Gravitation and Electromagnetism ; Correlation and Grand Unification

Fran De Aquino
Physics Department, Maranhão State University, S. Luís, MA, Brazil.

It is demonstrated that gravitational and inertial masses are correlated by an electromagnetic factor. Some theoretical consequences of the correlation are: incorporation of Mach's principle into Gravitation Theory; new relativistic expression for the mass ; the generalization of Newton's second law for the motion; the deduction of the differential equation for entropy directly from the Gravitation Theory. Another fundamental consequence of the mentioned correlation is that , in specific ultra-high energy conditions, the gravitational and electromagnetic fields can be described by the same Hamiltonian , i.e., in these circumstances, they are *unified* ! Such conditions can have occurred *inclusive* in the Initial Universe , before the first spontaneous breaking of symmetry.

Key Words : Gravitation , Quantum Cosmology , Unified Field .

INTRODUCTION

Several experiments[1,2,3,4,5,6], have been carried out since Newton to try to establish a correlation between gravitational mass m_g and inertial mass m_i. However, only recently has it been discovered that a particle's gravitational mass decreases with the increasing temperature and that only in absolute zero (T=0 K) are gravitational mass and inertial mass equivalent[7].

The purpose of this work is to show that the old suspicion of a correlation between gravitation and electromagnetism is true. Initially, using formal techniques let us showing that there is an adimensional electromagnetic factor which relates gravitational to inertial mass. Afterwards, we will see fundamental consequences of this correlation, such as, the generalisation of Newton's second law for the motion, the deduction of the differential equation for *entropy* (second law of Thermodynamics), and the possibility of the electromagnetic control of the gravitational mass. In addition, we will see that , in specific conditions of ultra-high energy, the gravitational field can be described by the same Hamiltonian which allows to describe the electromagnetic field. Such conditions can have occurred in the initial Universe, before the first spontaneous breaking of symmetry.

1. CORRELATION

Using elementary arguments from Quantum Mechanics, J.F. Donoghue and B.R. Holstein[7], have shown that the renormalized mass for temperature T = 0 is expressed by $m_r = m + \delta m_o$ where δm_o is the *temperature-independent mass shift*. In addition, for T > 0, mass renormalization leads to the following expressions for inertial and gravitational masses, respectively: $m_i = m + \delta m_o + \delta m_\beta$; $m_g = m + \delta m_o - \delta m_\beta$, where δm_β is the *temperature-dependent mass shift*.

The expression of δm_β obtained by Donoghue and Holstein refers solely to thermal radiation. It is then imperative to obtain the generalised expression for any type of electromagnetic radiation.

The electromagnetic wave equations in an absorbing medium,

$$\nabla^2\boldsymbol{E}+\omega^2\mu\varepsilon[1+\sigma/\omega\varepsilon i]\boldsymbol{E}=0 \quad \text{and} \quad \nabla^2\boldsymbol{H}+\omega^2\mu\varepsilon[1+\sigma/\omega\varepsilon i]\boldsymbol{H}=0 \qquad (1.01)$$

express the fact that electromagnetic fields of cyclic frequency ω , $\omega=2\pi f$, propagate in a medium with electromagnetic characteristics, ε, μ and σ, at speed

$$v = c\left\{\tfrac{1}{2}\varepsilon_r\mu_r\left[\left(1+(\sigma/\omega\varepsilon)^2\right)^{1/2}+1\right]\right\}^{-1/2} \qquad (1.02)$$

If an electromagnetic radiation with velocity v strikes a particle (or is emitted from a particle) of rest inertial mass m_i , and U is the electromagnetic energy absorbed (or emitted) by the particle, then, according to Maxwell's prediction, a momentum $q=U/v$ is transferred to it.

Mass shift δm_β , dependent on the external electromagnetic energy, equals the inertial mass shift dependent on the increment of energy in the particle. Since in this case the inertial mass shift does not depend on the particle's velocity $\boldsymbol{V}$, i.e., it is related only to the momentum q absorbed, it can be obtained by making $\boldsymbol{p}=0$ in variation $\Delta H=H'-H= c\,[q^2+(m_ic)^2]^{1/2}- m_ic^2$ from the particle's inertial Hamiltonian.Consequently, the expression of δm_β , is written as:

$$\delta m_\beta = \Delta H / c^2 = \left\{\sqrt{1+\left\{\frac{U}{m_ic^2}\sqrt{\frac{\varepsilon_r\mu_r}{2}\left(\sqrt{1+(\sigma/\omega\varepsilon)^2}+1\right)}\right\}^2}-1\right\}m_i \qquad (1.03)$$

Comparing now the expression of m_i and m_g we have $m_g=m_i-2\delta m_\beta$. By replacing δm_β in this equation, given by equation above, we obtain *the expression of the correlation between gravitational mass and inertial mass*.i.e.,

$$m_g = m_i - 2\left\{\sqrt{1+\left\{\frac{U}{m_ic^2}\sqrt{\frac{\varepsilon_r\mu_r}{2}\left(\sqrt{1+(\sigma/\omega\varepsilon)^2}+1\right)}\right\}^2}-1\right\}m_i \qquad (1.04)$$

We see that only in the absence of electromagnetic radiation on the particle ($U=0$) is the gravitational mass equivalent to the inertial mass.

Note that the electromagnetic characteristics, ε ,μ and σ do not refer to the particle, but to the outside medium around the particle in which the incident radiation is propagating. For an *atom* inside a body , the incident radiation on this atom will be propagating inside the body , and consequently , $\sigma=\sigma_{body}$, $\varepsilon=\varepsilon_{body}$, $\mu=\mu_{body}$. So , if $\omega << \sigma_{body}/\varepsilon_{body}$, equation above reduces to :

$$m_g = m_a - 2\left\{\sqrt{1+\left\{\frac{U}{m_ac^2}\sqrt{\frac{c^2\mu_{body}\sigma_{body}}{4\pi f}}\right\}^2}-1\right\}m_a \qquad (1.05)$$

where m_a is the *inertial* mass of the atom .

Thus we see that, *atoms* (or *molecules*) can have their *gravitational masses* strongly reduced by means of extra-low frequency (ELF) radiation.

For the particular case of $\mu_r = \varepsilon_r \cong 1$, $\omega >> \sigma / \varepsilon$ and $U << m_i c^2$ the expression (1.04) is reduced to:

$$m_g = \left[1 - \left(U/m_i c^2\right)^2 \right] m_i \qquad (1.06)$$

In the case of thermal radiation, it is common to relate the energy of photons to temperature, through the relation, $\langle h\nu \rangle \sim k\mathrm{T}$ where $k = 1.38 \times 10^{-23}$ J/K is the Boltzmann's constant. Thus, in this case, the energy absorbed by the particle will be $U = \eta \langle h\nu \rangle \sim \eta k\mathrm{T}$, and equation above may be rewritten as:

$$m_g = \left[1 - \left(\eta k\mathrm{T}/m_i c^2\right)^2\right] m_i \qquad (1.07)$$

If we take T~ 300 K, and m_i as the electron mass, we will have: $\left(\eta k\mathrm{T}/m_i c^2\right)^2 \sim 2.5 \times 10^{-15} \eta^2$. For $\eta \sim 0.1$, a value is obtained is agreement with that obtained by Donoghue and Holstein, in this case. That is , $2/3\ \pi\alpha(\mathrm{T}/m_i)^2 \sim 3 \times 10^{-17}$.

2. **FUNDAMENTAL CONSEQUENCES**

As we know, Lagrange's function (or lagrangean) for a particle is expressed by $L = -\psi c[1 - V^2/c^2]^{1/2}$, where ψ characterises the given particle. In Classical Mechanics, every particle is characterised by its mass, so that it was established that $\psi = m_i c$ .However, as a consequence of new expression of the gravitational mass, we can easily see that m_g characterises the particles in a more general way than m_i , thus, we should make $\psi = m_g c$.

The (−) sign in Lagrange's function comes from the fact that ψ, in action integral $S = -\psi \int ds$, was considered as always positive and, thus, the (−) sign was introduced because the aforesaid integral preceded by the (+) sign could not have a minimum; preceded by the (−) sign, it manifestly has a minimum along a world-line.

Nevertheless, with the new expression of ψ , we see that it may assume positive and negative values, since *gravitational mass*, as opposed to inertial mass, may be negative. Consequently, the action for a free particle is:

$$S = -|\psi| \int_a^b ds = -|m_g|\, c \int_a^b ds , \qquad (2.01)$$

and the Lagrangean,

$$L = -\left|m_g\right| c^2 \sqrt{1 - V^2/c^2}\ . \qquad (2.02)$$

It follows from equation above , that:

$$\boldsymbol{p} = \partial L/\partial \boldsymbol{V} = \ |m_g|\, \boldsymbol{V} \left[1 - V^2/c^2\right]^{-1/2} \qquad (2.03)$$

$$\boldsymbol{F} = d\boldsymbol{p}/dt = |m_g| \left[1 - V^2/c^2\right]^{-1/2} d\boldsymbol{V}/dt \qquad (2.04)$$

$$or \quad d\boldsymbol{p}/dt = |m_g| \left[(1 - V^2/c^2)^3\right]^{-1/2} d\boldsymbol{V}/dt$$

Note that equation (2.04) , in the absence of external electromagnetic fields on the particle ($U = 0$), and $V<<c$, reduces to $\boldsymbol{F}=m_i\boldsymbol{a}$ (Newton’s 2nd Law).

From mentioned equation , we deduce *the new expression for the inertial forces,* i.e. ,

$$\boldsymbol{F} = |M_g|\, \boldsymbol{a} \qquad (2.05)$$

where

$$|M_g| = |m_g| \left[1 - V^2/c^2\right]^{-1/2} \qquad (2.06)$$

is *the new relativistic expression for the mass.*

According to the new expression for the inertial forces, we see that these forces have origin in the gravitational interaction between the body and the other masses of the Universe, just as *Mach’s principle* predicts. Hence mentioned expression incorporates the Mach’s principle into Gravitation Theory, and furthermore reveals that a body’s inertial effects can be reduced and even annulled if its gravitational mass may be reduced or annulled, respectively.

The new relativistic expression for the mass show that, a particle with null gravitational mass isn't subject to relativistic effects , because under these circumstances its gravitational mass doesn't increase with increasing velocity .i.e., it stays null independently of the particle's velocity. This means that , a particle with null gravitational mass , can reach and even surpass the light speed . It becomes a particle with *momentum* $\boldsymbol{p} = |M_g|\, \boldsymbol{V} = 0$ and *energy* $E = |M_g|\, c^2 = 0$ .There is nothing of stranger with this particle type . In fact , we know that they appear in a natural way, in General Relativity , as solutions that predict the existence of "ghost" neutrinos[8]. This neutrinos are so called , because with momentum null and energy null , they cannot be detected. But even so , they can be present because still exists a *wave function* describing its presence.

The fact that a non-inertial reference frame is equivalent to a certain gravitational field (modern version of *equivalence principle*) presupposed $m_i \equiv m_g$ because the inertial forces was expressed by $\boldsymbol{F}_i = m_i \boldsymbol{a}_i$, while the equivalent gravitational forces , by $\boldsymbol{F}_g=m_g\boldsymbol{a}_g$. So, to satisfy the equivalence $\boldsymbol{a}_i=\boldsymbol{a}_g$, $\boldsymbol{F}_i\equiv\boldsymbol{F}_g$ it was *necessary that* $m_i\equiv m_g$.

Now, due to the new expression of the inertial forces, i,e., $\boldsymbol{F}=|m_g|\boldsymbol{a}_i$, we can easily verify that the equivalence $\boldsymbol{a}_i\equiv\boldsymbol{a}_g$, $\boldsymbol{F}_i\equiv\boldsymbol{F}_g$ is self-evident, it no longer being necessary that $m_g\equiv m_i$. In other words, although preserving the modern version of the equivalence principle (also known as the *strong* equivalence principle), the primitive conception of the equivalence principle (also called the *weak* equivalence principle) , where the equivalence of the gravitational and inertial masses was fundamental, is eliminated.

Therefore, once the validity of the equivalence principle is reaffirmed, the equations of the General Relativity Theory will obviously be preserved.

We define the particle's energy E to be [9] , $E=\boldsymbol{p}.\boldsymbol{V}-L$. Thus, by substituting the equations (2.02) and (2.03) of L and $\boldsymbol{p}$ in this expression, we obtain:

$$E=\frac{|m_g|c^2}{\sqrt{1-V^2/c^2}} \qquad (2.07)$$

By squaring the expressions for $\boldsymbol{p}$ and E and comparing them, we find the following relationship between energy and momentum of a particle:

$$E^2/c^2=p^2+m_g^2c^2 \qquad (2.08)$$

This equation in the form $E=c[p^2+(m_gc)^2]^{1/2}$ is the particle's *gravitational Hamiltonian* . It is the expression of particle's *internal energy*.

Here, when we say "particle" we are not saying "elementary". So, these equations are equally valid for all complex bodies (constituted of several particles); this way, m_g will be the total mass, and $\boldsymbol{V}$ the velocity of the body.

Therefore, in the case of a particles system, at rest ($\mathbf{p}=0$), within vacuum ($\mu_r=\varepsilon_r=1$, $\sigma=0$), where the external electromagnetic energy U is *only thermal* (and $U<<m_ic^2$ *),the internal energy* E of the system is reduced to:

$$E=m_gc^2=\left(m_i-2\delta m_\beta\right)c^2=\left[m_i-\left(\frac{\eta k}{c^2}\right)^2\frac{T^2}{m_i}\right]c^2, \qquad (2.09)$$

If we consider the expression of δm_β and also $m_i=m+\delta m_0+\delta m_\beta$, it is possible to rewrite this equation in the following form:

$$E=m_gc^2=\left(m_ic^2\right)-T\frac{\partial(m_ic^2)}{\partial T} \qquad (2.10)$$

whence we recognise the *inertial Hamiltonian* which, as we know, is identified with the *free energy* (F) of the system,

$$H=F \qquad (2.11)$$

So, the expression for E can be rewritten in the following form:

$$E=F-T\frac{\partial F}{\partial T} \qquad (2.12)$$

This is a well-known equation of Thermodynamics. On the other hand, remembering $\partial Q=\partial\tau+\partial E$ (1st principle of Thermodynamics) and $F=E-TS$

(Helmholtz function), we can easily obtain from expression for E , for a isolated system $\partial\tau = 0$, that

$$\partial Q = T\partial S \ . \qquad (2.13)$$

This is the well-known *Entropy Differential Equation*.

3. **UNIFICATION**

The T_i^k expression of the energy-momentum tensor for a particle is, as we know, given by $T_i^k = \rho c^2 \mu_i \mu^k$ where ρ is the particle's *gravitational* mass density. So, m_g is fundamental for describing the gravitational field produced by the particle, because once known T_i^k, we can derive the gravitational field equation by means : $R_i^k = \frac{8\pi G}{c^4}(T_i^k - \frac{1}{2}\delta_i^k T)$.

As was stated previously, a particle's gravitational mass can be expressed in the following form:

$$m_g = m_i - 2\delta m_\beta = m_i - 2(H' - H)\big/c^2 = \left[m_i + 2\sqrt{(p/c)^2 + m_i^{\,2}}\right] - 2H'/c^2 \qquad (3.01)$$

Thus, we can say that starting point for describing the gravitational field is, basically the Hamiltonian H' , given by:

$$H' = H + \delta m_\beta c^2 = c\sqrt{p^2 + m_i^2 c^2} + \delta m_\beta c^2 . \qquad (3.02)$$

Particularly, in the case of elementary particles in the *vacuum* ,we can place $\varepsilon_r = \mu_r = 1$ and $\sigma = 0$ in expression of δm_β (eq.1.03), so we have:

$$\delta m_\beta c^2 = \left\{\sqrt{1 + (U/m_i c^2)^2} - 1\right\} m_i c^2 \qquad (3.03)$$

If $U >> m_i c^2$, then $\delta m_\beta c^2 = U$ and the expression for H' will be given by:

$$H' = \frac{m_i c^2}{\sqrt{1 - V^2/c^2}} + U \qquad (3.04)$$

The absorbed electromagnetic energy, U , depends on the particle's interaction with the electromagnetic field. The properties of the particle are defined, with respect to its interaction with the electromagnetic field, for only just one parameter: the particle's *electric charge*, Q .On the other hand, the properties of the field in and of itself are characterized by the *potential* , φ ,of the field. So, absorbed electromagnetic energy , U , depends only on Q and φ.The product $Q\varphi$ has the dimensions of energy, so that we can write $U = Q\varphi$ once any proportionality factor can be included in the φ expression. So, the expression for H' becomes equal to the well-known Hamiltonian,

$$\mathcal{H} = \frac{m_i c^2}{\sqrt{1 - V^2/c^2}} + Q\varphi , \qquad (3.05)$$

for a charge Q in an electromagnetic field.

From this equation its possible obtain a complete description of the electromagnetic field, because starting from this Hamiltonian we can write the

Hamilton-Jacobi equation that allows us to establish the equations of motion for a charge in an electromagnetic field. The Hamilton-Jacobi equation, as we know, constitutes the starting point of a general method of integrating the equations of motion .

Then, we conclude that, when $U >> m_i c^2$, the gravitational field can be described starting from the *same* Hamiltonian ,which allows description of the electromagnetic field. This is equivalent to saying that in these circumstances, the gravitational and electromagnetic fields are *unified* !

In the GUTs, the Initial Universe was simplified for just two types of fundamental particles: the *boson* and the *fermion*. However, bosons and fermions are unified in *Supergravity*: one can be transformed into another , just as quarks can be transformed into leptons in the GUTs. Thus, in the period where gravitation and electromagnetism were unified. (which would have occurred from time zero up to a critical time $t_c \cong 10^{-43}$s after Big-Bang) , the Universe should have been extremely simple – with just *one* particle type (*protoparticle*) .

The temperature T of the Universe in the $10^{-43}\text{s} < t < 10^{-23}$s period can be calculated by means of the well-known expression[10] $T \sim 10^{22}(t/10^{-23})^{-1/2}$. Everything indicates that, $T \sim 10^{32}$K ($\sim 10^{19}$GeV) in the t_c instant (when the *first* spontaneous breaking of symmetry occurred).

In the 0-t_c period, the electromagnetic energy absorbed by the *protoparticles* was $U \sim \eta < h\nu > = \eta k T >> m_{pp}c^2$. ($m_{pp}$ is the *protoparticle's inertial mass* and η , as we have seen , is a particle-dependent absorption coefficient) .This means that *the gravitational and electromagnetic fields unification condition* ($U >> m_i c^2$) was satisfied in the aforementioned period, and consequently the gravitational and electromagnetic interactions were themselves *unified*.

APPENDIX A

Here we examine a possible experimental test for equation(1.04).Let us consider the apparatus in figure 1. The Transformer has the following characteristics:

- Frequency : 60 Hz
- Power : 11.5kVA
- Number of turns of coil : $n_1 = 12$, $n_2 = 2$
- Coil 1 : copper wire 6 AWG
- Coil 2 : ½ inch diameter copper rod (with insulation paint).
- Core area : 502.4 cm^2 ; ϕ=10 inch (Steel).
- Maximum input voltage : $V_1^{max} = 220$ V
- Input impedance : $Z_1 = 4.2\ \Omega$
- Output impedance : $Z_2 < 1\text{m}\ \Omega$ (ELF antenna impedance : 116 mΩ)
- Maximum output voltage with coupled antenna : 34.8V
- Maximum output current with coupled antenna : 300 A

In the system-G the *annealed pure iron* has an electric conductivity $\sigma_i = 1.03\times10^7$ S/m, magnetic permeability $\mu_i = 25000\mu_0$ [11],thickness 0.6 mm (to absorb the ELF radiation produced by the antenna).The *iron powder* which encapsulates the ELF antenna has $\sigma_p \approx 10$ S/m ;$\mu_p \approx 75\mu_0$ [12]. The antenna physical length is $z_0 = 12$ m, see Fig.1c.The power radiated by the antenna can be calculated by the well-known *general* expression ,for $z_0 << \lambda$:

$$P = (I_0\, \omega\, z_0)^2 / 3\pi\varepsilon v^3 \{[1+ (\sigma/\omega\varepsilon)^2]^{½} + 1\}$$

where I_0 is the antenna current amplitude ; $\omega = 2\pi f$; f =60Hz ; $\varepsilon = \varepsilon_p$;$\sigma = \sigma_p$ and v is the wave phase velocity in the *iron powder* (given by Equation 1.02). The radiation efficiency e = $P / P+P_{ohmic}$ is nearly 100%.

The atoms of the *annealed iron* absorb an ELF energy $U=\eta P_a /f$, where η is a particle-dependent absorption coefficient (the maxima η values occurs, as we know, for the frequencies of the atom's *absorption spectrum*) and P_a is the incident radiation power on the atom ; $P_a=DS_a$ where S_a is the atom's *geometric* cross section and $D=P/S$ the radiation power density on the iron atom (P is the power radiated by the antenna and S is the *annealed iron* toroid area(S = 0.374 m^2 ,see Fig.1b)) . So, we can write :

$$U = \eta S_a (I_0 z_0)^2\ \omega / 3S\varepsilon_i\, v^3 \{[1+ (\sigma_i/\omega\varepsilon_i)^2]^{½} + 1\} .$$

Consequently, according to Eq.(1.04) , for $\omega<<\sigma_i/\varepsilon_i$, the gravitational masses of these iron atoms, under these conditions, will be given by :

$$m_g = m_a - 2 \{[1 + 8\times10^{-8} (\mu_i\, \sigma_i\, \sigma_p)(\mu_p)^3 (z_0)^4\ \ I_0^4]^{½} - 1\}m_a$$

Note that the equation above doesn't depend on ε_p or ε_i .In addition it shows that the *gravitational masses* (m_g) of the atoms of the annealed iron toroid can be *nullified* for a value $I_0 \approx 130$A. Above this critical value the gravitational masses become negatives (anti-gravity).

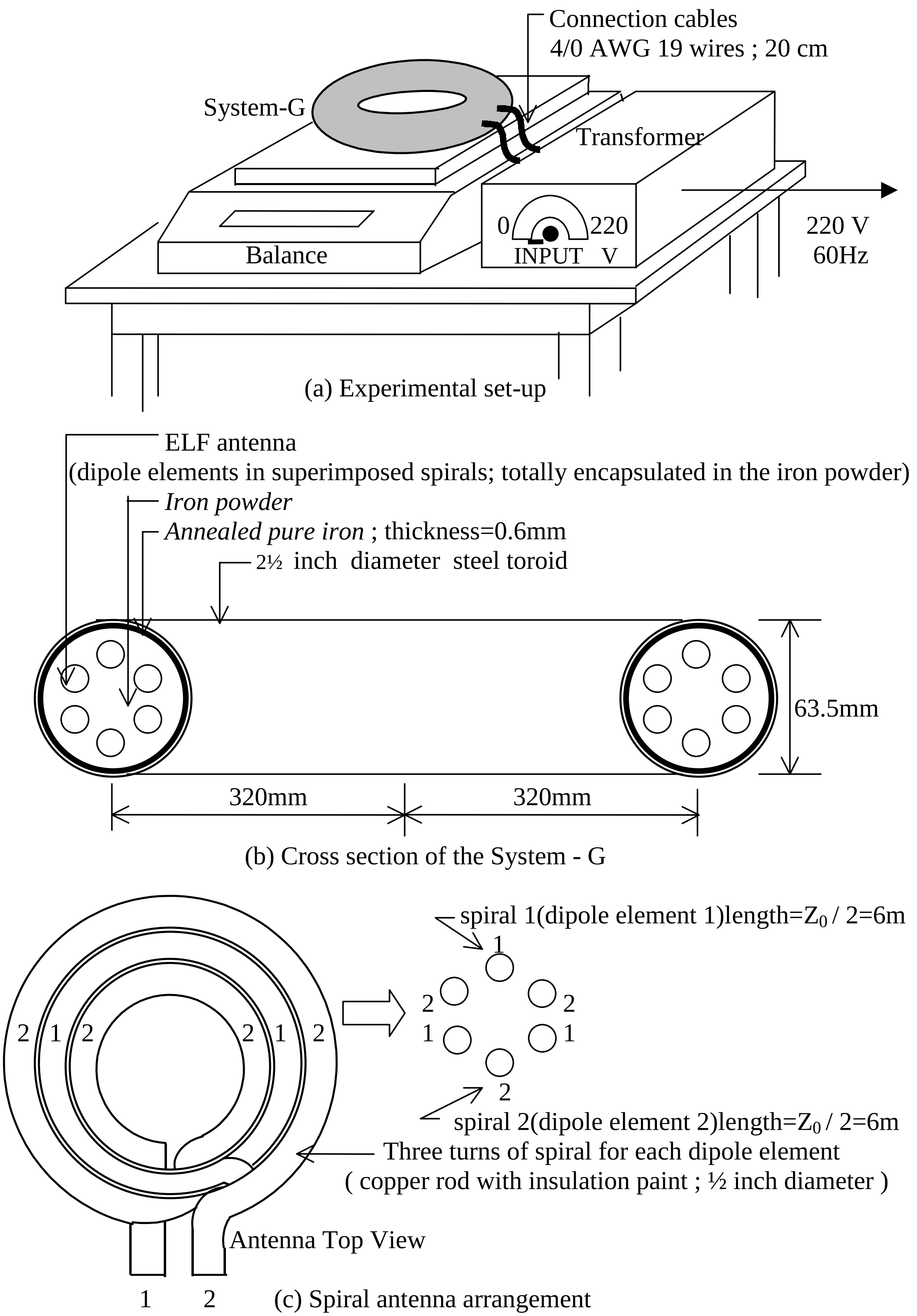

Fig. 1 – Schematic View of the Experimental Apparatus

APPENDIX B

It is known that photons have *null* inertial mass ($m_i = 0$) and that they do not absorb others photons ($U = 0$) . So , if we put $m_i = 0$ and $U = 0$ in Eq.(1.04) , the result is $m_g = 0$ .Therefore photons have *null* gravitational mass .

Let us consider a point source of radiation with power P , frequency f and radiation density at distance r given by $D = P/4\pi r^2$ .Due to the *null* gravitational mass of the photons, it must be possible to build a *shield* of photons around the source, which will impede the exchange of gravitons between the particles inside the *shield* and the rest of the Universe. The *shield* begins at distance r_s from the source where the radiation density is such that there will be a photon in opposition to each incident graviton . This critical situation occurs when $D = hf^2/S_g$, where S_g is the geometric cross section of the *graviton*. Thus r_s is given by the relation,

$$r_s = (r_g / f)(P/h)^{1/2} .$$

We then see that the ELF radiation are the most appropriate to produce the *shield*. It can be easily shown that, if $f \ll 1$mHz , the radiation will traverse any particle . It is not difficult to see that in this case, there will be "clouds" of photons around the particles inside the *shield*. Due to the null gravitational mass of the photons , these "clouds" will impede the exchange of gravitons between the particle inside the "cloud" and the rest of the Universe. Thus, we can say that the gravitational mass of the particle will be null with respect to the Universe, and that the space-time *inside the shield* (out of the particles)becomes *flat* or *euclidean* . It is clear that the space-time which the particles occupies remains non-euclidean.

In an *euclidean* space-time the maximum speed of propagation of the interactions is *infinite* ($c \to \infty$) because , as we know, the metrics becomes from *Galilei*. Therefore, the interactions are *instantaneous* . Thus , in this space-time the speed of *photons* must be *infinite*, simply because they are the *quanta* of the *electromagnetic* interaction. So, the speed of photons will be infinite *inside the shield*.

On the other hand , the new relativistic expression for mass, Eq.(2.06) , shows that a particle with null gravitational mass isn't submitted to the increase of *relativistic mass* , because under these circumstances its gravitational mass doesn't increase with increasing velocity .i.e., it remains null independently of the particle's velocity. In addition , the gravitational potential $\varphi = GM_g/r$ for the particle will be null and, consequently , the component $g_{00} = -1-2\varphi/c^2$ of the metric tensor will be equal to -1 .Thus , we will have $ds^2 = g_{00}(dx_0')^2 = g_{00}(icdt')^2 = c^2(dt')^2$ where t' is the time in a clock moving with the particle , and $ds^2 = c^2dt^2$ where t is the time indicated by a clock at rest ($dx = dy = dz = 0$). From the combination of these two equations we conclude that $t' = t$ .This means that the particle will be not more submitted to the relativistic effects predicted in Einstein's theory. So, it can reach and even surpass the speed of light .

We can imagine a spacecraft with *positive* gravitational mass equal to (m) kg , and *negative* gravitational mass (see System-G in appendix A) equal to $-$ (m $-$ 0.001) kg . It has a *shield* of photons , as above mentioned. If the photons, which produce the *shield* , radiate from the *surface* of the spacecraft , then the space-time that it occupies remains *non-euclidean* ,and consequently , for an observer in this space-time , the *total* gravitational mass of the spacecraft, will be $| M_g | = 0.001$ kg . Therefore , if its propulsion system produces F=10N (only) the spacecraft acquires acceleration $a = F/ | M_g | = 10^4 m/s$ (see Eq.(2.05)).

Furthermore, due to the “cloud” of photons around the spacecraft its gravitational interaction with the Universe will be null , and therefore, we can say that its gravitational mass will be null with respect to the Universe. Consequently, the inertial forces upon the spacecraft will also be null, in agreement with Eq.2.05 (Mach’s principle) .This means that the spacecraft will lose its *inertial properties* . In addition, the spacecraft can reach and even surpass the speed of light because , as we have seen , a particle with null gravitational mass will be not submitted to the relativistic effects .

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