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Harmonic Oscillator Study of Pure Gauge Theory with SU (2) Group and Glonon Semi-Particle

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Abstract: **In this paper, the harmonic part of the effective Hamiltonian operator $\hat{H}^{0}_{eff}$ of the sixth degree, is taken with the group SU(2),and numerically studied. Two operators of creation and annihilation are used, and the energy levels from E_0 to E_{11} are calculated and demonstrated, .Furthermore, the degree of decomposition is properly derived and, the semi-particle glonon is believed.**

Keywords: **Harmonic oscillator, Quarks and gluons plasma.**

1. INTRODUCTION

-Quantum- chrome- dynamic (QCD) is the theory of the strong interaction which represents the confinement of quarks and gluons at a low temperature and the system turns to the phase of quarks and gluons plasma at an enough high temperature [1-10].

-The real time evolution of quarks and gluons plasma is studied using the pure gauge theory and gauge theory with the two groups SU(2) and SU(3), respectively in[4] and [7-10]. The method of semi-classical expansion which depends on Wigner representation was used. The effective Hamiltonian operator expansion was taken until the fourth degree in [4],[7-8].The evolution of average value is calculated by adding the evolution of classical average value to the first quantum correction.

In [9-10] the effective Hamiltonian operator expansion was taken until the sixth degree and all quantum corrections were calculated. This simply means that the complete quantum solution was reached by the semi-classical expansion.

_The real time evolution of quarks and gluons plasma was studied for the pure gauge theory with the two groups SU(2) and SU(3) in [5-6]. In these studies, the perturbation theory which depends on the creation operator $\hat{D}^{+}$ and annihilation operator $\hat{D}$, was used .The effective Hamiltonian operator expansion was taken into consideration until the fourth degree.

_In this work the harmonic oscillator of pure gauge theory with group SU(2) is studied numerically using creation operator $\hat{D}^{+}$ and annihilation operator $\hat{D}$. A semi-particle, called glonon which is a boson similar to a phonon but differs in the color charge; is believed,

2. RESEARCH METHODOLOGY

“ Introduction to our research in words ”

According to [3], the Hamilton operator of pure gauge theory with group SU(2) can be described in loop (L^3)

$$L\hat{H}_{eff}=\frac{1}{2}\left(\frac{1}{g^2(L)}+\alpha_0\right)^{-1}\hat{\Pi}^a_i\hat{\Pi}^a_i+\alpha_1\hat{B}^a_i\hat{B}^a_i+\frac{1}{4}\left(\frac{1}{g^2(L)}+\alpha_2\right)\hat{F}^a_{ij}(B)\hat{F}^a_{ij}(B)$$

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$+\alpha_3\left(\hat{B}_i^a\hat{B}_i^a\hat{B}_j^b\hat{B}_j^b + 2\hat{B}_i^a\hat{B}_j^a\hat{B}_i^b\hat{B}_j^b\right) + \alpha_4\hat{B}_i^a\hat{B}_i^a\hat{B}_i^b\hat{B}_i^b + \alpha_5\sum_i\left(\hat{B}_i^a\hat{B}_i^a\right)^3$

$+\alpha_6\sum_{i\neq j}\hat{B}_i^a\hat{B}_i^a\left(\hat{B}_j^b\hat{B}_j^b\right)^2 + \alpha_7\hat{B}_1^a\hat{B}_1^a\hat{B}_2^a\hat{B}_2^a\hat{B}_3^a\hat{B}_3^a + \alpha_8\hat{F}_{ij}^a(B)\hat{F}_{ij}^a(B)\hat{B}_k^b\hat{B}_k^b$

$+\alpha_9\sum_{i\neq j}\hat{F}_{ij}^a(B)\hat{F}_{ij}^a(B)\hat{B}_j^b\hat{B}_j^b + \alpha_{10}\left(\hat{B}_1^a\hat{B}_2^a\hat{B}_3^a\right)^2 + 0\left(\hat{B}^8\right) \qquad (1)$

where i,j=1,2,3 the guide of local coordinates,.

-a,b=1,2,3 are the evidences of group SU(2) generators,.

$\alpha_1, \dots, \alpha_{10}$ are constants resulted from quantization of inhomogeneous modes of gauge field by the method of paths integration.

α_0 is a constant resulted from quantization of inhomogeneous time derivative modes of gauge field by the method of paths integration and it has the following values [3]:

$$\alpha_0 = 0.021810429, \alpha_1 = -0.30104661, \alpha_2 = 0.024624$$

$$\alpha_3 = 0.0021317, \alpha_4 = -0.0078439, \alpha_5 = 4.9676959\text{x}10^{-5}$$

$$\alpha_6 = -5.5172502\text{x}10^{-5}, \alpha_7 = -1.2423581\text{x}10^{-3}, \alpha_8 = -1.1130266\text{x}10^{-4}$$

$$\alpha_9 = -2.1475176\text{x}10^{-4}, \alpha_{10} = -1.2775652\text{x}10^{-3} \qquad (2)$$

F_{ij}^a are tensors of the magnetic field intensity represented as [3]:

$$F_{ij}^a = \varepsilon^{abc}B_i^bB_j^c \qquad (3)$$

$\hat{B}_i^a$ is the operator of homogeneous magnetic field, and $\hat{\Pi}_i^a$ is the operator of momentum.

$$\varepsilon^{abc} = \begin{cases} 1 \text{ At direct replacement} \\ 0 \;\; \textit{When two evidences are equal} \\ -1 \text{ At indirect replacement} \end{cases}$$

$0\left(\hat{B}^8\right)$ indicates that the limits of degree greater than B^6 are neglected.

$g^2(L)$ is a coupling constant represented in the following relation [3]:

$$g^2(L) = -\frac{1}{2b_0\log(\Lambda_{ms}L)} - \frac{b_1\log[-2\log(\Lambda_{ms}L)]}{4b_0^3[\log(\Lambda_{ms}L)]^2} + \cdots \qquad (4)$$

where:

$$b_0 = \frac{22}{3}(4\pi)^2, b_1 = \frac{136}{3}(4\pi)^4, \Lambda_{ms} = 74.1705\text{MeV}$$

$\Lambda_{ms} = 74.1705\text{MeV}$ represents an identified constant by minimum subtraction of dimension organization.

L is the loop length in all spatial directions.

According to this method of Hamilton operator $\hat{H}_{eff}$, the study of pure gauge theory with group SU(2) becomes a form of quantum mechanics with group SU(2), This mean that the study of infinite number of particles and freedom degrees (quarks and gluons plasma), has been physically transformed to a study of three global particles .naemly, to confine the study to nine harmonic oscillators. nine freedom degrees and particularly nine anhamonic oscillators.

$\hat{H}_{eff}^0$ is the harmonic part of the operator $\hat{H}_{eff}$:

$$L\hat{H}_{eff}^0 = \sum_{a=1}^3\sum_{i=1}^3\left[\frac{1}{2}\left(\frac{1}{g^2(L)} + \alpha_0\right)^{-1}\hat{\Pi}_i^a\hat{\Pi}_i^a + \alpha_1\hat{B}_i^a\hat{B}_i^a\right]$$

$$L\hat{H}_{eff}^0 = \sum_{a=1}^3\sum_{i=1}^3\left[\frac{1}{2}\tilde{\alpha}_0\hat{\Pi}_i^a\hat{\Pi}_i^a + \frac{1}{2}\tilde{\alpha}_1\hat{B}_i^a\hat{B}_i^a\right] \qquad (5)$$

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Where:

$\tilde{\alpha}_0 = \left(\frac{1}{g^2(L)} + \alpha_0\right)^{-1}$, $\tilde{\alpha}_1 = 2\alpha_1$

, the creation operator can be identified as the following [5,6]:

$$\hat{D}^{+a}_{i} = \sqrt{\frac{\sqrt{\frac{\tilde{\alpha}_1}{\tilde{\alpha}_0}}}{2\hbar}}\hat{B}_i^a - \frac{i}{\sqrt{2\hbar\sqrt{\frac{\tilde{\alpha}_1}{\tilde{\alpha}_0}}}}\hat{\Pi}_i^a \tag{6}$$

and annihilation operator is defined as:

$$\hat{D}_i^a = \sqrt{\frac{\sqrt{\frac{\tilde{\alpha}_1}{\tilde{\alpha}_0}}}{2\hbar}}\hat{B}_i^a + \frac{i}{\sqrt{2\hbar\sqrt{\frac{\tilde{\alpha}_1}{\tilde{\alpha}_0}}}}\hat{\Pi}_i^a \tag{7}$$

$\hbar = 1$ (Plank constant) in a system of natural units .

In this case, we find that:

$$\left[\hat{D}_i^a, \hat{D}^{+b}_{j}\right]_- = \delta_{ij}\delta^{ab} \tag{8}$$

$$\left[\hat{D}_i^a, \hat{D}_j^b\right]_- = \left[\hat{D}^{+a}_{i}, \hat{D}^{+b}_{j}\right]_- = 0 \tag{9}$$

δ_{ij}, δ^{ab} are Kroanker symbols of spatial coordinates and evidences of generating group SU(2). These Kroanker constants are respectively, defined as:

$$\delta_{ij} = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases} \tag{10.a}$$

$$\delta^{ab} = \begin{cases} 1 & a = b \\ 0 & a \neq b \end{cases} \tag{10.b}$$

The result of adding the equation (6) to (7) is the operator of homogeneous magnetic field:

$$\hat{B}_i^a = \sqrt{\frac{\hbar}{2\sqrt{\frac{\tilde{\alpha}_1}{\tilde{\alpha}_0}}}}\left(\hat{D}^{+a}_{i} + \hat{D}_i^a\right) \tag{11}$$

The result of subtracting the equation (6) out of (7) is the operator of momentum given as:

$$\hat{\Pi}_i^a = i\sqrt{\frac{\hbar\sqrt{\frac{\tilde{\alpha}_1}{\tilde{\alpha}_0}}}{2}}\left(\hat{D}^{+a}_{i} - \hat{D}_i^a\right) \tag{12}$$

After calculating $\frac{1}{2}\tilde{\alpha}_0\,\hat{\Pi}_i^a\hat{\Pi}_i^a, \frac{1}{2}\tilde{\alpha}_1\hat{B}_i^a\hat{B}_i^a$:

$$\frac{1}{2}\tilde{\alpha}_0\,\hat{\Pi}_i^a\hat{\Pi}_i^a = \frac{\hbar}{4}\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\left[\hat{D}^{+a}_{i}\hat{D}_i^a - \hat{D}^{+a}_{i}\hat{D}^{+a}_{i} + \hat{D}_i^a\hat{D}^{+a}_{i} - \hat{D}_i^a\hat{D}_i^a\right] \tag{13.a}$$

$$\frac{1}{2}\tilde{\alpha}_1\hat{B}_i^a\hat{B}_i^a = \frac{\hbar}{4}\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\left[\hat{D}^{+a}_{i}\hat{D}^{+a}_{i} + \hat{D}^{+a}_{i}\hat{D}_i^a + \hat{D}_i^a\hat{D}^{+a}_{i} + \hat{D}_i^a\hat{D}_i^a\right] \tag{13.b}$$

and after compensating (13.a) and (13.b) by (5) we find:

$$L\hat{H}^0_{eff} = \sum_{a=1}^{3}\sum_{i=1}^{3}\frac{\hbar}{4}\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\left[2\hat{D}^{+a}_{i}\hat{D}_i^a + 2\hat{D}_i^a\hat{D}^{+a}_{i}\right] \tag{14}$$

Depending on the two equations (10.a) and (10.b), the equation will become (8):

$$\left[\hat{D}_i^a, \hat{D}^{+a}_{i}\right]_- = 1 \Rightarrow \hat{D}_i^a\hat{D}^{+a}_{i} - \hat{D}^{+a}_{i}\hat{D}_i^a = 1 \Rightarrow \hat{D}_i^a\hat{D}^{+a}_{i} = 1 + \hat{D}^{+a}_{i}\hat{D}_i^a$$

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Depending on this relation, the equation (14) becomes:

$$L\widehat{H}^0_{eff} = \sum_{a=1}^{3}\sum_{i=1}^{3} \frac{\hbar}{4}\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\ \left[2\widehat{D}^{+a}_{\ i}\widehat{D}^a_i + 2\widehat{D}^{+a}_{\ i}\widehat{D}^a_i + 2\ \right]$$

$$L\widehat{H}^0_{eff} = \sum_{a=1}^{3}\sum_{i=1}^{3}\ \hbar\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\ \left[\widehat{D}^{+a}_{\ i}\widehat{D}^a_i + \frac{1}{2}\ \right] \qquad (15)$$

We make $\widehat{N}^a_i = \widehat{D}^{+a}_{\ i}\widehat{D}^a_i, \widehat{N} = \sum_{a=1}^{3}\sum_{i=1}^{3}\widehat{N}^a_i$

After the substitution into Eq. (15), we have

$$L\widehat{H}^0_{eff} = \hbar\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\left(\widehat{N} + \frac{9}{2}\right) \qquad (16)$$

Following [5,6], using the equations

$$\widehat{D}^a_i|\dots n^a_i \dots\rangle = \sqrt{n^a_i}|\dots n^a_i - 1 \dots\rangle \qquad (17)$$

$$\widehat{D}^{+a}_{\ i}|\dots n^a_i \dots\rangle = \sqrt{n^a_i + 1}|\dots n^a_i + 1 \dots\rangle \qquad (18)$$

$$\widehat{N}^a_i|\dots n^a_i \dots\rangle = n^a_i|\dots n^a_i \dots\rangle \qquad (19)$$

$$\widehat{D}^a_i|\dots 0 \dots\rangle = 0\ \ , \widehat{N}^a_i|\dots 0 \dots\rangle = 0 \qquad (20)$$

The Hamiltonian matrix of harmonic oscillator can be calculated as:

$$LH_{n^a_i,m^a_i} = \langle n^a_i|L\widehat{H}|m^a_i\rangle = \hbar\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\left(\sum_{a=1}^{3}\sum_{i=1}^{3} m^a_i\ \delta_{n^a_i,m^a_i} + \frac{9}{2}\right) \qquad (21)$$

$$LH_N = \hbar\sqrt{\tilde{\alpha}_0\tilde{\alpha}_1}\left(N + \frac{9}{2}\right) \qquad (21.a)$$

The relations from (6) to (21.a) are generalization to the same relations in simple harmonic oscillator with one degree of freedom in quantum mechanics.

3. RESULTS AND DISCUSSION

In [11], Landau and Lifshitz use the complex energy to describe the particles which can be decayed or decomposed by this relation:

$$E = E_0 - \frac{1}{2}i\Gamma \qquad (22)$$

i.e. the Hamiltonian operator becomes non-hermetical.

Since the operator $\widehat{H}$ is complex, the energy can be written as E_i:

$$E_i = |H_i| = \sqrt{H_i H_i^*} \qquad : i = 0,\dots,11 \qquad (23)$$

That: $1fm = \frac{1}{197}(MeV^{-1}) = \frac{1000}{197}(GeV^{-1}) = 5.076142131(GeV^{-1})$

The coupling constant is calculated from equation (4), the energy levels from E_0 until E_{11} are calculated, then multiplied by $\frac{1}{L\ (GeV^{-1})}$ in order to evaluate the energy level by GeV.

The numeral results of harmonic energy level values are shown in table (1):

Table (1): shows the values of harmonic energy levels and according to coupling constant g(L).

g
0.549915534
0.599009088
0.649775708
0.698013648
0.799669744
0.893003919
0.996810855
1.097106472
1.198054106
1.298620381
1.398613975
1.499088396
1.599938721
1.699870674
1.799998265
1.899885714
1.998481321
2.098360361
2.199974688

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$E_0(GeV)$	$E_1(GeV)$	$E_2(GeV)$	$E_3(GeV)$	$E_4(GeV)$	$E_5(GeV)$	$E_6(GeV)$	$E_7(GeV)$	$E_8(GeV)$	$E_9(GeV)$
0.151461368	0.185119458	0.218777549	0.25243556	0.286093651	0.319751742	0.353409832	0.387067923	0.420726014	0.454384104
0.164110924	0.200580106	0.237049131	0.273518313	0.309987337	0.346456519	0.382925543	0.419394725	0.45586375	0.492332932
0.177160843	0.216529937	0.25589903	0.295268046	0.334637139	0.374006233	0.413375327	0.452744421	0.492113436	0.53148253
0.18953026	0.231648156	0.273765975	0.315883871	0.358001689	0.400119508	0.442237326	0.484355222	0.52647304	0.568590859
0.21549422	0.26338185	0.31126948	0.359157033	0.407044664	0.454932216	0.502819847	0.550707477	0.598295107	0.646482738
0.239200015	0.292355582	0.34551115	0.398666717	0.451822285	0.504977853	0.55813342	0.611288988	0.664444555	0.717600045
0.265403625	0.324382234	0.383360766	0.442339375	0.501317985	0.560296594	0.619275203	0.678253735	0.737232344	0.796210645
0.290545649	0.355111324	0.419677075	0.484242749	0.5488085	0.613374174	0.677939849	0.742505523	0.807071505	0.871636641
0.31566407	0.385811641	0.455959212	0.526106783	0.596254355	0.666401926	0.736549497	0.806696915	0.876844639	0.946992364
0.340488267	0.416152369	0.491816394	0.567480496	0.643144598	0.718808624	0.794472878	0.870136598	0.945801082	1.021464802
0.364961729	0.446064361	0.527166994	0.608269549	0.689372181	0.770474813	0.851577064	0.932680078	1.013782328	1.094885342
0.389330734	0.4758487	0.562366667	0.648884557	0.735402599	0.821920413	0.908438151	0.994956651	1.081474389	1.167992127
0.413555629	0.505456787	0.597358097	0.689259255	0.78116026	0.873061647	0.964963033	1.056864419	1.148765805	1.240666431
0.437316466	0.534497886	0.631679306	0.728860726	0.826041918	0.923223946	1.020405214	1.117586482	1.21476775	1.311949019
0.460870726	0.563286477	0.665702152	0.7681239	0.870533578	0.972949025	1.075365231	1.177780679	1.280196885	1.382612332
0.484106689	0.591685995	0.699265226	0.806844229	0.914423763	1.022003297	1.129582073	1.237161606	1.34474114	1.452319916
0.506777029	0.619394062	0.732011172	0.844628508	0.957245693	1.069862121	1.182479306	1.295096491	1.407713676	1.520330861
0.529465567	0.647124573	0.764783656	0.882442738	1.00010182	1.117760902	1.235419984	1.35307831	1.470737392	1.588396474
0.552254615	0.674977888	0.797701312	0.920424359	1.043147405	1.165871207	1.288594253	1.4113173	1.534040346	1.656764148

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$E_{10}(GeV)$	$E_{11}(GeV)$
0.488042195	0.521700285
0.528801956	0.565271138
0.570851623	0.610220717
0.610708755	0.652826573
0.69437029	0.742257921
0.77075569	0.823911103
0.85518964	0.914167863
0.936202546	1.000768451
1.017140088	1.087287047
1.097129286	1.172793000
1.175987592	1.257090606
1.254509864	1.341028364
1.332567817	1.424469203
1.409131046	1.506312314
1.485027779	1.587443986
1.55989945	1.667478984
1.632948046	1.745565231
1.706055557	1.823714639
1.779487195	1.902210241

g	$E_0(GeV)$	$E_1(GeV)$	$E_2(GeV)$	$E_3(GeV)$	$E_4(GeV)$	$E_5(GeV)$	$E_6(GeV)$
2.399626926	0.596140787	0.72861656	0.861091955	0.993568105	1.1260435	1.25851965	1.390995046
2.598905472	0.638729802	0.780669665	0.922609605	1.064549544	1.206489483	1.348429423	1.490369362
2.792966579	0.679001048	0.829890212	0.980779	1.13166854	1.282557327	1.433446868	1.584335655
2.999278861	0.72048424	0.880591557	1.04069925	1.200806942	1.360914635	1.521022328	1.68113002
3.199628273	0.759436984	0.928200258	1.096964283	1.265728308	1.434491581	1.603255606	1.772019631
3.398312073	0.796759448	0.973816853	1.15087501	1.327932414	1.504989819	1.682047224	1.85910538

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$E_7(GeV)$	$E_8(GeV)$	$E_9(GeV)$	$E_{10}(GeV)$	$E_{11}(GeV)$
1.523471196	1.655946591	1.788422741	1.920898136	2.053374286
1.632309301	1.77424924	1.91618918	2.058129119	2.200069058
1.735225195	1.886113983	2.03700277	2.18789231	2.338781098
1.841237713	2.001345406	2.161453099	2.321560039	2.481667732
1.940782904	2.109546929	2.278310202	2.447074227	2.615838252
2.036162785	2.21322019	2.390278346	2.567335751	2.744393156

It is noticeable that:$E_0(\text{GeV}) < E_1(\text{GeV}) < E_2(\text{GeV}) \ldots < E_{11}(\text{GeV})$ for all g values.

_The graphic curve of harmonic classical potential is represented by:

$$V(GeV) = \frac{1}{L}\sum_{i=1}^{3}\sum_{a=1}^{3}\tilde{\alpha}_1\, B_i^a B_i^a$$

The harmonic classical potential is related to the homogenous gauge fields through the compound $B_i^a = B_i n^a$ .In this case, $n^a n^a = 1$, and the result are shown in figures (1,2,3,4,5,6,7,8) which represents the classical potential and energy levels according g(L).

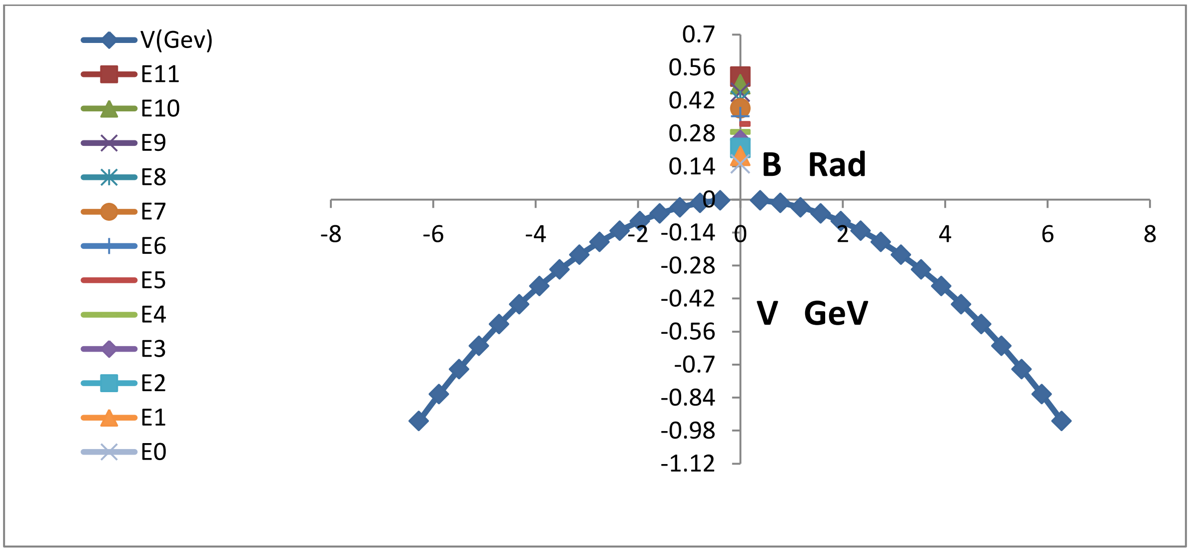

Figure (1): shows the harmonic classical potential and illustrates the energy levels for the values of g=0.549915534 .

From Figure (1) it is clear that:$0.151461368 \leq E_i(GeV) \leq 0.521700285$.

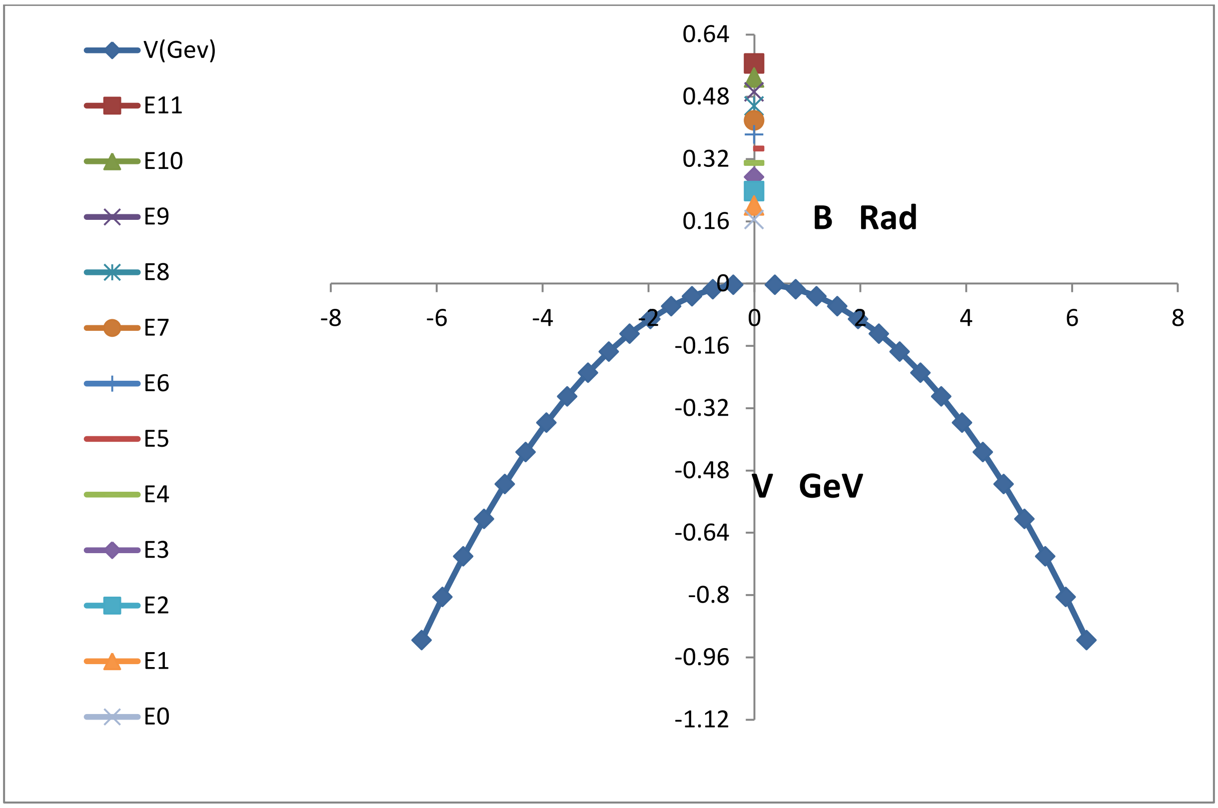

Figure (2): shows the harmonic classical potential and illustrates the energy levels for the values of *g*=0.599009088 .

From Figure (2) it is clear that: $0.164110924 \leq E_i(GeV) \leq 0.565271138$.

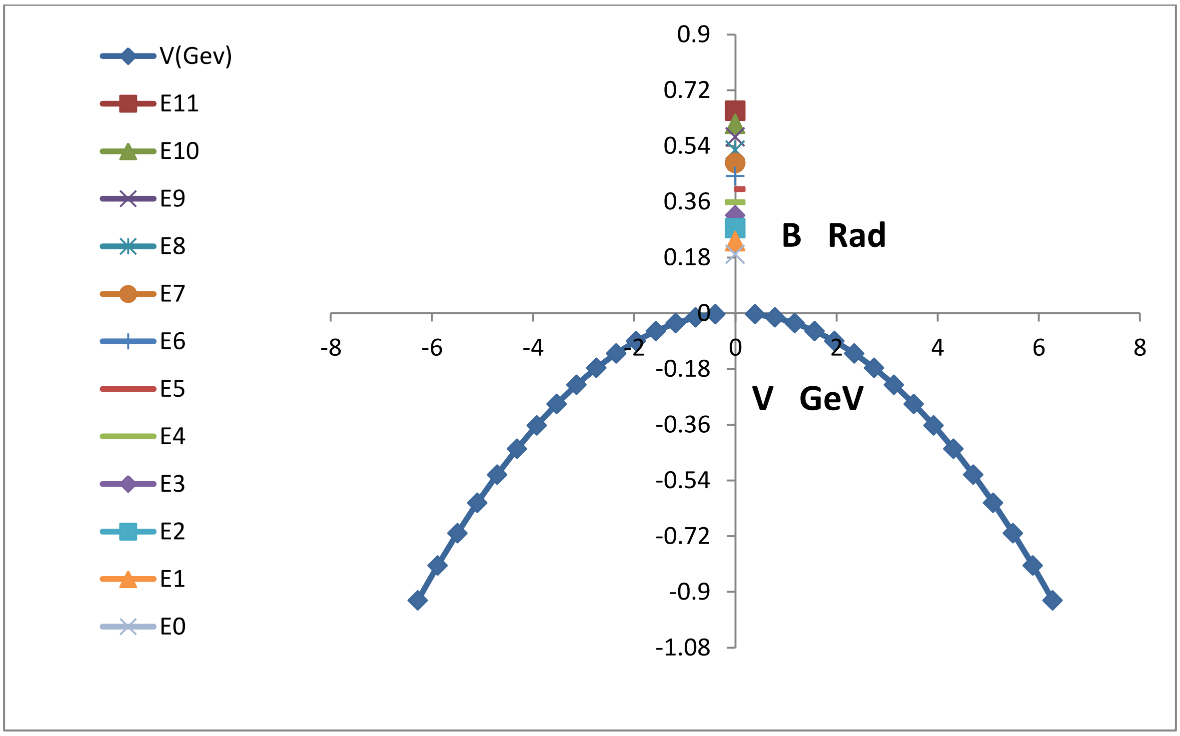

Figure (3): shows the harmonic classical potential and illustrates the energy levels for the values of *g*=0.698013648 .

From Figure(3) it is clear that: $0.18953026 \leq E_i(GeV) \leq 0.652826573$.

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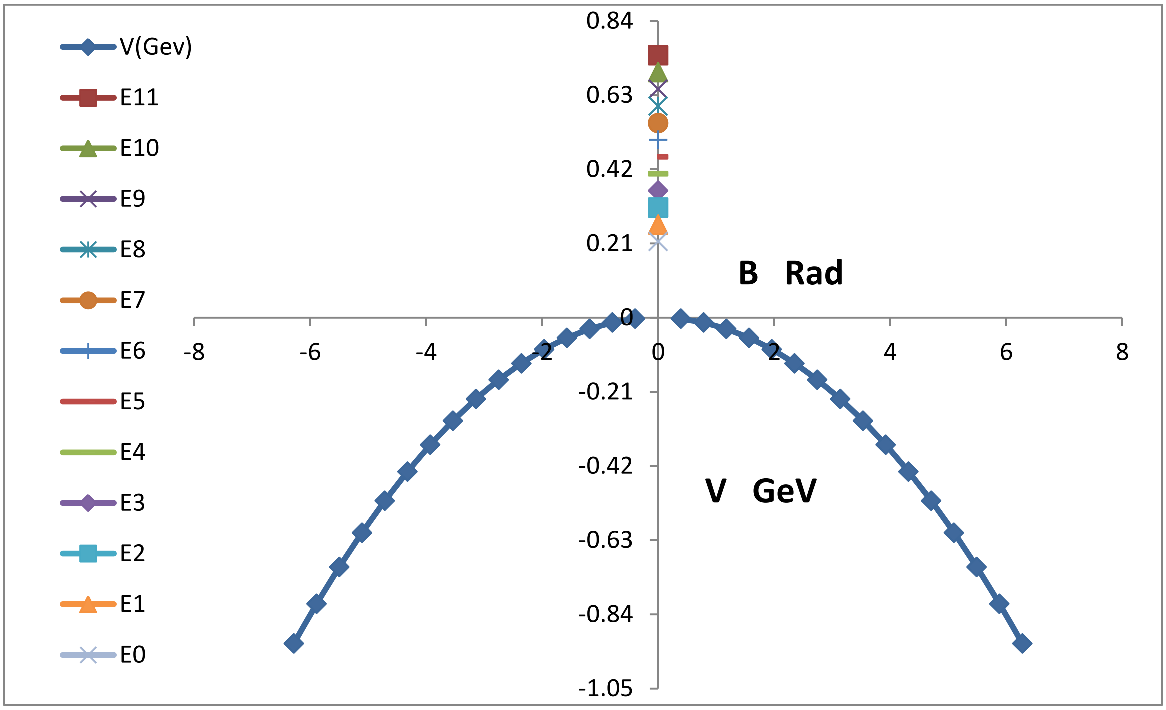

Figure (4): shows the harmonic classical potential and illustrates the energy levels for the values of *g=0.799669744* .

From Figure (4) it is clear that:$0.21549422 \leq E_i(GeV) \leq 0.742257921$.

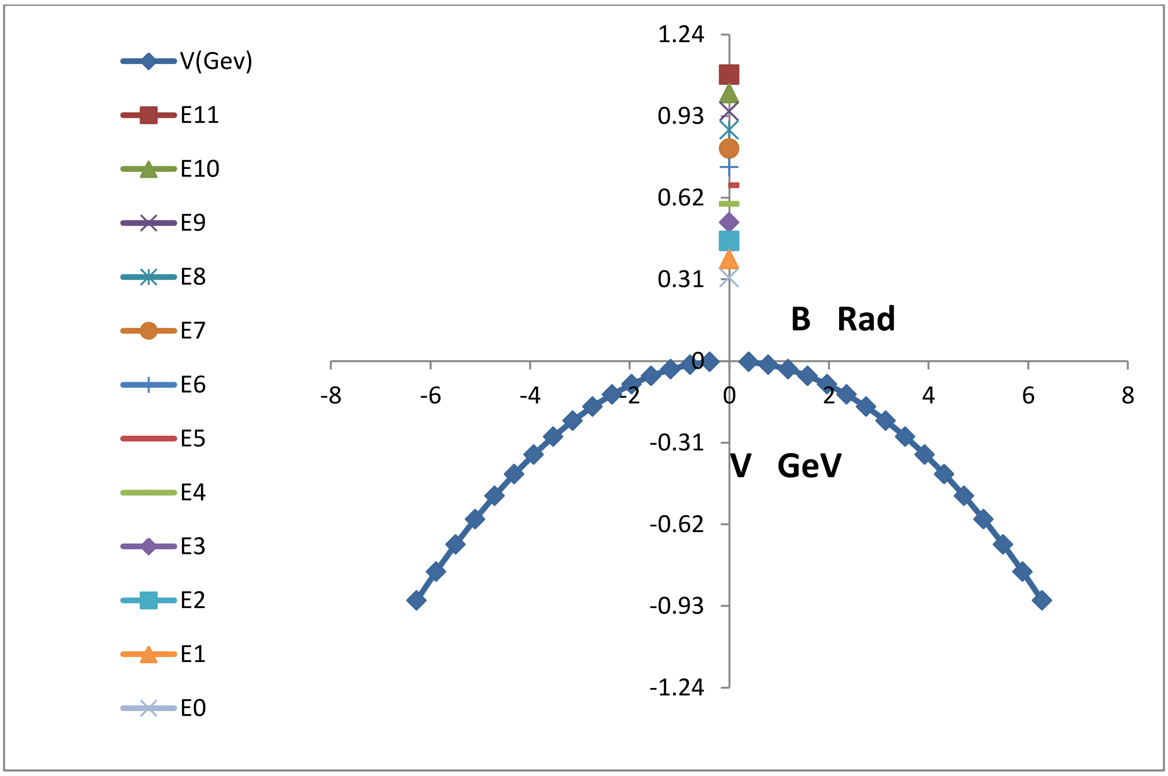

Figure (5): shows the harmonic classical potential and illustrates the energy levels for the values of *g=1.198054106* .

From Figure (5) it is clear that:$0.31566407 \leq E_i(GeV) \leq 1.087287047$.

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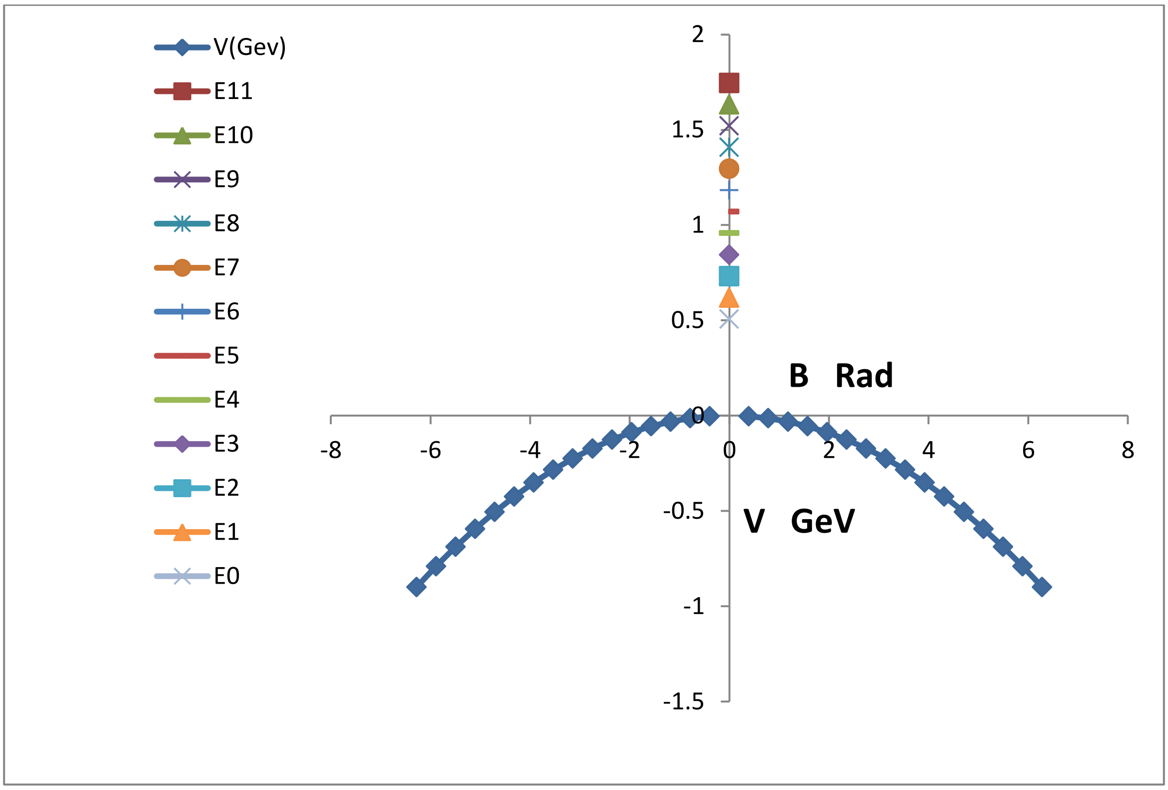

Figure (6): shows the harmonic classical potential and illustrates the energy levels for the values of *g=1.998481321* .

From Figure (6) it is clear that:$0.506777029 \leq E_i(GeV) \leq 1.745565231$.

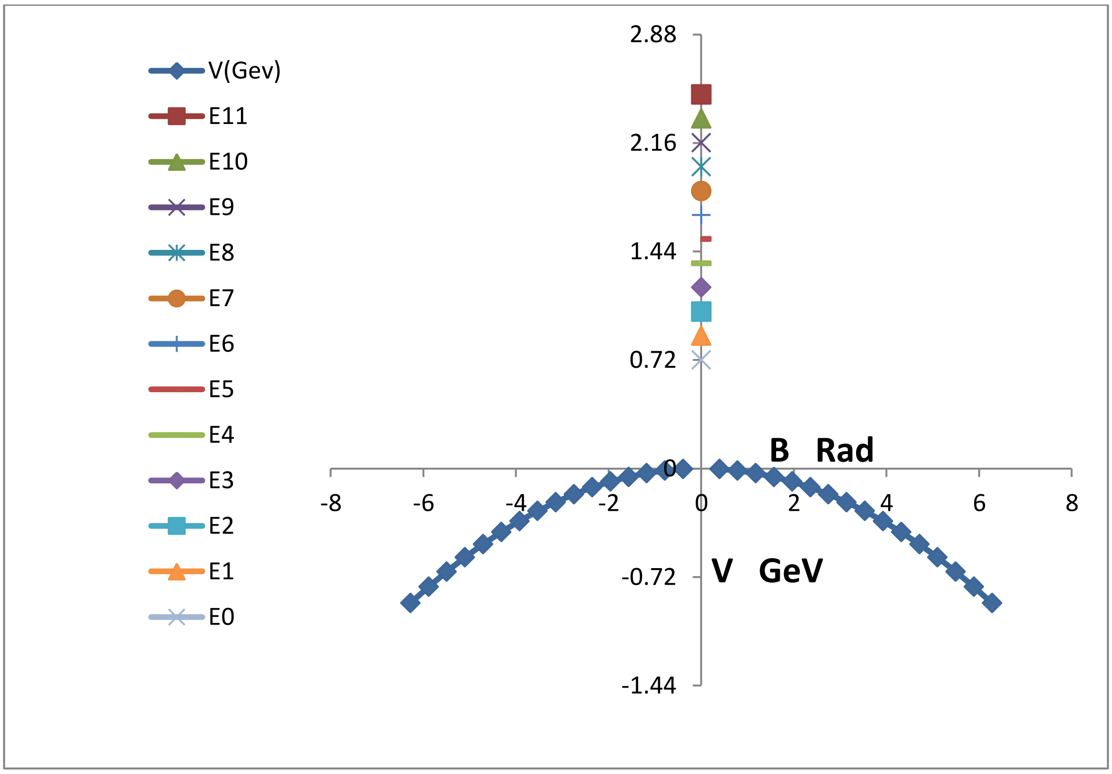

Figure (7): shows the harmonic classical potential and illustrates the energy levels for the values of *g=2.999278861* .

From Figure (7) it is clear that:$0.72048424 \leq E_i(GeV) \leq 2.481667732$.

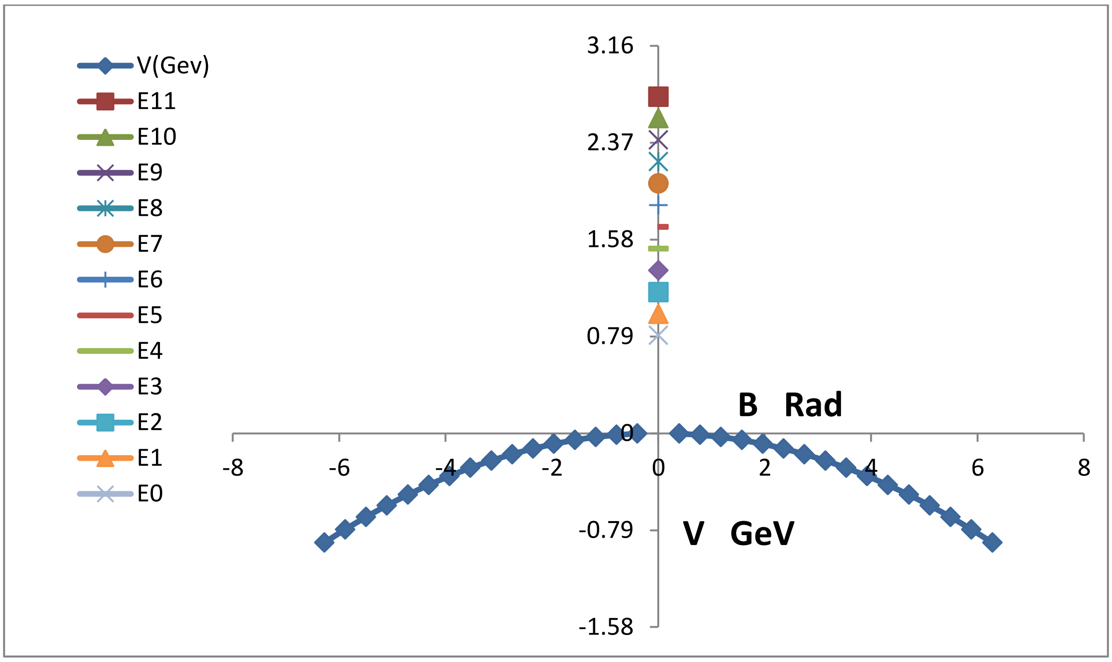

Figure (8): shows the harmonic classical potential and illustrates the energy levels for the values of *g=3.398312073* .

From Figure (8) it is clear that:$0.796759448 \leq E_i(GeV) \leq 2.744393156$.

It also shows the differences of energy levels according g(L).

The harmonic classical potential according for g(L) in figures (1-8) have opposite directions to the harmonic classical potential for the simple harmonic oscillator with one degree of freedom.

The energy levels according g(L) are similar to the energy levels for the simple harmonic oscillator with one degree of freedom in quantum mechanics.

_The degree of decomposition is given in this relation:

$d = \frac{(N+8)!}{N!\ \ 8!}$

The difference among energy levels believe in its existence a semi-particle called glonon, it is a boson similar to a phonon in a solid particle. But at the same time, a glonon has a color charge, thus the glonons interact the effect among each other's. in this case, we can understand the difference between a phonon and a glonon which is the same difference between photon and a gluon.

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, the use of a harmonic oscillator with nine degrees of freedom is proposed and for the first time in quantum mechanics. In addition, a believe semi-particle called Glonon. In this paper , it is recommend that studying the harmonic oscillator should be done with twenty four freedom degrees, i.e. the gauge theory with group SU(3).

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