



## Dimensional Analysis of Thrusting by Electromagnetic Inertia

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### Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

### Article Information

DOI: 10.9734/BJAST/2016/29799

Editor(s):

(1) Joo Miguel Dias, Habilitation in Department of Physics, CESAM, University of Aveiro, Portugal.

Reviewers:

(1) Arto Annala, University of Helsinki, Finland.

(2) Aliyu Bhar Kisabo, Centre for Space Transport Propulsion (CSTP), Nigeria.

(3) Anonymous, Ministero dell'Istruzione, dell'Università e della Ricerca, Italy.

(4) Michal Malk, Technical University of Liberec, Czech Republic.

Complete Peer review History: <http://www.sciencedomain.org/review-history/17245>

Received: 29<sup>th</sup> September 2016

Accepted: 15<sup>th</sup> November 2016

Published: 15<sup>th</sup> December 2016

**Original Research Article**

### ABSTRACT

We investigate the so called Biefeld-Brown effect in terms of dimensional analysis and in the frame of classical electrodynamics. These general considerations apply when addressing electromagnetic propulsion devices.

*Keywords: Basic electromagnetic quantities; classical electrodynamics; artificial satellites; classical field theory; electrostatics; dielectric devices; dimensional analysis; model similarity.*

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## NOMENCLATURES

$B$	=	Magnetic field, in $T$
$c$	=	Speed of light in vacuum, in $m s^{-1}$
$d$	=	The distance between the electrodes
$D$	=	Telectric displacement, in $C m^{-2}$
$E$	=	Electric field in $N C^{-1}$
$\epsilon$	=	Dielectric permittivity of the material, in $F m^{-1}$
$f'^m$	=	Density of force acting on the medium, in $kg m^{-3}$
$f^A$	=	Abraham's density of force, in $N m^{-3}$
$f^M$	=	Lorentz's density of force, in $N m^{-3}$
$F,K$	=	Resultant force acting on the vehicle, in $N$
$F_y$	=	Y component of the resultant pressure force acting on the vehicle
$\mathcal{F}$	=	Function dependent on the ratio $S/d$
$G$	=	Numerical factor (constant)
$G^M$	=	Minkowsky's momentum, in $kg m s^{-1}$
$G^A$	=	Abraham's momentum, in $kg m s^{-1}$
$H$	=	Magnetic field strength, in $A m^{-1}$
$I$	=	Leakage current, in $A$
$\mu$	=	Magnetic permeability, in $H m^{-1}$
$M$	=	Mass of the vehicle, in $kg$
$\omega$	=	Frequency of the pulsed current, in $rad s^{-1}$
$Q$	=	Electric charge, in $C$
$r$	=	Radial distance, in $m$
$\rho_m$	=	The kind of material used between the masses
$\mathcal{R}$	=	Electric resistance of the dielectric cylinder, in $\Omega$
$\sigma_{\alpha\beta}$	=	$\alpha, \beta$ -component of the stress force, in $N m^{-2}$
$S$	=	The surface area of the electrodes
$T$	=	Density of force, in $N m^{-2}$
$V$	=	The voltage differential between the electrode

## 1 INTRODUCTION

The so called Biefeld-Brown effect is hypothetically a means to convert electrostatic energy into a propulsive force, even in a vacuum medium. It was discovered by Thomas Townsend Brown and Dr. Paul Alfred Biefeld. In 1921 Brown discovered this effect when experimenting with a Coolidge X-ray tube. The tube consisted of two asymmetrical electrodes separated by a dielectric in a vacuum environment. When connected to a high-voltage source a force acted on the tube, forcing its motion in the direction of the positive electrode [1,2,3,4]. In case this effect is real the associated potential for propulsion and as a source of energy is enormous since no expenditure of fuel is necessary, the all process is most probably connected to action-reaction type of momentum-transfer. Tests made at NASA report thrust produced for various voltages,

polarities and ground configurations, leading to design asymmetrical capacitors for propulsion [5] (see also Refs.[6,7,8,9]).

In 1893 Heaviside [10] proposed the separation of gravitation in electric and magnetic components, introducing a special force field, the cogravitational, or Heaviside's field. Heaviside attempted to correlate gravitation with electromagnetism introducing a field produced by moving masses, The cogravitational field, and later some Authors use the weak-field approximation to modify the equations of the general theory of gravitation in a structurally similar kind of equations as the Maxwell equations of the electromagnetism [11]. We can find also in Iwanaga[12] a review of some field propulsion methods based on general relativity theory. Nevertheless, so far proposed concepts to control gravity for possible use on space propulsion don't lead to no breakthrough [13,14].

Another interpretation relies on the standard atmospheric electrodynamic model of the global electric circuit. The global electric circuit is composed by the spherical conductor of the earth, the spherical conductor of the ionosphere. Thunderstorms act as charge generators, charging negatively the earth surface and charging the ionosphere positive. Statistically the electric field strength reaches maximums (at 18:00 UTC) and minimums (at 04:00 UTC) everywhere on earth according to UTC time and not the local time. This was experimentally verified with data taken on board the ship Carnegie and that is why is characteristic diurnal curve is known as the "Carnegie curve". The self-potential measured by Brown with a capacitor and a rock sample between the electrodes acting as a dielectric, exposed to the Earth background electric field apparently shows several parallels. Stephenson [15] suggested that the Biefeld-Brown effect is a secondary electrostatic effect related to the global electric field. This interpretation precludes any relationship with the electrogravitic nature of the effect.

Through a Lagrangian formulation Feigel [16] shown that a body receives a recoil momentum from the vacuum equal to the Minkowski's momentum, opening the possibility of contribution of vacuum to the motion of dielectric liquids in crossed electric and magnetic fields. Exploring different possibilities, Maclay and Forward [17] proposed a mechanism to propel a spacecraft based on the Casimir effect, in which electromagnetic radiation is emitted when an uncharged mirror is properly accelerated in vacuum.

Loder [18] gives an overall account of technologies applications for the 21<sup>st</sup> century. In [19] it is discussed the possibility of engineering the zero-point field and polarizable vacuum for propellantless propulsion and an idealized system composed of two parallel semiconducting boundaries separated by an empty gap variable width can, under appropriate transformation, generate work [20].

The aim of this work is to analyze the Biefeld-Brown effect and to obtain a reliable equation for the claimed propulsive force, using arguments

from dimensional analysis and proving its consistency in pure theoretical electromagnetic grounds. In Section I it is introduced the general context of the BB effect. In Section II, it is given the parameters in which depends the phenomenon. Section III introduces the dimensional analysis technique. Sections IV makes the analysis of the problem at the light of classical electromagnetic theory, obtaining the propulsive force of the device operating on the BB effect principles. We conclude with Section V.

## 2 WHAT IS COMMON KNOWLEDGE ABOUT THE BIEFELD-BROWN EFFECT

According to a set of experiments done by Thomas Townsend Brown, which lead to several patents registered in US and Great Britain [1,2,3], the propulsive effect is dependent on the following factors:

1. the surface area of the electrodes,  $S$ ;
2. the voltage differential between the electrodes,  $V$ ;
3. the distance between the electrodes,  $d$ ;
4. the kind of material used between the masses,  $\rho_m$ ;
5. the dielectric permittivity of the material placed between the electrodes,  $\epsilon_r$ .

This information suggests that the force is directly dependent on the system capacitance and the total charge developed,  $Q = CV$ , as the dimensional analysis of Section 2 clearly shows. The role of the "mass between the plates",  $\rho_m$ , as stated by Brown, in fact the mass of the dielectric, was never sufficiently clarified, but we included in the analysis this parameter [1,2,3,4].

## 3 A DIMENSIONAL ANALYSIS: RESULTS AND DISCUSSION

We now apply the Buckingham's Pi theorem expecting to obtain the relationship between the operational variables related to this problem, in particular, according to the Biefeld-Brown investigations. In Table 1 we present the electromagnetic magnitudes with relevance to our problem, in order to systematise the problem.

**Table 1. Dimensions of the relevant physical variables**

Permittivity of vacuum	$[\varepsilon_0] =$	$Q^2T^2M^{-1}L^{-3}$
Electric scalar potential	$[V] =$	$ML^2T^{-2}Q^{-1}$
Force	$[F] =$	$MLT^{-2}$

Hence, the variables controlling the process are the following:  $F$ ,  $\rho$ ,  $V$ ,  $\frac{S}{d}$  (associating the capacitor),  $\dot{D}$  (associating the leakage current, as it is generally believed to rely on the corona discharge), having the total of  $n = 5$  variables. Two variables repeat,  $\rho$  and  $S/d$ , in which case  $k = 2$ , therefore, remaining  $n - k = 3$  non-dimensional variables, we obtain

$$\pi_1 = \frac{F}{\rho S^2 \omega^2} \quad (3.1)$$

$$\pi_2 = \frac{S}{d^2} \quad (3.2)$$

$$\pi_3 = \frac{1}{\rho c S} \epsilon \mu V \frac{\partial J}{\partial t} \quad (3.3)$$

where  $\pi_1$ ,  $\pi_2$  and  $\pi_3$  are the necessary three non-dimensional numbers, and considering in  $\pi_3$  that  $I = J/S$ . Then, the functional relationship between them is

$$f\left(\frac{F}{\rho c^2 S}, \frac{S}{d^2}, \frac{1}{\rho c} \epsilon \mu V \frac{\partial D}{\partial t}\right) = 0. \quad (3.4)$$

That is,

$$F = \rho c^2 S g\left[\frac{S}{d^2}, \frac{1}{\rho c S} \epsilon \mu V \dot{J}\right], \quad (3.5)$$

where  $g$  is a new function of  $\pi_2$  and  $\pi_3$ , and  $\dot{J} = \epsilon \partial E / \partial t$ . Therefore, we conclude that the resulting force in the electromagnetic device must have the following dependency:

$$F = G \frac{1}{c} \epsilon \frac{V^2}{d} \omega \mathcal{F}\left(\frac{S}{d^2}\right), \quad (3.6)$$

where  $G$  is a constant to be determined by means of a theoretical explanation (as done later in this investigation), or by means of available experimental data, and  $\mathcal{F}(S/d^2)$  is a function dependent on the ratio  $S/d^2$ .

### 3.1 Interaction with the Vacuum

We want now to justify theoretically the foundation of the above found Eq. 3.6. Several

arguments against the actual formulation of Newton's third law of motion can be raised [21], but the statement that action and reaction always occurs by pairs,  $\mathbf{F} = -\mathbf{F}'$  still holds.

According to the Maxwell's theorem, the resultant of  $\mathbf{K}$  forces applied to bodies situated within a closed surface  $S$  is given by the integral over the surface  $S$  of the Maxwell stresses:

$$\int \mathbf{T}(n) dS = \int \mathbf{f} d\Omega = \mathbf{K}. \quad (3.7)$$

Here,  $\mathbf{f}$  is the ponderomotive forces density and  $d\Omega$  is the volume element. The vector  $\mathbf{T}(n)$  under the integral in the left-hand side (lhs) of the equation is the tension force acting on a surface element  $dS$ , with a normal  $\mathbf{n}$  directed toward the exterior. In cartesian coordinates, each component of  $\mathbf{T}(n)$  is defined by

$$T_x(n) = t_{xx} \cos(n, x) + t_{xy} \cos(n, y) + t_{xz} \cos(n, z), \quad (3.8)$$

with similar expressions for  $T_y$  and  $T_z$ . The 4-dimensional momentum-energy tensor is a generalization of the 3-dimensional stress tensor  $T_{lm}$ . If electric charges are inside a conducting body in vacuum, in presence of electric  $E$  and magnetic  $H$  fields, then Eq. 3.7 must be modified to the form:

$$\int \mathbf{T}(n) dS - \mathbf{K} = \int \frac{1}{4\pi c} \left( \frac{\partial[\mathbf{E} \times \mathbf{H}]}{\partial t} \right) d\Omega. \quad (3.9)$$

In the right-hand side of the above equation it now appears the temporal derivative of  $\mathbf{G} = \int \mathbf{g} d\Omega$ , the electromagnetic momentum of the field in the entire volume contained by the surface  $S$  (with its momentum density).

In the case the surface  $S$  is filled with a homogeneous medium without true charges, Abraham proposed to write instead

$$\int \mathbf{T}(n) dS = \frac{\partial}{\partial t} \int \frac{\epsilon \mu}{4\pi c} [\mathbf{E} \times \mathbf{H}] d\Omega, \quad (3.10)$$

with  $\epsilon$  and  $\mu$  denoting, resp., the dielectric constant of the medium and its magnetic permeability.

Eq. 3.10 can be written in the form of a general conservation law:

$$\frac{\partial \sigma_{\alpha\beta}}{\partial x_\beta} - \frac{\partial g_\alpha}{\partial t} = f_\alpha \quad (3.11)$$

where  $\alpha = 1, 2, 3$ . This equation can be reduced to the form

$$\frac{\partial \sigma_{\alpha\beta}}{\partial x_\beta} = f_\alpha^L + \frac{1}{4\pi c} \frac{\partial}{\partial t} [\mathbf{D} \times \mathbf{B}]_\alpha + f'_{m,\alpha}. \quad (3.12)$$

Here,  $f'_m$  is the force acting in the medium [22],  $\mathbf{f}^L = \rho_e \mathbf{E} + \frac{1}{c} [\mathbf{j} \times \mathbf{B}]$  is the Lorentz force density, with  $\rho_e$  denoting the charge density, and  $\mathbf{j}$  the current density.

Of course, the field and the the medium (or the matter) form together a closed system and it is usual to catch the momentum conservation law in the general form [23,24]

$$\frac{\partial (T_{\alpha\beta}^{Field} + T_{\alpha\beta}^{Matter})}{\partial x_\beta} = 0. \quad (3.13)$$

The general relation between Minkowski and Abraham momentum, free of any particular assumption, holding particularly for a moving medium, is given by

$$\mathbf{P}^M = \mathbf{P}^A + \int \mathbf{f}^A dt dV. \quad (3.14)$$

For clearness, we shall distinguish between the parts of a system, the body carrying currents and the currents themselves (the structure for short), the fields and the vacuum.

The impulse transmitted to the structure is just

$$\mathbf{P}^K = \int \mathbf{f}^A dt dV = \mathbf{P}^M - \mathbf{P}^A, \quad (3.15)$$

where  $\mathbf{f}^A$  is the Abraham's force density:

$$\mathbf{f}^A = \frac{\varepsilon_r \mu_r - 1}{4\pi c} \frac{\partial [\mathbf{E} \times \mathbf{H}]}{\partial t}. \quad (3.16)$$

This is in agreement with experimental data [25] and was proposed by others [26,27]. As this force is acting over the medium, it is expected nonlinearities related to the behavior of the dielectric to different applied frequencies, temperature, pressure, and large amplitudes of the electric field when a pure dielectric response of the matter is no longer proportional to the electric field (see Ref.[28] on this topic).

The momentum conservation law can be rewritten as (see Ref. [22])

$$\frac{\partial \sigma_{\alpha\beta}}{\partial x_\beta} = f_\alpha^L + \frac{1}{4\pi c} \frac{\partial}{\partial t} [\mathbf{D} \times \mathbf{B}]_\alpha + f'_{m,\alpha}, \quad (3.17)$$

with  $f'_m$  denoting the force acting on the medium. The second term in the lhs of above equation could possible be called vacuum-interactance term [29] - in fact, Minkowski term. Already according to an interpretation of Einstein and Laub [30], the integration of above equation over all space, the derivative over stress tensor gives a null integral and the Lorentz forces summed over all the universe must be balanced by the quantity  $\int_\infty \varepsilon_0 \mu_0 \frac{\partial [\mathbf{E} \times \mathbf{H}]}{\partial t} dV$  in order Newton's third law be preserved.

As is well known, Maxwell's classical theory introduces the idea of a real vacuum medium. After being considered useless by Einstein's special theory of relativity, the ether (actually replaced by the term *vacuum* or *physical vacuum*) was rehabilitated by Einstein in 1920 [31]. In fact, the general theory of relativity describes space with physical properties by means of ten functions  $g_{\mu\nu}$  (see also [32]). According to Einstein,

The ether of general relativity is a medium that by itself is devoid of *all* mechanical and kinematic properties but at the same time determines mechanical (and electromagnetic) processes.

Dirac felt the necessity to introduce the idea of ether in quantum mechanics [33]. In fact, according to quantum field theory, particles can condense in vacuum giving rise to space-time dependent macroscopic objects, for example, of ferromagnetic type. Besides, stochastic electrodynamics shown that the vacuum contains measurable energy called zero-point energy (ZPE) described as a turbulent sea of randomly fluctuating electromagnetic field. Quite interestingly, it was recently shown that the interaction of atoms with ZPF guarantees the stability of matter and, in particular, the energy radiated by an accelerated electron in circular motion is balanced by the energy absorbed from the ZPF [34].

Graham and Lahoz made three important experiments [35,36,37]. While the first

experiment provided an experimental observation of Abraham force in a dielectric, the second one provided a measurement of a reaction force which appear in magnetite. The third one provided the first evidence of free electromagnetic angular momentum created by quasistatic and independent electromagnetic fields  $E$  and  $B$  in the vacuum [38]. Whereas the referred paper by Lahoz provided experimental evidence for Abraham force at low frequency fields, it still remains to gather evidence of its validity at higher frequency domain, although some methods are presently outlined [39].

All this is known since a long time and we only try to put more clear the theoretical framework, that only needs to be experimentally tested for proof of principles.

In view of the above, we will write the ponderomotive force density acting on the composite body of arbitrarily large mass (formed by the current configuration and its supporting structure) in the form

$$\rho \frac{d\mathbf{V}}{dt} = \rho_c \mathbf{E} + [\mathbf{J} \times \mathbf{B}] + \nabla \cdot \mathbf{T} + \frac{\partial}{\partial t} (\varepsilon_0 \mu_0 [\mathbf{E} \times \mathbf{H}]). \quad (3.18)$$

Hence, the composite body is acted on by Minkowski force in such a way that:

$$M\mathbf{V} = -\mathbf{G}^M + \mathbf{G}^A. \quad (3.19)$$

The Minkowski momentum is transferred only to the field in the structure and not to the structure and the field in the medium [22,37,40].

It seems that, in general, natural locomotory propulsion by oscillating flukes or wings are characterized by periodic shedding of wake vortices (the so called Von Karman streets) inducing jet flows carrying momentum, and, in return, the body will experience a reaction force that propel it through the fluid [41]. In a similar way, a nearly analogue process seems to occur with Minkowski force, which is a vortex structure formed in the physical vacuum, and that, in return, induces a reaction force on the body, propelling it through the physical vacuum.

## 4 PONDEROMOTIVE FORCE VIA VECTOR POTENTIAL

Difficulties related to the Minkowski-Abraham [42,43] controversy maybe avoided formulating the problem in term of canonical momentum, instead of ponderomotive forces. Canonical momentum allows a clear cut view of the phenomena. In this theoretical frame, there is no violation of action-to-reaction law. In fact, the massless propulsion is achieved obtaining mechanical momentum through electromagnetic momentum exchanged with the medium.

According to Trammel [44] (see also, Refs. [45,46,47,48]), the total momentum acting over the composite body in an inertial frame can be also written in the form

$$\mathbf{P} = \rho \mathbf{V} + \sum_i \rho_{c,i} \mathbf{V}_i + \sum_i \rho_{c,i} \mathbf{A}_i. \quad (4.1)$$

This is supposed to apply to a structure and current-carrying wires integrated inside the structure. It is assumed to exist a current density  $\mathbf{J} = \sum_i \rho_{c,i} \mathbf{V}_i$ . To simplify, we will assume that in the structure inertial frame the current undergoes arbitrary small acceleration, i.e., the current is quasi-stationary. Also, we discard the effect of the motion on the electromagnetic field.

We will assume a very simple geometric design, with two electrodes below and above a dielectric cylinder (e.g, baryum titanate). The leakage current will flow along z-axis and, consequently, so do the potential vector  $\mathbf{A} = A_z \mathbf{u}_z$ . Hence, the propulsive force will be acting along axis Oz:

$$\mathbf{F}_z = M \frac{dV_z}{dt} = -Q \frac{dA_z}{dt}, \quad (4.2)$$

where  $M$  (an arbitrary large mass) and  $V_z$  are the mass of the composite body and its velocity along z-axis. The electromagnetic part of momentum acting over the charge  $Q$  developed on electrodes making part of the structure of mass  $M$  is  $QA_z$ .  $A_z$  is the vector potential component along Oz, given by:

$$A_z(r) = \frac{\mu_0 J_z}{4} r^2. \quad (4.3)$$

Eq. 4.3 is independent of z-coordinate, depending only on the radial position. We denote

by  $J_z$  the current density,  $R$  the electrodes radius (by default, the lower smaller radius) and  $d$  the capacitors width. The total charge  $Q$  present on each electrode is such that  $Q = C(V_1 - V_2)$ .

After integration over the charged electrode, the final expression for the force is readily obtained:

$$F_z = -\frac{1}{8c_0^2} \varepsilon_r \omega I \frac{R^2}{d} (V_1 - V_2). \quad (4.4)$$

Our result, obtained along a different approach, is consistent with Hector's [49] finding, who obtained an analogous expression to Eq. 4.4. In fact, Eq. 4.4 is consistent with the dimensional analysis done above using Buckingham' Pi theorem, since it shows a dependency on energy retained between the electrodes. If we restrain ourselves to simple considerations to keep it simple, and as long as the leakage current is given as  $I \approx \Delta V / \mathcal{R}$ , with  $\mathcal{R}$  representing now the electrical resistance of the dielectric cylinder, we obtain that the force is approximately given by:

$$F_z \approx \frac{10^{-7}}{2} \frac{C\omega}{\mathcal{R}} \Delta V^2. \quad (4.5)$$

Eq. 4.4 is also consistent with Eq. 3.6 obtained through dimensional analysis, but now we have determined explicitly the form of the function  $\mathcal{F}(S/d^2)$ .

## 5 CONCLUSION

We investigate the so called Biefeld-Brown effect, or the working mechanism of devices operating on electromagnetic forces, in terms of dimensional analysis and in the framework of classical electrodynamics. In particular, we obtained explicitly the function dependent form  $\mathcal{F}$ . This result can be helpful when addressing electromagnetic propulsion devices for space exploration.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

## References

- [1] Rahman Md. M, Saha TK, Bhuiyan Md. A. Implementation of RSA algorithm for speech data encryption and decryption. IJCSNS International Journal of Computer Science and Network Security. 2012;12(3):74-82.
- [2] Brown TT US Patent 2,949,550; 1960.
- [3] Brown TT US Patent 3,187,206; 1965.
- [4] Brown TT GB Patent 300,311; 1928.
- [5] Brown TT. Science and invention magazine; 1929.
- [6] Canning FX, Melcher C, Winet E. NASA/CR-2004-213312.
- [7] Bahder TB, Fazi C. Final report. ARL-TR-3005, NTIS Number ADA416740; 2002.
- [8] Talley RL. Twenty first century propulsion concept", U.S. Air Force report no. PL-TR-91-3009. Available from the National Technical Information Service; 1991.
- [9] Forward RL. Guidelines to antigravity. Am. J. Phys. 1963;31(3):166-170.
- [10] Buehler DR. Exploratory Research on the Phenomenon of the Movement of High Voltage Capacitors. Journal of Space Mixing. 2004;1-21.
- [11] Heaviside O. A gravitational and electromagnetic analogy. The Electrician. 1893;31:2812.
- [12] Tajmar M, de Matos CJ. Coupling of electromagnetism and gravitation in the weak field approximation. Journal of Theoretics. 2001; 3(1)
- [13] Iwanaga N. Reviews of some field propulsion methods from the general relativistic standpoint. AIP Conf. Proc. 1999;458:1051.
- [14] Tajmar M, Bertolami O. arXiv:physics/0412176v3 [physics.space-ph].
- [15] Bertolami O. Report ESA CR(P). 2002;4365.
- [16] Stephenson GV. The Biefeld-Brown Effect and the Global Electric Circuit, preliminary -10/25/01 peer review copy, Seculine consulting, Bellevue, WA 98006; 2001.

- [17] Feigel A. quantum vacuum contribution to the momentum of dielectric media. *Phys. Rev. Lett.* 2004;92(2):020404-1.
- [18] Maclay GJ, Forward RL. A gedanken spacecraft that operates using the quantum vacuum (Dynamic Casimir Effect). *Found. Phys.* 2004;34(3):477.
- [19] Loder TC. Outside the box" space and terrestrial transportation and energy technologies for the 21st century. American Institute of Aeronautics and Astronautics. Paper number AIAA-2002-1131; 2002.
- [20] Puthoff HE, Little SR, Ibison M. Engineering the zero-point field and polarizable vacuum for interstellar flight. *JBIS.* 2002;55:137-144.
- [21] Pinto F. Engine cycle of an optically controlled vacuum energy transducer. *Phys. Rev. B.* 1999;60(21):14740.
- [22] Cornille P. The Lorentz force and Newton's third principle. *Can. J. Phys.* 1995;73:619.
- [23] Ginzburg VL, Ugarov VA. Remarks on forces and the energy-momentum tensor in macroscopic electrodynamics. *Sov. Phys. Usp.* 1976;19(1): 94101.
- [24] Thirring W. *Dynamical systems and field theories.* (New York: Springer); 2003.
- [25] Landau LD, Lifshitz EM. *Fluid Mechanics.* (Oxford: Pergamon) Secs. 1987;133/134.
- [26] Jones RV, Richard JSC. The pressure of radiation in a refracting medium. *Proc. R. Soc. A.* 1954;221:480-498.
- [27] Gordon JP. Radiation forces and momenta in dielectric media. *Phys. Rev. A.* 1973;8(1):14-21.
- [28] Tangherlini FR. Particle approach to the Fresnel coefficients. *Phys. Rev. A.* 1975;12(1):139-147.
- [29] Böttger U. *Polar Oxides: Properties, Characterizing, and Imaging.* (Germany: WILEY-VCH Verlag GmbH) Edited by R. Waser, U. Böttger, and S. Tiedke; 2005.
- [30] Pinheiro MJ. The fourth law of motion in classical mechanics and electrodynamics. *AIP Conf. Proc.* 2010;1208:359.
- [31] Einstein A, Laub J. Über die im elektromagnetischen Felde auf ruhende Körper ausgeübten ponderomotorischen Kräfte. *Annls. Phys.* 1908;26: 541.
- [32] Einstein A. *Aether und Relativitaetstheorie.* Berlin: Springer; 1920.
- [33] Ginzburg VL, Frolov VP. Vacuum in a homogeneous gravitational field and excitation of a uniformly accelerated detector. *Soviet Physics Uspekhi.* 1987;30(12):1073.
- [34] Dirac PAM. Is there an ther. *Nature.* 1951;168:906.
- [35] Kozlowski M, Marciak-Kozłowska J. Thermal processes using attosecond laser pulses: When Time Matters (Germany: Springer). 2006;193.
- [36] Walker GB, Lahoz DG. Mechanical forces of electromagnetic origin. *Nature.* 1975;253:339.
- [37] Lahoz DG, Graham GM. Observation of electromagnetic angular momentum within magnetite. *Phys. Rev. Lett.* 1979;42(17):1137.
- [38] Graham GM, Lahoz DG. Observation of static electromagnetic angular momentum in vacua. *Nature.* 1980;285(5761):154.
- [39] We quote from Lahoz DG, Graham GM. Observation of electromagnetic angular momentum within magnetite. *Phys. Rev. Lett.* 1979;42(17):1137, this passage ("According to Maxwell-Poynting ideas, the last (Minkowski's) term in [our Eq.1] can be interpreted as a local reaction force acting on charges and currents when the vacuum surrounding them is loaded with electromagnetic momentum."
- [40] Antoci S, Mihich L. Detecting Abraham's force of light by the Fresnel-Fizeau effect. *EPJdirect.* 1998; D1:1-14.
- [41] Skobel'tsyn DV. The momentum-energy tensor of the electromagnetic field. *Sov. Phys. Usp.* 1973: 16(3); 381-401
- [42] Hedenström A. A general law for animal locomotion? *Trends Ecol. Evol.* 2004;19(5):217-219.
- [43] Abraham M. Zur Elektrodynamik der bewegter Körper. *Rend. Circ. Matem. Palermo.* 1909;t:XXVIII.



- [44] Abraham M. Sull'Elettrodinamica di Minkowski. Rend. Circ. Matem. Palermo. 1910; t:XXX.
- [45] Trammel GT. Aharonov-Bohm Paradox. Phys. Rev. 1964;134(5B):B1183-B1184.
- [46] Shockley W, James RP. Try Simplest Cases" Discovery of Hidden Momentum Forces on Magnetic Currents. Phys. Rev. Lett. 1967;18(20):876.
- [47] Taylor TT. Electrodynamic paradox and the center-of-mass principle. Phys. Rev. 1965;137(2B):B467.
- [48] Aharonov Y, Bohm D. Significance of electromagnetic potentials in the quantum theory. Phys. Rev. 1959;115:485.
- [49] Brito HH. experimental status of thrusting by electromagnetic. inertia manipulation. Acta Astron. 2004;54:547-558.

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