

Non local motional electrodynamics

JORGE GUALA-VALVERDE, ROBERTO BLAS, PEDRO MAZZONI,

Fundación Julio Palacios, Alderete 285 (8300) Neuquén – Argentina
fundacionjuliopalacios@usa.net

ABSTRACT. We report some recent experiments on motional induction, performed on partially shielded circuits. Both electro and ponderomotive forces are insensitive to magnetic shielding. Laplace and Lorentz local forces must be applied with considerable care when dealing with motional induction.

KEYWORDS. Motional induction, homopolar devices, non local actions, Lorentz force.

1 Introduction

The physics underlying motional electromagnetic induction was advanced in 2001 [1] and recent overviews on the whole issue can be found in the literature [2,3,4].

Figure 1(left) sketches a homopolar generator in which a radial probe is spun at ω (rad/sec) whilst both the permanent magnet and the closing wire remain stationary in the lab (first Faraday homopolar generator).

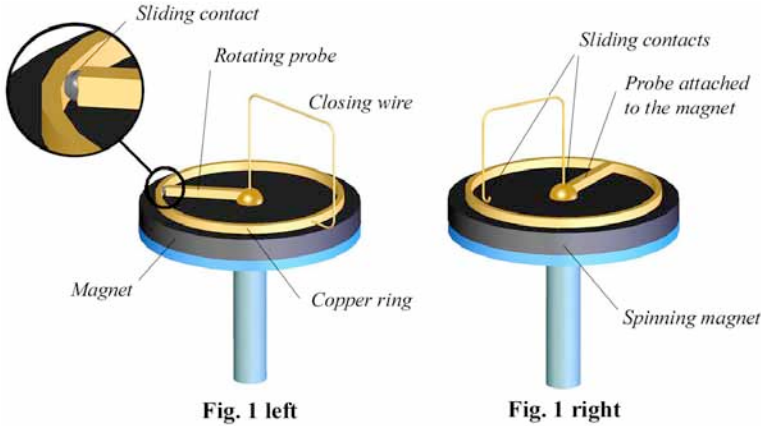


Figure 1

The relevant features of homopolar induction for two equivalent arrangements

The probe, at relative motion with the magnet, becomes an electromotive force (emf) source. The closing wire, at relative rest with the magnet, closes a current path. A conducting circular ring attached to the magnet enables electrical continuity. By inserting a meter between probe and closing wire, we measure e (volt). As far as motional induction is concerned, the probe acts as the *active* wire, whereas the closing wire plays a *passive* role [1-9].

An electrically equivalent configuration takes place when, with the magnet and the probe rotating at ω_0 , the closing wire remains at rest in the lab (second Faraday homopolar generator, Fig.1-right). Here the closing wire (active piece), at relative motion with the magnet, becomes the emf-source delivering the same e as above [1-9]. The probe, acting now as passive piece, provides a current path.

The third equivalent configuration takes place when, both magnet and probe remaining stationary in the lab, the closing wire is spun at $-\omega_0$.

Local Lorentz force, $\vec{F}_L = q(\vec{v} \times \vec{B})$, when applied to free to move charges in relative motion with respect to the magnet, suffices to explain the observed experimental facts. For such a charge located in the rotating probe (Fig.1, left) we get $\vec{F}_L = q(\vec{\omega} \times \vec{r} \times \vec{B})$, equation that becomes $\vec{F}_L(q\omega B)\vec{r}$ if \vec{B} remains constant on the probe. The quantity $\vec{F}_L / q \equiv \vec{E}_L = (\omega B)\vec{r}$ is usually known as motional induced Lorentz field.

The meaning of $\vec{\omega}$ in the above equations was a matter of endless discussions along the last 170 years. Nowadays we know [3, 6] that $\vec{\omega} = \omega_{Probe} - \vec{\omega}_{Magnet}$, wherein $\vec{\omega}_{Probe}$ ($\vec{\omega}_{Magnet}$) labels the angular velocity of the probe (magnet) as measured with respect to the lab. Hence, a counterclockwise probe rotation ($\vec{\omega}_{Probe} = \omega_0 \hat{z}$) with the magnet stationary in the lab ($\vec{\omega}_{Magnet} = 0$) becomes equivalent to a magnet counterclockwise rotation ($\vec{\omega}_{Magnet} = -\omega_0 \hat{z}$) with the probe at rest in the lab ($\vec{\omega}_{Probe} = 0$). Thus, updated motional Lorentz field reads [3]:

$$\vec{E}_L = [(\vec{\omega}_{Probe} - \vec{\omega}_{Magnet}) \times \vec{r}] \times \vec{B} \quad (1)$$

Lorentz force is a *local* one since it involves the magnetic field strength \vec{B} at the location of q [10].

Also an *action at a distance* rationale [11] based on Weber's force (framework in which the field concept has nothing to do), enables us to understand motional induction [12]. In both the above models the electromotive force delivered is worth $e = \omega BR^2 / 2$, B being the magnetic field strength on the active wire.

2 Exploring additive homopolar generators

If we adhere to *local action* models, it becomes natural to design engines in which we can alter, deliberately, \vec{B} -field actions on some of the active wires. *Additive* engines involving a N -turns coil instead of a single wire would be possible. The output of such engine would be Ne (volt). The only we need for such purpose, within a local action rationale, is to shield \vec{B} -field actions on a branch of the coil, whilst the complementary branch remains nude (unshielded).

Figure 2 sketches a uniform permanent magnet spinning in the neighborhood of a N loops partially shielded conducting coil. Whilst the near branch X remains nude, the complementary one Y was embedded in soft iron pipe (magnetic shield). As we know [1,4,5] each loop, at relative motion with the magnet, behaves as two emf sources connected in opposition being

$$e_X = \omega B_X R^2 / 2 \quad (2)$$

$$e_Y = \omega B_Y R^2 / 2 \quad (3)$$

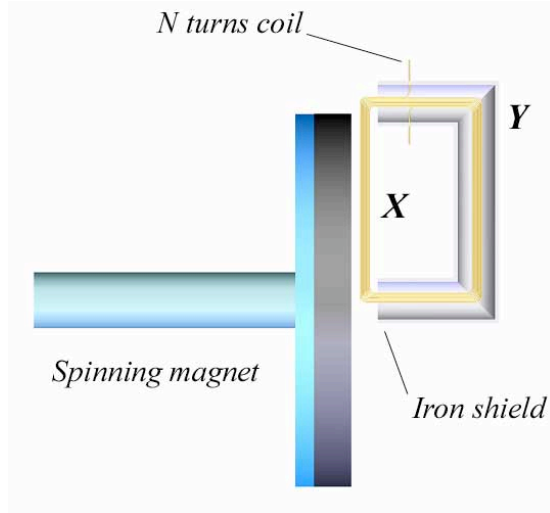


Figure 1

Taking as granted local actions, the engine would behave as an additive generator

Thus, according to a local action model, the emf delivered by the whole coil would be $N \omega R^2 (B_X - B_Y) / 2$. Here B_X (B_Y) labels the *local* magnetic field strenght on the X (Y) branch.

3 Experimental

3.1 Spinning magnet with a partially shielded coil stationary in the lab

In the actual setup performed in order to check the standard local action rationale, B on the X branch ($N = 200$, 5 cm height) amounts at least some 300 gauss (0,03T). Soft iron pipe (3mm outer radius, 1 mm inner radius) ensures a shielding factor (Appendix 1) greater than 10 on the Y branch: $B_Y < B_X / 10$.

For a typical run at $\omega = 200$ rad/sec, we would expect some 1 volt output. Measurements performed with the aid of a high impedance meter never surpassed the experimental uncertainty ($\pm 0,2$ mvolt). Experiments disprove equations (2), (3), since shielding appears to be unable to diminish the electromotive force developed on the Y branch of the generator.

3.2 Spinning magnet with the closing wire stationary in the lab.

Figure 3 sketches a single loop arrangement performed In order to reinforce the output of the experiment III.1. As in figure 1, the radial probe co-

rotates with the magnet, whilst the shielded closing wire remains stationary in the lab. The probe remains connected with the closing wire via sliding contacts touching the copper ring (photo 1).

In a typical run at $\omega = 200$ rad/sec, with some 600 gauss on the probe and $B_{\text{Closing-Wire}} < B_{\text{Probe}} / 10$, the measured emf was as high as 14 mV, i.e., the same as if the shielding were absent on the closing-wire.

Again experimental evidence runs against magnetic shielding, as applied to inductive phenomena.

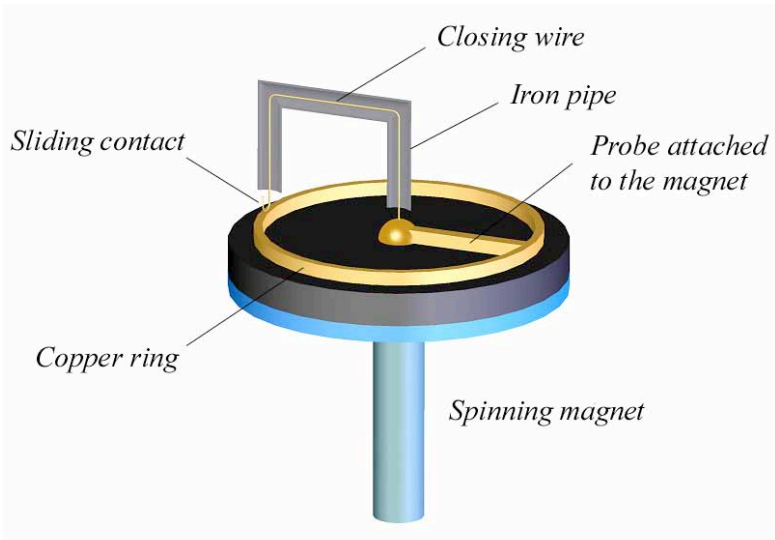


Figure 3

The output of the engine is not sensitive to magnetic shielding on the closing wire

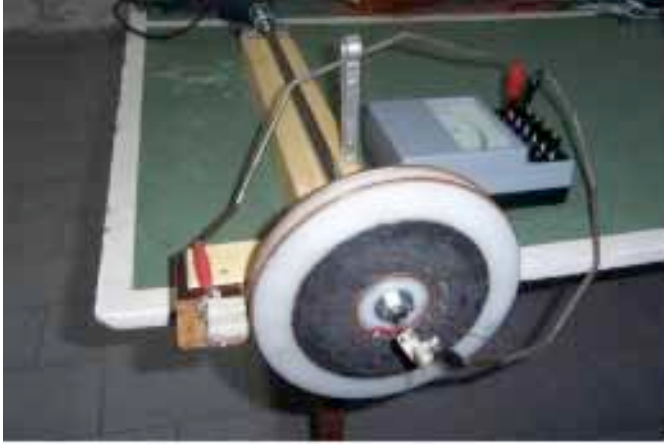


Photo 1

3.3 Spinning shielded probe with the magnet at rest in the Lab

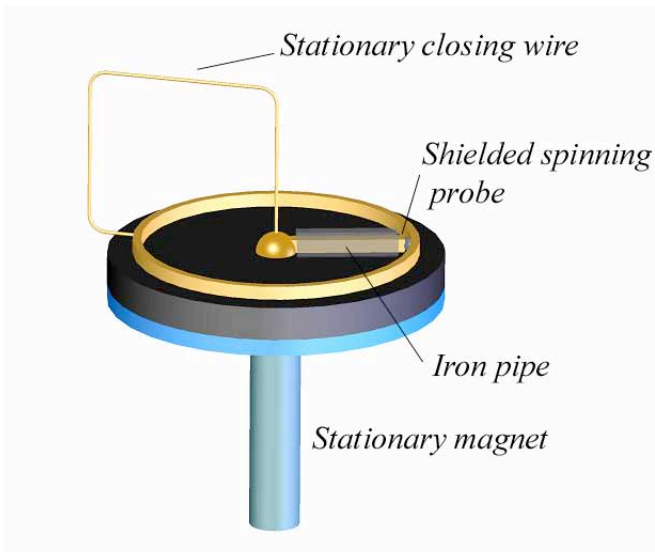


Figure 4

The output of the engine is not sensitive to magnetic shielding on the spinning probe

Figure 4 shows the free to spin shielded radial probe with both the magnet and the closing wire stationary in the lab. When the probe is spun at some 200 rad/sec the measured voltage amounts to 14 mV, i.e., the same as if the shielding were absent on the spinning probe, working in identical topological conditions.

Photo 2 shows the actual setup employed in the lab. The probe and accessories were anchored to a plexiglass plate able to spin on the magnet. The iron pipe (bottom) screens the insulated probe whose ends contact with the inner face of the brass cylinder and with the axial collector through sliding carbon electrodes. In order to balance the rotating device we soldered a radial brass rod (without electrical connection with the conducting cylinder) and two coins to the plexiglass plate on the magnet (top).



Photo 2

From all the above experiments we infer that motional Lorentz field is insensitive to magnetic shielding. In other words, the magnetic field strength \vec{B} appearing in equ.1 is that due to the magnetic sources at relative motion with the wires, but not the local field on them.

Ferromagnetic materials suffer induced magnetization when placed near permanent magnets or carrying current wires [13]. Figure 5 shows the induced poles generated on the surfaces of a soft iron cylinder (magnetic shield) located on the North pole of a permanent magnet.

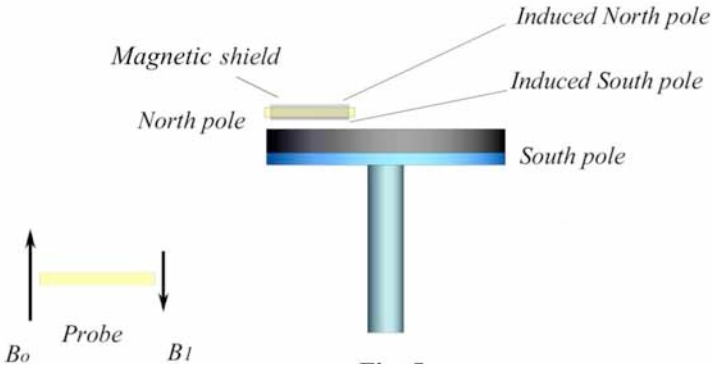


Figure 5

Sketching external and induced fields acting on the probe

Also a probe wire, embedded into the cylinder, is shown in the figure. The above wire “sees” two opposite poles beneath it (the original North pole due to the magnet plus the induced South pole on the shield), and the induced North pole on the farther face of the shield.

The *apparent magnetic charges* raised on the iron surfaces are the responsible for the induced field \vec{B}_I which, added to the external field \vec{B}_O , gives us the local field on the probe:

$$\vec{B}_{\text{Local}} = \vec{B}_O + \vec{B}_I \quad (4)$$

Note that \vec{B}_I acts in *opposition* to \vec{B}_O . The above reported experiments show, beyond any doubt, that the fields whose sources are at relative rest with the wires don’t contribute to motional Lorentz field. All happens as if the magnetic shielding were absent. The non-local action of the spinning magnet on the wire gives account for the performed experiments, despite being the active wires shielded. In the archaic language of “B-lines cutter” believers, being the wire at relative rest with the shielding, is unable to “cut” \vec{B}_I -lines.

The shield itself, although unable to perturb motional induction, becomes electrically polarised in the same way as the branches X and Y. Briefly speaking, and as far as motional induction is concerned, ferromagnetic shielding on the wires behaves as a bulk of dielectric, paramagnetic or diamagnetic material enclosing the above wire. The non local nature of motional induction is fully supported by experimentation.

4 Induction in Weber's rationale

The starting point of Weber's electrodynamics, *an action at a distance* (i.e. non local) theory, is Weber's force, $F_W = F_C [1 + (1/c^2)(r\ddot{r} - \dot{r}^2/2)]$, wherein F_C means Coulomb's force and the dots mean time derivatives [11].

Assis and Thober were able to explain, within the above framework, homopolar induction [12]. They modeled the permanent magnet with the aid of two charged rotating shells ($Q, R, \omega_M / -Q, R+ dR, \omega_{M+} \omega_N$). After some straightforward calculations A&T get the force acting on a free charge q of a spinning (at ω) conductor :

$$\vec{f} = (qQ/12 \pi \epsilon_0 c^2 R)[\omega_N^2 + 2 \omega_N(\omega_M - \omega)] \vec{r} \quad (3')$$

\vec{r} being the position vector to the axis z , so that r is the distance between q and this axis. A&T wrote: " Classically this situation of a double shell would give rise to a uniform magnetic field inside the shells given by

$$\vec{B} = - (\mu_0 Q \omega_N / 6 \pi R) \vec{z} \quad (4')$$

We may consider ω_M as the rotation of the magnet itself as usually the positive charges are fixed in the lattice. So ω_N may be considered as the drifting angular velocity of the electrons responsible for the current and for the magnetic field."

After some physically tenable considerations eqs. (3',4') lead to

$$\vec{f} = - qB(\omega_M - \omega) \vec{r}$$

in full agreement with equ.1.

The important conclusion is retained that the physics underlying motional induction

is enclosed in Equ. (1'), where only charges at relative motion and distances are involved.

Magnetic field strenght, as given by Equ. (4'), appears here only as secondary magnitude, disproved of any physical meaning beyond its own definition.

5 Motor configuration

The role of relative motion in both motional electromotive and ponderomotive phenomena, and the full reversibility between generator-motor configurations, has been duly proven [1-9]. Consequently, we cannot expect weakening of ponderomotive forces acting on current carrying wires attached to magnetic shields.

By applying *local* Laplace force $d\vec{F} = Id\vec{l} \times \vec{B}$ to a shielded wire, we only need to remember equation (4). Figure 6-a shows a non rotating homopolar motor in which its left branch, traversed by a centripetal DC, suffers a CCW-torque and its right branch, traversed by a centrifugal DC, suffers an equal but opposite torque [1,7]. Both branches, located on the North pole of the permanent magnet, are acted on by Laplace force F_o . Being the two above branches soldered to a bearing free to rotate about the magnet axis [1,7], rotation becomes forbidden. The only observable effect (disregarding Joule heating) is the bending of the branches [1].

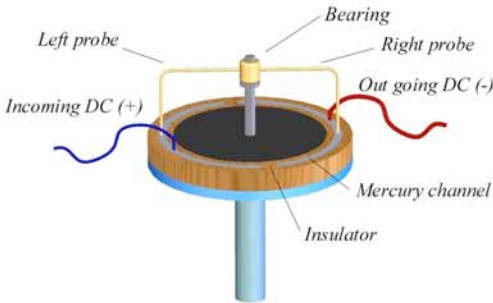


Fig. 6 a

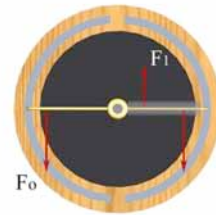


Fig. 6 b

The essential features of homopolar motor

6 Experimental

6.1 Torque cancellation in unshielded two-branches homopolar motor

The experimental verification of torque cancellation in the above described configuration was fully verified in the past [1-9].

6.2 Partially shielded carrying current coil located on the magnet, both free to rotate in the lab

Photo 3 (see also Fig.2) shows a 250 turns coil in which X (near) branch remains nude whereas Y branch has been shielded with soft iron. Low friction bearings allow the coil to rotate about magnet axis. Mean magnetic strength on the near branch amounts to some 500 gauss. We failed to detect the slightest rotation when DC was raised from 1 to 10 A. Of course, no rotation was observed on the magnet. The highest force on the X branch, $NLIB$, amounts to some $250 \times 0.05 \times 10 \times 0.05 \approx 6$ N, giving rise to a torque roughly evaluated as $(FL/2) \approx (6 \times 0.05)/2 = 0.15$ Nxm. The frictional torque in our actual setup never surpassed 0.01 Nxm. This experiment clearly shows that the torque acting on the nude branch of the coil is *exactly* cancelled by an opposite torque acting on the shielded branch. All happens as if the shield were absent.

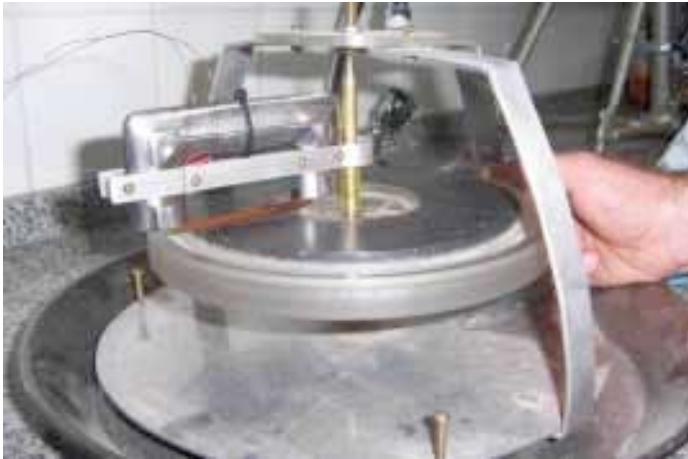


Photo 3

6.3 Two branches (on of them shielded) homopolar motor with restricted motion relative to the shielding

We performed a slight modification of Fig. 6a in which the right branch was screened with (8 mm inner major radius, 2 mm thickness) soft iron pipe attached to the magnet (Fig.6b + Photo 4).

When DC (centripetal on the left branch) amounting to some 2 A was injected, the whole wire moved in CCW sense until the wire was stopped by the pipe. The antagonistic induced field B_I is the responsible for the force F_I on the shielded wire, breaking the equilibrium described in VI.1.



Photo 4

6.4 Two branches (on of them shielded) homopolar motor without restricted motion relative to the shielding

The shielding pipe was soldered to the bearing and to the right wire, both free to rotate about the magnet axis (Photo 5). No rotation of the wires was detected when current was raised from 1 to 50 A. Being the wire attached to the pipe, action-reaction cancellation forbids relative motion between the pipe and the wire. The shielded branch is only acted by the field due to the magnet, B_O , and all happens as if the shielding were absent.

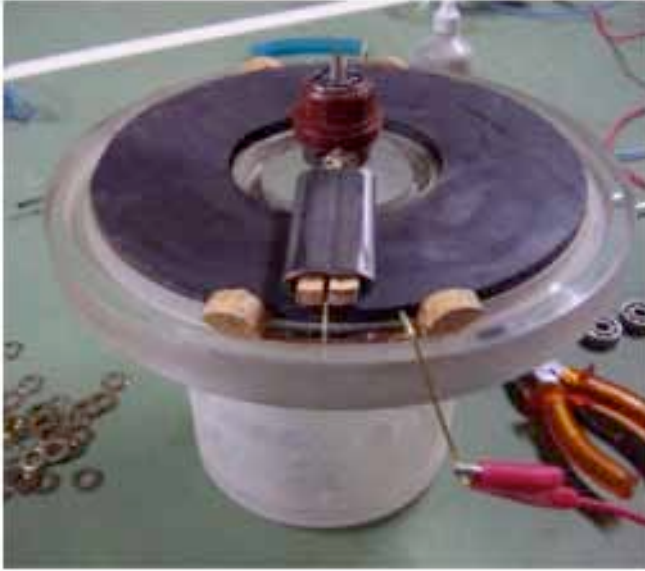


Photo 5

7 Miscellaneous conditions

The whole set of reported measurements was performed within a global experimental uncertainty amounting $\pm 5\%$.

Non local induction due to time-varying currents is a well known matter for engineers who design transformers. Let us consider a long solenoid carrying a time-dependent current. The magnetic field remains mainly confined inside the solenoid, being negligible outside it. Nevertheless, by encircling the above solenoid with an arbitrarily shaped wire, induction takes place on the wire, despite being the magnetic strength null on it [14]. Some authors try to save locality with the aid of the magnetic potential vector ($\vec{B} = \nabla \times \vec{A}$), but such attempts become illusory due to the nature of \vec{A} :

- 1) The magnetic potential vector, as defined by F. Neumann in order to derive Faraday induction law from Ampère force [11], only involves currents and distances being, consequently, a mathematical tool derived from an *action at a distance* rationale.
- 2) We don't know a direct physical meaning of the potential vector (\vec{A} is unable to move the compass-needle). Therefore, we must consider the po-

tential vector as being a suitable mathematical contrivance useful when performing calculations.

Microphysics *i.e.*, quantum physics, exhibits a manifest non local nature (Pauli exclusion principle, Aharonov-Bohm effect, Bell's inequality violation, entanglement ...)

Giving confidence to local actions rationale, D. Dameron advanced to us the idea developed in this work [15], *i.e.* to build homopolar devices in which some wires were magnetically shielded.

Incomplete physics. After the disclosure of the true physics of motional electromagnetic induction, widespread wrong statements as [16,17] must be abandoned as soon as possible:

“The important conclusion is retained that motion (rotation in this case) of the source of magnetic field does not affect any physical process, so long as such motion does not produce a time-varying field.”

Dangerous interpretations. In the eyes of absolutists like Kennard [1] and pseudo relativists like Panofsky [16] and Feynman [18], who besides advocate local actions, the null output of experiment III.1 would be interpreted as sustaining the above wrong statement.

Einstein's vindication. Einstein was right when wrote, at the beginning of his famous 1905 paper [19]:

“It is known that Maxwell electrodynamics (as usually understood at the present time) when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena”. True relativists [20, 21] promptly recognized the full validity of rotational relativity as applied to electrodynamics.

Physics vs. mathematics. Since Newton the concept of interaction is the heart of physics, being *force* the operational link existent between two or more interacting particles. It is Newton's third law the masterpiece which enhances the concept of force giving to newtonian fruitful physics its indestructible signature. Modern field theoreticians think on different ways;

*“Although \vec{E} and \vec{B} thus first appear just as convenient for forces produced by distributions of charge and current, they have other important aspects. First, their introduction **decouples conceptually the sources from the test bodies** experiencing electromagnetic forces. If the fields \vec{E} and \vec{B} from two sources distributions are the same at a given point in the space, the*

force acting on a test charge or current at that point will be the same, regardless of how different the source distributions are” [22].

The above statements deserve thorough critical revision since if we wish to replace a physical entity by another one, we need to be sure on the *completeness* of the involved replacement. Homopolar electromagnetic induction offers us a striking example in which such replacement (*i.e.* to decouple \vec{B} - *sources* from the test charge) leads to manifestly wrong physics, unable to fit with experimental observation. The field isn't the relevant piece here, but its sources and its state of motion.

Hertz first order invariant (under Galilei transformation) formulation of Maxwell's equations deserves to be seriously taken into account for a better understanding of electrodynamics. As far as we know, the best prospect offered on the issue is that due to T.E. Phipps [24, 25] which, essentially, rest on the replacement of the non-invariant operator $\partial/\partial t$ by the first order invariant derivative d/dt . Here $d/dt = \partial/\partial t + (\vec{v}_a \cdot \nabla)$, and Phipps interprets \vec{v}_a as velocity of the test charge, field detector, radiation absorber, etc.

It is worthwhile to quote that some authors [16, 22, 23] were aware of the relevance of the operator $\partial/\partial t + (\vec{v} \cdot \nabla)$ when dealing with motional induction (Faraday law) but they remained ambiguous concerning the meaning of \vec{v} . Thus, in Stratton words [23, chapter V], “*If by \vec{E} we understand the total force per unit charge in a moving body, then $\nabla \times \vec{E} = - \partial \vec{B} / \partial t + \nabla \times (\vec{v} \times \vec{B})$. Moreover, $d \vec{B} / dt = \partial \vec{B} / \partial t + (\vec{v} \cdot \nabla) \vec{B}$, so that $\nabla \times \vec{E} = - d \vec{B} / dt$ ”.*

shielding were absent.

APPENDIX

Taken from Page and Adams [13], page 143.

“ A sensitive magnetic instrument can be shielded very effectively from outside fields by placing it inside a cylindrical shell made of soft iron of high permeability. We shall investigate the field in the interior of a cylindrical shell of constant permeability placed in a uniform magnetic field at right angles to the axis of the cylinder”. After solving Laplace's equation for the magnetostatic potential, the above authors get the shielding ratio $g = (\mu/4)[1 - (a/b)^2]$, wherein a (b) means inner (outer) radius

Acknowledgments

To T.E. Phipps, Jr. for a thorough revision of the manuscript.

To Maximilian Blas for his valuable technical support.

References

- [1] J. Guala-Valverde & P. Mazzoni, *Apeiron*, **8**,41 (2001)
- [2] J. Guala-Valverde, *Apeiron* **11**, 327 (2004)
- [3] J. Guala-Valverde, *Journal of Theoretics*, **6-5,5**; **6-6,2** (2004)
- [4] J. Guala-Valverde, *Physics*, N° 14 in www.andrijar.com
- [5] J. Guala-Valverde, *Physica Scripta* (Royal Swedish Acad. Sciences), **66**, 252 (2002)
- [6] J. Guala-Valverde, *Spacetime & Substance Journal*, **3**, 140 (2002)
- [7] J. Guala-Valverde, P. Mazzoni and R. Achilles, *Am. J. Physics*, **70**, 1052 (2002)
- [8] J. Guala-Valverde, *Spacetime & Substance Journal*, **3**, N° 3, 140 (2002)
- [9] J. Guala-Valverde, *Galilean Electrodynamics*, **14**, 120 (2003)
- [10] P. and N. Graneau, « *Newtonian Electrodynamics* », Chapters 4,5. World Scientific Pub. Co. Singapore (1996)
- [11] A.K.T. Assis, “*WEBER ELECTRODYNAMICS*”, Kluwer, Dordrecht (1994)
- [12] A.K.T. Assis and D.S. Thober, *Frontiers of Fundamental Physics*, Plenum NY, 409 (1994)
- [13] L. Page & N. I. Adams, “*Principles of Electricity*”, Chapter 4. Van Nostrand, NY (1949).
- [14] J. Guala-Valverde, *Spacetime & Substance Journal*, **3**, N° 2, 94 (2002)
- [15] D. Dameron, private communication. Letter to J. Guala-Valverde, dated Feb 2004
- [16] W.K.H. Panofsky & M. Phillips, “*Classical Electricity and Magnetism*”, Addison-Wesley, New York (1955)
- [17] W.K.H. Panofsky, private comm. Letter to J. Guala-Valverde, dated Jan. 30 1995
- [18] R. Feynman, “*Feynman Lectures*”, Addison-Wesley, New York (1964)
- [19] A. Einstein, “*Zur Elektrodynamik Bewegter Körper*”, *Annalen der Physik*, **17** 1905
- [20] F. Rohrlich, private comm. Letter to J. Guala-Valverde, dated Oct. 21 2002
- [21] G. Cavalleri, private comm. Letter to J. Guala-Valverde, dated Feb. 2003
- [22] J.D. Jackson, “*Classical Electrodynamics*”, 2nd Edition, John Wesley & Sons, NY (1975)

- [23] J.A. Stratton, *Electromagnetic Theory*, Mc Graw-Hill, New York (1941)
- [24] T.E. Phipps, Jr., *Physics Essays* **6**, 249 (1993)
- [25] T.E. Phipps, Jr., “*Hertzian Invariant Forms of Electromagnetism- Advanced Electromagnetism Foundations, Theory and Applications*”. T.W. Barret and D.M. Grimes, eds. World Scientific, Singapore, pp. 332-354, (1995)

(Manuscrit reçu le 28 mai 2005)