IJST EXPLORE
International Journal of Science and Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-7318

International Journal of Science and Technology Volume 1 No. 12, December, 2012

Experimental Evaluation of the Earth's Magnetic Field in Lapai, Northern Nigeria

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ABSTRACT

The earth's magnetic field is a natural and an ever changing phenomenon due to the continuous convectional activities that take place within the earth. When the field is so intense and it interacts with the atmosphere, magnetic storms occur. It is therefore necessary to monitor the field within one's vicinity. The magnetic field intensity within Lapai, Nigeria was determined using an experimental approach. Three experimental set ups were used and the average magnetic field obtained was 34.91±1.13µT. This result agreed, within the limits of experimental error, with the estimated result by the National Geophysical Data Centre for Lapai (latitude $9^0$03'00"N and longitude $6^0$34'00"E at an elevation of 162m) which was 33.9178 µT within the same period of investigation. This value portrays no danger of magnetic storm in the area.

Keywords: *Convection, magnetic field, magnetic storm, Lapai*

1. INTRODUCTION

Lapai is a local government area in Niger State adjoining the Federal Capital Territory, Abuja. Its headquarter is in Lapai town, located along A124 highway at latitude $9^0$30'00"N and longitude 6^o34'00"E (http://en.wikipedia.org/wiki/Lapai) at an elevation of 162m, with a land mass of 3,051km^2 and a population of 110127 according to 2006 census.

The Earth's magnetic field is believed to be produced by electric currents circulating in the core of the earth. These currents are thought of as being generated by the complicated churning of molten iron within the earth's core. The fact that a suspended permanent magnet always aligns itself to the geographical poles of the earth is again due to the magnetic force between the currents in the earth's core and the current in the magnet (Buffett, 2007).

Magnetic field lines appear to originate near the south geographic pole, i.e. magnetic north pole, and terminate near the north geographic pole, i.e. magnetic south pole. This however, does not mean there exist magnetic monopoles as no claims of such have been established. Magnetic field lines are therefore in closed circular paths.

The magnetic properties of materials are classified in a number of ways. One classification is into: diamagnetic, paramagnetic, and ferromagnetic based on how these materials react to the magnetic field (Blume, 2008)

According to Telford et al. (1976), diamagnetic materials, when placed in a magnetic field, have a magnetic moment induced in them that opposes the direction of the magnetic field. Thus, diamagnetic substances have negative susceptibilities. Paramagnetic substances on the other hand, have positive magnetic susceptibilities. This behavior results in materials when the applied magnetic field lines up all the existing magnetic moments of the individual atoms or molecules that make up the material. While ferromagnetic substance is one that retains a magnetic moment even when the external magnetic field is reduced to zero. This effect is a result of a strong interaction between the magnetic moments of the individual atoms or electrons in the magnetic substance that causes them to line up parallel to one another.

A greater understanding of the atomic origins of magnetic properties recently has resulted in the discovery of other types of magnetic ordering. Substances are known in which the magnetic moments interact in such a way that it is energetically favourable for them to line up antiparallel; such materials are called anti-ferromagnetic materials.

Other more complex atomic arrangements of magnetic moments include ferrimagnetic substances which have at least two different kinds of atomic magnetic moments, which are oriented antiparallel to one another. Because the magnetic moments are of different sizes, a net magnetic moment remains, unlike the situation in an anti-ferromagnetic material where all the magnetic moments cancel out, (Telford et al., 1990).

Understanding the environment in which one lives makes one conscious of the activities that take place within his vicinity and possible actions could be taken to harness environmental gains and discard the ensuing frivolities. Everyone is familiar with weather systems on Earth like rain, wind and snow. But space weather – variable conditions in the space surrounding Earth – has important consequences for our lives inside Earth's atmosphere. Solar activity occurring miles outside Earth's atmosphere, for example, can trigger magnetic storms on Earth (http://www.usgs.gov/blogs/features/usgs 2012). These storms are visually stunning, but they can set our modern infrastructure spinning. Consequently, the study of the magnetic field of one's environment is encouraged and that is what was done in Lapai, Nigeria by the authors.

2. MATERIALS AND METHODS

Oersted showed that a magnetic field is produced whenever current flows through a wire. The magnitude and direction of the field at points near the wire depends on the shape of the wire as well as the amount of current flowing through the wire. One particularly useful geometry that commonly occurs is a single circular loop of wire. The magnetic field, B, at the centre of such a loop is given by Griffiths (1988) as:

$$\boldsymbol{B} = \frac{\mu_0 \boldsymbol{I}}{2R} \qquad (1)$$

Where μ_o = 4π x 10^{-7} Tesla-m/amp, I is the current in amps and R is the radius of the loop in meters. The direction of **B** is given by the right hand rule.

The earth's magnetic field **B**$_e$ can be decomposed into a component B_h which is parallel to the plane of the horizon and a component B_v which is perpendicular to the plane of the horizon (Figure 1a). These components are related by the expression:

$$B_e = \frac{B_h}{cos(\theta_i)} \qquad (2)$$

where θ_i is the angle of inclination.

If a compass needle is subjected to a known external magnetic field B_x which acts perpendicularly to B_h, the compass needle will deflect through an angle θ_x away from magnetic south (Figure 1b). Consequently, B_h is related to B_x by:

$$B_h = \frac{B_x}{tan(\theta_x)} \qquad (3)$$

Equations (3) and (2) relate the earth's magnetic field, which is unknown, to the magnetic field B_x. Whenever current passes through the coil, a magnetic field is produced perpendicular to the plane of the coil. The magnitude of the magnetic field B_x at the centre of the coil can be obtained from equation (1) as:

$$B_x = \mathrm{N}\ \frac{B(4\pi\times10^{-1})\mathrm{I}}{D}\mathrm{mT} \qquad (4)$$

Where N is the number of turns which the coil comprises, D is the diameter of the coil measured in meters, and I is the current through the coil measured in amps.

The experimental setup was as shown in figure 2. A location in the laboratory was chosen as far as possible from any magnetic materials (iron, pipes, etc) and the plane of the current coil of the galvanometer was aligned as closely as possible with the direction of the earth's magnetic field as shown by the compass at the center of the coil.

The knob for both current and voltage settings of the power supply (variable source with ammeter embedded) were set to enable the compass needle deflect. Using the angular markings on the compass, the coil was rotated by 90°with respect to the compass needle, so that any magnetic field generated by the coil will be perpendicular to the horizontal component of the earth's magnetic field.

The current setting was set at zero initially and subsequently slowly increased until the compass needle deflected 45^o, i.e. $q_x = 45^0$. The polarity of the connections at the power supply was then reversed ensuring that the compass needle deflected approximately 45^0, in the opposite direction and the value of the current I was recorded.The procedure was repeated for fourteen other values in the interval of 5° and the results recorded in tables 1, 2 and 3.

Using equations (2), (3) and (4), the values of B_e, B_h and $B_x$were respectively calculated and recorded in the tables. The same procedure was repeated for two other set ups with different coil diameters.

The angle of inclination q_i was measured with the aid of the compass needle to be 25^o A comparison was then made between experimental results and that of National Geophysical Data Center (NGDC) for a possible correlation.

Given a set of data $x_i(i$ = 1……N) corresponding to a quantity whose true value is x_t. If each of the x_i differs from x_t, because each x_i includes a random error ε_i then an unbiased estimate of x_t is $x_t = \bar{x}$ given by:

$$\bar{x} = \sum_{i=1}^{N} x_i \qquad (5)$$

and the unbiased standard error is

$$\boldsymbol{\sigma} = \frac{\sigma_{N-1}}{\sqrt{N}} \qquad (6)$$

where

$$\sigma_{N-1} = \sqrt{\sum_{i=1}^{N} \frac{(x_i - x)^2}{N-1}} \qquad (7)$$

Therefore,

$$\boldsymbol{\sigma} = \frac{\sqrt{\sum_{i=1}^{N} \frac{(x_i - x)^2}{N-1}}}{\sqrt{N}} \qquad (8)$$

3. RESULTS AND DISCUSSIONS

The horizontal and total components of the magnetic field were evaluated for various angular and current variations together with the information on the diameter of the coil and the number of turns, for the three experimental set ups using equations (2), (3) and (4). The results are shown in tables 1, 2 and 3.

Using $\theta_i = 25^0$ and the information in table 1.

The average value of B_e= 30.84 μT

From equation (8) with N = 15 and the information in table 1,

σ = 1.20

Therefore $B_{e\,=}$ 30. 84 ±1.20μT

From table 2

Average Values of B_e = 33.91(μT)

Using equation (8) and the information in table 2 gives:

σ = 0.90

Therefore $B_{e\,=}$ 33.91± 0.90μT

From table 3

Average Values of B_e(μT) = 39.98

and the Standard Error(**σ**) = 3.78

Therefore $B_{e\,=}$ 39.98 ± 3.78 μT

Total average of earth's magnetic field B_e(μT) for three experimental set ups :

$$B_e = \frac{30.84 + 33.91 + 39.98}{3}$$
$$= 34.91\mu T$$

Total average of standard error (σ) for three experimental set ups

$$\frac{1}{S_m^2} = \frac{1}{S_1^2} + \frac{1}{S_2^2} + \frac{1}{S_3^2}$$

$$\frac{1}{S_m^2} = \frac{1}{1.20^2} + \frac{1}{0.90^2} + \frac{1}{3.78^2}$$

$$s_m = \sqrt{\frac{1}{0.021304517}} = 1.13$$

Figures 3, 4 and 5 represent respectively, the graphical representation of the variation of the earth's magnetic field with current for the different diameters of the coils used in the three experimental setups. The graphs show the geomagnetic jerks due to the applied current. The jerks are most significantly typified at lower currents as seen on the graphs.

4. CONCLUSION

The best estimate that was obtained for magnetic field intensity (B_e) in Lapai using magnetostatic and elementary vector analysis was 34.91 ±1.13μT. This value was inperfect agreement to the standard value obtainable from the National Geophysical Data Center (NGDC) for the location of Lapai, which was 33.92 μT. The slight variation of this value from the NGDC value was accounted for in the evaluated experimental errors. The methodology and the limitation of the instrument used in the experiment may be responsible for the slight differences. The difference could have been more salient if advanced equipment were employed in the magnetic field determination. The strong agreement of the experimental value with the NGDC value and the comparatively low nature of the values indicates that no danger of magnetic storm may be envisaged in the area.

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Table 1: Variation of magnetic field components with current for a coil of Diameter, D = 0.11m and Number of turns, N = 30 and angle of inclination θ_i =25^0

Exp.No	θ_x^o	I(A)	$B_x(\mu T)$	$B_h(\mu T)$	$B_e(\mu T)$	$(B_e - \bar{B}_e)$	$(B_e - \bar{B}_e)^2$
1	15	0.026	8.911	33.256	36.694	5.855	34.286
2	20	0.033	11.311	31.076	34.289	3.450	11.902
3	25	0.043	14.738	31.605	34.873	4.034	16.271
4	30	0.050	17.138	29.683	32.752	1.913	3.659
5	35	0.060	20.565	29.369	32.405	1.567	2.454
6	40	0.070	23.993	28.593	31.549	0.710	0.505
7	45	0.086	29.477	29.477	32.525	1.686	2.842
8	50	0.100	34.276	28.760	31.733	0.895	0.800
9	55	0.120	41.131	28.800	31.778	0.939	0.881
10	60	0.150	51.414	29.683	32.752	1.913	3.659
11	65	0.180	61.697	28.769	31.743	0.904	0.818
12	70	0.210	71.980	26.198	28.907	-1.932	3.734
13	75	0.280	95.973	25.715	28.374	-2.465	6.078
14	80	0.370	126.822	22.362	24.674	-6.165	38.006
15	85	0.530	181.664	15.893	17.536	-13.303	176.963

Table 2: Variation of magnetic field components with current for a coil of diameter =0.08m and number of turns = 30

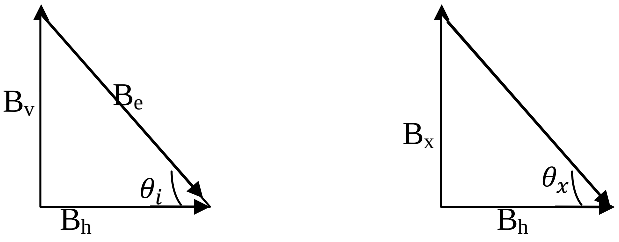
Exp.No	θ_x^o	I(A)	$B_x(\mu T)$	$B_h(\mu T)$	$B_e(\mu T)$	$(B_e - \bar{B}_e)$	$(B_e - \bar{B}_e)^2$
1	15	0.016	7.540	28.139	31.048	-2.859	8.171
2	20	0.023	10.839	29.779	32.858	-1.049	1.100
3	25	0.030	14.139	30.321	33.456	-0.451	0.203
4	30	0.040	18.852	32.652	36.028	2.121	4.499
5	35	0.050	23.565	33.654	37.133	3.227	10.411
6	40	0.060	28.278	33.700	37.184	3.277	10.742
7	45	0.070	32.991	32.991	36.402	2.495	6.226
8	50	0.080	37.704	31.637	34.908	1.001	1.002
9	55	0.100	47.130	33.000	36.412	2.505	6.275
10	60	0.110	51.843	29.931	33.025	-0.881	0.777
11	65	0.150	70.695	32.965	36.373	2.466	6.083
12	70	0.190	89.547	32.592	35.962	2.055	4.223
13	75	0.240	113.112	30.308	33.441	-0.465	0.216
14	80	0.330	155.529	27.423	30.258	-3.649	13.312
15	85	0.530	249.789	21.853	24.112	-9.794	95.930

Table 3: Variation of magnetic field components with current for a coil of Diameter, D=0.09m and Number of turns, N = 30

Exp.No	θ_x^o	I(A)	$B_x(\mu T)$	$B_h(\mu T$	$B_e(\mu T)$	$(B_e - \overline{B_e})$	$(B_e - \overline{B}_e)^2$
1	15	0.010	4.189	15.633	17.249	-22.729	516.623
2	20	0.023	9.635	26.471	29.208	-10.771	116.011
3	25	0.030	12.568	26.952	29.738	-10.240	104.860
4	30	0.040	16.757	29.023	32.024	-7.955	63.282
5	35	0.050	20.946	29.913	33.006	-6.973	48.622
6	40	0.060	25.136	29.955	33.052	-6.927	47.978
7	45	0.070	29.325	29.325	32.357	-7.622	58.091
8	50	0.100	41.893	35.152	38.786	-1.192	1.422
9	55	0.120	50.272	35.200	38.839	-1.139	1.298
10	60	0.160	67.029	38.699	42.700	2.721	7.406
11	65	0.200	83.786	39.070	43.109	3.131	9.802
12	70	0.270	113.112	41.169	45.425	5.447	29.667
13	75	0.380	159.178	42.655	47.065	7.086	50.217
14	80	0.690	289.033	50.969	56.239	16.260	264.386
15	85	2.000	837.778	73.303	80.882	40.903	1673.056

Table 4: Showing the results for experiment and NGDC

EXPERIMENT NO.	EXPERIMENTAL RESULT B_e (μT)	NGDC RESULT B_e (μT)
1	30.84±1.20	33.92
2	33.91± 0.90	
3	39.98 ± 3.78	



(a) **(b)**

Figure 1: The horizontal and vertical component of the earth's magnetic field

Figure 2: Experimental set-up

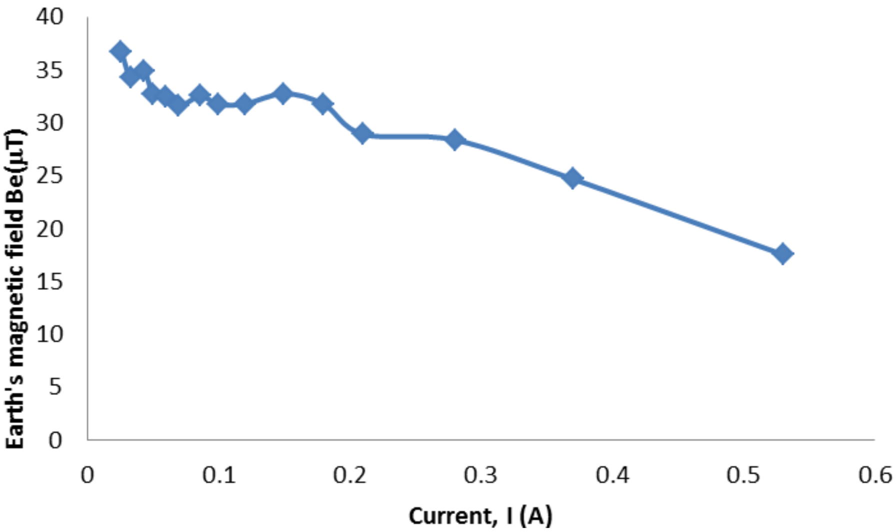


Fig. 3: Variation of the earth's magnetic field with current for a 0.11mm diameter coil

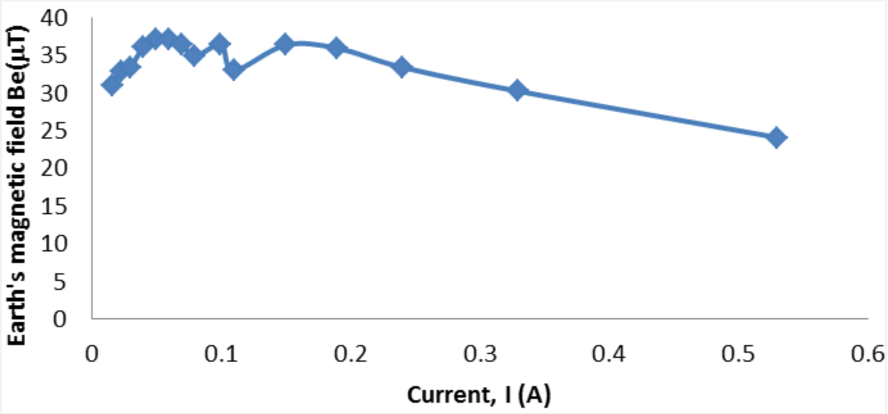


Fig. 4: Variation of the earth's magnetic field with current for a 0.08mm diameter coil

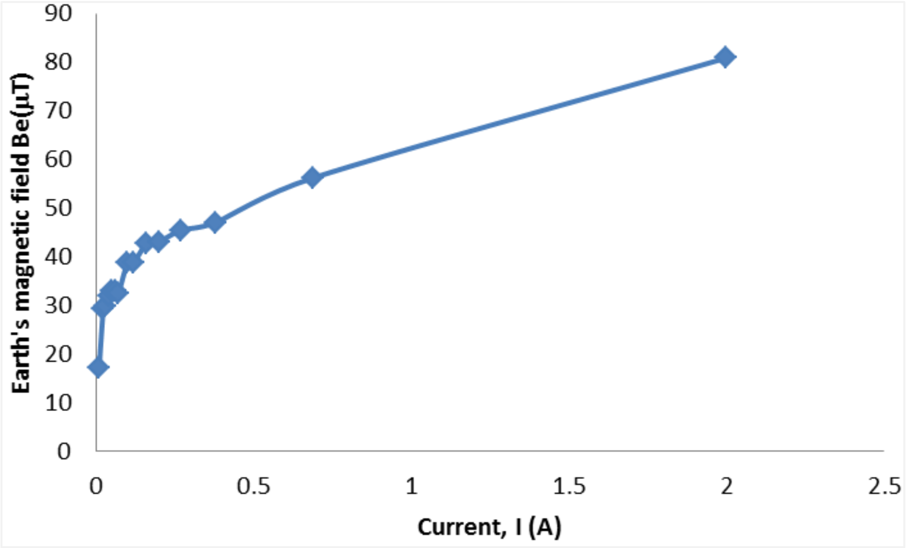


Fig. 5: Variation of the earth's magnetic field with current for a 0.09mm diameter coil