for this purpose. Work is in progress along this direction.

3.2. A circular disk and ring:

It is interesting to observe where and how the MMs and VPs were distributed in a magnetic material of different geometries, such as a circular disk or ring. A disk of 8.5 cm in diameter and 0.025 cm in thickness (which was the cover of a jar for making can food) was used for this test. The results are similar to the case of a steel bar. There are normally two MMs, one on each side of the disk. Sometimes three MMs 120 degrees apart appeared also. They are all situated very close to the edge of the sample. The refraction effect was observed on all MMs, this makes the appearance of the focal point at a different location as shown in Fig. 3. The real locations of these MMs were confirmed by the Gauss meter.

Additional measurements were done to map out the lines of equal magnetic field strength on the surface of the disk. These lines which were perpendicular to the directions of the field lines are just the equipotential lines between two magnetic poles (Fig. 3). They look exactly like the curves between two opposite electrical charges [8].

3.3. The refraction effect

The appearance of virtual poles (VP) in some of the experiments needs some explanation. When the magnetic field lines going through two Medias of different permeability, it is refracted at the boundary [9]. This is the main reason for the existence of VPs; they normally come in pairs for a steel bar, one on each side (Fig. 1 and 4). They appeared in circular disk and rings as well. In some cases they look as if they were located outside of the body, but in fact they are not located outside physically. This was checked by a Gauss meter. Some are very near to the edge of the disc and ring (see Figs. 3 and 5).

Here is a simple example to illustrate how one can deduce some numerical parameters from the measurement [9]. In the experiment of the steel bar, one can measure the incidence and refracted angles, θ_1, $\theta 2$ of a particular field line near the boundary. We have θ_1= 18 deg. and θ_2= 64 deg. Using the equation $\mu_2 \tan \theta_1 = \mu_1 \tan \theta_2$, we get $\mu_2 = 6.4\ \mu_1 = 6.4\ \mu_0$ (μ_0 is the permeability in vacuum). Here μ_2 is the permeability of the steel bar being used in our experiment. One noticed that it is a simple way to measure the permeability of a material. One interesting application is that it is possible to measure the permeability of the earth and other magnetic planets if the MMs were to be found and measured in some location near the north and south poles. It is believed that this refraction effect is unique to the property of MMs and VPs; it would not be the same from a magnetic dipole.

3.4. The magnetic field and equipotential lines

Many samples of different geometries and magnetic materials were also measured. Nails, long iron screws, elliptical shape tin can cover, square shape thin plate and small permanent magnet were used as testing pieces. They all show different locations of the MMs and VPs depending on the geometry.

In particular, we like to show the results of two small permanent magnets, each about 2.6 cm long and 0.6 cm in diameter. It shows the field lines with opposite magnetic charges placed nearby to each other (Fig. 6). One noticed that the field pattern was the same as that of any two magnets would except the appearance of the MMs near the end of each pole. This also conforms to the similar field lines appeared with two opposite electrical charges [8].

Same measurements were done with a *ring* of 8.5 cm in diameter and about 0.5cm in width (this is part of the cover of the food can). In this case, the only difference is that there are VPs instead of the MMs due to the same refraction effect. One other interesting feature were being observed, that are also the field lines going along the rim of the ring (see Fig. 5). These two lines as strings show the strong connections between the two VPs (or MMs) in analogous to what Dirac described in [1].

3.5. The forces between two monopoles

The experiments of measuring the forces between two permanent magnets are not new. However we can deduce the magnetic charges from this simple experiment.

Similar to the use of the electroscope to detect the single charges, one can also make a magnetoscope to measure the magnetic charges. Put two small permanent magnets together with the same polarities facing each other. They immediate moved apart, just like the electroscope for the same electric charges. Knowing the weight and the angle of opening, one can estimate the magnetic charge Q_m in each of the magnets. To calculate the Q_m, we use the equation:

$$F = Mg \cot \theta = (\mu_0 /4 \pi)(Q_m^2/[L/2]^2 \sin^2 \theta)$$

With the values from the experiment: μ_0 =4 π x 10^{-7} N/A^2, L=4x 10^{-2} m, M=4.73x 10^{-3} kg, g= 9.8 m/s^2 and θ =30^0 (half the angle extended by the two magnets), we obtained Q_m= 8.98 A-m.

Using the equations and numbers formulated by Errede [10] where Q_m^0 = 3.29 x 10^{-9} A-m is one unit of quantized magnetic charges. One can estimate the number of flux quantum associated with the magnetic charge Q_m to be n=8.98/Q_m^0 =2.71 x 10^9, a very large number. According to [10], the ratio of forces between the magnetic charges to that of electric charges is 4700 x n^2= 3.47 x 10^{22}. This shows that the forces between the magnetic poles are so many orders of magnitude larger than between the electric poles. This may be part of the reason why we only find the magnetic dipoles (with two MMs) much more often than the electric ones. Furthermore the magnitude of Q_m is very large as compared with that of electric charges.

3.6. The characteristics of magnetic monopoles

As we described earlier that the MMs are just a collections of either N or S magnetic charges concentrated in a very small point within a magnetic material. The associated flux lines are a three-dimensional structure. In nature, perhaps the best visual analogy is to a dandelion blossom (just before its spreading of seeds). The lines of magnetic force going out (N) or in (S) toward the point source behave exactly like a point source of electric charges [7] (either + or -) (see Fig.2).

There are a few specific features of MMs in terms of their locations. One noticed that it appears near the center of a semi-circle if that is the shape of the end of a steel bar. But it will be near the surface if the piece is flat at the end. The virtual poles (VPs) appeared if the surface is curved, such as that in a ring or a circular disk.

It is important to point out that most of the MMs appeared in pairs in a given magnetic material of any given size and shape of a bar, one on each end with opposite magnetic charges. This could be considered to be a *DIPOLE* of two MMs. Each MM maintains its own separate point locations and magnetic charges as a *single entity* just like the electric point charges does in an electric dipole. The appearance of the MMs in a permanent magnet (or in any magnetized body) with their lines of forces as a whole are different from the regular pictures presented in the Physics textbook [11]. For example, in a horse shoe permanent magnet, the difference of the two is to include the MMs as is clearly shown in Fig. 7a and 7b.

The pair of MMs of opposite charges is very strongly connected by a string similar to what Dirac [1] described his paper. They pulled the two MMs together in the sample for a one-dimensional steel bar. In a *ring* sample, the two strings go along the rim in a semi-circular path. In the case when a bar magnet breaks up into two, this string of flux connecting the MMs immediately generate two more MMs of opposite charges to two separate pieces. In addition, in some cases, there are more than two or even three MMs in one piece of sample; this is very different from the case of a dipole in the sample.

CONCLUSIONS

In the present work we have presented the first direct evidence of pointed-like magnetic monopoles which were connected by the extended Dirac strings. It provides convincing evidence for the separation of north and south poles -the splitting of the dipoles- in the magnetic system**.** These strings can make connections between the MMs up to a significant distance of ten meters and transmit magnetic charges up to 30 meters.

This work may set the magnetic materials to the same status as electronic materials in our society because magnetic materials are becoming more important in all aspects of our daily life.

From the theoretical point of view, the fundamental equations of Maxwell are now more complete to include the magnetic monopoles and magnetic current. The modified equations are symmetric under the duality transformation [2, 12]. The unified theory in quantum field theory may also be modified among many other fields of interest.

However there are more open questions remain to be answered. For example, why the magnetic charges would congregate to a point as MM and how? What are the interactions between MMs? And what are the spins, mass, magnetic moment, angular momentum, etc. of MMs? Therefore it opened up a series of questions both in terms theories and experiments.

FIGURE CAPTIONS AND LEGENDS

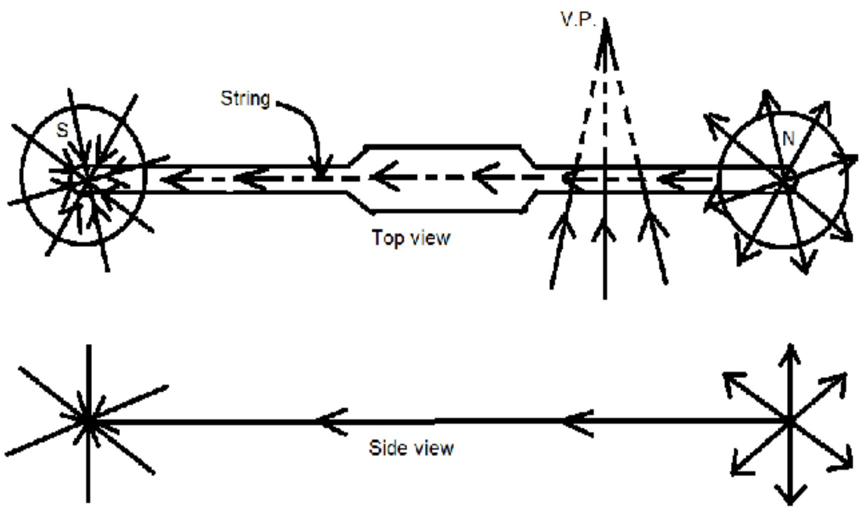

Figure 1. The magnetic monopoles at both ends of a thin steel bar.

The two monopoles were connected by the Dirac string in between. Since the magnetic flux lines of the monopoles are directing outward at the North pole and inward at the South pole in three dimensions, a side view helps to make a better picture. Only one virtual pole is showing for simplicity, normally two, one on each side is present.

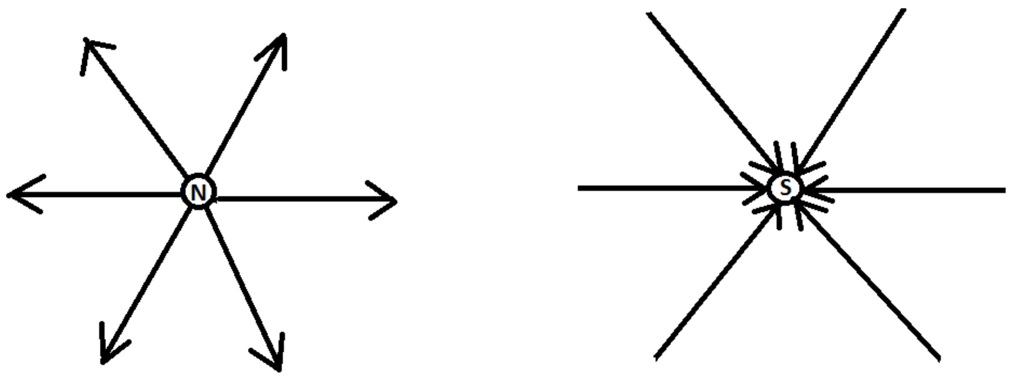

Figure 2. The magnetic field lines of single magnetic charges of monopoles.

Just like the electric charges of single electric poles, the field lines emanating from the monopoles in all directions. In nature, perhaps the best visual analogy to a magnetic monopole is a dandelion blossom (just before the spreading of seeds).

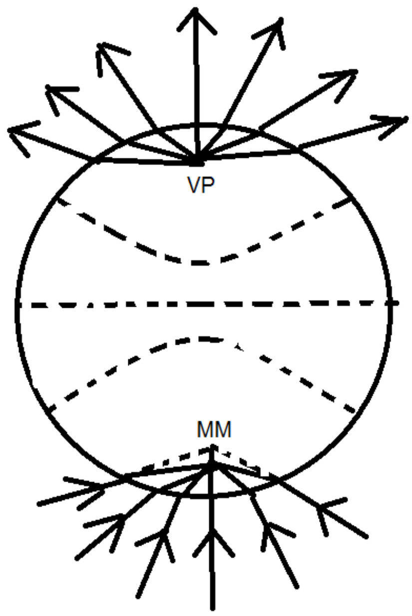

Figure 3. The refractive effect of virtual poles in a disk.

The magnetic monopoles at two ends were displaced by the refraction to shallower locations. For simplicity, only one virtual pole and monopole are shown here. The equipotential lines are also shown. For simplicity the magnetic field lines (which are perpendicular to these lines) are not showing here.

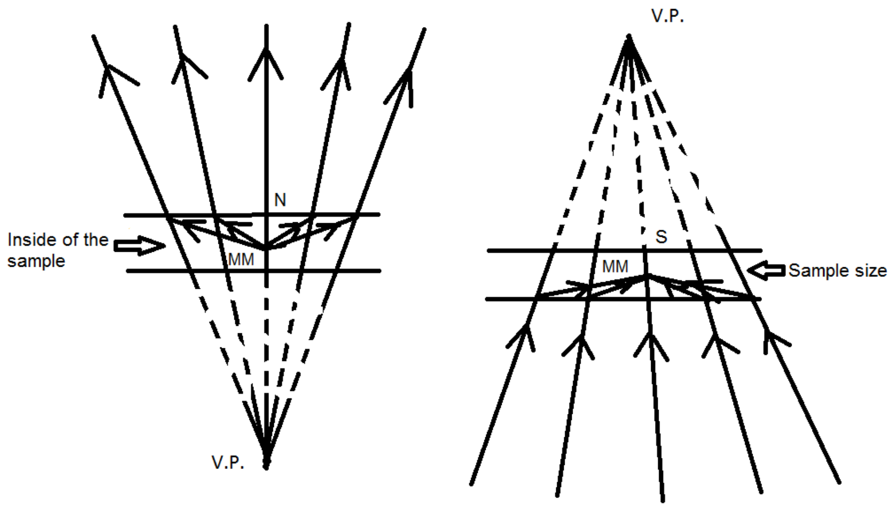

Figure 4. The virtual poles are located outside of the sample.

Two virtual poles (V.P.), one on each side of a thin steel bar were normally observed. This refractive effect makes the real monopoles too far than one thinks. The effect is similar to observe an object under water in reverse.

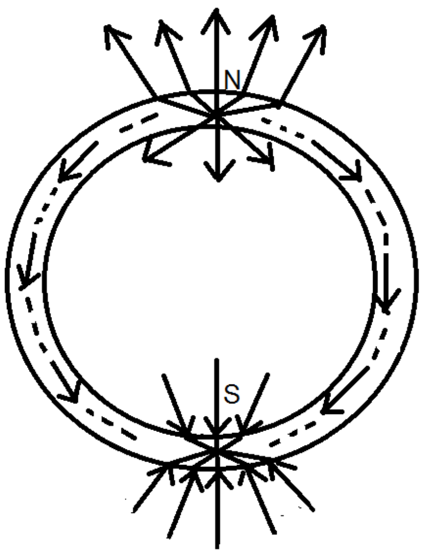

Figure 5. Two magnetic monopoles of a ring sample.

In a ring sample, there are two strings going around the semi-circle between the two monopoles. The same refraction effect was observed for the virtual poles.

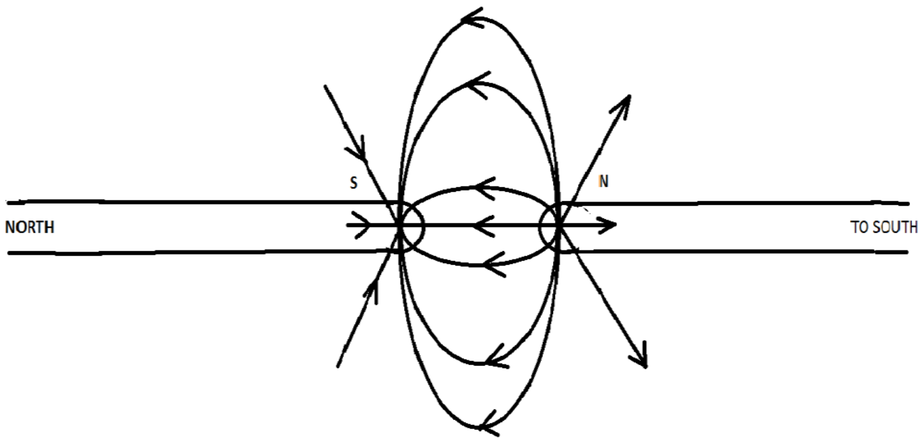

Figure 6. the magnetic field lines between two monopoles of opposite charges from two permanent magnets.

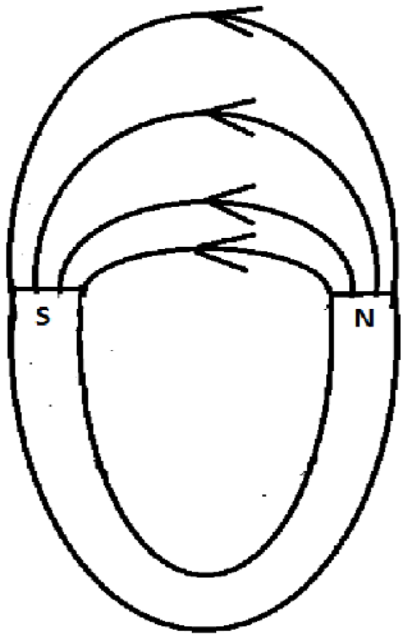

Figure 7a. The regular drawing in Physics textbook for the field lines from a horse shoe permanent magnet.

There are no magnetic monopoles included here.

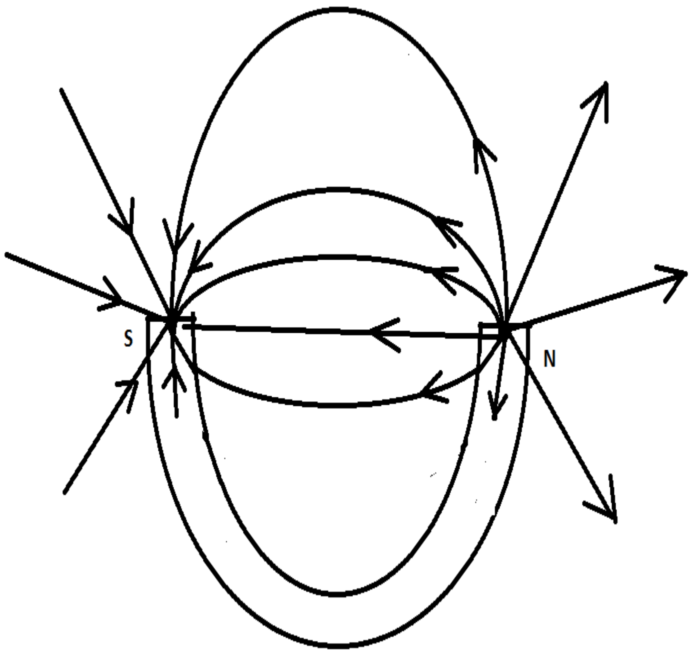

Figure 7b. The field lines of a horse shoe magnet to include magnetic monopoles should look like this.

The magnetic field lines should include the magnetic monopoles from the present work**.**

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[7] Giancoli D C, *PHYSICS FOR SCIENTISTS AND ENGINEERS*, (Third Edition) (2000), (Prentice Hall, Upper Saddle River, N.J.) ISBN 0-13-029096-3, p.578, Figure 22-7: The electric field lines of a single charge.

[8] Giancoli D C, *PHYSICS FOR SCIENTISTS AND ENGINEERS*, (Third Edition) (2000), (Prentice Hall, Upper Saddle River, N.J.) ISBN 0-13-029096-3, p.600 , Figure 23-14: The equipotential and field lines for two equal and opposite electric charges.

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