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Organization of Quantum Dots

Alternative to General Relativity

Highlights

Effects of Indium Composition

Static Mantle Density Distribution

Discovering Thoughts, Inventing Future

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Effects of Indium Composition and the Size on the Electronic Structure Ns-Np of Quantum Dots in N/In$_x$ga$_{1-X}$n/Ligand

By F. Benhaddou, H. Abboudi, I. Zorkani, A. Jorio & S. J. Edrissi
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Abstract- The electronic structure of homogeneous and inhomogeneous quantum dots involves fascinating optoelectronic properties. Herein, a detailed theoretical and numerical investigation of the electronic structure of spherical inhomogeneous quantum dots InN/$In_xGa_{1-x}N$/Ligand, based Indium and Gallium Nitride, with a variable composition x of Indium. A more real profile is adopted with a finite potential shell and variable thickness. The ligand and solution impose external confinement. With such shell $In_xGa_{1-x}N$, a minimum of defects is ensured at the interface, and the structure is passivated. Along with this work, we will explore the effects of the various parameters of this nanosystem on its gap, on the location of charge carriers and the distribution of nS-nP energy levels. We will show how the dimensions of the material core InN, the material shell $In_xGa_{1-x}N$, and the Indium-composition x control the characteristics of the nanosystem and consequently improve the electronic and optical properties. Then a detailed calculation of the electronic structure will be made.

Keywords: *inhomogeneous quantum dot; core/shell; electronic structure; two levels system; quantum efficiency; photostability.*

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EFFECTSOFINDIUMCOMPOSITIONANDTHESIZEONTHEELECTRONICSTRUCTURENSNPOFQUANTUMDOTSINNINGANLIGAND

Strictly as per the compliance and regulations of:

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F. Benhaddou [α], H. Abboudi [σ], I. Zorkani [ρ], A. Jorio [Ѡ] & S. J. Edrissi [¥]

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I. Introduction

Since the 80s[1-4] the advent of nanotechnology and the development of growth techniques quantum dots has advanced a lot in favor of the development of optoelectronic components, [5-10] light-emitting diodes,[11] biological applications,[12] photovoltaic[13] and quantum information.[14] These nanostructures have remarkable properties, especially the quantum confinement of the charge carriers, which induces a total discretization of their energy levels. Luminescence is their strongest point but far from being the only one. They are thus emitters of single photons and even at room temperature. Also, around 1990, when these nanostructures were enveloped by shells[15,16] to form a quantum dot core/shells system ; these properties became fascinating. In today's scientific field, quantum dots take up an important place and greatly attract the curiosity and interest of researchers. We obtain the sources of light with a very fine spectrum, photo-stables, and with excellent quantum efficiency.[17,18] They are controlled by size and shape.[19-24] To remedy the defects still presented by these nanostructures such as the blinking[25] and to functionalize them in various environments for multiple applications, growth design has improved by adsorption of ligands covering the outer shell. The hetero-nanosystems thus obtained core/shell/Ligand[25,26] would become true light emitters.[27] These properties essentially arise from the electronic structure they possess. Many structures based on II-VI or III-V semiconductor core have already been analyzed and studied as CdSe, HgS, ZnS, and CdS.[5][28] In parallel, other materials are also currently attracting researchers such as indium nitride and gallium nitride.[29,30] This current work is a theoretical investigation of the characteristics of colloidal quantum dots $InN/In_xGa_{1-x}N$/Ligand. We will focus our study on the calculation of the electronic structure of levels nS-nP and the effects of the composition and size on their electronic and optical properties. We want to say how we can control these

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characteristics and how to make it capable of improving the fascinating properties of homogeneous quantum.

II. Model and Formalism

The study of quantum dots core/shell has aroused the interest of researchers for their important properties. In those studies, various geometric confinement models have adopted. The current investigation, the confinement of shell is modeled by a continuous and finite potential while that imposed by the colloidal solution, and the ligand is infinite. The graphic 1 is a schematic representation of potential with the values calculated in the case where the composition of indium $x = 0.3$. The height of the barrier for the electron is at 1.672eV and at -0.469eV for the hole. The bottom of the gap is taken as the origin of the potentials.

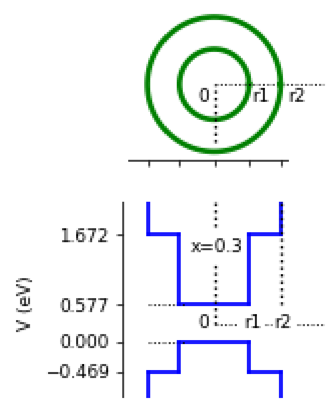

Figure 1: Schematic representation of QD and potential profile for indium composition $x = 0.3$

In the isotropic, nondegenerate parabolic approximations and under effective mass approach the energy E and envelope wave function $\Psi(\vec{r})$ of the electron or hole are determined by solving the eigenvalues equation in spherical coordinates of Hamiltonian :

$$H\Psi(\vec{r}) = E\Psi(\vec{r}) \quad \text{with} \quad H = (\frac{\hbar}{i}\nabla)\frac{1}{2m^*}(\frac{\hbar}{i}\nabla) + \mathrm{V}(r) \tag{1}$$

The envelop wave function is expressed by the form $\Psi_{n\ell}(\vec{r}) = R_{n\ell}(r)Y_\ell^m(\theta,\varphi)$, where $Y_\ell^m(\theta,\varphi)$ is the spherical harmonic. $R_{n\ell}(r)$ radial components and the integer numbers n, ℓ, m check the values : $n = 1,2,3......$ $\ell = 0,1,2......$ $m = 0, \pm1, \pm2, ..., \pm\ell$. The potential $\mathrm{V}(r)$ and effective mass are respectively given by :

$$\mathrm{V}(r) = \begin{cases} 0 & 0 < r \le r_1 \\ \mathrm{V}_0^{e,h}(x,T) & r_1 \le r \le r_2 \\ \infty & r \ge r_2 \end{cases} \qquad m^*(r) = \begin{cases} m^*(\mathrm{InN}) & 0 < r \le r_1 \\ m^*(\mathrm{In}_x\mathrm{Ga}_{1-x}\mathrm{N}) & r_1 \le r \le r_2 \end{cases} \tag{2}$$

For solving the equation (1) of eigenvalues and in our following calculations, we will use the average mass between InN material and $In_xGa_{1-x}N$ alloy. To use the effective mass of alloy.[31]

$$m^*_{e,h}(In_xGa_{1-x}N) = xm^*_{e,h}(InN) + (1-x)m^*_{e,h}(GaN)$$

Rearrange with the values of parameters in table 1 to give :

$$\bar{m}^*_e / m_0 = -0.0700x + 0.1200 \quad (3)$$

$$\bar{m}^*_h / m_0 = -0.0175x + 0.8225 \quad (4)$$

Denoted later m^*_e / m_0 and m^*_h / m_0. The confinment potential $V_0^{e,h}(x,T)$ is function of indium composition x and temperature T according:[32.33]

$$V_0^{e,h}(x,T) = h_{e,h}(E_g(In_xGa_{1-x}N,T) - E_g^{InN}(T))$$

by substitution[34] of $E_g(In_xGa_{1-x}N,T) = xE_g^{InN}(T) + (1-x)E_g^{GaN}(T)$. we get

$$V_0^{e,h}(x,T) = h_{e,h}((1-x)(E_g^{GaN}(T) - E_g^{InN}(T)) - bx(1-x))$$

Where $h_e = 0.7$; $b = 1.43eV$ are respevtivly the rate of electronic confinement and bowing parameter[35-37] and $h_h = 1 - h_e$.

Let $$E_g^{GaN}(T) = E_g^{GaN}(0) - (0.593/(600+T)).10^{-3}.T^2$$

$$E_g^{InN}(T) = E_g^{InN}(0) - (0.245/(624+T)).10^{-3}.T^2$$

And introdicing the follow temperature[32] parameter.

$$f = \left(0.593/(600+T) - 0.245/(624+T)\right).10^{-3}.T^2$$

Giving: $$V_0^{e,h} = h_{e,h}\left[(1-x)\Delta E_g(0) + (x-1)f - bx(1-x)\right] \quad (5)$$

Denoted later V_0, where $\Delta E_g(0) = E_g^{GaN}(0) - E_g^{InN}(0)$ calculated using the values given in table 1. Modifying the temperature from 0K to 300K, V_0 varies slightly, therefore the temperature has no marked effect on the confinement of this nanostructure and our calculations will be at 300K temperature. However, when the indium composition increases, V_0 decreases, and the confinement decreases all the more for the holes.

Table 1: The characteristic parameters of InN and GaN.[38]

Parameters	GaN	InN
$E_g(0)$ (eV)	3.3	0.6
m^*_e / m_0	0.19	0.054
m^*_h / m_0	0.81	0.835
ε_∞	5.75	8.4

In this spherical symmetry we use spherical cordinates so the equation (1) becomes :

$$-\frac{1}{r}\frac{\partial^2}{\partial r^2}(rR_n^{\ell}(r)) + \left[\frac{\ell(\ell+1)\hbar^2}{r^2} + \frac{2m^*}{\hbar^2}(V(r) - E)\right]R_n^{\ell}(r) = 0$$

We are interested after that in bound states such that the energy E verifies $E < V_0$. According to this our above main equation becomes :

$$-\frac{1}{r}\frac{\partial^2}{\partial r^2}(rR_{n\ell}(r)) + \left[\frac{\ell(\ell+1)}{r^2} - k^2\right]R_{n\ell}(r) = 0 \qquad 0 < r \le r_1 \quad (6)$$

$$-\frac{1}{r}\frac{\partial^2}{\partial r^2}(rR_{n\ell}(r)) + \left[\frac{\ell(\ell+1)}{r^2} + K^2\right]R_{n\ell}(r) = 0 \qquad r_1 \le r \le r_2 \quad (7)$$

Where $k^2 = \frac{2m^*E}{\hbar^2}$; $K^2 = \frac{2m^*(V_0 - E)}{\hbar^2}$ and $K^2 = k_0^2 - k^2$

Above relations constitute two forms of the generating equation of Bessel functions. To solve these equations we proceed to change variables from r to $\rho = kr$ for the first equation, from r to $\rho = iKr$ for the second and by using the function $Z = \rho^{1/2} R_{n\ell}(r)$ instead $R_{n\ell}(r)$. If replaced into the above equations the solution is :

$$\rho^{-1/2} Z(\rho) = \begin{cases} \mathrm{C}_1.(kr)^{-1/2} J_{\ell+1/2}(kr) + \mathrm{D}_1.(kr)^{-1/2} Y_{\ell+1/2}(kr) & 0 < r \le r_1 \\ \mathrm{A}_1.(iKr)^{-1/2} I_{\ell+1/2}(Kr) + \mathrm{B}_1.(iKr)^{-1/2} K_{\ell+1/2}(Kr) & r_1 \le r \le r_2 \end{cases} \tag{8}$$

A_1, B_1, C_1 and D_1 are constants. $J_{\ell+1/2}$ and $Y_{\ell+1/2}$ are the classical Bessel functions, respectively of the first and second kind. $Y_{\ell+1/2}$ is infinite at the origin, so the constant D_1 must have a null value. $I_{\ell+1/2}$ and $K_{\ell+1/2}$ are the modified or hyperbolic Bessel functions of the first and second kind. These functions are designed to give a real solution. In our case, we will use the spherical Bessel functions $j_\ell(kr)$ and spherical Hankel functions $h_\ell^{(1)}(iKr)$ of the first kind, which is more suitable and simple with spherical symmetry. Therefore the solution is :

$$R_{n\ell}(r) = \begin{cases} \mathrm{C}_1\sqrt{2/\pi}.j_\ell(kr) & 0 < r \le r_1 \\ \mathrm{A}_1\sqrt{2/\pi}.e^{-i\ell\pi/2}.j_\ell(iKr) + \mathrm{B}_1\sqrt{\pi/2}.e^{i\ell\pi/4}.h_\ell^{(1)}(iKr) & r_1 \le r \le r_2 \end{cases}$$

Simplify this
$$R_{n\ell}(r) = \begin{cases} \mathrm{C}.j_\ell(kr) & 0 < r \le r_1 \\ \mathrm{A}e^{-i\ell\pi/2} j_\ell(iKr) + \mathrm{B}e^{i\ell\pi/4} h_\ell^{(1)}(iKr) & r_1 \le r \le r_2 \end{cases} \tag{9}$$

Where $\mathrm{C} = \mathrm{A}_1.\sqrt{2/\pi}$; $\mathrm{A} = \mathrm{A}_1.\sqrt{2/\pi}$ and $\mathrm{B} = \mathrm{B}_1.\sqrt{2/\pi}$.

We focus at this step of determining the wave functions and energies for the nS and nP states. At this point, by applying the matching condition of $R_{n0}(r)$ in r_2 we can express $\mathrm{B} = -\beta.(\mathrm{A}/2)$ where $\beta = 1 - e^{2Kr_2}$. Knowing that $j_0(\rho) = \sin(\rho)/\rho$ and $h_0^{(1)}(iKr) = -(1/Kr)e^{-Kr}$ the relation (8) gives the wavefunction for nS states

$$R_{n0}(r) = \begin{cases} \mathrm{C}\dfrac{\sin(kr)}{kr} & 0 < r \le r_1 \\ \mathrm{A}\left[\dfrac{1}{2Kr}(e^{-Kr} - e^{Kr}) - \beta\dfrac{e^{-Kr}}{2Kr}\right] & r_1 \le r \le r_2 \end{cases} \tag{10}$$

Furthermore by applying the conditions of continuity to the wavefunction in r_1 we obtain the expression of C as a function of A and after normalization we can calculate numerically A for fixed values of the composition x, the radius r_1 and the thickness $\Delta = r_2 - r_1$.

Employing the matching conditions for the wavefunction which give the following system :

$$\begin{cases} \mathrm{C}\dfrac{\sin(kr_1)}{kr_1} = \mathrm{A}(\dfrac{e^{-Kr_1} - e^{Kr_1}}{2Kr_1} - \beta\dfrac{e^{-Kr_1}}{2Kr_1}) \\ \mathrm{C}k(\dfrac{\cos(kr_1)}{kr_1} - \dfrac{\sin(kr_1)}{(kr_1)^2}) = \mathrm{A}K(\dfrac{e^{Kr_1} - e^{-Kr_1}}{2(Kr_1)^2} - \dfrac{e^{Kr_1} + e^{-Kr_1}}{2Kr_1} + \beta\dfrac{e^{-Kr_1}}{2(Kr_1)^2} + \beta\dfrac{e^{-Kr_1}}{2Kr_1}) \end{cases}$$

Canceling the determinant of this system it follows

$$\frac{\tan(kr_1)}{kr_1} = \frac{1}{Kr_1}\frac{1 - e^{2K(r_2 - r_1)}}{1 + e^{2K(r_2 - r_1)}} \tag{11}$$

Rearrange to give a quantification function $Q^{\mathrm{S}}_{r_1,r_2,k,x}(\mathrm{X})$ with a reduced variable X :

$$Q^{\mathrm{S}}_{r_1,r_2,k,x}(\mathrm{X}) = \frac{\tan(\alpha\mathrm{X})}{\alpha\mathrm{X}} - \frac{1}{\alpha\mathrm{Y}}\frac{1 - \exp(2\alpha\mathrm{Y}\Delta r/r_1)}{1 + \exp(2\alpha\mathrm{Y}\Delta r/r_1)} \tag{12}$$

Where $\alpha = k_0 r_1$. $X = kr_1 / \alpha$.$\Delta r = r_2 - r_1$ and $Y = Kr_1 / \alpha = \sqrt{1-X^2}$

Let's do the same for the nP states. We use the matching condition of wavefunction for $r = r_2$ we can express $B = -\beta.(A/2)$ where $\beta = 1 + ((Kr_2 - 1)/(Kr_2 + 1))\exp(2Kr_2)$. We replace the following items $j_1(kr) = (\sin(kr)/(kr)^2) - (\cos(kr)/kr)$ and $h_1^{(1)}(iKr) = i((1/Kr) + (1/(Kr)^2)\exp(-Kr)$ in relation (9) wich becomes :

$$R_{n1}(r) = \begin{cases} C\left(\dfrac{\sin(kr)}{(kr)^2} - \dfrac{\cos(kr)}{kr}\right) & 0 < r \le r_1 \\ A\left[\left(\dfrac{1}{2(Kr)^2}(e^{-Kr} - e^{Kr}) + \dfrac{1}{2Kr}(e^{-Kr} + e^{Kr})\right) - \beta\left(\dfrac{1}{Kr} + \dfrac{1}{(Kr)^2}\right)e^{-Kr}\right] & r_1 \le r \le r_2 \end{cases} \quad (13)$$

The conditions of continuity to the wavefunction for $r = r_1$ give the expression of C as a function of A and, the normalization condition allows us to calculate A for each (x . r_1 r_2). In this case too, using the same calculation methods with the same variable we have :

$$\frac{1}{\alpha X \tan(\alpha X)} - \frac{1}{(\alpha X)^2} = \left(\frac{1}{\alpha Y} + \frac{1}{(\alpha Y)^2}\right)\omega(r_1, r_2, Y)$$

Where $$\omega(r_1, r_2, Y) = \frac{((\alpha Y r_2 / r_1 - 1)/(\alpha Y r_2 / r + 1)) - (\alpha Y - 1)/(\alpha Y + 1)e^{-2\alpha Y(r_2 - r_1)/r_1}}{((\alpha Y r_2 / r_1 - 1)/(\alpha Y r_2 / r + 1)) + e^{-2\alpha Y(r_2 - r_1)/r_1}}$$

Therefore the quantification is determined by $Q^{P}_{r_1, r_2, k, x}(X)$:

$$Q^{P}_{r_1, r_2, k, x}(X) = \frac{1}{\alpha X \tan(\alpha X)} - \frac{1}{(\alpha X)^2} - \left(\frac{1}{\alpha Y} + \frac{1}{(\alpha Y)^2}\right)\omega(r_1, r_2, Y) \quad (14)$$

The energies of the nS-nP states are given by the zeros of the quantization functions $Q^{S}_{r_1, r_2, k, x}(X)$ and $Q^{P}_{r_1, r_2, k, x}(X)$ gived by the expressions (12) and (14). But these functions cancel each other out if $\alpha X \rangle \frac{\pi}{2}$. That is to say :

$$X \rangle X_0(x, r1) = \pi\hbar^2 / 4m^* V_0 r \quad (15)$$

$X_0(x, r1)$ is increasing as fuction of the composition x according to the relation (4) but in reverse for core radius r_1. This condition constitutes a limit not to be exceeded for geometric confinement.

To study the distribution of the nS levels, we have established a function $F(E_{ns})$ which depends on the energy. For this, we have reformulated the equation (12) to give the relation :

$$F(E_{nS}) = \frac{\sin(kr_1)}{kr_1}.Kr_1.\frac{1 + \exp(-2K\Delta r)}{1 - \exp(-K\Delta r)} = \cos(Kr_1) \quad (16)$$

So $$-1 \le F(E_{ns}) \le +1$$

This function is limited and its graphic study, in figure 4, shows that the nS energies of the states are distributed according to disjoint allowed mini-bands AMB.

To give credibility to the physical context of our calculations, we are going to consider boundary behavior. The quantum dot with an infinite barrier is obtained when r_2 tends to infinity. Let's tend r_2 to infinity in the equation (11). the term

$(1-\exp(2K(r_2-r_1))/(1+\exp(2K(r_2-r_1))$ converges to -1. The equation is reduced to $\tan(kr_1)/kr_1=-1/Kr_1$. This is the relation effectively governing a quantum dot in continuous potential model.[28] When $r_1\to r_2$ this term tends to 0, so $\tan(kr_1)=0$ relation describing a quantum dot in infinite potential model. In the same way of nS-states, we will explore the behavior of nP-states at the limits. When $r_2\to+\infty$ then $\exp(-K(r_2-r_1))\to 0$ so $\omega\to 1$ and we find the result of the quantum dot in the finite potential for nP states characterized by the equation $(\cot an(kr)/kr)\text{-}(1/(kr)^2)=1/Kr+1/(Kr)^2$. When $r_1\to r_2$ $\omega\to 0$. the equation (13) is reduced to $\tan(kr_1)/kr_1=1/kr_1$. This is the same behavior that has been observed with the quantum dot in the infinite potential model[27].

III. Result and Discussion

As previously established, the wavefunction for nS states is given by the expression in relation (9). For a total radius $r_2=10$ nm and three values of Indium-composition $x=0$; 0.3 ; 0.6 we study the wavefunction of fundamental electronic state 1S and the associated radial probability over the entire nanostructure as function of the radius r of the quantum dot. The results are shown in graphics 2.a, 2.b, 3.a and 3.b. Figures 2 represent the wave functions of the electron and the hole in their ground states, and the figures 3 represent their radial probability of presence. Note that for a smaller radius $r_1=3$ nm, the particles are partially localized in shell, especially for the holes where the confinement is weaker. They are localized for a large radius core $r_1=7$ nm even if x varies from 0 to 0.6. This partial delocalization is considered as a defect for the photostability[5][17,18][25] and the quantum efficiency[5][17,18] of colloidal quantum dots core/shell type. The partial delocalization in the shell causes a spectral red shift[17] of the luminescence and it causes an increase in the times of de-excitation of the electron-hole pairs by radiative or non-radiative recombination**.**[25][39-41] We can see that with a core radius of the order of a few nanometers ensuring sufficient but not excessive confinement and with a thicker shell, the nanostructure ensures the location of electron-hole pairs in the core material.

An experimental study by P. Reiss et al. has shown that the growth of a fairly large layer of the shell improves photostability[5][17,18] and quantum efficency[5][17,18][25]. We notice then that the theoretical results above move in the same direction. They agree with this experimental study and show the crucial role of localization in this improvement. Other studies have highlighted the same conclusions.[19][41,42] Therefore the choice of the core radius, the shell-thickness and, the Indium-composition control the localization of the particles in the core material. The advantage of the shell is then to reinforce the confinement and to passivate the structure and consequently to improve the optical properties.

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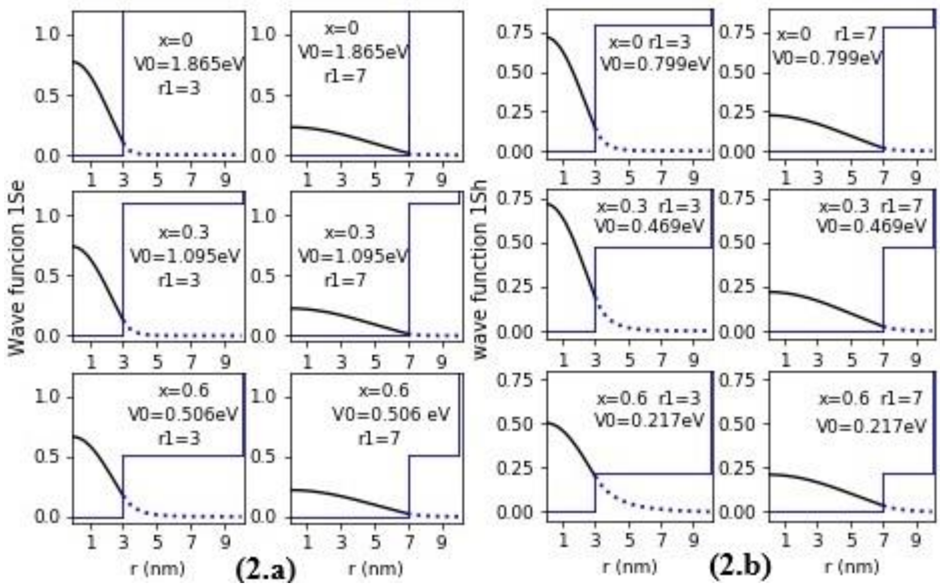

Figure 2: Continuous and dotted curves radius r dependent wave function of the ground state for various values of composition x, core radius r_1 and potential V_0. Blue square lines represent the potential. (2.a) electronic states (2.b) hole states

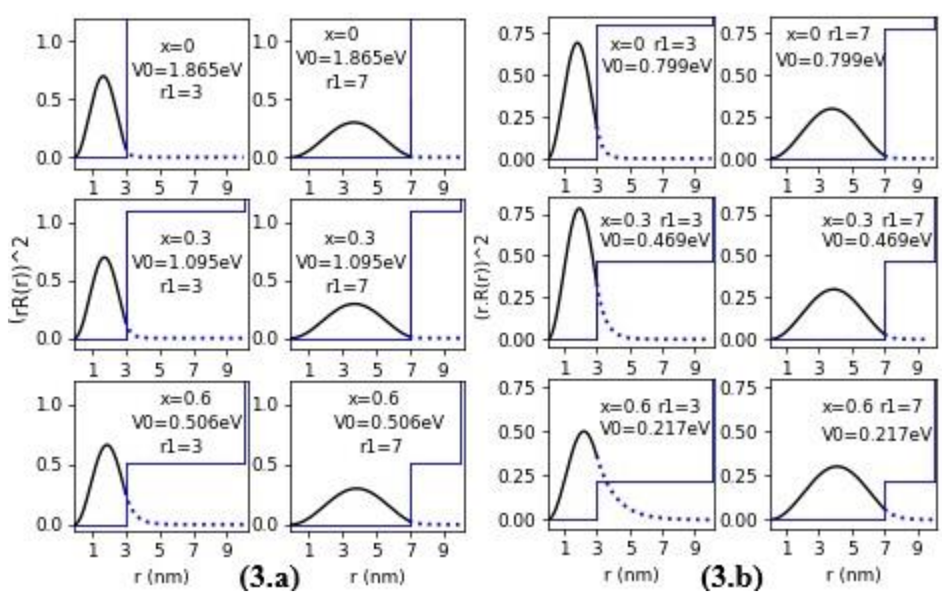

Figure 3: Curves in continuous or dotted lines represent the electronic radial probability in ground state vs radius r for various values of composition x, core radius r_1 and, potential V_0. Blue square lines represent the potential. (3.a) electronic states (3.b) hole states

About the distribution of nS levels. The graphical study of the relation (16) gives the figure 4. For each value of the trio (x, r_1, r_2), the energies $E_{nS} = E_{1s}, E_{2s}, E_{3s}$....... of the nS states are included in possible allowed mini-bands AMB. But only a few levels that can be authorized and occupied in these bands. The energies of these levels have been calculated and will be given in the following part. These mini-bands are separated by mini-gaps MG. Figure 4 shows the existence of these AMB and MG. These curves represent the

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function $F(E_{nS})$ given by expression (16) for the electron and hole with two values of indium composition.

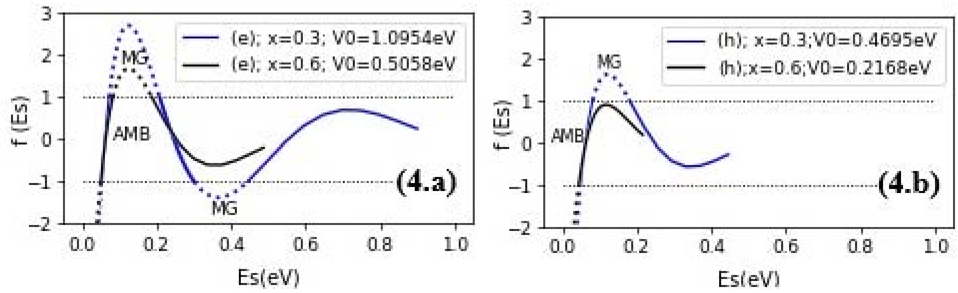

Figure 4: Showing curves of AMB and MG (4.a) for electron for the values x =0.3; 0.6. (4.b) for hole for the values x =0.3; 0.6.

For energies of nS and nP states, the formalism above, the numerical and graphical study of the zeros of the functions $Q^{S}_{r_1,r_2,k,x}(X)$ and $Q^{P}_{r_1,r_2,k,x}(X)$ defined in the expresions (12) and (14) give the quantification and allow the calculation repectivly of the energies E_{nS} of nS states and E_{nP} of nP states :

$$E_{nS} = \frac{\hbar^2 k_{nS}^2}{2m^*} = \frac{\hbar^2 k_0^2 X_{nS}^2}{2m^*} = V_0 X_{nS}^2 \tag{17}$$

$$E_{nP} = \frac{\hbar^2 k_{nP}^2}{2m^*} = \frac{\hbar^2 k_0^2 X_{nP}^2}{2m^*} = V_0 X_{nP}^2 \tag{18}$$

The table 2 lists the values found of E_{nS} and E_{nP}, by varying the composition x for $r_1 = 7\text{nm}$ and $r_2 = 10\text{nm}$. Note that these values respect the order observed in the atom or in a homogeneous quantum dot [27].

Table 2: Values of energy of nS and nP levels versus composition x for $r_1 = 7\text{nm}$. $r_2 = 10\text{nm}$. $T = 300K$.

x	E1s	E1p	E2s	E2p	E3s	E3p	E4s	E4p	E5s
0	0.0569	0.1164	0.2273	0.3209	0.5098	0.6259	0.9009	1.1242	1.3921
0.1	0.0597	0.1220	0.2381	0.3593	0.5332	0.7113	0.9392	1.1687	1.4375
0.2	0.0626	0.1279	0.2495	0.3763	0.5573	0.7422	0.9760	1.2064	
0.3	0.0657	0.1342	0.2615	0.3937	0.5815	0.7714	1.0050		
0.4	0.0689	0.1407	0.2735	0.4109	0.6035	0.7942			
0.5	0.0722	0.1472	0.2849	0.4262	0.6189				
0.6	0.0752	0.1530	0.2941	0.4365					
0.7	0.0775	0.1572	0.2989						
0.8	0.0785	0.1585							
0.9	0.0775								

Regarding the effect of various parameters on the energy of the ground state. The curves of figure 5 show the evolution of the 1S energy state calculated as a function of the indium composition, the radius of core and, thickness of the shell. We note in figure 4 the strong effect of confinement with the small sizes.[25][27][43] Indeed, the electronic energy of the ground state increases when the radius of the core material decreases. We notice the existence of maximums indexed on the curves by signs (+). The impact of the composition x is only felt for the low values of r_1. For a large value of x and a small value of r_1 there is no electronic bound state. Fixed size, the composition has only a slight effect on the ground state. Its effect is especially marked for the number of bound states and for higher levels.

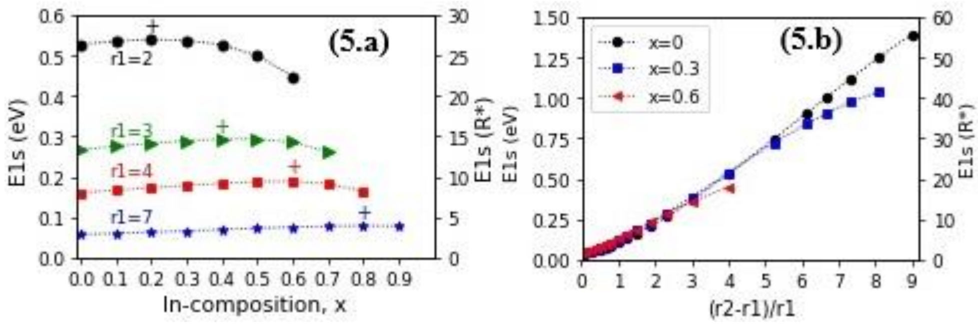

Figure 5: (5.a) Indium composition dependent energy E_{nS} for various values of r_1.
(5.b) Variation of E_{nS} vs $\Delta r / r_1$ for various values of x.

In table 2, and figure 5, for a structure with a total radius $r_2 = 10\text{nm}$, a core radius $r_1 = 7\text{nm}$ and indium composition $x = 0.9$, we obtain a two-level system 1Sh-1Se. Even for a Indium-composition value of 0.8 or 0.7, the difference $E_{1P} - E_{1S}$ is significant and the fundamentatl states 1Se and 1Sh are isolated. Our structure is equivalent to a two-level system characterizing the structure to be photostable and temporally coherent[27][44-46]. Indeed by resonant excitation 1Sh-1Se, we obtain a system where the only radiative emission is via the transition 1Se-1Sh and consequently the time of de-excitation 1Se-1Sh and the time between two successive photon emissions doe not change. This property is essential for the design of coherent light sources as Laser.

The quantum dots colloid core/shell are widely used as luminescent sources as light-emitting diodes, lasers, or as biological probes. Our system gives us optical control by radius core r_1 and thickness of shell $\Delta r = r_2 - r_1$. The gap can be varied in a wide spectral range. It has been shown in figures 6.a and 6.b that the effective band gap can be incraesed from 0.6391eV to 1.5319eV. For total radius $r_2 = 10$ nm of the nanostructure, we note that the gap increases by decreasing the radius of core material, or by increasing the thickness of shell. It is the effect of confinement in all nanostructures. Recall that by controlling the effective band gap we can choose the fundamental emission frequency.

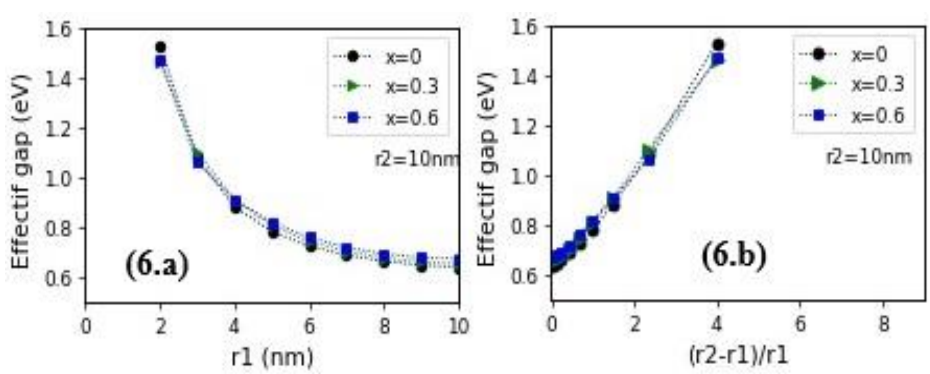

Figure 6: (6.a) Core radius dependent effect if gap. For various values of composition x.
(6.b) Thickness of shell dependent effectif gap. For various values of composition x.

Another time, figure 6 confirms what has been shown in the previous paragraph that the composition x has no marked effect on the gap or the ground state. The energies of the hole states have also been calculated. Below in the figure 7 we represent the electronic structure nS-nP of the inhomogeneous quantum dots InN/In$_x$Ga$_{1-x}$N/Ligand. The origin of the energies is taken on the height of the valence band. Only a few levels of the previously described nS energy bands AMB constitute possible levels. The nP levels can be found in the mentioned mini gaps MG and represented in figure 6. By comparing two structures with compositions 0.3 and 0.6 we notice that the number of bound states nS or nP decreases when x increases. The manipulation of the size and the Indium-composition allows the control of electronic structure design and consequently allows the control of electronic and optical properties of the nanostructure.

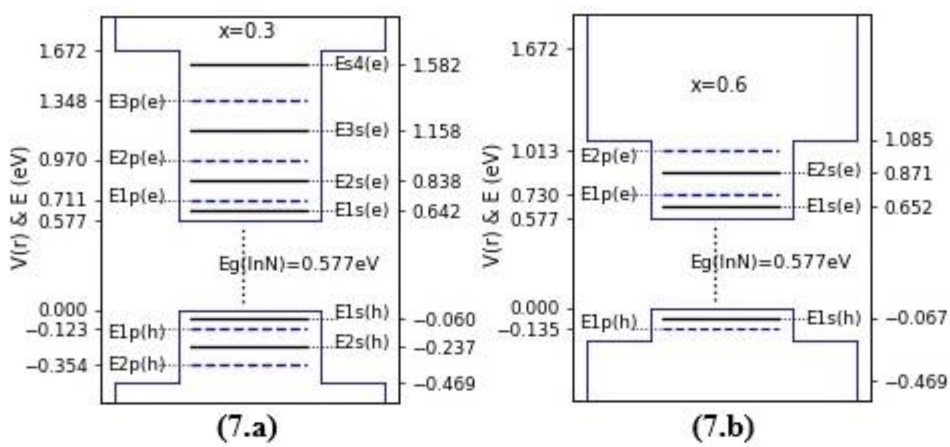

Figure 7: Electronic structure nS and nP for InN / In$_x$Ga$_{1-x}$N / Ligand for the values $x = 0.3;\ 0.6$ of indium composition and $T = 300K$

IV. Conclusion

Analytical and numerical methods were used to obtain electronic structure nS-nP of inhomogeneous quantum dots InN/InxGa1-xN/Ligand. The nanostructure allows a triple optoelectronic control. A wide range of gaps is allowed. The calculations show that a large value of core-radius, a small value of shell-thickness and a low value of Indium-composition, involve the localization of particles in the core material. This result reinforces the photostability and the qauntum efficiency of the nanostructure. These optical properties are essential for the realization of many devices such as light sources, detectors, biological markers. We conclude that in addition to the properties of the homogeneous quantum dot, the inhomogeneous quantum dot studied allows the electronic and optical control by shell thickness, and by Indium-composition. The presence of the shell improves the optical properties and the Indium-composition marks the design and the number of levels in the electronic structure. We can obtain a two levels system. This last result offers the condition of temporal coherence required to produce temporally coherent light sources such as a laser.

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Data Availability

The data that supports the findings of this study are available within the article or from the corresponding author upon reasonable request.

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2D Material-based Quantum Logic Gate Operating Via Self-Organization of Quantum Dots

By V. K. Voronov, O. V. Dudareva & L. A. Gerashchenko

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Abstract- In the paper, nanotrigger-based electronic device, capable of performing the quantum computation procedure, is described. The device represents a quantum logic gate formed from a two-dimensional material and controlled by a quantum dot. The operation of the quantum dot is analyzed. In the model representation, the transition between two states of the quantum dot, each of which controls the flow of the nanotransistor current (one of the shoulders of the nanotrigger), is equivalent to tunneling through an energy barrier separating the states. Fundamentally important is the fact that in one of these states the quantum dot is diamagnetic, and in the other it is paramagnetic. The paramagnetism of the quantum dot is due to the electronic exchange interaction, characteristic of the systems with unpaired electrons. Thus, the elementary self-organized 2D-material-derived logic gate disclosed in the present work can be employed for design of an electronic reversible unit. In other words, such a unit is able to prepare and to trigger the computation procedure.

Keywords: *logic gate, self-organized quantum dot, nanotrigger, quantum computer, graphene.*

GJSFR-A Classification: *FOR Code: 020699*

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V. K. Voronov [α], O. V. Dudareva [σ] & L. A. Gerashchenko [ρ]

Abstract- In the paper, nanotrigger-based electronic device, capable of performing the quantum computation procedure, is described. The device represents a quantum logic gate formed from a two-dimensional material and controlled by a quantum dot. The operation of the quantum dot is analyzed. In the model representation, the transition between two states of the quantum dot, each of which controls the flow of the nanotransistor current (one of the shoulders of the nanotrigger), is equivalent to tunneling through an energy barrier separating the states. Fundamentally important is the fact that in one of these states the quantum dot is diamagnetic, and in the other it is paramagnetic. The paramagnetism of the quantum dot is due to the electronic exchange interaction, characteristic of the systems with unpaired electrons. Thus, the elementary self-organized 2D-material-derived logic gate disclosed in the present work can be employed for design of an electronic reversible unit. In other words, such a unit is able to prepare and to trigger the computation procedure.

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I. Introduction

The idea of quantum computers has been first put forward by R. Feynman in his works published in the middle eighties of the twenty century [1,2]. The idea was based on an inference that memory and operating speed of classical computers are insufficient to solve quantum tasks. This fact can be illustrated by the following example. An *n*-particle system with two states with halfinteger spins has 2^n basic states. While solving a specific problem,2^n amplitudes of these states should be written to the computer memory and the corresponding computations should be performed. Since *n* can be arbitrarily large, the number of states to be operated on may also be very large. Eventually, the computations will face insuperable obstacles. Having this negative result in hand, Feynmann assumed that quantum computers would probably possess some features allowing enabling quantum problems to be solved. In addition to the aforesaid, it is pertinent to add that the creation of quantum computers is tightly connected with the problem of existence non-calculated functions and the related issue of algorithmically unsolvable tasks. These problems have been studied in detail in the works of Yu. Manin [3].We should also mention the papers of Paul Benioff, devoted to the behavior of quantum-mechanical objects simulating the operation of Turing machines [4-6].

It should be emphasized here that currently the application of quantum computers (if they were already created) could be effective not only for the solution of quantum physics problems. The last sixty years of the development of natural sciences were marked by appearance of new branches of knowledge, such as nonlinear optics, open system physics, and quantum information. Also, a novel area of science, which was originated at the border of several disciplines, deserves attention. We mean here the investigation of structure and dynamics of molecules. In a broad sense, this refers to the study of matter at the molecular level. The ultimate goal of such a study is electron and spatial structure of multielectron (molecular) systems as well as the nature of processes and phenomena occurring with participation of these systems. New fields of knowledge have stimulated formulation of tasks,the solution of which requires new computational devices. The problems of quantum rank high among these tasks.

Returning to the problem of quantum computer creation, it should be underlined that the most of the research performed so far involves the search for suitable individual quantum objects. At the same time it is believed that the development of the computation quantum schemes on the basis of these objects is rather a routine task. Figuratively speaking, the point is to address the issues of quantum information following the "bottom to up ideology" (see, for example, works [7-11] and the references cited therein). In this direction, there are some problems (in particular, the scaling and decoherence) that impede the creation of a true quantum computer. Also, one should bear in mind that the quantum computer, if it will be designed, represents a macroobject operating in a macroworld. Therefore, an alternative approach, "up to bottom", becomes possible. According to this approach, creation of devices suitable for quantum computations is based on application of initial systems of many quantum particles (available or specially obtained). Noteworthy that over the last forty – fifty years, the huge amount of new compounds with the most diverse spatial and electronic structure, and, therefore, with the most various physical and chemical

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properties has been synthesized and investigated. The compounds with strong electron correlations are spectacular example.

Concluding this brief survey of the publications devoted to the problem of quantum computer creation, we can state that certain experimental advances were achieved in implementation of the ideas of R. Feynman, Yu.I. Manin, and P. Benioff. However, the design of out true quantum computer still remains an urgent challenge. As for the Orion computers of the Canadian company D-Wave is concerned, this issue requires a special discussion [12,13].

Some aspects of the abovementioned "up to bottom" approach were considered in several works [14-17]. It was described in detail in a recently published paper [18], where the very idea of such an approach to solving the problem of quantum computer design was justified, and a block-scheme of electronic device, allowing this idea to be implemented, was proposed. In the present work, we extend the discussion of the device described in [18], which is really able of performing the quantum computation procedure. This material has not been published before. The authors of this work considered it appropriate to include a section with a description of the quantum computer structure at a qualitative level. Extensive literature is available on this subject[19-21].

II. Structure of Quantum Computer: General Representation

Schematically, the performance of a quantum computer can be represented as a sequence of three operations:

1. Recording (preparation) of the initial state.
2. Computation (unitary transformations of the initial states).
3. Output of the results (measurement, projection of the final state).

Recording of the initial state: Classic computers are based on transistor circuits having non-linear relationships between input and output voltages. Essentially, these are bistable elements. For example, at low input voltage (logic "0"), the output voltage is high (logic "1"), and vice versa. It is known that an ordinary (classical) computer operates with bits, Boolean variables that take values 0 and 1. Moreover, at any stage of the computation, the computer contains certain values that can be measured. At the first stage of computations, one should write the initial data into the register, a set of bits, each of which must have certain values (0 or 1).

Any mathematical action (multiplication, division, root extraction, etc.) ultimately reduces to addition. Therefore, the main task of the computer is addition of the numbers written in binary form. The corresponding computer element is called the adder. The latter can be built from the three simplest elements, which are connected to each other in an appropriate manner. These are logic elements or logical gates "NOT", "OR", "AND". They are called logical because they are responsible for certain logic operations (the name of each element corresponds to the performed logic function), i.e. they connect the input and output logic variables (zeros and ones). Using these three logic elements ("NOT", "OR", "AND"), it is possible to create not only an adder, but also a trigger, a decoder, a code converter and other devices that are required for a computer to function. The fact that these three elements are enough for design of almost any computer unit ultimately reflects undeniable truth: any thought can be expressed with a help of three logic connectives, "NOT", "OR", "AND". From the above gates one can go to other sets, sufficient for the manufacture of any computing device, for example, to such: "NOT", "OR-NOT", "AND-NOT".

A quantum computer operates with states. The simplest system that performs a function similar to bits in classic computers is a system with two possible states. To designate the state of such a quantum two-level system, a special term is proposed, q-bit (quantum bit of information). It describes state of a quantum system with two possible basic states $|0\rangle$ and $|1\rangle$ The general state of such a system is a superposition:

$$|q\rangle = C_0|0\rangle + C_1|1\rangle,$$

which is something more than boolean 0 or 1.Q-bit is a quantum superposition of two numbers: zero and one! It can therefore be said that the idea of a quantum computer is based on the fact that superposition of states is possible in quantum mechanics. A quantum system with two basis states (q-bits) allows encoding the numbers 0 and 1 in these states.

Physical systems that realize q-bits can involve any objects having two quantum states: polarization states of photons, electronic states of isolated atoms or ions, spin states of atomic nuclei, lower states in quantum dots. A full-scale quantum computer should contain a large number of q-bits (hundreds and even thousands), so that it can solve real computation problems. Therefore, the state of a quantum computer is nothing but a very complex, entangled state. Mathematically, it is described by the sum of a large and even huge number of terms. Each of these terms is a product of states of the type $|0\rangle$ or $|1\rangle$. The factors in this product describe the possible states of individual q-bits in a long chain. In other words, the state of a quantum system of n two-level particles is a superposition of 2^n basic states. Eventually, the quantum principle of superposition of the states can impartfundamentally new "abilities" to a quantum computer.

The very first operation of all (classical and quantum) computations, i.e. preparation of the initial state of the register, demonstrates the possible advantages of quantum operations with q-bits. When entering an initial number to a classical register consisting of n bits, n operations is required, i.e. the values 0 or 1 should be set on each bit. In this case, only one number of length n will be written. When performing certain unitary operations with each q-bit, it is possible to create a coherent superposition of all Q = 2^n states of the general quantum register system. Thus, instead of one number, all 2^n possible values of the register, a coherent superposition of all possible numbers for this register, can be prepared. Naturally, this property can be employed for quantum parallel computations.

It should be emphasized here that these cells are not some specific elements of scheme and not magnetic domains, onto which the necessary information is recorded. This refers to eigen values of the operator of a physical quantity characterizing the q-bits system, which, according to the laws of quantum mechanics, can be determined with varying degrees of probability. In a certain sense, we are talking here about a large set of virtually availabile cells, the use of which is far from obvious. This is one of the fundamental problems. Further, after information (for example, digital) is entered into these cells, the latter should somehow be controlled to perform computational operations. Finally, one should to find a way to output the results after completion of the computation. From the above it is easy to draw a conclusion about fundamental difficulties that have to be overcome in the way of creating a quantum computer.

Computation. Applying unitary transformations that perform certain logic operations to the prepared states, it is possible to create real quantum processor. q-Bits play the role of connectors, while unitary transformations serve as logic blocks (gates) for computation both in the classical and in quantum processor. This concept of a quantum processor and quantum logic gates was proposed in 1989 by D. Deutsch, who also found a universal logic unit for performance of quantum computations. In 1995, it was shown that one- and two-q-bit gates are enough to obtain the entire necessary set of transformations.

A single q-bit element (gate) can be defined by a 2×2 matrix, which has the following form

$$Q(\theta,\varphi)=\begin{pmatrix} \cos\frac{\theta}{2} & -i\exp(-i\varphi)\sin\frac{\theta}{2} \\ -i\exp(i\varphi)\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{pmatrix}.$$

The gate $Q(\theta,\varphi)$ describes the rotation of the q-bit state vector from the z axis to the polar axis defined by angles θ, φ. Physical implementation of this gate requires the external action a pulse on the quantum particle (q-bit) to transfer the latter from one state to another. The "OR-NOT" gate can be realized by the action of the corresponding sets of pulse sequences on two interacting q-bits (in particular, the spin). In this case, one q-bit should control the evolution of other. The toolkit of radio engineering and electronics has a wide range of pulsed radio-frequency sequences, which (at least, in principle) can ensure unitary transformations over a system of q-bits with a selective action on each of them.

Output of the result: In classical computer, the output of computation result does not differ from any other computational operation. The computations can be stopped at any point, the intermediate results can be read and calculations can be further continued. In a quantum computer, it is not the case. The ultimate result of quantum computation is the state of quantum register (after performance of unitary transformations), which represents a coherent superposition of all possible states for this register. Obviously, we cannot obtain all amplitudes of probability C_j in the decay of this superposition state. All that we can obtain from this single quantum object, according to the quantum theory, is quadratic forms $\sum_{i,j} C_i C_j^* R_{i,j}$, corresponding to measuring the average value of a certain physical quantity, which is designated by operator $\hat{R}$. It is obvious that the final result of quantum computation will change from one operation to other. However, even under such conditions of quantum uncertainties, quantum computers can significantly accelerate the computation of various mathematical problems.

The design of a quantum computer faces, first of all, physical problems. The major problem is the rapid decay of superposition states and their transformation into a mixture. This process, as noted above, is called decoherence. The latter imposes the main requirement on the physical elements that are supposed to be used in quantum computers: the time of state coherence conservation should exceed the time of computation. Hence, there are two ways of avoiding decoherence: (i) to find a quantum system that is isolated from the environment as much as possible, or (ii) to increase artificially the coherence time.

Another problem in design of quantum computers (it may be called technological)relates to the fact that after the computational process is complete, the states of q-bits should be measured to determine the results of the computation. To date, there are no reliable methods for such measurements. However, it is believed that the routes to the development of such methods are outlines: one should employ amplification procedures of quantum mechanics. For example, the state of nuclear spin *I* is transferred to the electronic spin

S. The latter defines the orbital wave function. Having the orbital wave function in hand, the transfer of charges (ionization) can be triggered. The presence or absence of a single electron charge can be detected by classical electrodynamic methods.

III. 2D Material-Based Elementary Self-Organized Logic Gate

In the introduction of this paper, we have mentioned that a quantum computer can be created using the "up to bottom" idea reported in [18].In that work it is proposed a block-scheme of possible electronic device, which, in principle, can help in implementation of this idea. The features of such a device are discussed below.

a) The device includes a block containing at least 10^{10} nanotriggers that perform a role of q-bits of quantum computation, which are formed from graphene (or other 2D material) nanoribbons and controlled by a special element. The latter represents a self-organizing quantum dot having two essentially different states in terms of magnetic properties. This quantum dot is prepared on the basis of a compound, the molecules of which are characterized by the intramolular rearrangement. The nanotriggers are employed to produce reversible logic blocks or gates. Each gate contains three triggers to perform logical operations.
b) This system of the nanotriggers correlates with all possible states of a quantum system that provide a large mathematical information resource.
c) Fundamentally important is that the quantum dot can be formed from materials based on compounds, in which intramolecular processes lead to the population of metal 3d-orbitals due to valence tautomerism.
d) The device represents an additional electronic unit that is embedded in a digital computer, which makes it possible to implement the computational process in accordance with the provisions of quantum physics.

The following explanation is needed here. If the proposed device is quantum in its essence, then it is obvious that its operation should obey to the laws of the microworld. In addition, the triggered device should perform certain operations (in the case of a quantum computer, these are computations) also in accordance with the laws of quantum physics. It is well known that the main elementary unit of a computer is a trigger. If it is obtained (as proposed in this paper) from two-dimensional material, for example, graphene, this will mean that the first condition indicated above is fulfilled. If the computation procedure is controlled by a quantum object, which is self-organized due to intramolecular dynamics, then the above second condition can also be considered feasible.

In the model representation, the transition between two states of a quantum dot, each of which controls the current flow of the nanotransistor (one of the shoulders of the nanotrigger), is equivalent to tunneling through an energy barrier that separates these states, which differ in their magnetic properties. This process is shown in Fig. 1.

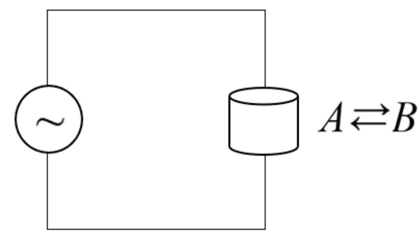

Fig. 1: Operation of a control quantum dot

Here *A* and *B* are the states, between which an intramolecular transition of molecules (or even clusters) occurs. A control quantum dot is formed on the basis of these states. We are talking about molecular (multielectron) systems with unpaired electrons, which properties are determined by electronic exchange interaction. It is pertinent to note here that in recent years intense research interest is focused on heterospin systems synthesized from the coordination compounds of paramagnetic transition metal ions with stable nitroxyl radicals. This is primarily due to the fact that such compounds allow obtaining detailed information on the nature of intramolecular interactions in multi-electron systems, the specificity of which is determined by the exchange magnetic interactions of unpaired electrons. Ultimately such information permits to solve fundamental problems related to the problem of the structure and dynamics of molecules. In turn, the solutions of these problems substantiate the preparation of materials with practically useful properties (see, for example, a comprehensive publication [22]).

Among fundamental processes, the intramolecular rearrangements involving delocalization of unpaired electrons from ligands to metal (e.g., cobalt) ion to change valency of the latter hold a specific place. Such rearrangements are commonly referred to as valence tautomerism. As applied to compounds of the first transition group, these intramolecular processes lead to the population of metal 3d-orbitals with unpaired electrons. The scheme given below illustrates the aforementioned rearrangement. The investigations have shown that magnetic properties of compounds can change dramatically in the course of transition of molecules from state *A* to state *B* and back. Fundamentally important is the fact that the molecules in state *A* are diamagnetic, while in state *B* they are paramagnetic. This takes places, for example, in the case of Co(SQ)$_2$(2-2´-dipyridine) complex, which is characterized by the above tautomerism [23].

$$Co^{III}(SQ)_2(2\text{-}2'\text{-dipyridine}) \rightleftarrows Co^{II}(SQ)_2(2\text{-}2'\text{-dipyridine}).$$

A ***B***

The intramolecular tautomerism can be compared with a process that ensures generation of electromagnetic oscillations at a quantum level. In this case, the periodic appearance of an unpaired electron spin on the coordination cobalt atom (which, in fact, acts as an antenna) corresponds to the radiation of the aforementioned oscillations, thus providing automatic control of the nanotrigger performance.

Fig. 2 shows a simplified standard equivalent scheme of switching on of the nanotransistor connection with a controlling quantum dot in the base circuit. The designations in this figure have generally accepted meanings.

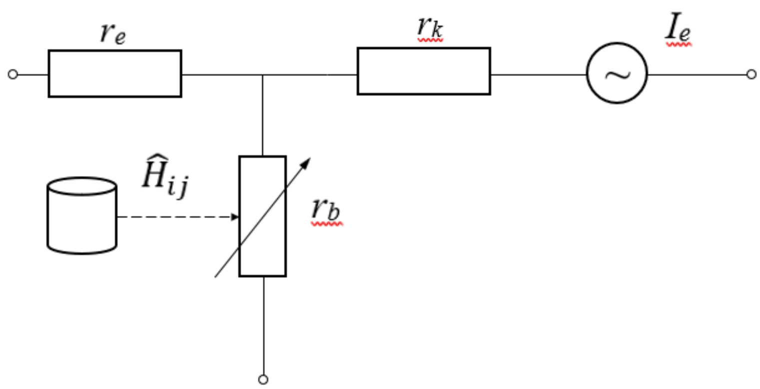

Fig. 2: A simplified equivalent scheme of switching on of nanotransistor connection with a control quantum dot in the base circuit (indices correspond emitter - e, collector - k, base - b).

A description of the performance characteristics of transistors, as well as the processes occurring in them, can be found in the corresponding books on electronics. Here, apparently, it is necessary to explain how the above quantum dot can switch on and off a transistor that reads information? At the level of the macroworld, this would naturally be done by the action of, for example, inductive coupling on the resistance of the circuit base. However, a quantum dot designed to control the operation of a nanotransistor (and the nanotrigger as a whole) is an object, which behavior is determined by the laws of quantum physics (at the microworld level). Therefore, a method for implementation of the action on the resistance of base should be sought starting from the above inference. Such method may comprise the exchange electron spin-spin coupling interaction, described in the Hamiltonian by $\hat{H}_{ij} \sim J_i J_k$ term. This coupling leads, as noted above, to the generation of uncompensated electron spin on the coordination ion (in our case, on the cobalt ion). As a result, the quantum dot is magnetized for a while. This paramagnetism will change the magnetic field with a frequency corresponding to the transition between states *A* and *B*. In this case, this corresponds to change in the magnetic permeability of the substance μ. It is well known that the latter parameter directly relates to the inductance *L*, which (other conditions being equal) determines the magnitude of the inductive current in the circuit. In turn, this dependence should periodically change the current (between its maximum and minimum values) in the transistor. This is shown in Fig. 2 where the base resistance r_b is variable.

The parameters μ and *L* allow explaining the possible changes of r_b by the integral action of the periodically occurring magnetization. However, if to take into consideration a deeper (molecular) level of such an action, then it is logical to use the band theory. According to this theory, the interaction described by the term of the hamiltonian $\hat{H}_{ij}$ will periodically change width of the band gap between the states with the minimum and maximum values of the probability of electron density in the base, and, consequently, the value of potential with respect to the collector.

It is easy to conclude that in each specific case, the operating mode of an electronic device can be set by selecting the molecular structure of the substance, on the basis of which the quantum dot is synthesized. In particular, the parameter characterizing a periodically induced magnetic field can be described by an expression $B_o cos\omega t$(B_0 is the amplitude value of the magnetic field induced by the quantum dot). Technologically, it is not so difficult to introduce a quantum dot with the corresponding intramolecular dynamics into the transistor, given the location of the base in this transistor.

The nanotrigger can be used to perform all logical operations involved in the computational process. Indeed, from the perspective of radio engineering, 2D material-derived trigger, which is controlled by a self-organized quantum, represents an inverter capable of independently performing the corresponding logical operation NOT. As for the logical operation OR-NOT is concerned, it can be performed, when a quantum dot is included in each shoulder of the nanotrigger. It is well known [21] that the operation CONDITIONAL NOT ("OR-NOT")

$$\hat{\boldsymbol{T}}_{XOR} = |\boldsymbol{0}\rangle_{11}\langle\boldsymbol{0}|\hat{\boldsymbol{J}}_2 + |\boldsymbol{1}\rangle_{11}\langle\boldsymbol{1}|\hat{\boldsymbol{T}}_{2NOT},$$

is applied to two q-bits, the first of which does not change its state under the action of $\hat{T}_{XOR}$, and the second one changes, but depending on the state of the first q-bit. For instance,

$$\hat{T}_{XOR}(\alpha|0\rangle_1 + \beta\langle 1|_1)|0\rangle_2 = \alpha|0\rangle_1|0\rangle_2 + \beta|1\rangle_1|1\rangle_2,$$

i.e. the operation $\hat{T}_{XOR}$ transforms superposition states into entangled ones and vice versa.

Thus, the nanotrigger corresponds to two q-bits. The load of such a trigger should be another trigger containing only one quantum dot. It should serve as the q-bit of the target.

In relation to the device described here, the first shoulder of the nanotrigger, in which the current is flowing, corresponds to the alpha state, and the second shoulder relates to the beta state. On cobalt, the spin is not equal to zero, the resistance (inductive, reactive, non-ohmic) is large, and current is absent in the circuit – it is 0. On cobalt, the spin is zero, the resitance is minimum, the current in the circuit is maximum – it is 1 (or vice versa). A device that autonomously periodically opens and closes can be compared to a self-oscillating process. Fundamental in this case is the selection the quantum dot material at the molecular (quantum) level.

The nanotrigger described above should be employed to design a reversible electronic block. In other words, such a block should prepare the computation procedure and trigger it. The continuation of the computation is the task of other computer elements. Naturally, this elementary (basic) block should operate, as already noted above, according to the laws of quantum physics. This condition imposes certain requirements on the computer architecture, including the interface used for communication with the macroworld. Such an elementary block can be compared with a generator, which once started to work, then arbitrarily performs an oscillation process. In this case, the feedback function, which is necessary to trigger the generation process), is performed by a quantum dot. The latter, due to the self-organization, reads the input information and triggers the computation (the transistor alternately changes between two states: when current is absent or present in the circuit). The output of such a transistor is connected to a block of two nano-transistors containing a quantum dot in the circuit, which are able to implement a logical operation OR-NOT. A quantum dot operates due to the energy equal to kT coming from the environment (heat reservoir).

It is appropriate to note here the features of 2D material-based electronic device disclosed in this paper. On the one hand, it employs the classical method for fixation of the state (zero and one) by a trigger. On the other hand, the application of the nanotrigger and quantum dot as a control element ensures steady operation of such a scheme. A nanotrigger can be associated with two connected q-bits, each of which symbolizes one shoulder of the nanotrigger. Classically, the input signal is a control signal. At the same time, it is employed for communication with the macroworld (interface). In the device proposed here, such a role is played by the quantum object controlled by the quantum dot. Thus, the entire computation process is performed according to the laws of quantum physics.

Finally, it should be emphasized that the idea of design of self-organized logical gate can be fundamental and quite fruitful. In fact, instead of the quantum dot proposed in this paper, which is characterized by intramolecular processes with two substantially different states (magnetic properties), one can offer any other objects (devices included in logical blocks) of the periodic transition of the trigger shoulders to the state of zero or one. It can also be assumed that different quantum dots used in a particular electronic device depending on their (these points) functions can also be employed in the above design.

IV. Conclusions

In the introduction, the idea of quantum computer design is briefly discussed. It is stressed that the most of the research performed so far involves the search for suitable individual quantum objects. At the same time it is believed that the development of the computation quantum schemes on the basis of these objects is rather a routine task. In other words, the point is to address the issues of quantum information following the "bottom to up ideology". In this direction, there are some problems (in particular, the scaling and decoherence) that impede the creation of a true quantum computer. Therefore, an alternative" up to bottom" approach becomes possible. According to this approach, creation of devices suitable for quantum computations is based on application of initial systems of many quantum particles (available or specially obtained). Therefore, the "top-down" approach seems to be possible. Here, the creation of devices suitable for quantum computing will be based on the use of initially systems of many quantum particles (existing or specially obtained materials). Earlier, one of the authors of this publication described a block-scheme of an electronic device based on a priory visualized states of q-bits. The role of the latter should be played by nanotriggers obtained from graphene or other 2D material, the performance of which is controlled by a self-organized quantum dot. In the present paper, the proposed electronic device is discussed in detail.

The operation of the quantum dot acting as a control element is described. In the model representation, the transition between two states of the quantum dot, each of which controls the flow of the nanotransistor current (one of the shoulders of the nanotrigger), is equivalent to tunneling through an energy barrier separating the states. Fundamentally important is the fact that in one of these states the quantum dot is diamagnetic, and in the other it is paramagnetic. The paramagnetism of a quantum dot is due to the electronic exchange interaction characteristic of systems with unpaired electrons. As a result, the quantum dot is magnetized for a while. This paramagnetism will change the magnetic field with a frequency corresponding to the transition between two states with different magnetic properties. In this case, this corresponds to change in the magnetic permeability of the substance μ. It is well known that the latter parameter directly relates to the inductance L, which (other conditions being equal) determines the magnitude of the inductive current in the circuit. In turn, this dependence should periodically change the current (between its maximum and minimum values) in the circuit. The nanotrigger can be associated with two connected q-bits, each of which symbolizes one shoulder of the nanotrigger. Classically, the input signal is a control signal. At the same time, it is employed for communication with the macroworld (interface). In the device proposed here, such a role is played by the quantum object controlled by the quantum dot. Thus, the entire computation process is performed according to the laws of quantum physics.

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Static Mantle Density Distribution 3 Dimpling and Bucking of Spherical Crust

By Tian-Quan Yun

South China University of Technology

Abstract- This paper is the third step of project "Static mantle distribution, Equation, Solution and Application". It consists of < Static Mantle Distribution 1 Equation>, < Static Mantle Density Distribution 2 Improved Equation and Solution>, and this paper. Our result on shape of core is a "X type", which differs from the traditional view that core is a sphere. Which one is correct? or, both are not correct? The aim of this paper is to study dimpling and bucking of the spherical crust under mantle loading. Dimpling analysis depends on the outer solution of non-homogeneous non-linear D. E., while bucking analysis depends on non-linear Eigen value of the homogeneous D. E The results based on two models and governing equations show that crust dimpled at poles is proved theoretically and numerical result well consists with pole radius, while the non-linear bucking Eigen value boundary problem is solved by decomposition method. The results show that bucking can occur, and the un-continuity of internal force per unit length causes un-continuity of masses by mantle material emitting to crust at turning point of "X". The growing of Tibet high-land might be viewed as an evidence of the mass $m_s(\theta_0)$ increasing due to mantle emission. Both poles radius and equatorial radius have been used to support our analysis. Question: how the nature makes cold at poles?

Keywords: mantle distribution, shell theory, shallow spherical shell, shell bucking/dimple, non-linear differential equations (d.e.), segmental non-linear eigen value boundary problem, operator and eigen value decomposition.

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STATICMANTLEDENSITYDISTRIBUTION3DIMPLINGANDBUCKINGOFSPHERICALCRUST

Strictly as per the compliance and regulations of:

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I. Introduction

This paper is the third step of project "Static mantle distribution, Equation, Solution and Application", consists of < Static Mantle Distribution 1 Equation> [1], < Static Mantle Density Distribution 2 Improved Equation and Solution> [2] and this paper. The major result on static mantle distribution inside the Earth is a "X type" in cross-section. There are three zones: the sink zone located in the waist of "X" including equator plane, where no negative mass exists, while the positive mass is uniformly distributed in it; the buoyed zone located in the head of "X" including poles, where on positive mass exists, while negative mass uniformly distributed in it; the neural zone is the boundary between sink zone and buoyed zone. Our results conflicts to the traditional view of the shape of core, where it is considered as a sphere[3], like an egg. Which one is correct ? or both are in-correct? Until now, human has no ability to observe the status of mantle directly. The knowledge or sources of information about interior of earth is obtained by indirect methods such as analysis of rocks from mining area, volcanic eruption, and earthquake etc. In such a situation, no directly observation and no experiment can be done, how to prove the accuracy of our results?

The target of this paper is to study the spherical crust under mantle loading. Two models, model of thin elastic spherical shell with resisting bending moment and model of membrane, and two governing equations, one in English and the other in Russian, have been used to study dimpling and bucking. Dimpling analysis depends on the outer solution of non-homogeneous D.E., while bucking analysis depends on Eigen value of the homogeneous D. E. The results show that dimpled crust at poles is proved theoretically and numerical result well consistent with poles' radius, while the high-order non-linear bucking Eigen value boundary problem is solved by decomposition method. The results show that non-zero Eigen value exists, i.e., bucking can occur, and the un-continuity of internal force per unit length causes un-continuity of masses by emitting of mantle material at turning point of "X". Both poles radius and equatorial radius have been used to support our analysis.

a) Previous study on shell

Shell has been studied widely in various cases[4]: The pure theory from shells with ideal form; shapes and materials; filled with liquid, gas; plastic deformation; variable thickness; loadings on part of space; dynamic loading; multilayer shell; mathematical analysis; energetic analysis. The pure theory from shells with initial imperfections; Combined theoretical-experimental studies from shell with ideal form and imperfections, etc.

Spherical shell has been studied for various cases. There are researches on dimpled and bucking shallow spherical shells or spherical shells. For examples, Polar dimpling of completed spherical shell [5], Shallow spherical caps under axis-symmetric sub-bucking pressure distributions [6]; Axis-symmetric behavior of elastic spherical shell compressed between rigid plated [7], Asymmetrical bucking of shallow shells under asymmetric concentrated and uniformly distributed loads had been studied by numerical analysis [8-11], experiments [12-13], and dynamic instability of

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asymmetric dimpled shallow spherical shells [14-15], In-extensional bending thin spherical shell compressed by two parallel rigid plates [16], etc.

b) *What is the feature of our study differed from previous study?*

Bucking and dimpling behavior have been studied previous for spherical shells created by mankind, like structure, container and nature bio-cell etc., but dimpling and bucking of spherical crust shell subjected to mantle loading and segmental non-linear Eigen value boundary value problem for crust have not been found. Furthermore, high-order non-linear Eigen value problem is solved by decomposition of operator and Eigen-values are also the feature of our study.

II. Mathematical Model of the Spherical Shell of Crust

a) *Basic Hypotheses*

(1). The Earth is considered as a thin sphere shell with thickness varied in 8 – 40 km, the mean radius 6,371.032 km[17]. The ratio of thickness/radius is less than and can be considered as a very thin shell.

(2) Material of the crust

The crust is considered as homogenous, linear isotropic elastic material.

(3) Axis-symmetric loading --- static loading from mantle; inertia centrifugal force.

(4) Thermal stress and mantle-crust co-reaction are neglect.

Since we consider that the Earth is in a stable equilibrium status, therefore no changing on thermal stress field and no changing on coherence between mantle and crust occur.

Coordinates:

Cylindrical coordinates: Let (r,ϑ,z) be the cylindrical coordinates of the geometric center of the Earth. The relation between (x, y) and (r,ϑ) is:

$$\begin{cases} x = r\cos\vartheta, \\ y = r\sin\vartheta, \end{cases} \quad (0 \le \vartheta \le 2\pi,\ 0 \le r < \infty, -\infty < z < \infty) \qquad (2.1\text{-}1)$$

$(\mathbf{i},\ \mathbf{j},\ \mathbf{k})$ and $(\mathbf{e}_r, \mathbf{e}\ ,\mathbf{k})$ denote the unit vectors of Cartesian and cylindrical coordinates respectively. In the following, for asymmetry loading, a point $f(r,\vartheta,z)$ independents to ϑ and can be simplified by $f(r,z)$, and discussion only focus on semi-sphere.

b) *Crust model*

(1) Recall of [2].

1. According to [2]: The mantle is divided into sink zone, neural zone and buoyed zone. The sink zone is located in a region with boundaries of a inclined line, angle $\alpha_0 = 35°15$, with apex at $O(0,0)$ revolving around the z-axis, inside the crust involving the equator. Where no negative mass exists, while positive mass is uniformly distributed. The buoyed zone is located in the remainder part, inside the crust involving poles. Where no positive mass exists, while negative mass is uniformly distributed. The neural zone is the boundary between the buoyed and sink zones. The substance of negative mass must be liquid, while the substance of positive mass could be gas, liquid or solid.
2. In SIN zone, $(0 \le \alpha \le 35°15')$, there is no negative mass (liquid), $m_n = 0$, while positive mass (solid) is uniformly distributed, i.e.,

$$\rho_{ps} = C_1 == \frac{6\sqrt{3}}{2\pi}\frac{\omega_c^2}{G}\left(\frac{z_0}{z_{real1}}\right)^3.$$

Two necessary conditions for stable equilibrium system are:

$$r_0^2 = 2z_0^2,\ \text{or}\ \tan\alpha_0 = 1/\sqrt{2} = z_0/r_0,\ \alpha_0 = 35°15\ , \qquad (3.2\text{-}20)\ \text{of [2]}$$

$$M_p^- = 6\sqrt{3}\frac{\omega_c^2}{G}z_0^3 = 2M_n^- \qquad (3.2\text{-}24)\ \text{of [2]}$$

In BUO zone, $(35°15' \leq \alpha \leq \pi/2)$, there is no positive mass, $m_p = 0$, while negative mass is uniformly distributed, i.e., $\rho_{nb} = C_4 =$

$$-\frac{3\sqrt{3}}{2\pi}\frac{\omega_c^2}{G}\left(\frac{z_0}{z_{real2}}\right)^3 \qquad (4.6\text{-}4) \text{ of [2]}$$

c) Mantle loading to the crust shell

On the boundary,

$$(r_s, z_s) \text{or} \ (r_b, z_b) = (R\cos\alpha, \mp R\sin\alpha) = (R\sin\theta, R\cos\theta); \quad H_s = (r_s^2 + z_s^2)^{3/2} = R^3;$$

where α is the meridional angle, i.e., the angle between vector R and the equator plane; θ is the angle between vector R and the z-axis.

$$\theta + \alpha = \pi/2, \qquad (2.2\text{-}1)$$

In SIN zone, by $\sum F_z = 0$ of an cylindrical element, we have

$$F_z(r_s, z_s) = G\frac{m_p M_p^-}{H_s} z_s = 6\sqrt{3} m_p \omega_c^2 z_0^3 H_s^{-1} z_s = 2 m_p \omega_c^2 z_s =$$

$$\sigma_z^0(r_s, z_s) dA_z,$$

$$\sigma_z^0(r_s, z_s) = 2\frac{dv}{dA_z} m_p \omega_c^2 z_s = 2\rho_p \omega_c^2 R^2 \cos\theta \sin\theta \qquad (2.2\text{-}2)$$

Where $\sigma_z^0\,(r_s, z_s)$ is the principle stress exerted only by Newton's attraction force applied at $m_p(r_s, z_s)$; $M_p^- = 6\sqrt{3}\frac{\omega_c^2}{G} z_0^3$ is the mass group located at central $O(0,0)$ (due to hypotheses 2 of [2]), represented total positive mass, except (r_s, z_s) itself; gravitational constant $G = 6.674 \times 10^{-11}, N.(\frac{m}{kg})^2$; $H_s = H_b = H_0 = (r_s^2 + z_s^2)^{3/2}$. $r_s^2 = r_b^2 = r_0^2 = 2z_0^2 = 2z_b^2 = 2z_s^2$.

By $\sum F_r = 0$ of an cylindrical element, we have

$$F_r(r_s, z_s) = \sigma_r^0(r_s, z_s) dA_r = m_p\left[-GM_p^- H_s^{-1} + \omega_c^2\right] r_s = -m_p \omega_c^2 r_s,$$

$$\sigma_r^0(r_s, z_s) = -m_p \omega_c^2 r_s \frac{dv}{dA_r} = \rho_p \omega_c^2 R^2 \sin\theta \cos\theta, \qquad (2.2\text{-}3)$$

Similarly, in BUO zone, we have

$$F_z(r_b, z_b) = G\frac{m_n M_n^-}{H_b} z_b = 3\sqrt{3} m_n \omega_c^2 z_0^3 H_b^{-1} z_b = m_n \omega_c^2 z_b,$$

$$\sigma_z^0(r_b, z_b) = m_n \omega_c^2 z_b \frac{dv}{dA_z} = \rho_n \omega_c^2 R^2 \cos\theta \sin\theta, \qquad (2.2\text{-}4)$$

$$\sigma_r^0(r_b, z_b) = m_n\left[GM_n^- H_b^{-1} - \omega_c^2\right] r_b \frac{dv}{dA_r} = 0, \qquad (2.2\text{-}5)$$

Where $m_n(r_b, z_b)$ is negative mass, $M_n^- = 3\sqrt{3}\frac{\omega_c^2}{G} z_0^3$ is the mass group located at central $O(0,0)$ (due to hypotheses 2 of [2]), represented total negative mass, except (r_s, z_s) itself. (2.2-5) shows the forces exerted by attraction force and by centrifugal force are in equilibrium.

$$\theta_0 = \frac{\pi}{2} - \alpha_0 = 54°45'$$

Summary: In SIN zone, $(\theta_0 \le \theta \le \pi/2),\ m_n = 0,\ \sigma_{z'}^0(r_s, z_s) = 2\rho_p \omega_c^2 R^2 \cos\theta \sin\theta$ exerted by attraction force, and is uniformly distributed attraction to crust; $\sigma_r^0(r_s, z_s) = \rho_p \omega_c^2 R^2 \sin\theta \cos\theta$ exerted by attraction force and centrifugal force and is uniformly distributed and against to crust.

In BUO zone, $(0 \le \theta \le \theta_0),\ m_p = 0,\ \sigma_z^0(r_b, z_b) = \rho_n \omega_c^2 R^2 \cos\theta \sin\theta$ exerted by attraction of negative masses, and is uniformly distributed against to crust; $\sigma_r^0(r_b, z_b) = 0$ exerted by attraction of negative masses, and centrifugal force, they are in equilibrium, neither against nor attraction to crust.

III. Dimpling of Shallow Spherical Shell

The governing equations

Using the Marguerre type elastic -dynamic shell theory, the behavior of a thin shell can be described by the non-dimensional governing equations [3,4,12,13]:

$$\left.\begin{aligned} \nabla^4 w - L[z + w, f] &= q(x) - b w_{,tt} \\ \nabla^4 f + L\left[z + \frac{w}{2}, w\right] &= 0, \end{aligned}\right\} (0 < x < 1), \qquad \begin{aligned}(3\text{-}1)\\(3\text{-}2)\end{aligned}$$

Where x and θ are polar coordinates in the basic plane (parallel to the equator plane),

$$(\,)' = \partial(\,)/\partial x,\ (\,)'' = \partial^2(\,)/\partial x^2,\ (\dot{\,}) = \partial(\,)/\partial\theta,\ (\ddot{\,}) = \partial^2(\,)/\partial\theta^2,$$

$$(\,)_{,tt} = \partial^2(\,)/\partial t^2,$$

$$L[g, s] = g''(s'/x + \ddot{s}/x^2) + s''(g'/x + \ddot{g}/x^2) - 2(\dot{g}/x)'(\dot{s}/x)',$$

$$\nabla^4(\,) = \nabla^2\nabla^2(\,),\ \nabla^2(\,) = (\,)'' + (\,)'/x + (\ddot{\,}),$$

The non-dimensional radius coordinate x, the un-deformed meridian curve z, the vertical deflection w, the stress function f, the loading q and inertia term b, are related in the corresponding physical variables by

$$x = r/r_0,\ z = (Z/r_0)(1/\varepsilon^2\varphi_0), \quad w = (W/r_0)(1/\varepsilon^2\xi_0),\ f = F/D,$$

$$q(x) = (r_0^3/D\xi_0\varepsilon^2)p(x),\ b = \rho r_0^3 h/D, \quad D = Eh^3/[12(1-\nu^2)],$$

$$\varepsilon^2 = h/\{[12(1-\nu^2)]^{1/2} r_0\xi_0\},\ \xi_0 = 2Z(r_0)/r_0,$$

r_0– radius of basic plane, h – thickness of the shell, E – elastic modulus, ν- Poisson's ratio, $Z = Z(r)$ – un-deformed meridian curve with Z(0)=0, $p(x)$ – non-dimension loading (stress/E), ρ mass density.

For shallow spherical shell, $Z(r) = r^2/2R$, R– the radius of the spherical shell. $H = Z(r_0)$ - the apex rise. $\xi_0 = r_0/R$.

The boundary conditions for a shell with completely clamped basic plane are the regular conditions at apex and at the outer edge:

$$x = 0,\ \ w = w' = f = f' = 0, \tag{3-3}$$

$$x = 1, w = w' = 0,\ \ f'' - \nu\ \left(f' + \ddot{f}\right) = 0,\ \ f''' - f'(1-\nu) + (2+\nu)\dot{f}' - 3\ddot{f} = 0, \tag{3-4}$$

For the cases of static axis-symmetric deflection $(w_{,tt} = 0)$, the above equations (3-1) – (3-4) are reduced to:

$$\varepsilon^2 x(\Phi_1'' + \Phi'_1/x - \Phi_1/x^2) - \Phi_1\Psi = 4kxP(x) + \varepsilon^2 xQ(x),\ \ (0 < x < 1) \tag{3-5}$$

$$\varepsilon^2 x(\Psi'' + \Psi'/x + \Psi/x^2) + (\Phi_1^2 - \Phi_0^2)/2 = 0,\ \ (0 < x < 1) \tag{3-6}$$

$$x = 0,\ \ \Phi_1 = 0,\ \ \Psi = 0, \tag{3-7}$$

$$x = 1,\ \ \Phi_1 = 1,\ \ \Psi' - \nu\ \ \Psi = 0, \tag{3-8}$$

where $\Phi_1 = \Phi_1(x) = \Phi\ (x) + \Phi_0(x),\ \ \varepsilon^2\xi_0 dZ/dr \equiv \Phi_0(x),\ \ \varepsilon^2\xi_0 dW/dr \equiv \Phi\ (x),\ \ z' = \Phi_0/\varepsilon^2,\ w' = \Phi\ (x)/\varepsilon^2,\ \Psi = \Psi(x) = \varepsilon^2 f',\ Q(x) = \Phi''_0 + \Phi'_0/x - \Phi_0/x^2,\ \ k = p_e/p_c,\ p_e$ the peak value of p(t), $P_c = \frac{2Eh^2}{\sqrt{3(1-\nu^2)}R^2}$, classical bucking load, a uniformly distributed compressed load [3].

For shallow spherical shells, $\Phi(x) = x,\ \ p_e = 2Eh^2/\left[R^2\left(3(1-\nu^2)\right)^{1/2}\right]$,

$$P(x) = (1/x)\int_0^x tp(t)\,dt, \tag{3-9}$$

If $\varepsilon^2 \ll 1$, from (3-5), (3-6), the leading term of outer solution for the

$$\text{case}\ \ \Phi_0(x) = x\ \ \text{and}\ \ p(x) = p_e(1 - c^2x^2), (c^2 > 1) \tag{3-10}$$

is [5,6,14,15]:

$$w'_d \sim -\frac{2x}{\varepsilon^2},\quad f'_d \sim kx(2 - c^2x^2)/\varepsilon^2,\qquad (0 \lesssim x < x_T) \tag{3-11}$$

$$w'_d \sim 0,\quad f'_d \sim -kx(2 - c^2x^2)/\varepsilon^2,\qquad (x_T < x < 1), \tag{3-12}$$

Where x_T is the dimensionless dimple base radius and is known to be $x_T = \sqrt{2}/c$ from $\Psi(x_T) = 0$. One can see from (3.11), (3.12) that the meridional slope of the deformed polar dimpling remains unchanged in $(x_T, 1)$ while it changes only the sign of the unchanged meridional slope is changed in $(0, x_T)$. According to [5], (3-11) and (3-12) hold for a wide range values of k, e.g., $\varepsilon^2 \ll k\varepsilon = O(1)$.

The above is repeated from [15].

a) For our case

Our analysis is all the same as above except the loading term $P(x)$.

Note that from (3-5), we have $-\Phi\Psi = 4kxP(x)$. or $\Psi = P(x)$.

$$\Phi(x) = 4kx.$$

Calculating P(x):

$$P(x) = (1/x)\int_0^x tp(t)\,dt,\quad (0 \le t \le x \le 1) \tag{3-9}$$

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$P(x)$ is an equivalent non-dimensional loading. Where t is a non-dimension distance, between 0 and p(t), $p(t) \perp \mathbf{t}$. $p(t) = p_e \cos\theta = p_e\sqrt{1-t^2}$ is a non- dimension force, and $tp(t)$ forms a non-dimension bending moment. $tp(t) = +$ is defined that the bending moment tp(t) causes the curvature of the shell segment increasing. Otherwise, $tp(t) = -$. $p_e = (m_n\omega_c^2)/E$ is the peak value of $p(t)$.

Determination of shell dimpling

Like the analysis of a cantilever beam or a tall building, the cantilever end or the upper part of the building is used as an isolated segment, the upper part of the spherical shell, i.e., in the BUO zone $(0 \le \theta \le \theta_0)$, is used as an isolated segment for analyze. The dimple of shallow spherical shell is characterized by the non-dimensional equivalent load $P(\theta)$ has multiple values at dimple θ_d, i.e.,

$$P(\theta_d) = \Psi(x_d) = 0 = \begin{cases} P(\theta_d - \delta), & \theta \le \theta_d \\ P(\theta_d + \delta), & \theta \ge \theta_d \end{cases} \quad (\delta > 0), \tag{3.1-1}$$

Before dimpling, $P(\theta) = P(\theta_d - \delta)$, after dimpling $P(\theta) = P(\theta_d +.\delta)$.

In BUO zone $(0 \le x = \sin\theta \le x_0)$, $m_p = 0$, $p_1(t) = p_e\sqrt{1-t^2}$, against to the shell, $p_2(t) = F_r/E = 0$.

$$P(\theta) = \left(\frac{1}{x}\right)\int_0^x tp_1(t)dt = \left(\frac{p_e}{x}\right)\int_0^x t\sqrt{1-t^2}\,dt = -\frac{p_e}{3x}[\sqrt{(1-x^2)^3} - 1], \quad (0 \le x \le x_0) \tag{3.1-2}$$ [18]

To find $\boldsymbol{\theta_d}$ or $\mathbf{x_d}$ such that $P(\theta_d) = \Psi(x_d) = 0$. Let

$$P(\theta_d) = 0, \tag{3.1-3}$$

By (3.1-2), we have:

$$\sqrt{\left(1-x_d^2\right)^3} - 1 = 0, \quad x_d = 0, \text{ 0r } \theta_d = 0 \tag{3.1-4}$$

x_d is the dimple base radius. When $x_d = 0$, $P(0) = 0/0$, Using L'Hospital rule we have $P(0) = O(1)$, That is $P(0-) = 0$, $P(0+) = \delta$. Comparing the loading $P(\theta)$ of (3-10) and (3.1-2), we have

$$w'_d \sim -\frac{x}{\varepsilon^2}, \quad f'_d \sim \left(\frac{p_e}{3}\right)[1 - \sqrt{\left(1-x_d^2\right)^3}]/\varepsilon^2, \quad (0 \le x < x_d), \tag{3.1-5}$$

$$w'_d \sim 0, \quad f'_d \sim -\left(\frac{p_e}{3}\right)[1 - \sqrt{\left(1-x_d^2\right)^3}]/\varepsilon^2, \quad (x_d < x < 1) \quad (3.1\text{-}6) \qquad (3.1\text{-}6)$$

Eq.(3.1-5) shows that the changed meridional slope $w'_d(x) = \Phi(x) = x$ is changed only in a minus sign in $(0, x_d)$ while (3.1-6) shows that it 264 remains unchanged in $(x_d, 1)$.

b) *Comparing the highness of the dimpled shell with poles' radius.*

The dimpling occurs at apex (pole) with dimple radius $x_d = 0$ for $k\varepsilon = \varepsilon p_e/p_c = O(1)$ (loading approaches critical load) theoretically, However, one can not calculate the dimple for $x_d = 0$ numerically. If a perturbation with small parameter δ adding to the stable equilibrium system, then the dimpling occurs at apex with $x_d = \sin\theta_d = \delta$. The highness of dimple h_d is:

$$h_d = \delta\sin\theta_d, \tag{3.2-1}$$

$$\delta = R\tan\theta_d, \tag{3.2-2}$$

$$2h_d = 2R\sin\theta_d \tan\theta_d \tag{3.2-3}$$

$$R_{pd} = R - 2h_d = R(1 - 2\sin\theta_d \tan\theta_d) \tag{3.2-4}$$

Where the mean radius $R = 6{,}371.032\,km$[17]. The dimple highness h_d is the raise of the un-deformed shell at apex. R_{pd} is the highness of the dimpled pole's radius.

Now, we choose $x_d = \delta = 0.00116$, or $\theta_d = 0°0'4''$, by (3.2-4), we have:

$$R_{pd} = 6{,}371{,}032 \times (1 - 2 \times 0.00116 \times 0.00116) = 6{,}371{,}014(km)$$

Comparing with poles' radius $R_p = 6{,}365{,}777km$[17], $\text{error} = \frac{R_{pd} - R_p}{R_{pd}} = \frac{6{,}371{,}014 - 6{,}365{,}777}{6{,}371{,}014} =$

$$0.001292887 \tag{3.2-5}$$

IV. Bucking Analysis

Dimpling analysis only uses local information of shallow spherical cap. Other information, e.g., loading and structure of the lower part, have not been included. Therefore, whole information must be used for analysis of whole behavior. That is that bucking analysis needs information of the whole spherical shell.

a) Bucking of segmental spherical shell

Since the mantle loading on crust of SIN zone is differed from the BUO zone, therefore, segmental governing equations with boundary conditions are set for these zones.

In SIN zone:

The governing equation, for axis-symmetry deformation, of a thin spherical shell, is[4]

$$D\nabla^4 w_s - R\nabla^2 F_s - L(F_s)w^0_{s\theta\theta} - \cot\theta\, w^0_{s\theta} F_{s\theta\theta} - R^2[T^0_{s1}$$

$$w_{s\theta\theta} + T^0_{s2} L(w_s)] = 0, \quad (\theta_0 \le \theta \le \pi/2) \tag{4.-1}$$**

$$\nabla^4 F_s + Eh\left[R\nabla^2 w_s + L(w_s)w^0_{s\theta\theta} + \cot\theta\, w^0_{s\theta} w_{s\theta\theta}\right] = 0, (\theta_0 \le \theta \le \pi/2) \tag{4.-2}$$**

Where $\nabla^4 = \nabla^2\nabla^2$; $\nabla^2(\,) = (\,)_{\theta\theta} + \cot\theta(\,)_\theta$; $()_\theta = \partial()/\partial\theta$; $L(\,) = \cot\theta(\,)_\theta$; F --- stress function, w --- displacement component.

$$F_{\theta\theta} = T_2 = k(\varepsilon_{22} + \nu\varepsilon_{11}),\ F_{\varphi\varphi} = T_1 = k(\varepsilon_{11} + \nu\varepsilon_{22}), \tag{4-3}$$

$k = \frac{Eh}{1-\nu^2}$; $D = \frac{Eh^3}{12(1-\nu^2)}$; E -- elastic modulus; v-- Poisson's ratio; h – hickness; w^0, T^0_1, T^0_2 are mid-plane w, inner forces per unit length in θ, φ (the latitude and longitude) directions respectively.

Dimension check: dimensions of each term of (4.-1) and (4.-2) should be the same. But Dim (i = 1,2,3,4,5,6) $:= (Eh^4, Eh^2, Eh^2, Eh^2, Eh^4, Eh^4)$. Dim $(i = 1,2,3,4) := (Eh, Eh^3, Eh^3, Eh^3)$ If given (4-1), (4-2) a little modified, like

$$(D/R^2)\nabla^4 w_s - R\nabla^2 F_s - L(F_s)w^0_{s\theta\theta} - \cot\theta\, w^0_\theta F_{s\theta\theta} - [T^0_{s1} w_{s\theta\theta} +$$

$$T^0_{s2} L(w_s)] = 0, \quad (\theta_0 \le \theta \le \pi/2) \tag{4.1-1}$$

$$\nabla^4 F_s + Eh\left[R\nabla^2 w_s + L(w_s)w^0_{s\theta\theta} + \cot\theta\, w^0_{s\theta} w_{s\theta\theta}\right]/R^2 = 0, \ (\theta_0 \le \theta \le$$

$$\pi/2) \tag{4.1-2}$$

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then, the dimensions of (4.1-1) and (4.1-2) are reduced to:

$$\mathrm{Dim}\ (i = 1,2,3,4,5,6)\ := (Eh^2, Eh^2, Eh^2, Eh^2, Eh^2, Eh^2)$$

Dim (i = 1,2,3,4) $:= (Eh, Eh, Eh, Eh)$ Therefore (4 -1) and (4-2) are in printing error, and (4.1-1) and (4.1-2) are corrected.
Similarly, In BUO zone: we have:

$$(D/R^2)\nabla^4 w_b - R\nabla^2 F_b - L(F_b)w^0_{b\theta\theta} - \cot\theta\, w^0_{b\theta} F_{b\theta\theta} - [T^0_{b1}$$
$$w_{b\theta\theta} + T^0_{b2} L(w_b)] = 0,\ (0 \le \theta \le \theta_0) \tag{4.1-4}$$

$$\nabla^4 F_b + Eh\left[R\nabla^2 w_b + L(w_b)w^0_{b\theta\theta} + \cot\theta\, w^0_{b\theta} w_{b\theta\theta}\right]/R^2 = 0,$$
$$(0 \le \theta \le \theta_0) \tag{4.1-5}$$

The above governing equations are coupled high order non-linear D.E. with unknown functions w and F. How to solve these equations?
First, combining (4.1-1) and (4.1-2) into one equation.
Substituting (4.1-2) into $\nabla^2\cdot\ (4.1-1)$, we have

$$\nabla^2 (D/R^2)\nabla^4 w_s + Eh\left[R\nabla^2 w_s + L(w_s)w^0_{s\theta\theta} + \cot\theta\, w^0_{s\theta} w_{s\theta\theta}\right]/R -$$
$$\nabla^2 L(F_s)w^0_{s\theta\theta} - \nabla^2 \cot\theta\, F_{s\theta\theta} w^0_{s\theta} - \nabla^2 [T^0_{s1} w_{s\theta\theta} + T^0_{s2} \cot\theta\, w_{s\theta}] = 0, \tag{4.1-6}$$

Similarly, in BUO zone, we have

$$\nabla^2 (D/R^2)\nabla^4 w_b + Eh\left[R\nabla^2 w_b + L(w_s)w^0_{b\theta\theta} + \cot\theta\, w^0_{b\theta} w_{b\theta\theta}\right]/R -$$
$$\nabla^2 L(F_b)w^0_{b\theta\theta} - \nabla^2 \cot\theta\, F_{b\theta\theta} w^0_{s\theta} - \nabla^2\left[T^0_{b1} w_{b\theta\theta} + T^0_{b2} \cot\theta\, w_{b\theta}\right] = 0, \tag{4.1-7}$$

Secondly, transforming the D.E. into Eigen value problem.

Eigen value problem related to vibration and dimpling or bucking problems have been widely studied. Introducing parameter λ, such that for some λ, the corresponding homogeneous D.E. have non-zero solution,

$$\nabla^2 w_s = -\lambda_s^2 w_s,\ (\theta_0 \le \theta \le \pi/2) \tag{4.1-8}$$

$$\nabla^2 F_s = -\lambda_s^2 F_s,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.1-9}$$

$$\nabla^2 w_b = -\lambda_b^2 w_b,\ (0 \le \theta \le \theta_0) \tag{4.1-10}$$

$$\nabla^2 F_b = -\lambda_b^2 F_b,\quad (0 \le \theta \le \theta_0) \tag{4.1-11}$$

Boundary conditions of the crust shell

$$\theta = 0,\ w_b = R - R_p + \epsilon_1,\ F_{b\theta\theta} = T^0_{b1} = 0, \tag{4.1-12}$$

$$\theta = \theta_0,\quad w_s(\theta_0) = w_b(\theta_0),\ F_{s\theta}(\theta_0) - F_{b\theta\theta}(\theta_0) = \delta, \tag{4.1-13}$$

$$\theta = \pi/2,\ w_s\left(\frac{\pi}{2}\right) = R_e - R + \epsilon_2,\ F_{s\theta\theta}(\pi/2) = \left(\sum\left(m_p + m_n\right) / 4\pi Re=0,\right.$$ [2] (4.1-4)

b) Calculation of $\mathbf{T^0_{s1}}, \mathbf{T^0_{s2}}, \mathbf{T^0_{b1}}, \mathbf{T^0_{b2}}$*, due to mantle loading:*

In BUO zone: $(0 \leq \theta \leq \theta_0),\ m_p = 0,$

$\sigma^0_z(r_b, z_b) = \rho_n \omega_c^2 R^2 \cos\theta \sin\theta$, against to crust.

$\sigma^0_r(r_b, z_b) = 0$, attraction to crust.

Let the upper part $(0 \leq \theta \leq \theta_0)$ of the shell be an isolated system, by the equilibrium equation $\sum F_z = 0$ of the system, we have:

$$2\pi R \sin\theta\, T^0_{b2}(\theta) h \sin\theta = \pi (R\sin\theta)^2 \rho_n \omega_c^2 R^2 \cos\theta \sin\theta \tag{4.2-1}$$

$$T^0_{b2}(\theta) = \frac{R^3}{2h}\rho_n \omega_c^2 \cos\theta \sin\theta, \quad (0 \leq \theta \leq \theta_0) \tag{4.2-2}$$

Where stress is uniformly distributed along the thickness in T^0_{b1} and T^0_{b2}.
Let the half of the upper part of the shell, cut by cross-section perpendicular to equatorial plane, be an isolated body, by the equilibrium equation $\sum F_r = 0$ of the body, we have:

$$\int_0^\theta 2hT^0_{b1}(\theta)\, d\theta = \int_0^\theta 2R \sin t\, \sigma^0_r(r_b, t) dt = 0 \tag{4.3-3}$$

$$T^0_{b1}(\theta) = 0, \qquad (0 \leq \theta \leq \theta_0) \tag{4.2-4}$$

In SIN zone, $(\theta_0 \leq \theta \leq \pi/2),\ m_n = 0,$

$\sigma^0_z(r_s, z_s) = 2\rho_p \omega_c^2 R^2 \cos\theta \sin\theta$ attraction to crust.

$\sigma^0_r(r_s, z_s) = \rho^p \omega_c^2 R^2 \sin\theta \cos\theta$, against to crust,

Let the upper part $(\theta_0 \leq \theta \leq \pi/2)$ of the shell be an isolated system, by the equilibrium equation $\sum F_z = 0$ of the system, we have:

$$2\pi R \sin\theta\, T^0_{s2}(\theta) h \sin\theta =$$

$$-\pi (R\sin\theta)^2 \rho_n \omega_c^2 R^2 \cos\theta \sin\theta + \pi (R\sin\theta)^2 2\rho_p \omega_c^2 R^2 \cos\theta \sin\theta,$$

$$T^0_{s2}(\theta) = 2\frac{R^3}{h}\omega_c^2\left(2\rho_p - \rho_n\right)\cos\theta \sin\theta, \quad (\theta_0 \leq \theta \leq \pi/2), \tag{4.2-5}$$

Let the half of the upper part of the shell, cut by cross-section perpendicular to equatorial plane, be an isolated body, by the equilibrium equation $\sum F_r = 0$ of the body, we have:

$$\int_0^{\theta_0} 2hT^0_{b1}(t)\, dt + \int_{\theta_0}^{\theta} 2hT^0_{s1}(t) dt = 0 + \int_{\theta_0}^{\theta} 2hT^0_{s1}(t)\, dt =$$

$$\int_{\theta_0}^{\theta} 2R \sin t\, \sigma^0_r(r_s, t) dt = 2R^3 \rho_p \omega_c^2 \int_{\theta_0}^{\theta} (\sin t)^2 \cos t\, dt, \tag{4.2-6}$$

$$T^0_{s1}(\theta) = \frac{1}{3}\frac{R^3}{h}\rho_p \omega_c^2 [(\sin\theta)^3 - (\sin\theta_0)^3], \quad (\theta_0 \leq \theta \leq \pi/2), \tag{4.2-7}$$

c) *Calculation of* $F_{s\theta\theta}$ *and* $F_{b\theta\theta}$.

By (4-3), $F_{\theta\theta} = T_2 = k(\varepsilon_{22} + \nu\varepsilon_{11}),\ F_{\varphi\varphi} = T_1 = k(\varepsilon_{11} + \nu\varepsilon_{22})$.

In BUO zone, $(0 \le \theta \le \theta_0)$ by (4.2-2),

$$T_{b2} = \frac{R^3}{2h}\rho_n\omega_c^2 \cos\theta \sin\theta = F_{b\theta\theta} = k(\varepsilon_{22} + \nu\varepsilon_{11}), \tag{4.3-1}$$

By (4.2-4),

$$T_{b1} = 0 = F_{b\varphi\varphi} = k(\varepsilon_{11} + \nu\varepsilon_{22}) \tag{4.3-2}$$

we have $\varepsilon_{11} = -\nu\ \varepsilon_{22}$, then (4.3 -1) becomes to:

$$F_{b\theta\theta} = k\varepsilon_{22}(1-\nu^2) = \frac{R^3}{2h}\rho_n\omega_c^2 \cos\theta \sin\theta \tag{4.3-3}$$

In SIN zone, $(\theta_0 \le \theta \le \pi/2)$ by (4.2-5),

$$F_{s\theta\theta} = k(\varepsilon_{22} + \nu\varepsilon_{11}) = T_{s2}^0 = 2\frac{R^3}{h}(2\rho_p - \rho_n)\omega_c^2 \cos\theta \sin\theta \tag{4.3-4}$$

d) *Solution of non-linear Eigen value equation by decomposition method.*

The non-linear Eigen value equation is decomposed, where the operator and Eigen value are decomposed.

The general form of second order non-linear Eigen value equation

$$\nabla^2(X) = A\frac{d^2}{d\theta^2}(X) + B\frac{d}{d\theta}(X) = -\lambda_0^2(X), \tag{4.4-1}$$

Where $A = A(\theta), B = B(\theta)$ are known functions, X is an unknown function, λ_0^2 is an Eigen value, subscript 0 can be s (SIN zone) or b (BUO zone).

Decomposition of operator ∇^2 *into* d^2 *and* d *Eigen values* λ_0^2 *into* λ_{0A}^2 *and* λ_{0B}^2. *That is:*

$$A(\theta)\frac{d^2}{d\theta^2}(X_A) = -\lambda_{0A}^2(X_A) \tag{4.4-2}$$

Integration both sides of (4.4-2) twice, we have:
In BUO zone,

$$\frac{d}{d\theta}\int_0^\theta \frac{1}{X_A} dX_A = -\lambda_{bA}^2 \int_0^\theta A^{-1}\, d\theta,$$

$$\int_0^\theta d\left[\frac{\ln X_A(\theta)}{\ln X_A(0)}\right] = d\int_0^\theta \left[\frac{\ln X_A(\theta)}{\ln X_A(0)}\right] = \left[\frac{\ln X_A(\theta)}{\ln X_A(0)}\right] = -\lambda_{bA}^2 \int_0^\theta d\theta \int_0^\theta A^{-1}\, d\theta,$$

$$\frac{X_A(\theta)}{X_A(0)} = \exp\left[-\lambda_{bA}^2 \int_0^\theta d\theta \int_0^\theta A^{-1}\, d\theta\right],\ (0 \le \theta \le \theta_0) \tag{4.4-3}$$

In SIN zone,

$$\frac{X_A(\theta)}{X_A(\theta_0)} = \exp\left[-\lambda_{sA}^2 \int_{\theta_0}^\theta d\theta \int_{\theta_0}^\theta A^{-1}\, d\theta\right],\ (\theta_0 \le \theta \le \pi/2) \tag{4.4-4}$$

$$B(\theta)\frac{d}{d\theta}(X_B) = -\lambda_{0B}^2(X_B) \tag{4.4-5}$$

Integration both side of (4.4-5), we have:
In BUO zone:

$$\frac{\ln X_B(\theta)}{\ln X_B(0)} = \int_0^\theta \frac{dX_B}{X_B} = -\lambda_{0A}^2 \int_0^\theta B^{-1}\, d\theta,$$

$$\frac{X_B(\theta)}{X_B(0)} = \exp\left[-\lambda_{bB}^2 \int_0^\theta B^{-1} d\theta\right],\ (0 \le \theta \le \theta_0) \qquad (4.4\text{-}6)$$

In SIN zone,

$$\frac{X_B(\theta)}{X_B(\theta_0)} = \exp\left[-\lambda_{sB}^2 \int_{\theta_0}^\theta B^{-1} d\theta\right], (\theta_0 \le \theta \le \pi/2) \qquad (4.4\text{-}7)$$

$$\nabla^2(X) = Ad^2(X_A) + Bd(X_B) = -\lambda_0^2(X), \qquad (4.4\text{-}8)$$

$$\nabla^4(X) = \nabla^2\nabla^2(X) = [Ad^2(X_A) + Bd(X_B)][Ad^2(X_A) + Bd(X_B)] = \lambda_0^4(X), \qquad (4.4\text{-}9)$$

$$\nabla^2(X) = -\lambda_0^2(X) = Ad^2(X_A) + Bd(X_B) = -\lambda_{0A}^2(X_A) - \lambda_{0B}^2(X_B) \qquad (4.4\text{-}10)$$

$$\lambda_0^2(X) = \lambda_{0A}^2(X_A) + \lambda_{0B}^2(X_B) \qquad (4.4\text{-}11)$$

$$\nabla^4(X) = \lambda_0^4(X) = Ad^4(X_A) + 2Ad^2(X_A)Bd(X_B) + Bd^2(X_B) = \lambda_A^4(X_A) +$$

$$2(-\lambda_A^2)(-\lambda_B^2)(X_A)(X_B) + \lambda_B^4(X_B) \qquad (4.4\text{-}12)$$

$$\lambda_0^4(X) = \lambda_A^4(X_A) + 2\lambda_A^2\lambda_B^2(X_A)(X_B) + \lambda_B^4(X_B), \qquad (4.4\text{-}13)$$

For our case, the particular form of A and B of (4.4-1).

$$\nabla^2(X) = \frac{d^2}{d\theta^2}(X_A) + \cot\theta \frac{d}{d\theta}(X_B) = -\lambda_0^2(X) \qquad (4.4\text{-}14)$$

$$\frac{d^2}{d\theta^2}(X_A) = -\lambda_{0A=1}^2(X_A), \qquad (A = 1) \qquad (4.4\text{-}15)$$

By (4.4-3), we have

$$\frac{X_A(\theta)}{X_A(0)} = \exp\left[-\frac{1}{2}\lambda_{bA=1}^2\theta^2\right],\ (0 \le \theta \le \theta_0) \qquad (4.4\text{-}16)$$

By (4.4-4), we have

$$\frac{X_A(\theta)}{X_A(\theta_0)} = \exp\left[-\frac{1}{2}\lambda_{sA=1}^2(\theta-\theta_0)^2\right],\ (\theta_0 \le \theta \le \pi/2) \qquad (4.4\text{-}17)$$

$$\cot\theta \frac{d}{d\theta}(X_B) = -\lambda_{0B}^2(X_B),\ (B = \cot\theta) \qquad (4.4\text{-}18)$$

By (4.4-6), we have

$$\frac{X_B(\theta)}{X_B(0)} = \exp\left[-\lambda_{bB}^2 \int_0^\theta \tan\theta\, d\theta\right] = \exp\left[\lambda_{bB}^2 \frac{\ln\cos\theta}{\ln\cos\theta_0}\right] = \exp[\lambda_{bB}^2]\frac{\cos\theta}{1},$$

$$(0 \le \theta \le \theta_0) \qquad (4.4\text{-}19)$$

By (4.4-7), we have

$$\frac{X_B(\theta)}{X_B(\theta_0)} = \exp\,[\lambda_{sB}^2]\,\frac{\cos\theta}{\cos\theta_0},\quad (\theta_0 \le \theta \le \pi/2) \tag{4.4-20}$$

e) *Calculating* $T_{s1}^0 w_{s\theta\theta}, T_{s2}^0 \cot\theta w_{s\theta}, T_{b1}^0 w_{b\theta}, T_{b2}^0 \cot\theta w_{b\theta}$ *by Eigen value.*

$$w_{s\theta\theta} = \frac{d^2}{d\theta^2} w_s = -\lambda_{sA=1}^2 w_s,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.5-1}$$

$$T_{s1}^0 w_{s\theta\theta} = -\lambda_{sA=1}^2 \frac{1}{3}\frac{R^3}{h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_s, \tag{4.5-2}$$

$$w_{b\theta\theta} = \frac{d^2}{d\theta^2} w_b = -\lambda_{bA=1}^2 w_b,\quad (0 \le \theta \le \theta_0) \tag{4.5-3}$$

$$T_{b1}^0 w_{b\theta\theta} = 0, \tag{4.5-4}$$

$$\cot\theta\, w_{s\theta} = \cot\theta \frac{d}{d\theta} w_s = -\lambda_{sB}^2 w_s,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.5-5}$$

$$T_{s2}^0 \cot\theta\, w_{s\theta\theta} = -\lambda_{sB}^2 \frac{2R^3}{h}\omega_c^2(2\rho_p - \rho_n)\cos\theta\sin\theta\, w_s \tag{4.5-6}$$

$$\cot\theta\, w_{b\theta} = \cot\theta \frac{d}{d\theta} w_b = -\lambda_{bB}^2 w_b,\quad (0 \le \theta \le \theta_0) \tag{4.5-7}$$

$$T_{b2}^0 \cot\theta\, w_{b\theta} = -\lambda_{bB}^2 \frac{R^3}{h}\rho_n\omega_c^2\cos\theta\sin\theta\, w_b \tag{4.5-8}$$

f) *Calculating* $F_s w_{s\theta\theta}^0, F_{s\theta} w_{s\theta}^0, F_b w_{b\theta\theta}^0, F_{b\theta} w_{b\theta}^0,\ w_s w_{s\theta}^0,\ w_{s\theta} w_{s\theta\theta}^0, w_b w_{b\theta}^0,\ w_{b\theta} w_{b\theta\theta}^0$
by Eigen value.

By (4.5-1) and (4.5-3), we have

$$F_s w_{s\theta\theta}^0 = -\lambda_{sA=1}^2 w_s F_s,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.6-1}$$

$$F_b w_{b\theta\theta}^0 = -\lambda_{bA=1}^2 w_b F_b,\quad (0 \le \theta \le \theta_0), \tag{4.6-2}$$

$$F_{s\theta} w_{s\theta}^0 = \frac{d}{d\theta}F_s \frac{d}{d\theta} w_s = \lambda_{sB=1}^2 \lambda_{sB=1}^2 F_s w_s,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.6-3}$$

$$F_{b\theta} w_{b\theta}^0 = \frac{d}{d\theta}F_b \frac{d}{d\theta} w_b = \lambda_{bB=1}^2 \lambda_{bB=1}^2 F_b w_b,\quad (0 \le \theta \le \theta_0) \tag{4.6-4}$$

$$w_s w_{s\theta}^0 = w_s \frac{d}{d\theta} w_s = -\lambda_{sB=1}^2 w_s^2,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.6-5}$$

$$w_b w_{b\theta}^0 = w_b \frac{d}{d\theta} w_b = -\lambda_{bB=1}^2 w_b^2,\quad (0 \le \theta \le \theta_0) \tag{4.6-6}$$

$$w_{s\theta} w_{s\theta\theta}^0 = \frac{d}{d\theta} w_s \frac{d^2}{d\theta^2} w_s = \lambda_{sB=1}^2 \lambda_{sA=1}^2 w_s^2,\quad (\theta_0 \le \theta \le \pi/2) \tag{4.6-7}$$

$$w_{b\theta} w_{b\theta\theta}^0 = \frac{d}{d\theta} w_b \frac{d^2}{d\theta^2} w_b = \lambda_{bB=1}^2 \lambda_{bA=1}^2 w_b^2,\quad (0 \le \theta \le \theta_0) \tag{4.6-8}$$

g) Application of decomposition method ---Putting down the order of non-linear Eigen value equation
Using (4.1-8) --- (4.1-11), (4.4-1) --- (4.6-8), one can put down the order of Eigen value equation. For example, (4.1-6) can be reduced to:

$$(D/R^2)\lambda_s^4 w_s - Eh\lambda_s^2 w_s - \frac{[Eh\lambda_{sB}^2 w_s w_{s\theta}^0 + Eh\lambda_{sB}^2 w_{s\theta} w_{s\theta\theta}^0]}{R} +$$

$$\nabla^2\lambda_{sB}^2(-\lambda_{sA=1}^2 F_s w_s) + \nabla^2\lambda_{sB}^2\lambda_{sB=1}^4 F_s w_s^0 -$$

$$\nabla^2[T_{s1}^0 w_{s\theta\theta} + T_{s2}^0 \cot\theta\, w_{s\theta}] = 0,$$

Or, again use (4.1-8) --- (4.6-8) to reduce the $\nabla^2$and other terms, we have:

$$(\frac{D}{R^2})\lambda_s^4 w_s - Eh\lambda_s^2 w_s - \frac{[-Eh\lambda_{sB}^2\lambda_{sB=1}^2 w_s^2 + Eh\lambda_{sB}^2\lambda_{sB=1}^2\lambda_{sA=1}^2 w_s]}{R} +$$

$$\lambda_{sB}^2\lambda_s^2\lambda_{sA=1}^2 F_s w_s^0 - \lambda_{sB}^2\lambda_s^2\lambda_{sB=1}^4 F_s w_s^0 + \nabla^2[T_{s1}^0 w_{s\theta\theta} + T_{s2}^0 \cot\theta\, w_{s\theta}] = 0,$$

$$(\theta_0 \le \theta \le \pi/2) \tag{4.7-1}$$

Calculating $\nabla^2[T_{s1}^0 w_{s\theta\theta} + T_{s2}^0 \cot\theta\, w_{s\theta}]$

Let $X = T_{s1}^0 w_{s\theta\theta}$, by (4.4-14), then, we have

$$\nabla^2(X) = \frac{d^2}{d\theta^2}(X_A) + \cot\theta\frac{d}{d\theta}(X_B) = -\lambda_{sA=1}^2(X_A) - \lambda_{sB}^2(X_B) = -\lambda_s^2(X),$$

$$(\theta_0 \le \theta \le \pi/2) \tag{4.7-2}$$

Where by (4.5-2), (4.4-17) and (4.4-20), we have:

$$X = T_{s1}^0 w_{s\theta\theta} = -\lambda_{sA=1}^2 \frac{R^3}{3h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_s, \tag{4.7-3}$$

$$\frac{X_A(\theta)}{X_A(\theta_0)} = \exp\,[\tfrac{1}{2}\lambda_{sA=1}^2(\theta-\theta_0)^2],\ (\theta_0 \le \theta \le \pi/2) \tag{4.7-4}$$

$$\frac{X_B(\theta)}{X_B(\theta_0)} = \exp(\lambda_{sB}^2)\frac{\cos\theta}{\cos\theta_0},\ (\theta_0 \le \theta \le \pi/2) \tag{4.7-5}$$

Let $Y = T_{s2}^0 \cot\theta\, w_{s\theta}$, by (4.4-14), then, we have:

$$\nabla^2(Y) = \frac{d^2}{d\theta^2}(Y_A) + \cot\theta\frac{d}{d\theta}(Y_B) = -\lambda_{sA=1}^2(Y_A) - \lambda_{sB}^2(Y_B) = -\lambda_s^2(Y),$$

$$(\theta_0 \le \theta \le \pi/2) \tag{4.7-6}$$

Where by (4.5-6), (4.4-17) and (4.4-20), we have:

$$Y = T_{s2}^0 \cot\theta\, w_{s\theta\theta} = -\lambda_{sB}^2 \frac{2R^3}{h}\omega_c^2(2\rho_p - \rho_n)\cos\theta\sin\theta\, w_s,\ (\theta_0 \le \theta \le \pi/2) \tag{4.7-7}$$

$$\frac{Y_A(\theta)}{Y_A(\theta_0)} = \exp\left[\frac{1}{2}\lambda_{sA-1}^2(\theta-\theta_0)^2\right],\ (\theta_0 \le \theta \le \pi/2) \tag{4-7-8}$$

$$\frac{Y_B(\theta)}{Y_B(\theta_0)} = \exp(\lambda_{sB}^2)\frac{\cos\theta}{\cos\theta_0}, \quad (\theta_0 \le \theta \le \pi/2), \tag{4.7-9}$$

Substituting (4.7-2) --- (4.7-9) into (4.7-1), we have:

$$\left(\frac{D}{R^2}\right)\lambda_s^4 w_s - Eh\lambda_s^2 w_s - \frac{[-Eh\lambda_{sB}^2\lambda_{sB=1}^2 w_s^2 + Eh\lambda_{sB}^2\lambda_{sB=1}^2\lambda_{sA=1}^2 w_s]}{R}$$

$$+ (\lambda_{sB}^2\lambda_s^2\lambda_{sA=1}^2 - \lambda_{sB}^2\lambda_s^2\lambda_{sB=1}^4)F_s w_s^0$$

$$- (\lambda_s^2 + \lambda_{sA=1}^2)\left(\frac{R^3}{3h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_s\right)$$

$$-(\lambda_s^2 + \lambda_{sB}^2)\left[\frac{2R^3}{h}(2\rho_p - \rho_n)\omega_c^2\cos\theta\sin\theta\, w_s\right] = 0, \tag{4.7-10}$$

By (4.7-5) or (4.7-9), for $\theta = \theta_0$, we have

$$\lambda_{sB}^2 = 0 \tag{4.7-11}$$

Substituting (4.7-11) into (4.7-10), we have

$$\left(\frac{D}{R^2}\right)\lambda_s^4 w_s - Eh\lambda_s^2 w_s$$

$$-(\lambda_s^2 + \lambda_{sA=1}^2)\left(\frac{R^3}{3h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_s\right) - \lambda_s^2[\frac{2R^3}{h}\omega_c^2$$

$$(2\rho_p - \rho_n)\cos\theta\sin\theta\, w_s] = 0, \tag{4.7-12}$$

Similarly, in BUO zone, we have

$$\left(\frac{D}{R^2}\right)\lambda_b^4 w_b - Eh\lambda_b^2 w_b$$

$$- (\lambda_b^2 + \lambda_{bA=1}^2)\left(\frac{R^3}{3h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_b\right) - \lambda_b^2$$

$$[\frac{2R^3}{h}\omega_c^2(2\rho_p - \rho_n)\cos\theta\sin\theta\, w_b] = 0, \tag{4.7-13}$$

Eqs. (4.7-12) and (4.7-13) are lowest order Eigen value equations, obtained from original high order non-linear D.E. (4.1-6) and (4.1-7) by decomposition method.

h) The membrane model.

Like a balloon, the membrane is so thin, that it can not bear or resist bending and twisting moment, but it can only resist tensile stress. For axis-symmetry deformation, there is no shearing stress on the cross-sections of a cylindrical element, while tensile stress is uniformly distributed along thickness. That is: the resisting bending rigidity D = 0,

$$D/R^2 = \frac{Eh^3}{12(1-\nu^2)R^2} = 0 \tag{4.8-1}$$

$$T_1 = T_1^0,\ T_2 = T_2^0,\ w = w^0 \tag{4.8-2}$$

Substituting (4.8-1) into (4.7-12) and (4.7-13), we have:

$$Eh\lambda_s^2 w_s + (\lambda_s^2 + \lambda_{sA=1}^2)\left(\frac{R^3}{3h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_s\right) +$$

$$\lambda_s^2(\frac{2R^3}{h}\omega_c^2(2\rho_p - \rho_n)\cos\theta\sin\theta\, w_s) = 0,\ (\theta_0 \le \theta \le \pi/2) \tag{4.8-3}$$

$$Eh\lambda_b^2 w_b + (\lambda_b^2 + \lambda_{bA=1}^2)\left(\frac{R^3}{3h}\rho_n\omega_c^2[(\sin\theta)^3 - (\sin\theta_0)^3]w_b\right) +$$

$$\lambda_b^2(\frac{2R^3}{h}\omega_c^2(2\rho_p - \rho_n)\cos\theta\sin\theta\, w_b) = 0,\ (0 \le \theta \le \theta_0) \tag{4.8-4}$$

i) The boundary conditions (4.1-12) --- (4.1-14) and boundary Eigen values problem

There are 6 basic unknowns $w_s, F_s, w_b, F_b, \lambda_s^2, \lambda_b^2$ in boundary Eigen value problem (4.8-3) and (4.8-4), we need 6 boundary conditions to determine 6 unknowns. That is constraints shown in (4.1-12) --- (4.1-14). Eqs. (4.8-3) and (4.8-4) are linked by boundary condition (4.1-13).

The boundary conditions (4.1-12), by (4.3-3), show that

$$w_b(0) = R - R_p + \epsilon_1 \tag{4.9-1}$$

$$F_{b\theta\theta}(0) = T_{b2}(0) = 0 \tag{4.9-2}$$

By (4.4-3), $F_{b\theta\theta}(0) = -\lambda_{bA=1}^2 F_s(0) = 0$, we have

$$\lambda_{bA=1}^2 = 0 \tag{4.9-3}$$

The boundary conditions (4.1-14) , by (4.3-4), show that

$$w_s(\pi/2) = R_e - R + \epsilon_2, \tag{4.9-4}$$

$$F_{s\theta\theta}(\pi/2) = \left(\sum(m_p + m_n)/(4\pi R_e)\right) = 0, \text{[2]} \tag{4.9-5}$$

Substituting $\theta = \theta_0$, (4.9-3) into (4.8-3) and (4.8-4), by

$$w_s(\theta_0) = w_b(\theta_0), \tag{4.9-6}$$

we have:

$$\lambda_s^2 = \lambda_b^2, \tag{4.9-7}$$

By (4.1-13), (4.3-3) and (4.3-4), we have

$$F_{s\theta\theta}(\theta_0) - F_{b\theta\theta}(\theta_0) = T_{s2}(\theta_0) - T_{b2}(\theta_0) = \delta \tag{4.9-8}$$

$$\delta = \left[2\left(2\rho_p - \rho_n\right) - \frac{1}{2}\rho_n\right]\frac{R^3}{h}\omega_c^2 \cos\theta_0 \sin\theta_0 \qquad (4.9\text{-}9)$$

Let

$$m_s(\theta_0) := \frac{hT_{s2}(\theta_0)}{\omega_c^2} = 2\left(2\rho_p - \rho_n\right)R^3 \cos\theta_0 \sin\theta_0 \qquad (4.9\text{-}10)$$

$$m_b(\theta_0) := \frac{hT_{b2}(\theta_0)}{\omega_c^2} = \frac{1}{2}\rho_n R^3 \cos\theta_0 \sin\theta_0, \qquad (4.9\text{-}11)$$

be the masses of crust at θ_0 of SIN zone and BUO zone respectively. Then, (4.9-9) means that the internal force per unit length $T_{s2}(\theta_0) \neq T_{b2}(\theta_0)$, the un-continuity of T_2 due to mantle loading can be viewed as masses $m_s(\theta_0) \neq m_b(\theta_0)$ un-continuity at θ_0.

$$m_s(\theta_0) - m_b(\theta_0) = \frac{h\delta}{\omega_c^2} = \left[2\left(2\rho_p - \rho_n\right) - \frac{1}{2}\rho_n\right] R^3 \cos\theta_0 \sin\theta_0 \qquad , (4.9\text{-}12)$$

Where the masses are formed from mantle emission. Since the static steady process is concerned, which independents of time. The growing of Tibet high-land might be viewed as an evidence of the mass $m_s(\theta_0)$ increasing due to mantle emission in the process.

Substituting (4.9-3), (4.8-3) into (4.9-4), we have:

$$w_s(\pi/2) = R_p - R + \epsilon_2 = \lambda_s^2 C_s w_s(\pi/2) \qquad (4.9\text{-}13)$$

$$\text{Or } \lambda_s^2 = \lambda_b^2 = C_s^{-1} = \left[Eh - \frac{R^3}{2h}\rho_n\omega_c^2(\sin\theta_0)^3\right]^{-1} \neq 0 \qquad (4.9\text{-}14)$$

Eq. (4.9-14) shows that non-zero Eigen value exists. The corresponding Eigen function $w_s(\theta)$, by (4.8-3), is:

$$w_s(\theta) =$$

$$Eh + \frac{R^3}{2h}\rho_n\omega_c^2((\sin\theta)^3 - (\sin\theta_0)^3) + \frac{2R^3}{h}\left(2\rho_p - \rho_n\right)\omega_c^2 \cos\theta \sin\theta,$$

$$(\theta_0 \leq \theta \leq \pi/2) \qquad (4.9\text{-}15)$$

Substituting (4.9-15) into (4.9-4), we have

$$\epsilon_2 = |R_e - R| = 6378160 - 6371032 = 7128\ (\text{km}),^{[17]} \qquad (4.9\text{-}16)$$

The related error $\epsilon = \frac{\epsilon_2}{R} = \frac{7128}{6371032} = 0.0011188.$

Similarly,

$$w_b(\theta) =$$

$$Eh + \frac{R^3}{2h}\rho_n\omega_c^2((\sin\theta)^3 - (\sin\theta_0)^3) + \frac{2R^3}{h}\left(2\rho_p - \rho_n\right)\omega_c^2 \cos\theta \sin\theta,$$

$$(0 \leq \theta \leq \theta_0) \qquad (4.9\text{-}17)$$

Substituting (4.9-17) into (4.9-1), we have

$$\epsilon_1 = \left|R - R_p\right| = 6371032 - 6356777 = 14255 \text{ (km)},^{[17]} \qquad (4.9\text{-}18)$$

The related error $\epsilon = \frac{\epsilon_2}{R} = \frac{14255}{6371032} = 0.002237.$

Now, the governing high-order non-linear coupled D.E. (4.1-1) ---(4.1-5) is transferred to Eigen value problem and solved by decomposition method.

V. Results and Conclusion

Analysis spherical crust is a complex problem, its governing equations, even for the simpler elastic spherical shell, involves high-order non-linear D.E. with coupled unknown functions w and F. We use two models, one with resisting bending moment, the other is a membrane model without resisting bending moment, two governing equations, one in English, the other in Russian, to study dimpling and bucking. Dimpling analysis follows the previous work but instead the loading by mantle loading. Dimpling study depends on outer solution of the non-homogeneous D.E., while bucking analysis depends on the non-zero solution of homogeneous D.E. Dimpling occurs at apex (poles), like an apple. Its analysis can just use local information, like a shallow spherical cap, but the bucking analysis needs the total information of the whole structure.

VI. Results

Dimpling occurring at poles, is proved theoretically and numerical analysis well consists with poles' radius.

Bucking analysis uses transformation to Eigen value problem and solves by decomposition method. The results show that non- zero Eigen value exits. That means bucking can occur under mantle loading. An other feature is that the un-continuity of internal force per unit length due to mantle loading causes masses un-continuity by mantle material emitting out to crust at the turning point of the "X".

Both poles radius and equatorial radius have been used to support our analysis.

Question: how the nature makes cold at poles?

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Lagrange Function of Charge in the Concept of the Scalar-Vector Potential

By F. F. Mende

Abstract- One of the methods for solving problems in mechanics is the use of Lagrangian formalism.By function of Lagrange or Lagrangian in the mechanics is understood the difference between the kinetic and potential energy of the system ofin question.If we integrate the Lagrangian with respect to time, we obtain the first main Hamilton function, called the action.In the general case kinetic energy of system depends on speed, and potential energy depends on coordinates. In the case of the conservatism of system during its motion she selects the way, with which the action is minimum. However, the record of Lagrangian, accepted in the electrodynamics does not entirely satisfy the condition of the conservatism of system. The vector potential, in which moves the charge, create the strange moving charges, and the moving charge interacts not with the field of vector potential, but with the moving charges, influencing their motion. But this circumstance does not consider the existing model, since. vector potential comes out as the independent substance, with which interacts the moving charge. Moreover, into the generalized momentum of the moving charge is introduced the scalar product of its speed and vector potential, in which the charge moves.

Keywords: lanrange function, scalar potential, vector potential. hamilton function, generalized momentum, scalar-vector potential.

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Keywords: lanrange function, scalar potential, vector potential. hamilton function, generalized momentum, scalar-vector potential.

I. Introduction

One of the methods for solving problems in mechanics is the use of Lagrangian formalism.By function of Lagrange or Lagrangian in the mechanics is understood the difference between the kinetic and potential energy of the system ofin question

$$L = W_k(t) - W_p(t).$$

If we integrate Lagrangian with respect to the time, then we will obtain the first main function Hamilton function, called action. Since in the general case kinetic energy depends on speeds, and potential - from the coordinates, action can be recorded as

$$S = \int_{t_1}^{t_2} L(x_i, v_i)dt$$

With the condition of the conservatism of this system Lagrange formalism assumes least-action principle, when system during its motion selects the way, with which the action is minimum.

In the electrodynamics Lagrangian of the charged particle, which is moved with the relativistic speed, is written as follows [1]:

$$L = -mc^2\sqrt{1-\frac{v^2}{c^2}} - q\left(\varphi + \mu_0(\vec{v}\vec{A}_H)\right). \qquad (1.1)$$

For non-relativistic speeds this expression will be written:

$$L = \frac{mv^2}{2} - q\left(\varphi + \mu_0(\vec{v}\vec{A}_H)\right)$$

where q, m, $\vec{v}$ - charge mass and the velocity of particle, c - the speed of light, μ_0 - magnetic permeability of vacuum, the scalar potential of electric field, $\vec{A}_H$ - the vector potential of magnetic field, in which it moves with particle. This expression and further all relations are written in the SI system of units. However, the record of Lagrangian, accepted in the electrodynamics does not entirely satisfy the condition of the conservatism of system. The vector potential, in which moves the charge, create the strange moving charges, and the moving charge interacts not with the field of vector potential, but with the moving charges, influencing their motion. But this circumstance does not consider the existing model, since. vector potential comes out as the independent substance, with which interacts the moving charge.

There are misunderstandings in [2], on p. 279 we read: "Therefore, even in the relativistic approximation, the Lagrange function in an electromagnetic field cannot be represented as the difference of kinetic and potential energy" (end of quote).

In relation (1.1), the author is confused by the term containing the scalar product of the charge velocity and the vector potential, and he does not know what kind of energy it belongs to.

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Among other things, this uncertainty is not over, and Landau works [3]. The introduction of the Lagrange function and moving charge in this work on paragraphs 16 and 17. With the introduction of these concepts in paragraph 16 is done the following observation: "The following below assertions it is necessary to examine to a considerable degree as the result of experimental data. The form of action for the particle in the electromagnetic field cannot be established on the basis only of general considerations, such as the requirement of relativistic invariance. (latter it would allow in action also the member of form integral of Ads, where A scalar function)" (end of quote).

But with the further consideration of this question of any experimental data the author does not give and it is not completely understandable, on what bases [Lagranzha]'s function introduces in the form (1.1). It is further - it is still worse. Without understanding the physical essence of Lagrangian, and in fact [ugadav] its (see relationship (17.4) into [3]), the author immediately includes the potential part (the scalar product of speed and vector potential) in generalized momentum, and then for finding the force is differentiated on the coordinate of Lagrangian, calculating gradient from this value (see relationship after equality (18.1) of [3]). But, finding gradient from the work indicated, the author thus recognizes his potential status.

In the mechanics by pulse is understood the work of the mass of particle to its speed. Multiplying pulse on the speed, mechanical energy is derived. In the electrodynamics, in connection with the fact that the charge has a mass; also is introduced the concept of angular impulse. But this not all. Is introduced also the concept of the generalized momentum

$$\vec{P} = m\vec{v} + q\vec{A},$$

when to the angular impulse is added the work of charge to the vector potential of magnetic field, in which moves the charge. Moreover even with the insignificant magnetic fields this additive considerably exceeds angular impulse. If generalized momentum scalar was multiplied by the speed

$$\vec{v}\vec{P} = m(\vec{v})^2 + q\vec{v}\vec{A}, \qquad (1.2)$$

that angular impulse will give kinetic energy. Scalar product of speed and vector potential will also give energy, here only this energy proves to be not kinetic, but potential. Here and is obtained composite solyanka, when it enters into the composition of energy of the moving charge and kinetic, and potential energy. With this is connected the incomprehension of physical nature of last term in the relationship (1.2), the having place in the work [2].

We already said that the record of Lagrangian (1.1) does not in the form satisfy the condition of the conservatism of system. This is connected with the fact that the vector potential, entering this relationship, it is connected with the motion of the strange charges, with which interacts the moving charge. A change in the charge rate, for which is located Lagrangian, will involve a change in the speed of these charges, and energy of the moving charge will be spent to this. In order to ensure the conservatism of system, it is necessary to know interaction energy of the moving charge with all strange charges, including with those, on which depends vector potential. This can be made a way of using the scalar-vector potential [4-7].

a) Concept of scalar- vector potential

The laws of induction have symmetrical nature [2-5]:

$$\begin{aligned} \oint \vec{E}'dl' &= -\int \frac{\partial \vec{B}}{\partial t} d\vec{s} + \oint \left[\vec{v} \times \vec{B}\right] dl' \\ \oint \vec{H}'dl' &= \int \frac{\partial \vec{D}}{\partial t} d\vec{s} - \oint \left[\vec{v} \times \vec{D}\right] dl' \end{aligned}, \qquad (2.1)$$

or

$$\begin{aligned} rot\vec{E}' &= -\frac{\partial \vec{B}}{\partial t} + rot\left[\vec{v} \times \vec{B}\right] \\ rot\vec{H}' &= \frac{\partial \vec{D}}{dt} - rot\left[\vec{v} \times \vec{D}\right] \end{aligned}. \qquad (2.2)$$

In these relationships: $\vec{E}$ and $\vec{H}$ - electrical and magnetic field, $\vec{D}$ and $\vec{B}$ - electrical and magnetic induction, $\vec{v}$ -relative speed between the shtrikhovannoy and reference system of counting (IRS).

For the constants pour on these relationships they take the form:

$$\begin{aligned} \vec{E}' &= \left[\vec{v} \times \vec{B}\right] \\ \vec{H}' &= -\left[\vec{v} \times \vec{D}\right] \end{aligned}. \qquad (2.3)$$

In the relations (2.1-2.3), assuming the validity of the Galileo transforms, the hatched and the not-hatched quantities represent the fields and elements in the moving and fixed IRS, respectively. It should be noted that transformations (2.3) previously could be obtained only from Lorentz transformations.

The relationship (2.3) attest to the fact that in the case of relative motion of frame of references, between the fields $\vec{E}$ and $\vec{H}$ there is a cross coupling, i.e., motion in the fields $\vec{H}$ leads to the appearance fields

$\vec{E}$ on and vice versa. From these relationships escape the additional consequences, which were for the first time examined in the work [2]. The electric field $E=\dfrac{g}{2\pi\varepsilon r}$ outside the charged long rod, per unit length of which the charge falls g, decreases according to the law $\dfrac{1}{r}$, where r is the distance from the central axis of the rod to the observation point.

If we in parallel to the axis of rod in the field E begin to move with the speed Δv another IRS, then in it will appear the additional magnetic field $\Delta H=\varepsilon E\Delta v$. If we now with respect to already moving IRS begin to move third frame of reference with the speed Δv, then already due to the motion in the field ΔH will appear additive to the electric field $\Delta E=\mu\varepsilon E\left(\Delta v\right)^2$. This process can be continued and further, as a result of which can be obtained the number, which gives the value of the electric field $E_v'(r)$ in moving IRS with reaching of the speed $v=n\Delta v$, when $\Delta v\to 0$, and $n\to\infty$. In the final analysis in moving IRS the value of dynamic electric field will prove to be more than in the initial and to be determined by the relationship:

$$E'\left(r,v_\perp\right)=\frac{gch\dfrac{v_\perp}{c}}{2\pi\varepsilon r}=Ech\frac{v_\perp}{c}.$$

If speech goes about the electric field of the single charge e, then its electric field will be determined by the relationship:

$$E'\left(r,v_\perp\right)=\frac{ech\dfrac{v_\perp}{c}}{4\pi\varepsilon r^2}, \qquad (2.4)$$

where $v_\perp$ - normal component of charge rate to the vector, which connects the moving charge and observation point.The potential can be called scalar-vector, because it depends not only on the absolute value of the charge, but also on the speed and direction of its movement with respect to the observation point. This potential has maximum value in the direction normal to the movement of the charge itself [8-11].

$$\varphi'(r,v_\perp)=\frac{ech\dfrac{v_\perp}{c}}{4\pi\varepsilon r}=\varphi(r)ch\frac{v_\perp}{c}, \qquad (2.5)$$

where $\varphi(r)$ - scalar potential of fixed charge. The potential of $\varphi'(r,v_\perp)$ can be named scalar- vector, since. it depends not only on the absolute value of charge, but also on speed and direction of its motion with respect to the observation point. Maximum value this potential has in the direction normal to the motion of charge itself.

b) Lagrange formalism in the concept of scalar- vector potential

The scalar potential $\varphi(r)$ at the point of the presence of charge is determined by all surrounding charges g_j and is determined by the relationship:

$$\varphi(r)=\sum_j\frac{1}{4\pi\varepsilon}\frac{g_j}{r_j}$$

Each moving charge creates a potential at the observation point, defined by relation (2.5).

If some quantity of moving and fixed charges surrounds this point of space, then for finding the scalar potential in the given one to point it is necessary to produce the summing up of their potentials:

$$\varphi'(r)=\sum_j\varphi(r_j)ch\frac{v_{j\perp}}{c}=\sum_j\frac{1}{4\pi\varepsilon}\frac{g_j}{r_j}ch\frac{v_{j\perp}}{c}.$$

Taking into account this circumstance Lagrangian of the charge e, which is found in the environment of the fixed and moving strange charges can be written down as follows:

$$L=-e\sum_j\frac{1}{4\pi\varepsilon}\frac{g_j}{r_j}ch\frac{v_{j\perp}}{c}.$$

If the charge e is moving relative to the selected IRS speed then its Lagrangian is determined by the ratio (2.1) except that as speeds are relative velocities $v_{j\perp}$ the relative velocities of the charges with respect to the charge e are taken and a term is added that determines the kinetic energy of the charge itself. The Lagrangian for low speeds in this case takes the form:

$$L=\frac{mv^2}{2}-e\sum_j\frac{1}{4\pi\varepsilon}\frac{g_j}{r_j}ch\frac{v_{j\perp}}{c}$$

This approach is deprived already of the deficiency indicated, since. it satisfies the complete conservatism of system, since in Lagrangian are taken into account all interactions charge with its surrounding charges.

II. Conclusion

One of the methods for solving problems in mechanics is the use of Lagrangian formalism.By function of Lagrange or Lagrangian in the mechanics is understood the difference between the kinetic and potential energy of the system ofin question.If we integrate the Lagrangian with respect to time, we obtain the first main Hamilton function, called the action.In the general case kinetic energy of system depends on speed, and potential energy depends on coordinates. In the case of the conservatism of system during its motion she selects the way, with which the action is minimum. However, the record of Lagrangian, accepted in the electrodynamics does not entirely satisfy the condition of the conservatism of system. The vector potential, in which moves the charge, create the strange moving charges, and the moving charge interacts not with the field of vector potential, but with the moving charges, influencing their motion. But this circumstance does not consider the existing model, since. vector potential comes out as the independent substance, with which interacts the moving charge. Moreover, into the generalized momentum of the moving charge is introduced the scalar product of its speed and vector potential, in which the charge moves. But this term presents not kinetic, but potential energy, which contradicts the determination of pulse in the mechanics. With these circumstances are connected those errors, which occur in the works on electrodynamics. In the work it is shown that use of a concept of scalar- vector potential for enumerating the Lagrangian of the moving charge gives the possibility to exclude the errors, existing in the contemporary electrodynamics.

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Disruptive Gravity: A Quantizable Alternative to General Relativity

By Ramsès Bounkeu Safo

Abstract- Gravity is the most problematic interaction of modern science. Questioning the very foundations of gravity might be the key to understanding it better since its description changed over time. Newton described it as a force, Einstein described it as a spacetime curvature and this paper shows how gravity can be described as a force able to bend spacetime instead. Applied to cosmology, gravity as a spacetime bending force doesn't require Dark Energy. Described as a spacetime bending force, gravity becomes quantizable as a force in curved spacetime which is compatible with the Standard Model of particle physics. Therefore, one could associate the Standard Model to this theory and achieve Quantum Gravity.

Keywords: *general relativity; modified gravity; mond; dark energy; quantum gravity; dark matter; gravitation; gravity.*

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DISRUPTIVEGRAVITYAQUANTIZABLEALTERNATIVETOGENERALRELATIVITY

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Disruptive Gravity: A Quantizable Alternative to General Relativity

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Keywords: general relativity; modified gravity; mond; dark energy; quantum gravity; dark matter; gravitation; gravity.

I. Introduction

Understanding gravity is one of the most important challenges of modern science. For a long time, General Relativity had no reason to be questioned since it was in line with the observations. That was until the observation of an unexpectedly high rotation speed of galaxies and then, more recently, the discovery of the accelerating expanding universe through observations of distant supernovae. Both are not explainable through General Relativity unless we hypothesize the existence of Dark Matter and Dark Energy respectively, accounting for 95% of the energy of the universe. Current research focuses on creating models to describe Dark Matter and Dark Energy instead of seriously questioning General Relativity. Thinking differently about gravitation might be the key to understanding it better.

Newton thought of it as a force, then Einstein theorized it as a spacetime curvature, but what if gravity could be described as a force able to bend spacetime instead? This paper shows that gravity can be consistently described as a spacetime bending force based on a physical principle inferred from the Schwarzschild metric. We show that, writing the Lagrangian of a force in curved spacetime, we get equivalent equations of motion as General Relativity thanks to a physically acceptable hypothesis. From a simple homogeneous universe model, we then show that it is possible to explain the accelerating expanding universe with no Dark Energy. As a spacetime bending force, gravity becomes quantizable as a force in curved spacetime analogous to electromagnetism.

In this paper, Greek letters range from 0 to 3 (representing spacetime) and Roman letters range from 1 to 3 (representing space). The metric signature is $(+---)$ and we use Einstein's summation convention. The Greek capital letter Φ is the gravitational potential.

II. A Preliminary Scalar Approach

In this section, we study a scalar approach of gravitation as a spacetime bending force as an introduction to the theory. It is a special case of the theory specified in Section III and IV.

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Einstein's General Relativity states that a body moving through gravity is just following a straight path in curved spacetime. This is described by the geodesic equations derived from the least action principle with the following Lagrangian:

$$L_0 = -m_0 c\sqrt{g_{\mu\nu}\dot{x^\mu}\dot{x^\nu}}$$

where $g_{\mu\nu}$ is the metric of the curved spacetime and m_0 is the rest mass of the body. If gravity were a force, in a scalar theory, the Lagrangian would be of the form:

$$L_0' = -m_0 c\sqrt{\eta_{\mu\nu}\dot{x^\mu}\dot{x^\nu}} - m_0\Phi$$

where $\eta_{\mu\nu}$ is Minkowsky's metric of a flat spacetime and Φ is the gravitational potential. We know this Lagrangian is not correct since it would lead to incorrect geodesic equations because it doesn't take into account spacetime curvature.

In a scalar approach, to describe gravity as a spacetime bending force, we need to include spacetime curvature and a potential term in the Lagrangian as follows:

$$L = -mc\sqrt{g_{\mu\nu}\dot{x^\mu}\dot{x^\nu}} - m\Phi$$

where m is the inertial mass. As such, we still wouldn't get the same geodesic equations as General Relativity. Is it possible to slightly change it in a physically acceptable way for it to become equivalent to General Relativity's Lagrangian? Speed of light cannot be modified since Special Relativity laws wouldn't apply anymore. The only thing that could be changed is the inertial mass of the body. Let's then hypothesize that the inertial mass is relative such that:

$$m = \alpha(\Phi)m_0$$

where the rest mass m_0 is defined as the inertial mass in case of zero potential. So we have: $\alpha(0) = 1$. Inertial mass relativity is physically acceptable since we already consider that the relativistic mass of a body is relative depending on its speed.

The Lagrangian becomes:

$$\boxed{L = -\alpha(\Phi)m_0 c\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu} - \alpha(\Phi)m_0\Phi} \tag{1}$$

For more clarity, let's also write: $\dot{s_0} = \sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu}$

We then have: $L = -\alpha(\Phi)m_0 c\dot{s_0} - \alpha(\Phi)m_0\Phi$ [i]

The Lagrangian equation restricted to space variables is:

$$\frac{\partial L}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L}{\partial \dot{x}^i} = 0 \quad \text{[ii]}$$

Since Φ doesn't depend explicitly on $\dot{x}^i$, we have:

$$-\frac{\partial\alpha(\Phi)m_0 c\dot{s_0}}{\partial x^i} - \frac{\partial\alpha(\Phi)m_0\Phi}{\partial x^i} + \frac{d}{d\tau}\frac{\partial\alpha(\Phi)m_0 c\dot{s_0}}{\partial \dot{x}^i} = 0 \quad \text{[iii]}$$

Leading to: $-\frac{\partial\alpha(\Phi)c\dot{s_0}}{\partial x^i} - \frac{\partial\alpha(\Phi)\Phi}{\partial x^i} + \frac{d}{d\tau}(\alpha(\Phi)\frac{\partial c\dot{s_0}}{\partial\dot{x}^i}) = 0$ [iv]

It comes:

$$-\alpha(\Phi)\frac{\partial c\dot{s_0}}{\partial x^i} - \frac{\partial\alpha(\Phi)}{\partial x^i}c\dot{s_0} - \frac{\partial\alpha(\Phi)\Phi}{\partial x^i} + \frac{d\alpha(\Phi)}{d\tau}\frac{\partial c\dot{s_0}}{\partial\dot{x}^i} + \alpha(\Phi)\frac{d}{d\tau}\frac{\partial c\dot{s_0}}{\partial\dot{x}^i} = 0 \quad \text{[v]}$$

We see the Lagrangian equation of General Relativity in the first and last terms of the equation [v]. Let $L_0 = -m_0 c\dot{s_0}$, it comes:

$$-\frac{\partial\alpha(\Phi)}{\partial x^i}c\dot{s_0} - \frac{\partial\alpha(\Phi)\Phi}{\partial x^i} + \frac{d\alpha(\Phi)}{d\tau}\frac{\partial c\dot{s_0}}{\partial\dot{x}^i} + \alpha(\Phi)(\frac{\partial L_0}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L_0}{\partial\dot{x}^i})/m_0 = 0 \quad \text{[vi]}$$

Parametrizing with the body's proper time, we have: $\dot{s_0} = c$. Thus:

$$-\frac{\partial(\alpha(\Phi)c^2 + \alpha(\Phi)\Phi)}{\partial x^i} + \frac{d\alpha(\Phi)}{d\tau}\frac{\partial c\dot{s_0}}{\partial\dot{x}^i} + \alpha(\Phi)(\frac{\partial L_0}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L_0}{\partial\dot{x}^i})/m_0 = 0 \quad \text{[vii]}$$

We see that, for it to give correct equations of motion in the Newtonian limit, we necessarily have:

$$\frac{\partial(\alpha(\Phi)c^2 + \alpha(\Phi)\Phi)}{\partial x^i} = 0 \quad \text{[viii]}$$

It yields: $\alpha(\Phi) = (1 + \Phi/c^2)^{-1}$ [ix]

Then: $$\frac{d\alpha(\Phi)}{d\tau} = \frac{\partial\alpha(\Phi)}{\partial\Phi}\frac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu = -(1 + \Phi/c^2)^{-2}\frac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu/c^2 \quad \text{[x]}$$

Hence, recasting in [vii] we get:

$$(\frac{\partial L_0}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L_0}{\partial\dot{x}^i})/m_0 = (1 + \Phi/c^2)^{-1}\frac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu\frac{\partial c\dot{s_0}}{\partial\dot{x}^i}/c^2 \quad \text{[xi]}$$

Notations can be misleading. We cannot replace $\dot{s_0}$ by c in the expression $\frac{\partial c\dot{s_0}}{\partial\dot{x}^i}$ since it's a partial derivative. We have in fact:

$$\frac{\partial c\dot{s_0}}{\partial\dot{x}^i} = c\cdot\frac{\partial\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu}}{\partial\dot{x}^i} = c\cdot\frac{2\cdot g_{\mu i}\dot{x}^\mu}{2\cdot\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu}} = c\cdot\frac{2\cdot\dot{x}_i}{2\cdot c} = \dot{x}_i$$

Hence: $(\frac{\partial L_0}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L_0}{\partial\dot{x}^i})/m_0 = (1 + \Phi/c^2)^{-1}\frac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu\dot{x}_i/c^2$ [xii]

And calculating $(\frac{\partial L_0}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L_0}{\partial\dot{x}^i})/m_0$ gives a known standard result of General Relativity [1] [2] [3] [4]:

$$(\frac{\partial L_0}{\partial x^i} - \frac{d}{d\tau}\frac{\partial L_0}{\partial\dot{x}^i})/m_0 = g_{\mu i}\ddot{x}^\mu + 1/2\cdot(-\partial^i g_{\mu\nu} + \partial^\mu g_{\nu i} + \partial^\nu g_{\mu i})\dot{x}^\mu\dot{x}^\nu \quad \text{[xiii]}$$

Thus, after multiplying [xii] by g^{ik} (which is the inverse of the restriction of the metric to space), defining Christoffel symbols as:

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$$\Gamma^k_{\mu\nu} = g^{ik}/2 \cdot (-\partial^i g_{\mu\nu} + \partial^\mu g_{\nu i} + \partial^\nu g_{\mu i})\dot{x}^\mu \dot{x}^\nu$$

(as said in the introduction, Roman letters span from 1 to 3 whereas Greek letters span from 0 to 3) we get:

$$\ddot{x}^k + \Gamma^k_{\mu\nu}\dot{x}^\mu \dot{x}^\nu = (1+\Phi/c^2)^{-1}\frac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu \dot{x}^k/c^2 \qquad \text{[xiv]}$$

After neglecting second order terms, it yields:

$$\boxed{\ddot{x}^k + \Gamma^k_{\mu\nu}\dot{x}^\mu \dot{x}^\nu = \frac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu \dot{x}^k/c^2} \; (2) \qquad \text{[xv]}$$

These equations of motion look like the geodesic equations of General Relativity. For weak-fields and low speeds, if $\alpha(\Phi) = (1+\Phi/c^2)^{-1}$ we trivially get the Newtonian limit.

Hence, if the inertial mass is relative such that:

$$\boxed{m = (1+\Phi/c^2)^{-1}m_0} \qquad (3)$$

gravity described as a spacetime bending force instead of a spacetime curvature yields similar results. The small deviation from General Relativity induced by $\partial^\mu\Phi\dot{x}^\mu\dot{x}^k/c^2$ makes this theory testable.

For more clarity, let's write: $m_0\dfrac{\partial\Phi}{\partial x^\mu}\dot{x}^\mu \dot{x}^k/c^2 = (-\vec{F}\cdot\vec{v})\cdot\vec{v}/c^2$

where $\vec{F}$ is the gravitational force and $\vec{v}$ the speed of the body. We can interpret it as an anomalous thrust unexpected from General Relativity. In the case of Mercury, its speed around the Sun is $v = 47km/s$ so $v^2/c^2 = 2.5\cdot 10^{-8}$ that makes it neglectable and hard to detect since the term $\Gamma^k_{\mu\nu}\dot{x}^\mu\dot{x}^\nu$ is of the same order of magnitude as the gravitational acceleration $\vec{F}/m_0$. Such an anomaly is expected to be measurable in the recently launched Parker Solar Probe if solar wind and radiation pressure can be neglected so close to the Sun. That would be a test of this theory.

In case of orbital motion, we see that for a circular trajectory, this force is null. Thus, it can be neglected for low eccentricities yielding the same predictions of orbit precession as General Relativity, especially Mercury's perihelion precession.

In this section, we described gravity with a scalar theory as an introduction. We need to extend it to a vectorial theory that would make it a special case. That is the aim of Section III and IV.

III. A Spacetime Bending Force

Describing gravity as a spacetime bending force has to yields equivalent equations of motion as General Relativity and account for predictions such as: Time Dilation, Light Bending, Shapiro Delay, Lens-Thirring and geodetic effects.

We know the Lens-Thirring and the geodetic effects are both well described by Gravitoelectromagnetism [5] which is a theory of gravity in a flat spacetime analogous to Maxwell's theory of electromagnetism. So including spacetime curvature in Gravitoelectromagnetism would still make those predictions.

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Analogous to electromagnetism in General Relativity, we can consider gravity as some kind of gravitoelectromagnetism in curved spacetime and see if it makes the same predictions as General Relativity. The Lagrangian of an electrically charged body in General Relativity is:

$$L = -mc\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu} - q\dot{x}^\mu A_\mu$$

where A_μ is the electromagnetic four-vector potential and q the electric charge of the body. The idea is to consider a gravitational four-vector potential G_μ analogous to the electromagnetic four-vector potential A_μ and consider the following Lagrangian:

$$L = -m_{inertial}c\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu} - m_{gravitational}\dot{x}^\mu G_\mu$$

where $m_{inertial}$ is the inertial mass of the body and $m_{gravitational}$ is its gravitational mass. For some reason that will become clear in Section IV, we define the gravitational mass as:

$$m_{gravitational} = \gamma^{-1} m_{inertial}$$

where γ is defined as $\gamma^{-1} = \sqrt{g_{\mu\nu}\dfrac{dx^\mu}{dx^0}\dfrac{dx^\nu}{dx^0}}$ similar to the Lorentz factor.

Same as Section II, we hypothesize that the inertial mass is relative such that:

$$m_{inertial} = \alpha(\Phi)m_0$$

where m_0 is the rest mass, defined as the inertial mass if the gravitational potential is null: $\alpha(0) = 1$. The Lagrangian becomes:

$$\boxed{L = -\alpha(\Phi)m_0c\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu} - \gamma^{-1}\alpha(\Phi)m_0\dot{x}^\mu G_\mu} \tag{4}$$

How the Gravitational four-vector potential G_μ is calculated is not of relevance in this paper since gravity is not postulated to be Newtonian. It should then be subject to further studies. It depends on the type of gravitational potential. If Newtonian, it would be the exact analogous of electromagnetism in curved spacetime as we would just have to replace ϵ_0 by $-1/4\pi\mathcal{G}$ where $\mathcal{G}$ is Newton's constant.

In electromagnetism, the four-vector potential is of the form $A_\mu = (V/c, \vec{A})$ where V is the electrical potential and $\vec{A}$ is the potential vector. G_μ remains to be calculated depending on the gravitational potential theory used (not necessarily Newtonian). But we know that analogously to electromagnetism, it is of the form $G_\mu = (\Phi/c, \vec{G})$ where Φ is the gravitational potential.

In electromagnetism, the magnetic field is derived as the curl of $\vec{A}$. Analogously, defining the gravitational tensor as:

$$F_{\mu\nu} = \partial_\mu G_\nu - \partial_\nu G_\mu = \begin{pmatrix} 0 & -\frac{1}{c}E^x_{\mathcal{G}} & -\frac{1}{c}E^y_{\mathcal{G}} & -\frac{1}{c}E^z_{\mathcal{G}} \\ \frac{1}{c}E^x_{\mathcal{G}} & 0 & B^z_{\mathcal{G}} & -B^y_{\mathcal{G}} \\ \frac{1}{c}E^y_{\mathcal{G}} & -B^z_{\mathcal{G}} & 0 & B^x_{\mathcal{G}} \\ \frac{1}{c}E^z_{\mathcal{G}} & B^y_{\mathcal{G}} & -B^x_{\mathcal{G}} & 0 \end{pmatrix}$$

provides a good description of the Lens-Thirring and the geodetic effects.

Another prediction of General Relativity is Gravitational Waves. It is not mentioned in the tests because it is due to a gauge choice. Whereas viewing gravity as a spacetime bending force, gravitational waves would not be due to a gauge choice since G_μ is Lorentzian by definition. Indeed, Lorentz gauge induces a wave equation of the potential.

IV. First Order Non-Relativistic Dynamics

As we said in the previous section, we consider the following Lagrangian:

$$L = -\alpha(\Phi)m_0c\sqrt{g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu} - \gamma^{-1}\alpha(\Phi)m_0\dot{x}^\mu G_\mu \qquad \text{[i]}$$

Let's demonstrate that this Lagrangian yields the special case scalar theory of Section II when the Lens-Thirring and the geodetic effects can be neglected in case of non-relativistic speeds and in weak-fields.

Let's first simplify the Lagrangian by neglecting second-order terms. If the Lens-Thirring and the geodetic effects can be neglected, then cross-terms between space and time can be neglected. Parametrizing with the body's proper time, we have $c^2 = g_{00}(\dot{x}^0)^2 + g_{ij}\dot{x}^i\dot{x}^j$ which yields for non-relativistic fields:

$$\dot{x}^0 \cdot \sqrt{g_{00}} = c \cdot (1 - 1/2 \cdot g_{ij}\dot{x}^i\dot{x}^j/c^2) \qquad \text{[ii]}$$

Similarly, with $\gamma^{-1} = \sqrt{g_{\mu\nu}\dfrac{dx^\mu}{dx^0}\dfrac{dx^\nu}{dx^0}}$, we have:

$$\gamma^{-1}/\sqrt{g_{00}} = \sqrt{g_{\mu\nu}/g_{00} \cdot \frac{dx^\mu}{dx^0}\frac{dx^\nu}{dx^0}} = \sqrt{1 + g_{ij}/g_{00} \cdot \frac{dx^i}{dx^0}\frac{dx^j}{dx^0}} \qquad \text{[iii]}$$

Since $\frac{dx^0}{d\tau} = \dot{x}^0$ and for non-relativistic speeds $\dot{x}^0 \approx c$, neglecting second-order terms it comes:

$$\gamma^{-1}/\sqrt{g_{00}} = \sqrt{1 + g_{ij}/g_{00} \cdot \dot{x}^i\dot{x}^j/(\dot{x}^0)^2} = 1 + 1/2 \cdot g_{ij}/g_{00} \cdot \dot{x}^i\dot{x}^j/c^2 \qquad \text{[iv]}$$

Since in weak-fields $1/g_{00} \approx 1 - 2\Phi/c^2$, neglecting second-order terms yields:

$$\gamma^{-1}/\sqrt{g_{00}} = (1 + 1/2 \cdot g_{ij}\dot{x}^i\dot{x}^j/c^2) \qquad \text{[v]}$$

Multiplying [ii] and [v] we get:

$$\gamma^{-1}\dot{x}^0 = c \cdot (1 + 1/2 \cdot g_{ij}\dot{x}^i\dot{x}^j/c^2 - 1/2 \cdot g_{ij}\dot{x}^i\dot{x}^j/c^2 - (1/2 \cdot g_{ij}\dot{x}^i\dot{x}^j/c^2)^2) \qquad \text{[vi]}$$

Neglecting second-order terms again it comes: $\gamma^{-1}\dot{x}^0 = c$ [vii]

The Lens-Thirring and the geodetic effects being neglected, we also have $G_0 = \Phi/c$ and $G_i = 0$ we get:

$$\dot{x}^\mu G_\mu = \dot{x}^0 G_0 = \dot{x}^0\Phi/c \qquad \text{[viii]}$$

Recasting [vii] yields: $\gamma^{-1}\dot{x}^\mu G_\mu = \gamma^{-1}\dot{x}^0\Phi/c = \Phi$ [ix]

Introducing Lorentz factor in the definition of the gravitational mass is convenient as it suppresses perturbative terms. Its physical meaning is quite intuitive though: the faster a body, the more massive it gets in terms of relativistic mass, and the less the influence of a force on it. Taking this into account implies the introduction of Lorentz factor in the definition of the gravitational mass.

The Lagrangian [i] becomes:

$$L = -\alpha(\Phi) m_0 c \sqrt{g_{\mu\nu}\dot{x}^{\mu}\dot{x}^{\nu}} - \alpha(\Phi) m_0 \Phi \qquad \text{[x]}$$

Which is the special case already studied in Section II. Thus, if the inertial mass is relative such that $m_{inertial} = (1+\Phi/c^2)^{-1} m_0$, describing gravity as a spacetime bending force yields equivalent equations of motion as General Relativity.

The Lagrangian of this theory is then:

$$\boxed{L = -(1+\Phi/c^2)^{-1} m_0 c \sqrt{g_{\mu\nu}\dot{x}^{\mu}\dot{x}^{\nu}} - \gamma^{-1}(1+\Phi/c^2)^{-1} m_0 \dot{x}^{\mu} G_{\mu}} \qquad (5)$$

with $\gamma^{-1} = \sqrt{g_{\mu\nu}\dfrac{dx^{\mu}}{dx^0}\dfrac{dx^{\nu}}{dx^0}}$.

The reader may have noticed that the Lagrangian's variables x^{μ} and $\dot{x}^{\mu}$ are not independent since parametrizing with the body's proper time we have $c^2 = g_{00}(\dot{x}^0)^2 + g_{ij}\dot{x}^i\dot{x}^j$. We then have to choose a set of independent variables. Since space and time are disjoint by hypothesis, it is convenient to choose x^i and $\dot{x}^i$ as a set of independent variables. This is why we restricted the Lagrangian equation to space variables in Section II.

We now have a vectorial theory of gravitation that yields equivalent equations of motion as General Relativity and accounts for the Lens-Thirring and the geodetic effects. We are then left with finding a way to derive the metric so that the Schwarzschild metric is a solution to this theory. If so, it would account for Mercury's Perihelion Precession, Time Dilation, Light Bending and Shapiro Delay. For that, let's first have a look at the physical implications of inertial mass relativity in the next section.

V. Physical Implications

The hypothesis of inertial mass relativity yields equivalent results as General Relativity in weak fields and non-relativistic speeds. This hypothesis has physical implications and interpretations that we study in this section.

Mathematically, a natural physical interpretation arises. Indeed, we can give a physical meaning to $E_{\Phi} = m_{inertial}c^2$ thanks to inertial mass relativity:

$$E_{\Phi} = m_0 c^2/(1+\Phi/c^2)$$

Generalized to a relativistic body, we have:

$E_{\Phi} = \gamma m c^2/(1+\Phi/c^2)$ where $\gamma = 1/\sqrt{1-v^2/c^2}$ is Lorentz factor [6].

Let's rewrite it as: $E_{\Phi} = \sqrt{m_0^2 c^4 + p_0^2 c^2}(1+\Phi/c^2)$

Or rather, for brevity : $\boxed{E_\Phi = E_0/(1+\Phi/c^2)}$ (6)

Applied to photons of energy $E_0 = h\nu_0$, with $E_\Phi = h\nu_\Phi$ we have:

$$\nu_\Phi = \nu_0/(1+\Phi/c^2)$$

That looks a lot like General Relativity's formula of gravitational redshift. Thus we define E_Φ as the Apparent Energy of the body.

Writing it as $E_\Phi = E_0/\sqrt{g_{00}}$, it's as if the energy of a body could be redshifted. It's as if a body was also a wave which we know accurate since De Broglie's hypothesis of wave-particle duality.

Apparent Energy is nothing new. When a wave is Doppler-shifted for a moving observer, the shifted frequency is said to be apparent frequency. Analogously, the energy of a photon for a moving observer doesn't change, but since its frequency is Doppler-shifted, the change in energy is its apparent energy.

This physical meaning implies the time dilation factor be: $g_{00} = (1+\Phi/c^2)^2$

This provides another testable deviation from General Relativity. Indeed in General Relativity we have:

$$g_{00,schwarzschild} = 1 + 2\Phi/c^2$$

The second-order difference is $(\Phi/c^2)^2$. It's measurable and is another testable deviation from General Relativity.

VI. Physical Meaning of the Schwarzschild Metric

In this section, we show that we can give a physical meaning to the Schwarzschild metric that is analogous to the speed of light invariance principle. From there, it is possible to derive the metric so that the Schwarzschild metric is a special case, as shown in Section VII and VIII.

Let's write the Schwarzschild metric [7] :

$$ds^2 = (1+2\Phi/c^2)c^2dt^2 - (1+2\Phi/c^2)^{-1}dr^2 - r^2(d\theta^2 + sin^2\theta d\psi^2)$$

Then let's consider the following equivalent metric in weak-fields:

$$ds^2 = (1+\Phi/c^2)^2c^2dt^2 - (1+\Phi/c^2)^{-2}dr^2 - r^2(d\theta^2 + sin^2\theta d\psi^2)$$

Space and time being disjoint, we can define the space metric:

$$ds^2_{Space} = (1+\Phi/c^2)^{-2}dr^2 + r^2(d\theta^2 + sin^2\theta d\psi^2)$$

The volume element of a Riemannian manifold is the square root of the determinant of the metric in absolute value times the coordinate elements. For the Schwarzschild space metric it yields:

$$dV = \sqrt{(1+\Phi/c^2)^{-2} \cdot r^2 \cdot r^2 sin^2\theta} \cdot drd\theta d\psi = (1+\Phi/c^2)^{-1} \cdot r^2|sin\theta|drd\theta d\psi$$

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It comes:

$$(1 + \Phi/c^2) \cdot dV = r^2 |sin\theta| dr d\theta d\psi$$

This doesn't depend on Φ, which is an invariance principle. Let's multiply by ρc^2 where ρ is a hypothetical mass density of the vacuum, we get:

$$(\rho c^2 + \rho\Phi) \cdot dV = \rho c^2 \cdot r^2 |sin\theta| dr d\theta d\psi$$

In other words, analogous to the invariance of the speed of light, we have the following principle:

"The energy of the vacuum is invariant".

It seems like the same way speed of light invariance induces time dilation, vacuum energy invariance induces space dilation. Just as the Strong Equivalence principle is a postulate of General Relativity, Vacuum Energy Invariance (VEI) can be taken as a postulate. We will see that it yields the Schwarzschild metric in weak-fields and therefore provides the same predictions as General Relativity.

In Section VII and VIII, we derive the metric thanks to this principle.

VII. Metric Derivation (Part I)

We showed in Section II, III, and IV that gravity can be coherently described as a spacetime bending force if the inertial mass is relative. We are left with how the metric can be derived such that the Schwarzschild metric is a particular case.

We naturally postulate that the metric $g_{\mu\nu}$ is of the form:

$$g = \begin{pmatrix} g_{00}(\Phi) & 0 \\ 0 & -g_s(\Phi) \end{pmatrix}$$

Indeed, in General Relativity, cross terms between space and time are responsible for the Lens-Thirring and the geodetic effects, but since these are already accounted for by considering gravity as spacetime bending force, we can postulate that space and time curvature are disjoint.

We then consider that space and time are independently dilated by the VEI.

Let's derive both $det(g_s)$ and g_{00} thanks to the VEI principle.

At a given point in time t, in a volume element $dx_1 dx_2 dx_3$, under zero gravity and with vacuum energy density $\mathcal{E}_0$, we have:

$$dE_0 = \mathcal{E}_0 dx_1 dx_2 dx_3$$

and under Φ-gravity potential, we have:

$$dE_\Phi = \mathcal{E}_0 (1 + \Phi/c^2) \sqrt{det(g_s)} dx_1 dx_2 dx_3$$

Applying VEI, we have: $dE_0 = dE_\Phi$.

It comes:

$$\boxed{det(g_s) = (1 + \Phi/c^2)^{-2}} \tag{7}$$

Let's apply the VEI in time domain to have a more rigorous way to find g_{00}.

The reasoning is a bit similar to the one for the derivation of the gravitational redshift. We reason in terms of observational events.

Let E_0 be the total vacuum energy and N be the number of observational events.

The total vacuum energy by time unit for an observer under a global 0-potential is:

$$P_0 = \frac{d(NE_0)}{dt}$$

The total vacuum energy by time unit for the same observer under a global Φ-potential is:

$$P_\Phi = \frac{d(NE_0(1 + \Phi/c^2))}{d\tau}$$

Applying VEI, we have: $P_0 = P_\Phi$

It comes: $E_0 dN d\tau = E_0(1 + \Phi/c^2)dNdt$

With $d\tau^2 = g_{00}dt^2$ it eventually comes:

$$\boxed{g_{00} = (1 + \Phi/c^2)^2} \tag{8}$$

The equation of motion [xvii] of Section II, for non-relativistic speeds becomes:

$$\ddot{x}^k + \Gamma^k_{00}\dot{x}^0\dot{x}^0 = 0$$

In weak-fields, a standard result of linearized General Relativity yields :

$$\ddot{x}^k = -1/2 \cdot \partial_k h_{00} c^2$$

where $h_{\mu\nu} = g_{\mu\nu} - \eta_{\mu\nu}$ is the perturbation of the metric.

We have $h_{00} = 2\Phi/c^2$ from the VEI, which yields Newton's law [8].

VIII. Metric Derivation (Part 2)

We still don't fully know g_s. Any g_s formula predicting a correct Light Deflection and reproducing the Schwarzschild metric for the Sun's mass distribution works to account for every experimental test.

Considering gravity as a spacetime bending force would give us a space metric g_s different from General Relativity. It doesn't change anything to the Newtonian limit since, in that case, only g_{00} is relevant for the equations of motion. The idea is to aggregate the contributions of every mass of the distribution to the space deformation. In case of a compact spherical distribution, far from the sphere, space dilation would be purely radial just as in the Schwarzschild metric, whereas it wouldn't be the case close to the mass distribution. A non-radial space dilation is a testable prediction of this theory.

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Space deformations induced by a single punctual mass must be radial for trivial physical reasons. Then in a local orthonormal basis $(\vec{e_r}, \vec{e_u}, \vec{e_v})$ where $\vec{e_r}$ is radial, space metric is $-g_{s,ruv}$ of the form:

$$g_{s,ruv} = \begin{pmatrix} \beta^{-2} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = I + (\beta^{-2} - 1) \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Applying VEI yields: $\beta = 1 + \Phi/c^2$.

Let M^T be the change of basis orthonormal matrix from $(\vec{e_r}, \vec{e_u}, \vec{e_v})$ to $(\vec{e_1}, \vec{e_2}, \vec{e_3})$. So with $\vec{e_r} = r_i \vec{e_i}$, $\vec{e_u} = u_i \vec{e_i}$ and $\vec{e_v} = v_i \vec{e_i}$, changing coordinates we have:

$$g_s = M^T g_{s,ruv} M \text{ with } M^T = \begin{pmatrix} r_1 & u_1 & v_1 \\ r_2 & u_2 & v_2 \\ r_3 & u_3 & v_3 \end{pmatrix}$$

Since $M^T M = I$, it comes: $g_s = I + (\beta^{-2} - 1) M^T \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} M$

Eventually:

$$g_s = I + (\beta^{-2} - 1) \begin{pmatrix} r_1^2 & r_1 r_2 & r_1 r_3 \\ r_2 r_1 & r_2^2 & r_2 r_3 \\ r_3 r_1 & r_3 r_2 & r_3^2 \end{pmatrix} \text{ or } g_{s,ij} = \delta_{ij} + (\beta^{-2} - 1) r_i r_j$$

In weak-fields, this is equivalent to the Schwarzschild metric written in Cartesian coordinates. This doesn't depend on the choice of $\vec{e_u}$ and $\vec{e_v}$. For a mass distribution, the unit vector pointing from a massive point towards a local point in space is the same as the radial vector $\vec{e_r}$ so we can aggregate their influence thanks to the above formula.

Indeed, for an infinitely small potential $d\Phi$, we have $\beta^{-2} - 1 = -2d\Phi/c^2$ and the metric becomes when integrating over every infinitely small potential:

$$g_{s,ij} = \delta_{ij} + \lambda \cdot \int -2 r_i r_j d\Phi/c^2 \text{ with } \lambda \text{ such that } det(g_s) = (1 + \Phi/c^2)^{-2}$$

Space being curved there might not be a unique choice of r_i. Therefore we introduce the potential angular distribution $\phi(\vec{\sigma})$, where $\vec{\sigma}$ is the observed direction. Leading to the following metric equation:

$$\boxed{g_{s,ij} = \delta_{ij} + \lambda \cdot \int -2\phi(\vec{\sigma})/c^2 \cdot r_i(\vec{\sigma}) r_j(\vec{\sigma}) d\sigma} \quad (9)$$

With: $$\boxed{B_{ij} = \int -2\phi(\vec{\sigma})/c^2 \cdot r_i(\vec{\sigma}) r_j(\vec{\sigma}) d\sigma} \quad (10)$$

We have: $g_{s,ij} = \delta_{ij} + \lambda B_{ij}$

In fact, for any 3x3 matricial function f such that $f(P^{-1}MP) = P^{-1} f(M) P$ and $f(M) = I + M$ if M is small, $g_s = f(\lambda B)$ would also be valid. For physical reasons, rather than summing the infinitely small perturbations, we should multiply the metrics induced by each infinitely small perturbations. That would yield:

$$\boxed{g_s = e^{\lambda B}} \tag{11}$$

Deriving λ is then straightforward. Since B is symmetric, it is diagonal in a certain basis, and $e^{\lambda B}$ would be a diagonal matrix in such a basis. Thus, the determinant of $e^{\lambda B}$ is the exponential of the sum of the eigenvalues of λB. The sum of the eigenvalues being the trace of λB, we have:

$$det(e^{\lambda B}) = e^{Tr(\lambda B)}$$

Applying the VEI principle we then have : $e^{\lambda Tr(B)} = (1 + \Phi/c^2)^{-2}$

Hence : $$\boxed{\lambda = -2 \cdot ln(1 + \Phi/c^2)/Tr(B)} \tag{12}$$

So in the weak-fields limit we have: $$\boxed{g_{s,ij} = \delta_{ij} - 2\Phi/c^2 \cdot B_{ij}/B_{kk}} \tag{13}$$

In the case of a punctual mass, space deformation is radial. Hence, in spherical coordinates we trivially obtain a Schwarzschild-like metric:

$$\boxed{ds^2 = (1 + \Phi/c^2)^2 c^2 dt^2 - (1 + \Phi/c^2)^{-2} dr^2 - r^2(d\theta^2 + sin^2\theta d\psi^2)} \tag{14}$$

So this predicts Mercury's Perihelion Precession and Light Deflection by the Sun since its mass is concentrated in its core. But in case of a homogenous spherical mass distribution like the Earth, the radial dilation would be smaller than the one predicted by the Schwarzschild metric because the deformation is fairly distributed according to the influence of every part of the mass distribution, inducing an azimuthal space dilation not predicted by General Relativity. This could be measured through interferometry and provides another test.

IX. Summary

Gravity as a spacetime bending force can be summarized by the following equations:

$$\Phi_0 = \Phi$$

$$L = -(1 + \Phi_0/c^2)^{\ 1} m_0 c \sqrt{g_{\mu\nu} \dot{x^\mu} \dot{x^\nu}} - \gamma^{-1}(1 + \Phi_0/c^2)^{-1} m_0 \dot{x^\mu} G_\mu$$

$$\gamma^{-1} = \sqrt{g_{\mu\nu} \frac{dx^\mu}{dx^0} \frac{dx^\nu}{dx^0}}$$

$$g = \begin{pmatrix} (1 + \Phi_0/c^2)^2 & 0 \\ 0 & -e^{\lambda B} \end{pmatrix}$$

$$B_{ij} = \int -2\phi_0(\vec{\sigma})/c^2 \cdot r_i(\vec{\sigma}) r_j(\vec{\sigma}) d\sigma$$

$$\lambda = -2 \cdot ln(1 + \Phi/c^2)/Tr(B)$$

This can be easily adapted to any violation of the Weak Equivalence principle by separating vacuum gravitational potential from the bodies' gravitational potential: $\Phi_0 \neq \Phi$

X. Universe Expansion

The Cosmological Redshift can as well be interpreted as due to an expanding universe if we postulate that the universe is homogeneous and isotropic and has a beginning. Indeed, if gravity is a force, gravitational potential propagates at the speed of light. The older the universe, the more propagated the gravitational potential, and the greater space dilation would be.

Let's see how the global vacuum gravitational potential evolves in a homogeneous and isotropic universe from its creation. The potential is induced by the mass in a cT radius sphere where T is the age of the universe. The gravitational potential is:

$$\Phi = \int_0^{cT} \phi(r)\rho \cdot 4\pi r^2 dr$$

Taking space dilation into account and conservation of matter, we have:

$$\rho = \rho_0 \cdot (1 + \Phi/c^2)^{-1}$$

And with the variable change $t = r/c$ we have:

$$\Phi = 4\pi\rho_0 c^3 \cdot \int_0^T \phi(ct)(1 + \Phi/c^2)^{-1} t^2 dt$$

Hence the following gravitational potential differential equation:

$$d\Phi/dT = 4\pi\rho_0 c^3 \cdot \phi(cT)(1 + \Phi/c^2)^{-1} T^2$$

Separating variables, we get:

$$\Phi + \Phi^2/2c^2 = 4\pi\rho_0 c^3 \cdot \int_0^T \phi(ct) t^2 dt$$

Hence the solution:

$$\boxed{1 + \Phi/c^2 = \sqrt{1 + 8c\pi\rho_0 \cdot \int_0^T \phi(ct) t^2 dt}} \tag{15}$$

The age T is the time elapsed from the point of view of an observer in a null gravitational potential, as if he was shielded from gravity.

Since the universe is homogeneous, VEI implies that the scale factor is $a = (1 + \Phi/c^2)^{-1/3}$ so recasting the solution yields:

$$\boxed{a(T) = (1 + 8c\pi\rho_0 \cdot \int_0^T \phi(ct) t^2 dt)^{-1/6}} \tag{16}$$

To be able to compare this model with Friedmann-Lemaitre-Robertson-Walker models, we need to express the dilation factor with a time equivalent to comoving observers. The time T_c of a comoving observer satisfies:

$$dT_c = \sqrt{g_{00}} dT = (1 + \Phi(T)/c^2) dT$$

It comes:

$$\boxed{T_c = \int_0^T (1 + 8c\pi\rho_0 \cdot \int_0^t \phi(c\tau)\tau^2 d\tau)^{1/2} dt} \tag{17}$$

Intuitively, the dilation factor has a positive acceleration because it is a division by a quantity that seems to near zero. The above equations show that the absolute time T can have a finite limit value when the comoving time T_c tends to infinity. That depends on the gravitational potential theory used. Let's do the calculation for a Newtonian potential $\phi(r) = -\mathcal{G}/r$. We have:

$$T_c = \int_0^T (1 - 4\pi\mathcal{G}\rho_0 t^2)^{1/2} dt$$

And: $a(T) = (1 - 4\pi\mathcal{G}\rho_0 T^2)^{-1/6}$

From this simple Newtonian model, we see the scalar factor has a positive acceleration. The potential is not necessarily Newtonian, but we see that an accelerating expanding universe would be more expected than a non-accelerating universe, especially for non-Newtonian potentials such that $\mathcal{G}/r \cdot \phi(r)^{-1} = o(1)$. This model doesn't require Dark Energy to explain such acceleration.

XI. Quantizing Gravity

Describing gravity as a force in curved spacetime, we now have a coherent way to blend gravity into the quantum realm. What follows is based on Fock's equation [9] as a curved spacetime version of Dirac equation:

$$[i\gamma^\mu(\partial_\mu - \Gamma_\mu - ieA_\mu) - m] \cdot \psi = 0$$

where γ_μ are the generalized gamma matrices defining the covariant Clifford algebra [10]: $\gamma_\mu\gamma_\nu + \gamma_\nu\gamma_\mu = 2g_{\mu\nu}$

where $g_{\mu\nu}$ is the spacetime metric, whose signature is $(+ - --)$, Γ_μ is the spinorial affine connection, and A_μ is the electromagnetic four-vector potential.

To take into account gravity, we just write $m = m_0(1+\Phi_0/c^2)^{-1}$ and we take into account the gravitational four-vector potential G_μ. We get:

$$\boxed{[i\gamma^\mu(\partial_\mu - \Gamma_\mu - ieA_\mu - im_0(1+\Phi_0/c^2)^{-1}G_\mu) - m_0(1+\Phi_0/c^2)^{-1}] \cdot \psi = 0} \quad (18)$$

XII. Conclusion

Gravity can be consistently described as a spacetime bending force based on an invariance principle inferred from the Schwarzschild metric. Analogous to the speed of light invariance which implies time dilation through speed, Vacuum Energy Invariance implies space dilation through gravitational potential. Writing the Lagrangian of a force in curved spacetime, we get equivalent equations of motion as General Relativity if the inertial mass is relative depending on the gravitational potential. This is a physically acceptable hypothesis since the relativistic mass of a body is already relative, depending on its speed.

This theory not only yields the same classical predictions as General Relativity such as Mercury's Perihelion Precession, Time Dilation or Light Bending but is also testable through many predicted deviations such as an anomalous thrust, a time dilation second-order correction and a non-radial space dilation described in Section II, V, and VIII, respectively.

This approach of gravitation is compatible with non-Newtonian gravitational potentials and violations of the weak equivalence principle. From there, one can develop many models to fit the available cosmological data. The reader can then

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complete this theory with a suitable description of the gravitational four-vector potential.

More than that, gravity as a force in curved spacetime analogous to electromagnetism is renormalizable. Therefore, it is compatible with the Standard Model of particle physics. The reader could adapt the Standard Model's Lagrangian to this theory to achieve Quantum Gravity.

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16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- o You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- o Give details of all of your remarks as much as possible, focusing on mechanisms.
- o Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- o One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- o Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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