Gravitational Atomic Synthesis at Room Temperature

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It is described a process for creating new atoms starting from pre-existing atoms. We show that all the elements of the periodic table can be synthesized, at room temperature, by a gravitational process based on the intensification of the gravitational interaction by means of electromagnetic fields.

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1. Introduction

Rutherford [1]was the first to observe transmutation of the atoms, and also the first to perform transmutation of the atoms. That gave him a double justification for being labeled an alchemist.

It is currently believed that the synthesis of precious metals, a symbolic goal long sought by alchemists, is only possible with methods involving either nuclear reactors or particle accelerators. However, it will be shown here that *all the elements* of the periodic table can be synthesized, at room temperature, by a gravitational process based on the intensification of the gravitational interaction by means of electromagnetic fields. The process is very simple, but it requires extremely-low frequency (ELF) magnetic field with very strong intensity ($B_{rms} > 2{,}500T$).

The strongest continuous magnetic field yet produced in a laboratory had *45 T* (Florida State University's National High Magnetic Field Laboratory in Tallahassee, USA) [2]. The strongest (pulsed) magnetic field yet obtained non-destructively in a laboratory had about *100T*. (National High Magnetic Field Laboratory, Los Alamos National Laboratory, USA) [3]. The strongest pulsed magnetic field yet obtained in a laboratory, destroying the used equipment, but not the laboratory itself (Institute for Solid State Physics, Tokyo) reach *730 T* . The strongest (pulsed) magnetic field ever obtained (with explosives) in a laboratory (VNIIEF in Sarov, Russia, 1998) reach *2,800T* [4].

2. Theory

The quantization of gravity showed that the *gravitational mass* m_g and the *inertial mass* m_i are correlated by means of the following factor [5]:

$$\chi = \frac{m_g}{m_{i0}} = \left\{1 - 2\left[\sqrt{1 + \left(\frac{\Delta p}{m_{i0}c}\right)^2} - 1\right]\right\} \tag{1}$$

where m_{i0} is the *rest* inertial mass of the particle and Δp is the variation in the particle's *kinetic momentum*; c is the speed of light.

When Δp is produced by the absorption of a photon with wavelength λ, it is expressed by $\Delta p = h/\lambda$. In this case, Eq. (1) becomes

$$\frac{m_g}{m_{i0}} = \left\{1 - 2\left[\sqrt{1 + \left(\frac{h/m_{i0}c}{\lambda}\right)^2} - 1\right]\right\}$$
$$= \left\{1 - 2\left[\sqrt{1 + \left(\frac{\lambda_0}{\lambda}\right)^2} - 1\right]\right\} \tag{2}$$

where $\lambda_0 = h/m_{i0}c$ is the *DeBroglie wavelength* for the particle with *rest* inertial mass m_{i0}.

In general, the *momentum* variation Δp is expressed by $\Delta p = F\Delta t$ where F is the applied force during a time interval Δt. Note that there is no restriction concerning the *nature* of the force, i.e., it can be mechanical, electromagnetic, etc. For example, we can look on the *momentum* variation Δp as due to absorption or emission of *electromagnetic energy* by the particle.

This means that, by means of electromagnetic fields, the *gravitational mass* can be decreased down to become negative and *increased* (*independently* of the inertial mass m_i). In this way, *the gravitational forces can be intensified*. Consequently, we can use, for example, oscillating magnetic fields in order to *intensify the gravitational interaction* between electrons and protons.

From Electrodynamics we know that when an electromagnetic wave with frequency f and velocity c incides on a material with relative permittivity ε_r, relative magnetic permeability μ_r and electrical conductivity σ, its *velocity is reduced* to $v = c/n_r$ where n_r is the index of refraction of the material, given by [6]

$$n_r = \frac{c}{v} = \sqrt{\frac{\varepsilon_r \mu_r}{2}\left(\sqrt{1+(\sigma/\omega\varepsilon)^2}+1\right)} \qquad (3)$$

If $\sigma >> \omega\varepsilon$, $\omega = 2\pi f$, Eq. (3) reduces to

$$n_r = \sqrt{\frac{\mu_r \sigma}{4\pi\varepsilon_0 f}} \qquad (4)$$

Thus, the wavelength of the incident radiation (See Fig. 2) becomes

$$\lambda_{\text{mod}} = \frac{v}{f} = \frac{c/f}{n_r} = \frac{\lambda}{n_r} = \sqrt{\frac{4\pi}{\mu f \sigma}} \qquad (5)$$

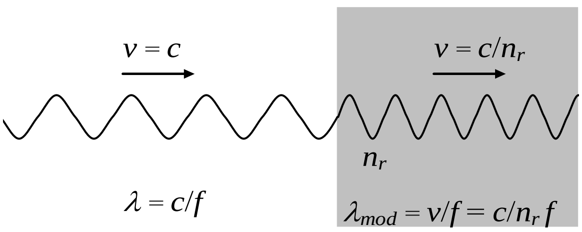

Fig. 2 – *Modified Electromagnetic Wave*. The wavelength of the electromagnetic wave can be strongly reduced, but its frequency remains the same.

If a lamina with thickness equal to ξ contains n atoms/m^3, then the number of atoms per area unit is $n\xi$. Thus, if the electromagnetic radiation with frequency f incides on an area S of the lamina it reaches $nS\xi$ atoms. If it incides on the *total area of the lamina*, S_f, then the total number of atoms reached by the radiation is $N = nS_f\xi$. The number of atoms per unit of volume, n, is given by

$$n = \frac{N_0 \rho}{A} \qquad (6)$$

where $N_0 = 6.02\times10^{26}\, atoms/kmole$ is the Avogadro's number; ρ is the matter density of the lamina (in *kg/m*^{3}) and A is the molar mass(*kg/kmole*).

When an electromagnetic wave incides on the lamina, it strikes N_f front atoms, where $N_f \cong (n\,S_f)\phi_m$, ϕ_m is the "diameter" of the atom. Thus, the electromagnetic wave incides effectively on an area $S = N_f S_m$, where $S_m = \frac{1}{4}\pi\phi_m^2$ is the cross section area of one atom. After these collisions, it carries out $n_{collisions}$ with the other atoms (See Fig.3).

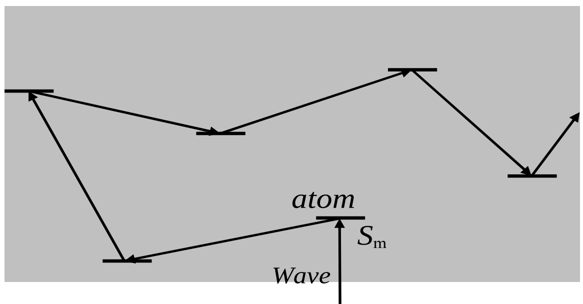

Fig. 3 – *Collisions inside the* lamina.

Thus, the total number of collisions in the volume $S\xi$ is

$$N_{collisions} = N_f + n_{collisions} = n_l S\phi_m + (n_l S\xi - n_m S\phi_m) = \\ = n_m S\xi \qquad (7)$$

The power density, D, of the radiation on the lamina can be expressed by

$$D = \frac{P}{S} = \frac{P}{N_f S_m} \qquad (8)$$

We can express the *total mean number of collisions in each atom*, n_1, by means of the following equation

$$n_1 = \frac{n_{total\ \ photons} N_{collisions}}{N} \qquad (9)$$

Since in each collision a *momentum* h/λ is transferred to the atom, then the *total momentum* transferred to the lamina will be $\Delta p = (n_1 N) h/\lambda$. Therefore, in accordance with Eq. (1), we can write that

$$\frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \left[(n_1 N)\frac{\lambda_0}{\lambda}\right]^2} - 1\right]\right\} =$$

$$= \left\{1 - 2\left[\sqrt{1 + \left[n_{total\ photons} N_{collisions}\frac{\lambda_0}{\lambda}\right]^2} - 1\right]\right\} \qquad (10)$$

Since Eq. (7) gives $N_{collisions} = n_l S \xi$, we get

$$n_{total\ \ photons} N_{collisions} = \left(\frac{P}{hf^2}\right)(n_l S \xi) \qquad (11)$$

Substitution of Eq. (11) into Eq. (10) yields

$$\frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \left[\left(\frac{P}{hf^2}\right)(n_l S \xi)\frac{\lambda_0}{\lambda}\right]^2} - 1\right]\right\} \qquad (12)$$

Substitution of P given by Eq. (8) into Eq. (12) gives

$$\frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \left[\left(\frac{N_f S_m D}{f^2}\right)\left(\frac{n_l S \xi}{m_{i0(l)} c}\right)\frac{1}{\lambda}\right]^2} - 1\right]\right\} \qquad (13)$$

Substitution of $N_f \cong (n_l S_f)\phi_m$ and $S = N_f S_m$ into Eq. (13) results

$$\frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \left[\left(\frac{n_l^3 S_f^2 S_m^2 \phi_m^2 \xi D}{m_{i0(l)} c f^2}\right)\frac{1}{\lambda}\right]^2} - 1\right]\right\} \qquad (14)$$

where $m_{i0(l)} = \rho_{(l)} V_{(l)}$.

Now, considering that the lamina is inside an ELF electromagnetic field with E and B, then we can write that [7]

$$D = \frac{n_{r(l)} E^2}{2\mu_0 c} \qquad (15)$$

Substitution of Eq. (15) into Eq. (14) gives

$$\frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \left[\left(\frac{n_{r(l)} n_l^3 S_f^2 S_m^2 \phi_m^2 \xi E^2}{2\mu_0 m_{i0(l)} c^2 f^2}\right)\frac{1}{\lambda}\right]^2} - 1\right]\right\} \qquad (16)$$

Note that $E = E_m \sin \omega t$. The average value for E^2 is equal to $\frac{1}{2}E_m^2$ because E varies sinusoidaly (E_m is the maximum value for E). On the other hand, $E_{rms} = E_m/\sqrt{2}$. Consequently we can replace E^4 for E_{rms}^4. Thus, for $\lambda = \lambda_{mod}$, the equation above can be rewritten as follows

$$\frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \left[\left(\frac{n_{r(l)} n_l^3 S_f^2 S_m^2 \phi_m^2 \xi E_{rms}^2}{2\mu_0 m_{i0(l)} c^2 f^2}\right)\frac{1}{\lambda_{mod}}\right]^2} - 1\right]\right\} \qquad (17)$$

Electrodynamics tells us that $E_{rms} = v B_{rms} = (c/n_{r(l)}) B_{rms}$. Substitution of this expression into Eq. (17) gives

$$\chi = \frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \frac{n_l^6 S_f^4 S_m^4 \phi_m^4 \xi^2 B_{rms}^4}{4\mu_0^2 m_{i0(l)}^2 f^4 \lambda_{mod}^2 n_{r(l)}^2}} - 1\right]\right\} \qquad (18)$$

Since $\lambda_{mod} = \lambda/n_{r(l)}$ then Eq. (18) can be rewritten in the following form

$$\chi = \frac{m_{g(l)}}{m_{i0(l)}} = \left\{1 - 2\left[\sqrt{1 + \frac{n_l^6 S_f^4 S_m^4 \phi_m^4 \xi^2 B_{rms}^4}{4\mu_0^2 m_{i0(l)}^2 c^2 f^2}} - 1\right]\right\} \qquad (19)$$

In order to calculate the expressions of χ_{Be} for the particular case of a *electron of the electrophere of a atom*, subjected to an external magnetic field B_{rms} with frequency

f, we must substitute in Eq. (19) n_l by $1/V_e = 1/\frac{4}{3}\pi r_e^3$, S_f by $(SSA_e)\rho_e V_e$ (SSA_e is the *specific surface area* for electrons in this case: $SSA_e = \frac{1}{2}A_e/m_e = \frac{1}{2}A_e/\rho_e V_e = 2\pi r_{xe}^2/\rho_e V_e$), S_m by $S_e = \pi r_{xe}^2$, ξ by $\phi_m = 2r_{xe}$ and $m_{i0(l)}$ by m_e. The result is

$$\chi_{Be} = \left\{1 - 2\left[\sqrt{1 + \frac{45.56\pi^2 r_{xe}^{22} B_{rms}^4}{c^2 \mu_0^2 m_e^2 r_e^{18} f^2}} - 1\right]\right\} \qquad (20)$$

In order to calculate the value of r_{xe} we start considering a hydrogen atom, where the electron spins around the proton with a velocity $v_e = 3\times10^6\, m.s^{-1}$. The electrical force acting on the proton is $F_e = e^2/4\pi\varepsilon_0 r_1^2$, which is equal to the centrifuge force $F_c = m_p\omega_e^2 r_0$ where ω_e is the angular velocity of the electron and r_0 is the distance between the inertial center of the proton and the center of the moving proton (See Fig. 5, where we conclude that $2(r_0 + r_p) = r_{xp} + r_p$, where r_{xp} is the radius of the sphere whose external area is equivalent to the increased area of the proton). Thus, we get $r_0 = \frac{1}{2}(r_{xp} - r_p)$.

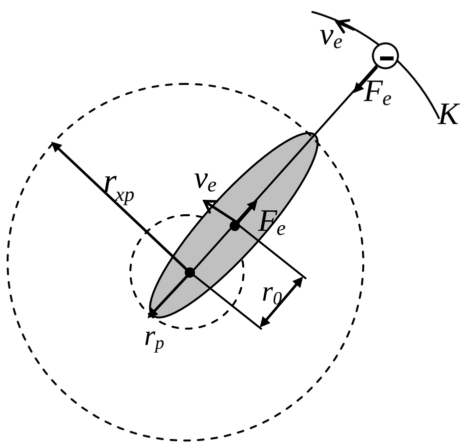

Fig. 5 – *The deformation of the proton.*

Substitution of this value into expression of $F_c = F_e$ gives

$$r_{xp} = \frac{e^2}{4\pi\varepsilon_0 m_p v_e^2} + r_p = 3.2\times10^{-14}\, m$$

Therefore, we can write that $r_{xp} = k_{xp} r_p$, where

$$k_{xp} = \frac{r_{xp}}{r_p} = 25.6$$

The electron is similarly deformed by the relative movement of the proton in respect to it. In this case, by analogy, we can write that

$$r_{xe} = \frac{e^2}{4\pi\varepsilon_0 m_e v_e^2} + r_e = 6.4\times10^{-11}\, m$$

and $r_{xe} = k_{xe} r_e$, where r_{xe} is the radius of the sphere whose external area is equivalent to the increased area of the electron. The radius of *free* electron is $r_e = 6.87\times10^{-14} m$ (See *Appendix* A). However, for *electrons in the atomic eletrosphere of atoms* the value of r_e must be calculated starting from Quantum Mechanics. The wave packet that describes the electron satisfies an *uncertainty principle* $(\Delta p \Delta x \geq \frac{1}{2}\hbar)$, where $\Delta p = \hbar\Delta k$ and Δk is the approximate extension of the wave packet. Thus, we can write that $(\Delta k \Delta x \geq \frac{1}{2})$. For the ``square" packet the full width in k is $\Delta k = 2\pi/\lambda_0$ ($\lambda_0 = h/m_e c$ is the average wavelength). The width in x is a little harder to define, but, lets use the first node in the probability found at $(2\pi/\lambda_0)x/2 = \pi$ or $x = \lambda_0$. So, the width of the wave packet is twice this or $\Delta x = 2\lambda_0$. Obviously, $2r_e$ cannot be greater than Δx, i.e., r_e *must be smaller and close to* $\lambda_0 = h/m_e c = 2.43\times10^{-12} m$. Then, assuming that $r_e \cong 2.4\times10^{-12}\, m$, we get

$$k_{xe} = \frac{r_{xe}}{r_e} = 26.6$$

Note that $k_{xe} \cong k_{xp}$.

Substitution of these values into Eq. (20) gives

$$\chi_{Be} = \left\{1 - 2\left[\sqrt{1 + 3.8\times10^{57}\frac{k_{xe}^{22} r_e^4 B_{rms}^4}{f^2}} - 1\right]\right\} =$$

$$= \left\{1 - 2\left[\sqrt{1 + 2.8\times10^{42}\frac{B_{rms}^4}{f^2}} - 1\right]\right\} \qquad (21)$$

Similarly, in the case of *proton* and *neutron* we can write that

$$\chi_{Bp} = \left\{1 - 2\left[\sqrt{1 + \frac{45.56\pi^2 k_{xp}^{22} r_p^4 B_{rms}^4}{c^2 \mu_0^2 m_p^2 f^2}} - 1\right]\right\} \qquad (22)$$

$$\chi_{Bn} = \left\{1 - 2\left[\sqrt{1 + \frac{45.56\pi^2 r_n^4 B_{rms}^4}{\mu_0^2 m_n^2 c^2 f^2}} - 1\right]\right\} \qquad (23)$$

In the case of the neutron, $k_{xn} = 1$ due to its electric charge be null. The radius of *protons inside the atoms* (nuclei) is $r_p = 1.2\times10^{-15}m$ [8,9], $r_n \cong r_p$, then we obtain from Eqs. (22) and (23) following expressions:

$$\chi_{Bp} = \left\{1 - 2\left[\sqrt{1 + 2.2\times10^{22}\frac{B_{rms}^4}{f^2}} - 1\right]\right\} \qquad (24)$$

$$\chi_{Bn} = \left\{1 - 2\left[\sqrt{1 + 2.35\times10^{9}\frac{B_{rms}^4}{f^2}} - 1\right]\right\} \qquad (25)$$

When a strong magnetic field B_{rms} is applied on the atom, the enormous value of χ_{Be} (See Eq. 21) makes the gravitational force between the electrons greater than the electric force due to its charges, and consequently, the electrons are jointed in pairs (Cooper pairs)[10]. However, due to the vales of χ_{Be} and χ_{Bp}, the gravitational attraction between the electrons of the K shell and the protons of the nucleus becomes greater than the nuclear force, i.e.,

$$G\frac{m_{gp} m_{ge}}{r_1^2} = \chi_{Bp}\chi_{Be} G\frac{m_p m_e}{r_1^2} > F_N \qquad (26)$$

Then, *the proton more weakly bound to the nucleus is ejected toward of the nearest electron*. When they collide occurs the formation of *one neutron* and one neutrino, according the well-known reaction $p + e \rightarrow n + \nu_e$. Since the neutron is beyond the reach of the nuclear force, it is not attracted to the nucleus and leaves the atom. *The final result is that the atom loses a proton and an electron and is transformed in a new atom*. But the transmutation is not completed until magnetic field be turned off. When this occurs the Cooper pairs are broken, and the *new atom* leaves the transitory state, and passes to the normal state.

In order to satisfy the condition expressed by Eq. (26), we must have

$$\chi_{Bp}\chi_{Be} > \frac{F_N r_1^2}{G m_p m_e} \approx 3\times10^{48} \qquad (27)$$

By substitution of Eq. (21) and (22) into Eq. (27), we obtain

$$\frac{B_{rms}^2}{f} > 6\times10^7$$

Thus, for $f = 0.1Hz$ we conclude that the required value of B_{rms} is

$$B_{rms} > 2{,}500T$$

This means that, if we subject, for example, an amount of ^{198}Hg (80 electrons, 80 protons, 118 neutrons) to a magnetic field with *B*$_{rms}$*>2,500 T* and frequency 0.1Hz the ^{198}Hg loses 1 proton and 1 electron and consequently will be transmuted to ^{197}Au (79 electrons, 79 protons, 118 neutrons) when the magnetic field is turned off. Besides the transformation of mercury into gold, we can make several transmutations. For example, if the ^{197}Au is after subjected to the same magnetic field it will be transmuted to ^{196}Pt (78 electrons, 78 protons, 118 neutrons). Similarly, if ^{110}Cd (48 electrons, 48 protons, 62 neutrons) is subjected to the mentioned field it will be transmuted to ^{109}Ag (47 electrons, 47 protons, 62 neutrons). Also ^{235}U can be easily obtained by this process, i.e., if we subject an amount of ^{236}Np (93 electrons, 93 protons, 143 neutrons) to the magnetic field with *>2,500 T* and frequency 0.1Hz, the ^{236}Np loses 1 proton and 1 electron and consequently will be transmuted to ^{235}U (92 electrons, 92 protons, 143 neutrons).

Appendix A: *The "Geometrical Radii" of Electron and Proton*

It is known that the frequency of oscillation of a simple spring oscillator is

$$f = \frac{1}{2\pi}\sqrt{\frac{K}{m}} \qquad (A1)$$

where m is the inertial mass attached to the spring and K is the spring constant (in N·m^{-1}). In this case, the restoring *force* exerted by the spring *is linear* and given by

$$F = -Kx \qquad (A2)$$

where x is the displacement from the equilibrium position.

Now, consider the gravitational force: For example, above the surface of the Earth, the force follows the familiar Newtonian function, i.e., $F = -GM_{g\oplus}m_g/r^2$, where $M_{g\oplus}$ is the mass of Earth, m_g is the gravitational mass of a particle and r is the distance between the centers. *Below* Earth's surface the *force is linear* and given by

$$F = -\frac{GM_{g\oplus}m_g}{R_\oplus^3}r \qquad (A3)$$

where $R_\oplus$ is the radius of Earth.

By comparing (A3) with (A2) we obtain

$$\frac{K}{m_g} = \frac{K}{\chi\, m} = \frac{GM_{g\oplus}}{R_\oplus^3}\left(\frac{r}{x}\right) \qquad (A4)$$

Making $x = r = R_\oplus$, and substituting (A4) into (A1) gives

$$f = \frac{1}{2\pi}\sqrt{\frac{GM_{g\oplus}\chi}{R_\oplus^3}} \qquad (A5)$$

In the case of an *electron* and a *positron*, we substitute $M_{g\oplus}$ by m_{ge}, χ by χ_e and $R_\oplus$ by R_e, where R_e is the radius of electron (or positron). Thus, Eq. (A5) becomes

$$f = \frac{1}{2\pi}\sqrt{\frac{Gm_{ge}\chi_e}{R_e^3}} \qquad (A6)$$

The value of χ_e varies with the density of energy [5]. When the electron and the positron are distant from each other and the local density of energy is small, the value of χ_e becomes very close to 1. However, *when the electron and the positron are penetrating one another*, the energy densities in each particle become very strong due to the proximity of their electrical charges e and, consequently, the value of χ_e strongly increases. In order to calculate the value of χ_e under these conditions ($x = r = R_e$), we start from the expression of correlation between *electric charge* q and *gravitational mass*, obtained in a previous work [5]:

$$q = \sqrt{4\pi\varepsilon_0 G}\; m_{g(imaginary)}\, i \qquad (A7)$$

where $m_{g(imaginary)}$ is the *imaginary* gravitational mass, and $i = \sqrt{-1}$.

In the case of *electron*, Eq. (A7) gives

$$\begin{aligned} q_e &= \sqrt{4\pi\varepsilon_0 G}\; m_{ge(imaginary)}\, i = \\ &= \sqrt{4\pi\varepsilon_0 G}\left(\chi_e m_{i0e(imaginary)} i\right) = \\ &= \sqrt{4\pi\varepsilon_0 G}\left(-\chi_e \tfrac{2}{\sqrt{3}} m_{i0e(real)} i^2\right) = \\ &= \sqrt{4\pi\varepsilon_0 G}\left(\tfrac{2}{\sqrt{3}}\chi_e m_{i0e(real)}\right) = -1.6\times10^{-19}C \qquad (A8) \end{aligned}$$

where we obtain

$$\chi_e = -1.8\times10^{21} \qquad (A9)$$

This is therefore, the value of χ_e increased by the strong density of energy produced by the electrical charges e of the two particles, under previously mentioned conditions.

Given that $m_{ge} = \chi_e m_{i0e}$, Eq. (A6) yields

$$f = \frac{1}{2\pi}\sqrt{\frac{G\chi_e^2 m_{i0e}}{R_e^3}} \qquad (A10)$$

From Quantum Mechanics, we know that

$$hf = m_{i0}c^2 \qquad (A11)$$

where h is the Planck's constant. Thus, in the case of $m_{i0} = m_{i0e}$ we get

$$f = \frac{m_{i0e}c^2}{h} \qquad (A12)$$

By comparing (A10) and (A12) we conclude that

$$\frac{m_{i0e}c^2}{h} = \frac{1}{2\pi}\sqrt{\frac{G\chi_e^2 m_{i0e}}{R_e^3}} \qquad (A13)$$

Isolating the radius R_e, we get:

$$R_e = \left(\frac{G}{m_{i0e}}\right)^{\frac{1}{3}}\left(\frac{\chi_e h}{2\pi\ c^2}\right)^{\frac{2}{3}} = 6.87\times10^{-14}m \qquad (A14)$$

Compare this value with the *Compton sized electron*, which predicts $R_e = 3.86\times10^{-13}m$ and also with standardized result recently obtained of $R_e = 4-7\times10^{-13}m$ [11].

In the case of *proton*, we have

$$\begin{aligned} q_p &= \sqrt{4\pi\varepsilon_0 G}\ m_{gp(imaginary)}\, i = \\ &= \sqrt{4\pi\varepsilon_0 G}\left(\chi_p m_{i0p(imaginary)} i\right) = \\ &= \sqrt{4\pi\varepsilon_0 G}\left(-\chi_p \tfrac{2}{\sqrt{3}}\, m_{i0p(real)} i^2\right) = \\ &= \sqrt{4\pi\varepsilon_0 G}\left(\tfrac{2}{\sqrt{3}}\,\chi_p m_{i0p(real)}\right) = -1.6\times10^{-19}C \qquad (A15) \end{aligned}$$

where we obtain

$$\chi_p = -9.7\times10^{17} \qquad (A16)$$

Thus, the result is

$$R_p = \left(\frac{G}{m_{i0p}}\right)^{\frac{1}{3}}\left(\frac{\chi_p h}{2\pi\ c^2}\right)^{\frac{2}{3}} = 3.72\times10^{-17}m \qquad (A17)$$

Note that these radii, given by Equations $(A14)$ and $(A17)$, are the radii of *free* electrons and *free* protons (when the particle and antiparticle (in isolation) penetrate themselves mutually).

Inside the atoms (nuclei) the radius of protons is well-known. For example, protons, as the hydrogen nuclei, have a radius given by $R_p \cong 1.2\times10^{-15}m$ [8,9]. The strong increase in respect to the value given by Eq. (A17) is due to the interaction with the electron of the atom.

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