On Gravity and Electricity's Indelible Scientific Link

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Abstract

This paper describes a new scientific link between gravity and electromagnetic forces (GE-Link) in the hope of finding the origin and secret of gravity. Despite having equal amount of positive and negative charge, neutral atoms and molecules do not interact by symmetrically identical attractive and repulsive electric forces. This is because the experimentally-verified intermolecular van der Waals interactions exhibit a well known asymmetrical characteristic property that tends to enhance attractive over repulsive energies on a microscopic level. When applied to large objects, this breakdown of symmetry provides the basis for the GE-Link as it leaves a clear non-zero net force synonymous with and indistinguishable from the force of gravity. This paper proposes a new general purpose electric model, the Tripole Atomic Model (TAM), capable of reproducing the forces between atoms and molecules in agreement with experiments. The TAM is then extended and applied to larger distances in order to probe the force of gravity between objects and establishes the GE-Link. Remarkably this produced an inverse square law force that is substantially in line with Newton's Law of Gravitation. It is hoped that the GE-Link may ultimately lead to a theory of gravity based entirely on electromagnetic principles. As an upshot, the GE-Link enables one to theoretically derive the complete underlying formula for the Newtonian gravitational "constant" *G*.

Keywords: gravity and electricity link, GE-Link, electric gravity, gravity, gravitation, quantum electrodynamics, van der Waals, corrections to gravitational constant, cosmology

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1. Introduction

This paper establishes a new scientific link between gravity and electromagnetic forces (GE-Link) and eventually between gravity and the quantum world via quantum electrodynamics (QED). Newton's Law of Gravitation (NLG) explains how the universe works, predicts the force of gravity and enables the successful landing on far away planets and moons. Apart from that, it provides no explanations as to the real cause of gravity and suffers from a number of anomalies. General Relativity (GR) upholds NLG and introduces improvements particularly at high field intensities, resolves the anomaly of the perihelion advance of Mercury and predicts a range of other phenomena confirmed by experiments. GR proposes the warping of space-time as the cause of gravity between objects. GR too has its own shortcomings like the problem with infinities and, when dealing with atoms and the realm of the highly successful fundamental theory of Quantum Mechanics (QM), it just completely breaks down [1]. What makes matter even worse is the fact that, hitherto, the nature and origin of gravity continue to be highly illusive and stubbornly incompatible with the other fundamental forces of nature like electromagnetic (EM) and atomic forces. The contemporary crises in physics and cosmology mainly arise from GR's incompatibility with quantum mechanics and the failure of any efforts to unite them [1,2]. Finding the secrets of gravity and making it compatible with the other fundamental forces of nature is considered as the Holy Grail in physics today.

As it turned out, the opposing attractive and repulsive forces between neutral atoms and molecules are not symmetrically identical due to the well known asymmetrical characteristic exhibited by the van der Waals interactions, which tend to enhance attractive over repulsive energies and forces on a microscopic scale. This leads the symmetry between the forces to breakdown and leaves a clear non-zero net force between objects synonymous with and indistinguishable from the force of gravity in line with Newton's. The GE-Link enables one to derive the underlying formula for the Newtonian gravitational "constant" *G*. As described below in more details, the following equations are derived from basic EM:

$$\mathbf{F}_{\mathrm{QEG}} = -G_{\mathrm{QE}} \frac{m_1 m_2}{r^2}\, \hat{\mathbf{r}} \qquad\qquad G_{\mathrm{QE}} = \frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0} T_{\mathrm{D}} \left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right) \to \left(\equiv G\right) \tag{1}$$

In this paper we shall proceed by highlighting the similarities between gravity and EM forces. We use QED to explain the modern views on the concept of action-at-a-distance and electric force mediation via virtual particles. We then analyse intermolecular van der Waals bonding forces using the Lennard-Jones potential, which exhibit a fundamental asymmetric energy and force behaviour. We then use this fundamental asymmetry to establish a link between gravity and electromagnetic forces. We develop a new general purpose electric model, the Tripole Atomic Model (TAM), to determine electromagnetic forces between atoms and molecules first at small distances, and then extend that to larger distances at which gravity operates. Using charge-mass relations we can then show how to determine object charge from its mass and eventually arrive at Newton's (NLG) and beyond. We shed some light on the gravitational parameter *G* and derive its equivalent quantum electric formula (G_{QE}). Finally we discuss some of the implications of the GE-Link.

2. Gravity and Electromagnetism

The similarities between gravitational and electromagnetic forces make one wonders whether the two can be linked together (GE-Link). Many scientists, including James Clerk Maxwell, pondered about a possible link between the two. In fact Albert Einstein dedicated the second half of his life to a unified field theory in attempt to combine gravity with electromagnetism. Both phenomena share some common attributes such as long-range, their force formulae have similar general form and both follow inverse square law. However, before combining the two forces one must first overcome some major issues, among them:

a) Magnitude – there is an enormous magnitude difference with EM/gravity force ratio ~1x10^{40}!
b) Polarity – gravity is attractive while EM forces can be both attractive and repulsive
c) Mass and charge – gravity interacts with mass while electromagnetism interacts with charge.

As we will see in more details below, one can resolve these issues and successfully combine gravity with electromagnetism via the GE-Link. As charge-neutral entities, atoms interact with other atoms via two types of EM forces of almost identical magnitudes; attractive and repulsive. Although these opposite direction forces largely cancel each other out, they leave a clear residue that resolves issues (a) and (b) above. The issue of mass and charge can be resolved because both are quite closely related in the standard model of particle physics. The long-range aspect of both gravity and EM forces is very fundamental and represents the crucial common attribute to the successful combination of the two forces, which would not otherwise be possible.

3. Electric and Magnetic Forces

3.1 Classical Electromagnetic Forces

Coulomb's Law defines the electric force between two charges q_1, q_2 distance r apart as [3]:

$$\mathbf{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\,\hat{\mathbf{r}} \tag{2}$$

The term $1/4\pi\varepsilon_0$ is also referred to as the proportionality constant, and $\hat{\mathbf{r}}$ is the unit vector. Coulomb's Law describes the interaction between static charges, but for moving charges one needs to include the motion-related magnetic forces [4,5]. The combined total electric and magnetic force $\mathbf{F}_{\mathrm{EM}}$ can be written as follows:

$$\mathbf{F}_{\mathrm{EM}} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}\,T_{\mathrm{D}}\,\hat{\mathbf{r}} \tag{3}$$

where T_{D} is a generic motion-dependent dynamic factor or term. For example, for a system comprising a source charge q_1 moving with constant velocity $\mathbf{v}_1$ and a test charge q_2 moving with constant velocity $\mathbf{v}_2$, the tangential term T_{Dt} can be determined using Lorentz Transformations [5] with factor γ, as follows:

$$T_{\mathrm{Dt}} = \gamma\left(1 - \frac{\mathbf{v}_1\,\mathbf{v}_2}{c^2}\right) = \left(1 + \frac{1}{2}\frac{\mathbf{v}_1^2}{c^2} - \frac{\mathbf{v}_1\,\mathbf{v}_2}{c^2}\cdots\cdots\right), \qquad \gamma = \left(1 - \left(\frac{\mathbf{v}_1}{c}\right)^2\right)^{-0.5} \tag{4}$$

where $\mathbf{v}_1$ and $\mathbf{v}_2$ are along the normal to r (distance between charges) and are less than the speed of light c. It does not matter whether q_1 is considered as the source charge and q_2 as the test charge, or vice versa.

3.2 Quantum Electrodynamics and EM Forces

Quantum Electrodynamics (QED) considers the EM forces as manifestations of random processes of exchange of messenger or mediator particles in the form of discrete randomly fluctuating virtual particles/photons [6,7,8,9] – see Appendix-A for more details. In QED, virtual photons share some similar properties with real photons including zero mass and emission in all directions in 3D space, except for the temporary violation of normal energy and momentum considerations in line with the Heisenberg Uncertainty principle. In the quantum vacuum, virtual photons are emitted from a source charge in all directions and their density decays with distance r from source, which in 3D space makes the density follows inverse square law and leads to the Coulomb forces [7,8]. Note that Coulomb's Law represents a statistical average of large number of QED particle interactions.

3.3 Empirical Intermolecular Energy and Force

Adjacent molecules, including single neutral atoms, interact by instantaneous dipole-induced dipole forces which are part of van der Waals (vdW) forces (London Dispersion forces). These interactions may be caused by quantum-induced instantaneous polarization. In molecules these forces are induced by instantaneous polarization multipoles that combine two types of forces, long range attractive and short range repulsive [10,11,12]. The attractive force pulls atoms and molecules closer together while the repulsive force pushes them apart; both forces progressively increase at shorter distances. At sufficiently short distances the outer shells of atoms (electron cloud regions) become too close and experience higher repulsive forces due to Pauli's exclusion principle. Van der Waals energies and forces can be determined using the Lennard-Jones (L-J) potential, which is a simple approximate pair potential between two molecules [10,11,12]. One form of L-J potential was first proposed by John Lennard-Jones back in 1924 [13]. The empirical L-J potential matches actual experimental data and is widely used in the field of Molecular Dynamics (MD) to simulate and determine intermolecular interactions. The empirical method was specifically developed to describe the short-range intermolecular interactions. One of the most popular forms of L-J potential is the 6-12 potential (or 12-6), which describes how the potential U_d varies with distance d, as follows [10]:

$$U_d = U_0\left[\left(\frac{d_0}{d}\right)^{12} - 2\left(\frac{d_0}{d}\right)^{6}\right] \tag{5}$$

where energy U_0 is the depth of the potential well, d is the distance between the particles and d_0 is the distance when the potential reaches its minimum $-U_0$ as shown in Figure 1. Equation (5) is plotted in Figure 1 using data for Argon, $U_0 = 1.68 \times 10^{-21}$ J, $d_0 = 3.82 \times 10^{-10}$ m. In (5) the first term is repulsive varying with $1/d^{12}$ while the second term is attractive varying with $1/d^{6}$. In Molecular Dynamics, the parameters in (5) are normally used to reproduce experimental data and/or data from accurate quantum chemistry analysis.

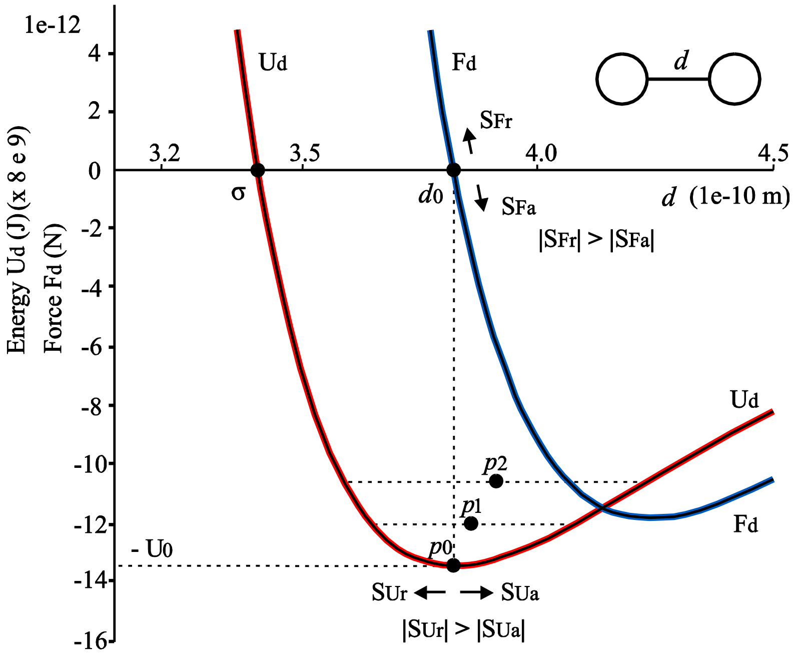

Figure 1 – Lennard-Jones Energy & Force – Argon

The force $\mathbf{F}_d$ can be determined by differentiating the potential in (5), as follows:

$$\mathbf{F}_d = -\frac{d}{dd}(U_d) = \frac{12U_0}{d_0}\left[\left(\frac{d_0}{d}\right)^{13} - \left(\frac{d_0}{d}\right)^{7}\right] \tag{6}$$

Equation (6) is also plotted in Figure 1 using data for Argon. As distance d decreases both the attractive and repulsive forces increase, but the rate of increase in the repulsive force exceeds that of the attractive force and, at a certain minimum distance (d_0), these two forces become equal with a zero net force $\mathbf{F}_d = 0$ and a minimum total energy $-U_0$ (or $-\varepsilon$), where the system reaches a balanced equilibrium state. The distance d at which the potential equals to zero is called σ and can be found from $\sigma = (2^{-1/6})\, d_0$. Due to its computational simplicity, the Lennard-Jones potential is used extensively in Molecular Dynamics's computer simulations even though other more accurate but complex potentials do exist.

4. Asymmetric Electric Coupling

The total energy U of a system comprising two interacting objects distance r apart comprises potential energy (U_r), kinetic energy (U_k) and internal energy (U_d) between the atoms and molecules within each object. The reason for including U_d is that each object exerts a "differential" force on the other which modifies its internal energy U_d due to the fact that the nearside always experiences larger forces than the far side. Differential forces may alternatively be called tidal forces and the two terms may be used interchangeably. Depending on polarity, attractive tidal forces tend to extend objects and increase U_d while repulsive tidal forces tend to contract objects and decrease U_d. In large objects the tidal forces may be quite large and may, for example, cause object deformations, heat generation and volcanoes. The total energy of the system can be written as:

$$U = U_r + U_d + U_k \tag{7}$$

Both tidal energy and U_d increase at shorter r values. When objects move, the distance between them changes and the energy is traded off between the various components in (7). Since they directly act on atoms and molecules, tidal forces will be superposed on intermolecular forces within the object. Assuming there are no non-conservative forces acting on the system, the total energy of the system (7) is conserved so one can write:

$$U_{r1} + U_{d1} + U_{k1} = U_{r2} + U_{d2} + U_{k2} \tag{8}$$

Or alternatively:

$$\Delta U_r + \Delta U_d + \Delta U_k = 0 \tag{9}$$

We shall analyse below the effect of variations in U_d and how this can affect potential energy U_r between two objects which is relevant to the GE-Link and gravity.

4.1 Asymmetric Properties of Intermolecular Bonding

The system in Figure 1 settles at a stable balanced equilibrium point p_0 (d_0). If disturbed by some force and/or distance r changes, the system will automatically readjust to achieve a new stable and balanced position at a new d-value where the net force $\mathbf{F}_d$ is zero. It is important to observe that the energy and force in L-J curve exhibit asymmetrical characteristic property about the equilibrium position p_0. At this position the energy and force required to decrease distance d (compression) are greater than that required to increase distance d (extension). As explained above, since attractive tidal forces increase d and cause extension while repulsive tidal forces decrease d and cause compression, we shall use subscript "a" for the former and "r" for the latter. The slopes of energy and force can be expressed as:

$$|S_{Ur}| > |S_{Ua}| \qquad\qquad |S_{Fr}| > |S_{Fa}| \tag{10}$$

where S_{Ua}, S_{Ur} are the energy slopes for extension and compression, respectively, and S_{Fa}, S_{Fr} are the force slopes for extension and compression, respectively. What (10) is saying is that it is harder to ***compress*** a material than it is to ***extend*** it by the same amount.

One can analyse the system of Figure 1 using a spring analogy [10] by treating the attractive and repulsive forces as though each is acting on its own respective mechanical spring of spring constants k_a, k_r, respectively. The effective spring constant (k) for small changes in d (Δd) can be calculated from (6) by substituting $d = d_0 + \Delta d_a$ in the attractive case (k_a) and $d = d_0 - \Delta d_r$ in the repulsive case (k_r). Using Hooke's Law ($\mathbf{F} = -k\,x$) we can write:

$$\mathbf{F}_{da} = -k_a\,\Delta d_a \qquad\qquad \mathbf{F}_{dr} = -k_r\,\Delta d_r \tag{11}$$

$$\Delta U_{da} = \frac{1}{2} k_a\,\Delta d_a^2 \qquad\qquad \Delta U_{dr} = \frac{1}{2} k_r\,\Delta d_r^2 \tag{12}$$

where $\mathbf{F}_{da}$, ΔU_{da}, k_a are the attractive force, energy change and spring constant, and $\mathbf{F}_{dr}$, ΔU_{dr}, k_r are the repulsive force, energy change and spring constant. Since the spring constant k is itself the actual slope (force/distance) in N/m, one can write the force slopes in (10) in terms of k as follows:

$$|k_r| > |k_a| \qquad\qquad \left|\frac{k_r}{k_a}\right| > 1 \tag{13}$$

The asymmetry in (10,13) is the main cause of a number of other fundamental physical phenomena including the ubiquitous phenomenon of thermal expansion. In thermal expansion, thermal energy causes the molecules to vibrate in all directions, but since it is easier for objects to expand than contract (Figure 1), the average distance (d_0) will increase (e.g. move from p_0 to p_1 and d_0 to d_1 in

Figure 1) and cause expansion [14,15]. In another phenomenon, most materials can withstand higher compressive than tensile strengths such as the case with air, for example, in which it is much harder to compress air molecules than to separate them as evident in the application of pneumatic tyres.

4.2 Response to External Forces

Let us see how a system of molecules bound by van der Waals bonding will respond to two external electric forces ($\mathbf{F}_r$), one attractive ($\mathbf{F}_{ra}$) and one repulsive ($\mathbf{F}_{rr}$), of identical absolute magnitudes, i.e. $|\mathbf{F}_{ra}| = |\mathbf{F}_{rr}|$. As explained in S-5 below, neutral atoms interact by these types of bipolar electrical forces because they comprise equal absolute magnitudes of positive and negative charge. The external forces will be superposed on the atoms of Figure 1 and give rise to tidal forces that will try to slightly move or nudge the atoms about their balanced position at d_0 (see Figure 1). Force $\mathbf{F}_{ra}$ will give rise to attractive tidal force $\mathbf{F}_{ta}$ while force $\mathbf{F}_{rr}$ will give rise to repulsive tidal force $\mathbf{F}_{tr}$. Force $\mathbf{F}_{ta}$ will try to pull the atoms apart by a force $\mathbf{F}_{da} = \mathbf{F}_{ta}$ while force $\mathbf{F}_{tr}$ will try to push the atoms closer together by a force $\mathbf{F}_{dr} = \mathbf{F}_{tr}$. It is here where the slopes in (10,13) will now make a difference and play an important role. Since $|\mathbf{F}_{ra}| = |\mathbf{F}_{rr}|$, the internal forces should also be equal, i.e. $|\mathbf{F}_{da}| = |\mathbf{F}_{dr}|$, which when substituted in (11) should lead to:

$$\Delta d_r = \left|\frac{k_a}{k_r}\right| \Delta d_a \tag{14}$$

By substituting (14) in (12) and making use of (13) one obtains the followings:

$$\left|\frac{\Delta U_{da}}{\Delta U_{dr}}\right| = \left|\frac{k_r}{k_a}\right| > 1 \tag{15}$$

Equation (15) is quite important because it states that if one applies external attractive and repulsive forces of exactly identical absolute magnitudes, the asymmetric characteristics property of intermolecular bonding will cause slightly greater internal attractive energy change (ΔU_{da}) in the object than repulsive energy change (ΔU_{dr}), i.e. ($|\Delta U_{da} / \Delta U_{dr}|$) > 1. But since energy is conserved (7-9), this should in turn produce slightly greater change in external attractive potential energy (ΔU_{ra}) than in repulsive potential energy (ΔU_{rr}), from which one can obtain the ratio of external potential energy change via (12,15), as follows:

$$\boxed{\left|\frac{\Delta U_{ra}}{\Delta U_{rr}}\right| = \left|\frac{k_r}{k_a}\right| > 1} \tag{16}$$

Since force $\mathbf{F} = -\mathrm{d}U/\mathrm{d}r$, one can conclude from (16) that the following should also be true:

$$\boxed{\left|\frac{\mathbf{F}_{ra}}{\mathbf{F}_{rr}}\right| = \left|\frac{k_r}{k_a}\right| > 1} \tag{17}$$

Note that despite applying initially equal forces $|\mathbf{F}_{ra}| = |\mathbf{F}_{rr}|$, the asymmetric property of van der Waals bonding should modify that to $|\mathbf{F}_{ra}| > |\mathbf{F}_{rr}|$, as in (17).

4.3 Asymmetric Quantum Electric Coupling Mechanism

Note that the automatic balancing mechanism above will always ***drive*** the system towards attaining the equilibrium condition $\mathbf{F}_d = 0$ at all r-values. This is a universal and ever-present blanket effect. It is at this equilibrium position that the system will cause more attractive energy to be traded off than repulsive energy and, consequently, ensures and guarantees that the conditions in (16,17) remain valid at all times, irrespective of distance r. In line with (16,17) one can propose a new mechanism responsible for the breakdown of symmetry between the otherwise symmetrically identical external forces. Such mechanism will tip the balance in favour of enhancing attractive over repulsive forces and leads to the following proposed non-identical dimensionless attractive and repulsive force multipliers P_a and P_r:

- **Matter slightly *enhances* external attractive energy & force → attractive multiplier P_a**
- **Matter slightly *resists* external repulsive energy & force → repulsive multiplier P_r**

- **Multipliers ratio should be in line with (16,17)** → $\boldsymbol{P_a / P_r > 1}$ **or** $\boldsymbol{P_a - P_r > 0}$

Since the asymmetric quantum electric coupling applies to all matter held together by vdW bonds exhibiting $\mathbf{F}_d = 0$ balanced condition, one needs to reflect this fundamental "blanket" effect in the force equation (3). One practical way to implement this phenomenon is by multiplying the force in (3) by multipliers P_a and P_r, as follows:

$$\boxed{\mathbf{F}_{att} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2} T_D P_a \hat{\mathbf{r}}} \qquad \boxed{\mathbf{F}_{rep} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2} T_D P_r \hat{\mathbf{r}}} \tag{18}$$

Multipliers P_a and P_r may be derived from theory using quantum chemistry, however in this paper we shall determine their values from experiments – see S-7. Had the characteristic property of van der Waals forces been symmetrical, then one would get $P_a = P_r = 1$ and $\mathbf{F}_{att} = \mathbf{F}_{rep}$ in (18). Additionally, without this asymmetry, thermal expansion too will cease to exist [15]. Note that similar mechanisms may also be presents with other types of bonding such as ionic, covalent and others as long as they exhibit similar asymmetric characteristics with auto-balancing equilibrium mechanism.

5. Analyses of Intermolecular Forces

The empirical method in S-3 is an approximate ad hoc formula valid for and specifically developed to reproduce experimental data at or near intermolecular distances ($r \sim d$) as is extensively used in the field of Molecular Dynamics calculations. It is not, however, suitable for much larger distances where $r >> d$ and, therefore, one cannot use it to probe the GE-Link because gravity operates at much larger distances. In this section we propose a new electric atomic model (Tripole) meeting the following stringent requirements:

- Simple and robust general purpose electric atomic model
- Derived from basic fundamental Electromagnetic theory
- Operating at all distances large and small ($d < r <$ infinity)
- As a pre-condition it must reproduce the tried and tested empirical formula for intermolecular energy and force at $r \sim d$, i.e. reproducing the characteristic property of vdW/L-J shown in Figure 1
- Only then would one feel confident enough to extend this model to large distances and scales in order to enable the assessment of the GE-Link between gravity and electricity.

5.1 Tripole Atomic Model - TAM

By and large matter exists in the form of charge-neutral entities having equal absolute magnitudes of positive and negative charge as in molecules, including single neutral atoms or monatomic molecules. The terms atoms and molecules may be used interchangeably to refer to charge-neutral entities. The properties of charge-neutral entities are described in Appendix-B. For electric force calculations, the atom can be represented by a simple effective electric model, comprising positive and negative charge such as any of the atoms shown in Figure 2. In this model, the positive quarks charge represents the total positive charge $+q$ in the atom, while the combined electron and negative quarks charge represents the total negative charge $-q$ in the atom. From Gauss Law [16], the positive $+q$ and negative $-q$ atomic charges can be treated as point charges located at the centre of their respective entity. However, one needs a more accurate representation of the distributed nature of charge particularly that of the electron cloud region. One good and simple method is to split the negative charge $-q$ into two parts one on either side of nucleus as shown in each atom of Figure 2. This approximates the atom into three point charges, hence the name "Tripole" Atomic Model (TAM). Although models with more charge points may be more accurate, the TAM greatly reduces calculations and simplifies the overall analysis. As we shall see below, the Tripole will prove to be quite powerful in that it will quite accurately trace and reproduce the characteristics property of van der Waals and L-J energy and force similar to that of Figure 1.

5.2 Electric Forces between Two Molecules – Tripoles

We shall consider electrical interactions between two neutral atoms or molecules as charge-neutral entities. In order to simplify the analysis we shall consider interactions between two simple or monatomic molecules like Argon although the same analysis should also apply to more complex molecules (SS-5.6). Figure 2 shows two neutral atoms 1 and 2 separated by distance r. Atom 1 comprises positive charge $+q_1$ and negative charge $-q_{1a}$, $-q_{1b}$ situated at distances a_1, b_1 from nucleus, respectively. Atom 2 comprises positive charge $+q_2$ and negative charge $-q_{2a}$, $-q_{2b}$ situated at distances a_2, b_2 from nucleus, respectively. In order to account for magnetic forces too (T_D), we assume that atom 1, 2 are moving at constant velocities $\mathbf{v}_1$ and $\mathbf{v}_2$, respectively in direction normal to r. The distance r between nuclei is taken as the average distance between the atoms. We assume that each atom is locally bound by asymmetric interatomic forces with its neighbouring atoms/molecules (not shown) and exhibiting the balanced equilibrium condition $\mathbf{F}_d = 0$ and $(P_a - P_r) > 0$, as described in S-3 and S-4 above.

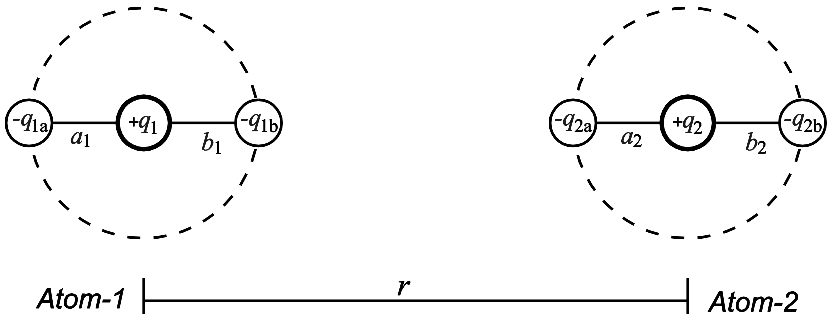

Figure 2 – Electrical Interaction between two Neutral Atoms using Tripole Atomic Model

It is instructive to express the total EM force between the atoms as the sum of two separate and independent main components, namely that of the attractive component ($\mathbf{F}_{att}$) and that of the repulsive component ($\mathbf{F}_{rep}$). This will pave the way for the GE-Link and, as we will see later, will enable one to account for the force of gravity by describing it as that force arising from the constant battle between these two giant forces that, when combined, leave a clear *residue* that one perceives as gravity. The total Coulomb's attractive and repulsive EM forces between atoms 1 and 2 can be determined using (18) by adding all corresponding attractive and repulsive components. Since there are six charge entities in Figure 2 ($+q_1$, $-q_{1a}$, $-q_{1b}$, $+q_2$, $-q_{2a}$, $-q_{2b}$), there is a total of nine interatomic force components, five repulsive and four attractive, as follows:

$$\mathbf{F}_{rep} = \frac{T_D P_r}{4\pi\varepsilon_0}\left(\frac{(+q_1)(+q_2)}{r^2} + \frac{(-q_{1a})(-q_{2a})}{(r+a_1-a_2)^2} + \frac{(-q_{1a})(-q_{2b})}{(r+a_1+b_2)^2} + \frac{(-q_{1b})(-q_{2a})}{(r-b_1-a_2)^2} + \frac{(-q_{1b})(-q_{2b})}{(r-b_1+b_2)^2}\right)\hat{\mathbf{r}} \tag{19}$$

$$\mathbf{F}_{att} = \frac{T_D P_a}{4\pi\varepsilon_0}\left(\frac{(+q_1)(-q_{2a})}{(r-a_2)^2} + \frac{(+q_1)(-q_{2b})}{(r+b_2)^2} + \frac{(+q_2)(-q_{1a})}{(r+a_1)^2} + \frac{(+q_2)(-q_{1b})}{(r-b_1)^2}\right)\hat{\mathbf{r}} \tag{20}$$

Since the negative charge is split into parts a and b, one on either side of nucleus and that the atomic charge is fixed, one would expect the followings to hold true for the TAM:

$$-q_{1a} = -q_1 x_{1a}, \quad -q_{1b} = -q_1 x_{1b}, \quad x_{1a} + x_{1b} = 1, \quad -(q_{1a} + q_{1b}) = -q_1 \tag{21}$$

$$-q_{2a} = -q_2 x_{2a}, \quad -q_{2b} = -q_2 x_{2b}, \quad x_{2a} + x_{2b} = 1, \quad -(q_{2a} + q_{2b}) = -q_2 \tag{22}$$

where parameter x denotes the charge multiplier fraction. Substituting (21,22) in (19,20) and taking common multiplier (q_1q_2/ r^2) outside yields:

$$\mathbf{F}_{\text{rep}} = +\frac{q_1 q_2}{4\pi\varepsilon_0 r^2} T_{\text{D}} P_{\text{r}} \left(\frac{1}{r^2} \left(1 + \frac{x_{1\text{a}} x_{2\text{a}}}{\left(1+\frac{a_1 - a_2}{r}\right)^2} + \frac{x_{1\text{a}} x_{2\text{b}}}{\left(1+\frac{a_1 + b_2}{r}\right)^2} + \frac{x_{1\text{b}} x_{2\text{a}}}{\left(1-\frac{b_1 + a_2}{r}\right)^2} + \frac{x_{1\text{b}} x_{2\text{b}}}{\left(1-\frac{b_1 - b_2}{r}\right)^2} \right) \right) \hat{\mathbf{r}}$$

(23)

$$\mathbf{F}_{\text{att}} = -\frac{q_1 q_2}{4\pi\varepsilon_0} T_{\text{D}} P_{\text{a}} \left(\frac{1}{r^2} \left(\frac{x_{2\text{a}}}{\left(1-\frac{a_2}{r}\right)^2} + \frac{x_{2\text{b}}}{\left(1+\frac{b_2}{r}\right)^2} + \frac{x_{1\text{a}}}{\left(1+\frac{a_1}{r}\right)^2} + \frac{x_{1\text{b}}}{\left(1-\frac{b_1}{r}\right)^2} \right) \right) \hat{\mathbf{r}} \tag{24}$$

If we denote the bracketed repulsive and attractive terms by T_{Trep}, T_{Tatt} in equations (23,24), respectively, we can simplify these terms using Binomial Expansions as detailed in Appendix-D to yield:

$$T_{\text{Trep}} = 2\left(\frac{1}{r^2} + \frac{Y_{\text{r3}}}{r^3} + \frac{3}{2}\frac{Y_{\text{r4}}}{r^4} + \cdots \right) \tag{25}$$

$$T_{\text{Tatt}} = 2\left(\frac{1}{r^2} + \frac{Y_{\text{a3}}}{r^3} + \frac{3}{2}\frac{Y_{\text{a4}}}{r^4} + \cdots \right) \tag{26}$$

where the terms Y_{rn} and Y_{an} are as defined in Appendix-D for n=3,4,5......... By substituting (25,26) in (23,24) we can re-write (23,24) in a simpler manner as follows:

$$\mathbf{F}_{\text{rep}} = +\frac{q_1 q_2}{2\pi\varepsilon_0} T_{\text{D}} P_{\text{r}} \left(\frac{1}{r^2} + \frac{Y_{\text{r3}}}{r^3} + \frac{3}{2}\frac{Y_{\text{r4}}}{r^4} + \cdots \right) \hat{\mathbf{r}} \tag{27}$$

$$\mathbf{F}_{\text{att}} = -\frac{q_1 q_2}{2\pi\varepsilon_0} T_{\text{D}} P_{\text{a}} \left(\frac{1}{r^2} + \frac{Y_{\text{a3}}}{r^3} + \frac{3}{2}\frac{Y_{\text{a4}}}{r^4} + \cdots \right) \hat{\mathbf{r}} \tag{28}$$

5.3 Net Force between Two Molecules – Tripoles

The repulsive and attractive forces (27,28) can now be added together to determine the total net force $\mathbf{F}_{\text{net}}$ which, after a little sign manipulation, yields the followings:

$$\mathbf{F}_{\text{net}} = \mathbf{F}_{\text{rep}} + \mathbf{F}_{\text{att}} \tag{29}$$

$$\boxed{\mathbf{F}_{\text{net}} = \frac{q_1 q_2}{2\pi\varepsilon_0 r^2} T_{\text{D}} \left(-\left(P_{\text{a}} - P_{\text{r}}\right) - \left(\frac{1}{r}\left(P_{\text{a}} Y_{\text{a3}} - P_{\text{r}} Y_{\text{r3}}\right) + \frac{1}{r^2}\frac{3}{2}\left(P_{\text{a}} Y_{\text{a4}} - P_{\text{r}} Y_{\text{r4}}\right) + \cdots \right) \right) \hat{\mathbf{r}}} \tag{30}$$

After re-arranging, equations (30) can be simplified and re-written as:

$$\boxed{\mathbf{F}_{\text{net}} = -\frac{q_1 q_2}{2\pi\varepsilon_0 r^2} T_{\text{D}} \left(T_{\text{macro}} + T_{\text{micro}} \right) \hat{\mathbf{r}}} \tag{31}$$

Where we have defined two new dimensionless terms T_{macro} and T_{micro}, as follows:

$$T_{\text{macro}} = \left(P_{\text{a}} - P_{\text{r}}\right) \tag{32}$$

$$T_{\text{micro}} = \frac{1}{r}\left(P_{\text{a}} Y_{\text{a3}} - P_{\text{r}} Y_{\text{r3}}\right) + \frac{1}{r^2}\frac{3}{2}\left(P_{\text{a}} Y_{\text{a4}} - P_{\text{r}} Y_{\text{r4}}\right) + \cdots \tag{33}$$

Equations (30,31) shows that the total EM force $\mathbf{F}_{\text{net}}$ between the two atoms (Figure 2) is proportional to the product q_1q_2 multiplied by a dimensionless factor T_{D} (...) and divided by the square of distance and permittivity of free space. The first term T_{macro} describes an inverse square law force synonymous with gravity, while the second term T_{micro} describes a force dependent on higher $1/r^{\text{n}}$ terms, where n=3, 4 .... The force equation (30) may alternatively be expressed as:

$$\mathbf{F}_{\text{net}} \equiv -\left(\mathbf{F}_{\text{r}2} \propto \frac{1}{r^2}\right) - \left(\mathbf{F}_{\text{r n}} \propto \sum_{n=3}^{n=\infty} \frac{Y_{\text{n}}}{r^n}\right) \equiv \text{Gravity} + \text{Intermolecular} \tag{34}$$

From the above analysis one can make the following interesting observations about the characteristic properties of the force (30,31,34):

a) The force has an inverse square term dominating at large distances ($r >> d$) where it is acting between the total absolute charge q_1, q_2 irrespective of how the charge is locally distributed
b) All other terms apart from the first one in (30,31,34) will produce higher dependency on $1/r^n$ terms, where n=3, 4 .... and thus departs away from inverse square law
c) Dominating the force equation at small distances ($r \sim d$), the multipole terms make the force depends on how the charge is locally distributed
d) Although the total force in (30,31,34) depends on both T_{macro} and T_{micro} terms, each dominates the force equation at its respective scale.
e) Therefore, the force equation (30,31,34) depends on infinite $1/r^n$ terms, from n=2,3,4.... What determines whether the force follows inverse square law or anything else is nothing other than a **Scale Factor** determined by distance r relative to intermolecular distances, as follows:
   i) The force follows Inverse Square Law for $r >> d$, which defines a "macro-scale"
   ii) The force depends on higher $1/r^n$ terms over and above inverse square for $r \sim d$, which defines a "micro-scale"
   iii) The force follows a combination of (i) and (ii) for $d < r < \textit{infinity}$

Thus, in the system of Figure 2 each charge is acted upon by almost identical attractive and repulsive forces that are superposed together, so much so they do largely but incompletely cancel each other out. In SS-5.5, SS-5.6 and S-6 we shall see how equations (30,31,34) can be applied to large astronomical objects that leads us to the GE-Link and electric gravity in line with Newton's and beyond. Equation (31) may alternatively be written as:

$$\mathbf{F}_{\text{net}} = -\frac{q_1 q_2}{2\pi\varepsilon_0 r^2} T_{\text{D}}\, T_{\text{macro}} \left(1 + \frac{T_{\text{micro}}}{T_{\text{macro}}}\right) \hat{\mathbf{r}} \tag{35}$$

5.4 Short–Range Electric Force - Tripole

The force equation (30,31) is actually quite powerful as it can reproduce the energy U and force **F** versus distance characteristics of vdW and L-J at $r \sim d$, with results similar to that shown in Figure 1. The way we do that is by making the following simple and reasonable assumptions. The electron cloud charge polarization and shift may be modelled by a dimensionless parameter like charge eccentricities ecc_1, ecc_2 for atoms 1, 2, respectively, as follows:

$$x_{1\text{a}} = \frac{1}{2} q_1 \left(1 + ecc_1\right), \quad x_{1\text{b}} = \frac{1}{2} q_1 \left(1 - ecc_1\right) \tag{36}$$

$$x_{2\text{a}} = \frac{1}{2} q_2 \left(1 + ecc_2\right), \quad x_{2\text{b}} = \frac{1}{2} q_2 \left(1 - ecc_2\right) \tag{37}$$

As mentioned in SS-3.3, charge polarization is caused by instantaneous dipole-induced dipole between neighbouring atoms and molecules. At these distances ($r \sim d$) eccentricity ecc can be quite large by virtue of proximity of atoms where a strong "correlated" coupling occurs as in (36,37). However, as r increases this correlated coupling decreases. Deriving a formula for correlated coupling from theory should be possible using quantum mechanical/EM means, but this is outside the scope of this paper. We shall use approximate values here in order to show characteristic trends.

In addition, the instantaneous polarization is a temporary and transient phenomenon lasting a short period of time, which must be assigned an appropriate duty cycle ratio. It was found that a duty cycle of ~ 1/250 was needed in order to match experimental data in line with that of vdW/L-J. The charge shift may also change the effective distances from nuclei in a similar manner to (36,37), as follows:

$$a_1 = a_{01}\left(1 + ecc_1\right) \qquad b_1 = a_{01}\left(1 - ecc_1\right) \tag{38}$$

$$a_2 = a_{02}\left(1+ecc_2\right) \qquad b_2 = a_{02}\left(1-ecc_2\right) \tag{39}$$

where we used a_{01} and a_{02} as the nominal atomic radii of atoms 1 and 2, respectively. Although variable, the eccentricity may be assigned some practically reasonable values such as for example:

$$ecc_1 = ecc_2 = 0.6 \tag{40}$$

As described below, parameter ($P_a - P_r$) can be determined from experiments with a value of ~ 4e-37 (see S-7). For plotting purposes one can use P_a = 1+2e-37 and P_r = 1–2e-37. In any case ($P_a - P_r$) is unlikely to impact the force at $r \sim d$ since higher r-terms (n >= 3) in (30,31) are independent of it (see Appendix-D). In order to plot force versus distance, one needs to evaluate (23,24) and then add them together to calculate total net force. Similarly for energy, one can remove the "squares" from denominators (23,24) then evaluate and sum up to find net energy. The value of atomic radii were assumed to be approximately $a_{01}=a_{02}$ =1.60e-10 m and the velocity term T_D = 1. The force for the TAM model $\mathbf{F}_{TAM}$ vs r and U_{TAM} vs r plots are shown Figure 3. For comparison, the vdW/L-J Force $\mathbf{F}_{L\text{-}J}$ and energy $U_{L\text{-}J}$ from Figure 1 are also shown in the Figure (broken lines).

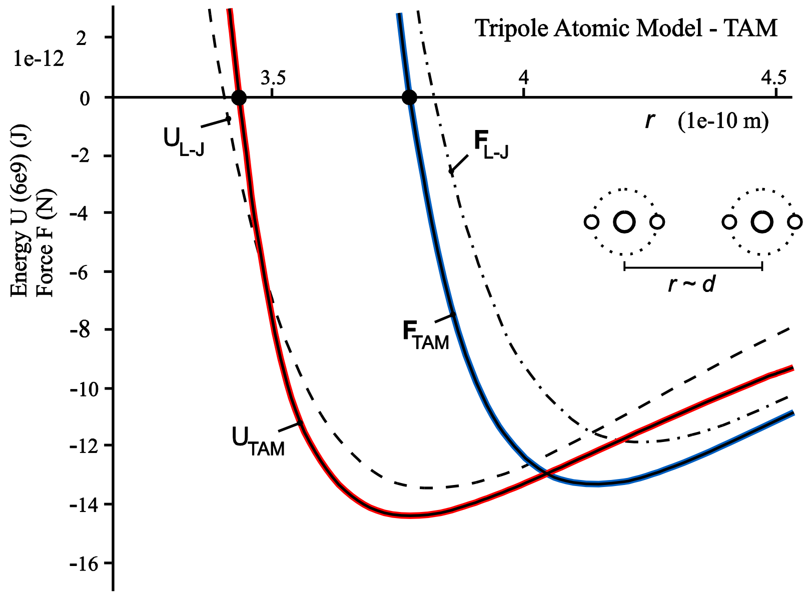

Figure 3 – Tripole Energy U_{TAM} & Force F_{TAM} vs distance ($r \sim d$) – Argon
Also shown are $U_{L\text{-}J}$ & $F_{L\text{-}J}$ vs distance (broken lines)

Note that part of the repulsive r-terms inside the bracket of (30) with n >= 4 (i.e. those multiplied by 6 in Appendix-D)) have no corresponding attractive counterparts r-terms, as detailed in Appendix-D. In fact this goes a long way to explain why L-J repulsive force component (depending on r^-13) is much higher than the attractive force component (depending on r^-7) – see (6).

The TAM curves in Figure 3 come quite close to the energy and force of van der Waals and L-J of Figure 1, which is a remarkably vindication of TAM and its validity at the short-range or "micro-scale" world $r \sim d$. The vindication of the TAM model provides the backing and confidence to extend the force (30,31) to the long-range force of gravity, which is at the other end of the distance scale, the "macro-scale" world $r >> d$, as explained below.

5.5 Long–Range Force – Inverse Square Law

Note that only the inverse square term T_{macro} depends on ($P_a - P_r$) > 0, which can explain why the force (and gravity) is so comparatively weak. Recall that the basis for ($P_a - P_r$) > 0 was the asymmetrical behaviour of interatomic bonding as derived using the L-J potential function in S-4. In S-7 below we shall determine the value of ($P_a - P_r$) from experiment.

The term T_{micro} dominates the force equation at intermolecular distances. On the other end of the scale, at larger distances such as $r >> d$, the term T_{micro} diminishes such that $T_{\text{micro}}/T_{\text{macro}} << 1$ (35), in which case one can ignore it ($T_{\text{micro}} \sim 0$), thus making (30,31) predominantly follow inverse square law:

$$\mathbf{F}_{\text{net}} = -\frac{q_1 q_2}{2\pi\varepsilon_0 r^2} T_{\text{D}}\, T_{\text{macro}}\ \hat{\mathbf{r}} \tag{41}$$

The force (41) is an inverse square law force, which can be synonymous with the force of gravity if one can derive object charge from its mass as will be explained in more details in S-6 below. Note that at larger distances ($r >> d$) the effective ecc-values are very small due to very low correlated coupling. Although the "local" ecc-values may be large due to the proximity of local adjacent atoms, these are random and uncorrelated in relation to that of the other object at distance r away. The effect of un-correlated random ecc-values should statistically average to zero.

5.6 Mathematical Proof of Inverse Square Law

The force equations (30,31,34) were derived using two single atoms, 1 and 2. But what would the force be like between two large (astronomical) objects comprising large number of atoms and molecules? In S-6 we describe how the force depends on the total number of atoms/molecules contained in object mass, but here we want to see if the force still follows inverse square law for large objects. As it turned out the force equation will have the same format as that of (30,31,34) irrespective of object size for the following reasons:

i) The distance between any two charge entities, one in each object, will always be:

$$(r \mp y), \qquad y = (y_1 \mp y_2), \qquad |y| < r \tag{42}$$

where y_1 and y_2 are local distances inside object 1 and 2, respectively, denoting how far away are these entities from the centre of their respective object (normally up to object's radius).

ii) When expanded via Binomial Expansion (multipoles), the force between any two charge entities in (i) will always have a first term of "$1/r^2$" as follows:

$$\frac{1}{(r \mp y)^2} = \frac{1}{r^2\left(1 \mp \frac{y}{r}\right)^2} = \frac{1}{r^2}\left(1 \mp \frac{y}{r}\right)^{-2} = \frac{1}{r^2}\left(1 \pm 2\frac{y}{r} + 3\left(\frac{y}{r}\right)^2 \cdots\right) \qquad \left|\frac{y}{r}\right| < 1 \tag{43}$$

Equation (43) confirms that for any value of y_1, y_2, the Binomial Expansion will always produce an inverse square force "component". When added together, these components will combine to make the overall inverse square ($1/r^2$) part of the force equation (30,31,34), when $|y| < r$.

iii) At long-range distances, the value of the first term of the overall force equation ($1/r^2$) will be greater than all other higher $1/r^n$ terms with n>2, thus making the force between objects follow inverse square law.

6. Electric Force between Two Objects

6.1 Force from Object Charge

For objects made up of large number of neutral atoms or molecules, one needs to determine the total charge for each object. A uniform spherical shell of charge behaves, as far as external points are concerned, as if all its charge is concentrated at its centre in accordance with Gauss Law [16]. For example, in SS-5.1 we considered the electron cloud as a shell with a total charge concentrated at the centre of the shell. Here we shall deal with objects of spherically symmetric charge distributions comprising a number of concentric spherical shells n of uniformly-distributed charge Q_{sh1}, Q_{sh2}, Q_{sh3} ..... Q_{shn}, the effective charge of each shell is located at the centre. Each shell may comprise a number of materials (atoms) uniformly distributed over the shell. Applying the principle of superposition, one can add the charges of all these shells to determine the total object charge Q positioned at the centre of the object, as follows:

$$Q = Q_{\text{sh1}} + Q_{\text{sh2}} + Q_{\text{sh3}} \cdots + Q_{\text{sh}n} = \sum_{i=1}^{n} Q_{\text{sh}i} \tag{44}$$

Note that Newton used a similar method (shell theorem) for treating mass of spherically symmetric bodies [17]. Therefore, for spherically symmetric objects 1, 2 of total charge Q_1, Q_2 each distributed over spherically symmetric uniform shells, one can treat charge Q_1, Q_2 as point charges located at the centre of objects 1, 2, respectively. Charges Q_1, Q_2 represent the absolute value of total positive or negative charge in the objects. The force $\mathbf{F}_{\text{net}}$ between the two objects can be determined by replacing charges q_1, q_2 in (31) with object charge Q_1, Q_2, respectively, as follows:

$$\mathbf{F}_{\text{net}} = -\frac{Q_1 Q_2}{2\pi\varepsilon_0 r^2} T_{\text{D}} \left(T_{\text{macro}} + T_{\text{micro}} \right) \hat{\mathbf{r}} \tag{45}$$

Since T_{D}, T_{macro} and T_{micro} are all dimensionless, the unit of force in (45) is Newton as in Coulomb's Law.

6.2 Force from Object Mass

In general, charges Q_1, Q_2 in equation (45) cannot be easily determined, particularly when each of objects 1, 2 is composed of different types of atoms. In this section we shall determine object charge from its mass and use this to determine the force directly from mass. To do that, we need to determine the atomic charge and the total number of atoms per unit mass.

6.2.1 Charge–Mass Relations

In the standard model of particle physics, the atomic charge includes electrons as well as nucleons or quarks charge and should, therefore, depend on the atomic number Z and mass number (nucleons number) A. One can define an atomic charge factor A_{q} for a neutral atom such that when multiplied by the fundamental electric charge e, A_{q} will yield the positive or negative charge contained in the atom, as follows:

$$q = A_{\text{q}}\, e \tag{46}$$

As shown in Appendix-C, the atomic charge factor A_{q} can be calculated as follows:

$$A_{\text{q}} = \frac{2}{3}\left(A + Z \right) \tag{47}$$

For example, the charge in a Carbon atom with Z=6 and A=12 can be calculated from (47) as:

$$q_{\text{Carbon12}} = \frac{2}{3}\left(A + Z \right) e = \frac{2}{3}\left(12 + 6 \right) e = 12e \tag{48}$$

In order to determine the number of atoms N in mass m, one should recall that what matters here is the quantity of "charge" contained in m. Mass m can be determined by weighing an object on a scale ($m = \mathbf{F}/\mathbf{g}$), i.e. by measuring Earth's force of gravity pulling on m. From the GE-Link perspective, the latter force arises from the electrical interactions between Earth and the charge contained in each and every atom in m, as defined by A_{q}. From electrical perspective (see SS-6.2.2), the weight of mass m can be viewed as a measure of how much effective "charge-related" pull the object possesses. Accordingly, in order to determine the number of atoms N in mass m one needs to determine how many units of "A_{q}" are contained in mass m, as follows:

$$N = N_{\text{A}} \frac{m}{A_{\text{q}}} \tag{49}$$

where N_{A}=6.022 x 10^{26} atoms/kg (or atoms/mole) is the Avogadro's Constant. Constant N_{A} is also related to the unified atomic mass unit u, u = $1/N_{\text{A}}$= 1.6605 x 10^{-27} kg, from which one may alternatively use $N = m/(\text{u}A_{\text{q}})$. The charge Q contained in mass m can now be determined from equations (46,49), as:

$$Q = q\,N = A_{\mathrm{q}}\, e\, N_{\mathrm{A}}\, \frac{m}{A_{\mathrm{q}}} = e\, N_{\mathrm{A}}\, m \tag{50}$$

Note that the atomic charge factor A_q appears in both numerator and denominator of (50) and so cancels out, which simplifies charge calculation directly from mass irrespective of object composition. It is clear from (50) that mass can be viewed as an electrical entity which may be referred to as the (equivalent) "electric mass". It is interesting to note from (50) that the charge and mass are intimately connected and that the ratio of charge/mass (Q/m) is a fixed quantity equals to the Faraday constant $F = eN_A = e/u = 9.6485 \times 10^7$ (NIST/CODATA). For a spherically symmetric uniform shell of mass m_{sh} one can determine the shell charge Q_{sh} from (50) as:

$$Q_{\mathrm{sh}} = e\, N_{\mathrm{A}}\, m_{\mathrm{sh}} \tag{51}$$

For a spherically symmetric object comprising a number of uniform concentric shells n of masses m_{sh1}, m_{sh2}, m_{sh3}....m_{shn}, one can apply the principle of superposition and substitute (51) in (44) to determine total object charge Q from object mass m, as follows:

$$Q = \sum_{i=1}^{n} Q_{\mathrm{sh}i} = e\, N_{\mathrm{A}} \left(m_{\mathrm{sh1}} + m_{\mathrm{sh2}} + m_{\mathrm{sh3}} \cdots + m_{\mathrm{sh}n} \right) = e\, N_{\mathrm{A}} \sum_{i=1}^{n} m_{\mathrm{sh}i} = e\, N_{\mathrm{A}}\, m \tag{52}$$

In a sense equation (52) combines the shell theorems of Gauss [16] and Newton [17] together. The total effective object charges Q_1, Q_2 located at the centre of objects 1, 2 can now be determined from total object masses m_1, m_2, respectively, using the charge-mass relation (52) as follows:

$$Q_1 = e\, N_{\mathrm{A}}\, m_1 \qquad\qquad Q_2 = e\, N_{\mathrm{A}}\, m_2 \tag{53}$$

6.2.2 Electric Force from Object Mass – the GE-Link

We can now express the force in terms of mass by substituting Q_1 & Q_2 from equations (53) in equation (45) to obtain the total net force F_{net} between the objects, as follows:

$$\mathbf{F}_{\mathrm{net}} = -\frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0} \frac{m_1 m_2}{r^2}\, T_{\mathrm{D}} \left(T_{\mathrm{macro}} + T_{\mathrm{micro}} \right) \hat{\mathbf{r}} \tag{54}$$

Equation (54) describes how (quantum) electric phenomena can give rise to a net attractive force between the masses of two objects, with properties and features synonymous with the force of gravity. Thus (54) provides a credible scientific link between gravity and electricity – the GE-Link. Note that the forces we dealt with so far are; a) all Electric (EM), b) all Quantum because EM is a quantum phenomenon and c) Intermolecular forces which are also Quantum Electric phenomena. Based on that, one may appropriately call/refer to the force in (54) as "Quantum Electric Gravity" (QEG), and re-write (54) as:

$$\mathbf{F}_{\mathrm{QEG}} = \mathbf{F}_{\mathrm{net}} = -\frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0}\, T_{\mathrm{D}} \left(T_{\mathrm{macro}} + T_{\mathrm{micro}} \right) \frac{m_1 m_2}{r^2}\, \hat{\mathbf{r}} \tag{55}$$

The QEG force $\mathbf{F}_{QEG}$ (55) may be rewritten in an alternative and more familiar form, i.e. similar to that of Newton's Law of Gravitation, as follows:

$$\boxed{\mathbf{F}_{\mathrm{QEG}} = -G_{\mathrm{QE}} \frac{m_1 m_2}{r^2}\, \hat{\mathbf{r}}} \tag{56}$$

where G_{QE} represents a new parameter, the quantum electric gravitational parameter, with roots firmly established in quantum mechanics and defined as:

$$G_{\mathrm{QE}} = \frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0}\, T_{\mathrm{D}} \left(T_{\mathrm{macro}} + T_{\mathrm{micro}} \right) \rightarrow \left(\equiv G \right) \tag{57}$$

One can observe from (55,56) that the force is proportional to $m_1 m_2 / r^2$ and G_{QE}. G_{QE} is proportional to terms T_{macro}, T_{micro}, T_D and a constant. The T_D term does not depend on r (SS-3.1). The T_{macro} term (32) depends on the difference in parameters ($P_a - P_r$) and makes the force dependent on the inverse square of distance. The T_{micro} term (33) comprises an infinite number of terms, and depends on $1/r^n$ and also on quantum parameters P_a and P_r. Term T_{micro} is expected to have negligible contribution to the force between objects, but become progressively more significant at smaller r-values, especially at interatomic and intermolecular scales. Since parameters T_D, T_{macro} and T_{micro} are all dimensionless, the units of G_{QE} should match that of Newton's gravitational constant G:

$$\frac{\mathrm{N\,m^2}}{\mathrm{C^2}}\frac{\mathrm{C^2}}{\mathrm{kg^2}} = \frac{\mathrm{N\,m^2}}{\mathrm{kg^2}} \equiv G \tag{58}$$

It is interesting to observe that equations (55-56) combine the hitherto irreconcilable theories of Newton's and quantum mechanics/physics. QEG achieves that despite the heretofore prevailing notion that Newton's gravity is different and otherwise seemingly unrelated paradigm to the disciplines of QM/EM on which QEG is founded. Equation (55) can alternatively be written as:

$$\mathbf{F}_{\mathrm{QEG}} = -\frac{1}{2\pi\varepsilon_0}\left(\frac{e}{\mathrm{u}}\right)^2 T_{\mathrm{D}}\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right)\frac{m_1 m_2}{r^2}\;\hat{\mathbf{r}} \tag{59}$$

Although we have derived the terms T_{macro}, T_{micro} and T_D in one dimension to simplify the analyses, one can use appropriate mathematical operators and techniques (Tensors ...) to derive appropriate more accurate 3D equivalents for these parameters and their individual sub-parameters.

6.2.3 Electric Force from Charge & Mass

Equations (45,53,55) can be combined to derive some interesting and versatile ways to calculate $\mathbf{F}_{QEG}$, namely from the mass of one object and the charge of the other or vice versa, as follows:

$$\mathbf{F}_{\mathrm{QEG}} = -\frac{eN_{\mathrm{A}}}{2\pi\varepsilon_0} T_{\mathrm{D}}\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right)\frac{Q_1 m_2}{r^2}\;\hat{\mathbf{r}} = -\frac{G_{\mathrm{QE}}}{e\,N_{\mathrm{A}}}\frac{Q_1 m_2}{r^2}\;\hat{\mathbf{r}} \tag{60}$$

Equations (60) may be quite useful in determining $\mathbf{F}_{QEG}$ on any form of charge, potentially including a postulated effective charge or that of virtual particle pairs associated with EM radiation. In equation (60) one can also express the acceleration of gravity $\mathbf{g}$ in terms of charge by letting $\mathbf{g} = \mathbf{F}_{QEG} / m_2$.

7. Experimental Determination of T_{macro} and G_{QE}

For over 300 years since its inception by Isaac Newton, the gravitational "constant" G had been shrouded with mysteries such as: what's the origin and cause of G, should it have some dependency on distance r, is it really a constant or does it change over time. It is interesting that GE-Link and QEG can shed some light on these issues and express G in terms of more fundamental physical parameters and entities. In Henry Cavendish's or like experiments it was determined that the proportionality constant (G) in Newton's gravity should have the value $G = 6.67259 \times 10^{-11}$. QEG can qualify this and replaces G with the quantum electric gravitational parameter G_{QE} (57) as follows:

$$G_{\mathrm{QE}} = \frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0} T_{\mathrm{D}}\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right) = G \tag{61}$$

Since there was no velocity involved in Cavendish's experiment, we can assume $T_D = 1$ to obtain:

$$\frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0}\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right) = G \tag{62}$$

$$\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right) = \frac{2\pi\varepsilon_0}{e^2 N_{\mathrm{A}}^2} G \tag{63}$$

$$\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right) = 3.9875\times10^{-37} \approx 4\times10^{-37} \tag{64}$$

Equation (64) can be substituted in (57) to write the quantum electric parameter G_{QE} (as determined in/from Cavendish's experiment) in general, as follows:

$$G_{\mathrm{QE}} = \frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0}\,4\times10^{-37}\,T_{\mathrm{D}} = 6.67259\times10^{-11}\,T_{\mathrm{D}} \tag{65}$$

It remains to be seen whether or not T_{macro} and T_{micro} may have some other dependencies which may, if any, reflect on the quantum gravitational parameter G_{QE}.

8. Discussion

1) The force equations (31,45,55) are quite versatile in that they are applicable to a wide range of *r*-values, from intermolecular to astronomical distances. At large distances where $r >> d$ equation (55) can account for gravity at the macro-scale. At small distances where $r \sim d$ equations (30,31) can account for intermolecular forces at the micro-scale. In between these scales at $d < r <$ *infinity* each term contributes to the total force by varying amounts depending on distance.

2) The neutrons are already included in the QEG force equation as charge constituent of mass – see SS-6.2. According to the standard model of particle physics, the neutrons are composed of up and down quarks of +2/3 *e* and –2/3 *e* charge, respectively. Scientists have experimentally observed that while electrically neutral on the whole, neutrons do have a positive charge core on the inside and a negative charge on the surface [18,19]. The neutron is stable only inside atoms otherwise it decomposes into a proton and an electron (and antineutrino) outside the atom within < 15 minutes. One can view neutrons as charge-neutral entities capable of interacting with other neutrons (or other charges) in a manner similar to neutral atoms (Appendix-B). Accordingly, it is expected that the neutron-neutron interactions may exhibit an auto-balanced equilibrium condition like molecules albeit at much smaller scale.

3) As explained above, the QEG force varies by discrete steps due to interactions between atomic charge entities and virtual particles/photons. Normally the resulting discrete steps in the force are difficult to detect in large objects. However, under certain appropriate conditions experiments can be conducted to monitor and detect the resulting stepwise discrete incremental motions (variations in *r*) of individual or a stream of charge-neutral particles. In one experiment [20] it was established that the gravitational quantum bound states of neutrons had been experimentally verified, which proves that neutrons falling under gravity do not move vertically in a continuous manner but rather jump from one height to another, as predicted by quantum theory [20]. The latter may be considered as experimental evidence in support of the GE-Link and QEG, which are based entirely on EM/QED.

4) Perihelion Advance of Mercury. Inner planets experience slightly larger forces than do outer planets, such as in the case of the perihelion advance of Mercury. The GE-Link and QEG provides two main reasons to explain that:

a) At reduced Planet-Sun distances the contribution of the T_{micro} term to the force equation (55) should increase accordingly. When taken into account, this should increase the force of gravity over and above that of inverse square law. As well as the perihelion advance of Mercury, force modification arising from the T_{micro} term could potentially explain some of the other phenomena associated with Einstein's General Theory of Relativity.

b) Inner planets travel at higher velocities than do outer planets, which alters T_{Dt} in (4) and increases the force.

The tangential velocity term (4) covers most situations encountered in practice, such as in circular or near-circular motions of planets around stars (Sun) and the orbital motion of binary star systems. However, for other and more complex arrangements, e.g. where the velocities may point along different directions, one would need to use Lorentz Transformations in 3D space [5] to derive appropriate relativistic formula for T_{D}. For other objects such as fast rotating stars, neutron stars, quasars and magnetars, one may follow the same methodology above to derive appropriate T_{D} formula, taking into account the different velocities of the various parts within each object.

5) Most phenomena relating to gravitational interactions with light predicted by general relativity had already been verified experimentally, including gravitational light bending, red shift, gravitational lensing, time dilation and frequency shift. In QEG most of these phenomena should come as no surprise, given that both QEG and light (EM radiation) are founded on common fundamental electromagnetic and QED principles, where there is stronger likelihood of inter-coupling. For example, in gravitational light bending the lower part of light ray should experience slightly stronger gravity and should be slightly retarded (phase-shifted) relative to the upper part. This is a similar situation to Young's double-slit optical experiment except that, in this case, light entering the bottom slit will be somewhat slightly retarded in comparison to the top part of beam. This latter action should result in an additional downward beam deflection or "optical" twisting in accordance with Huygens principle [21]. In the phenomenon of gravitational red shift, light's energy and frequency decrease when moving into a region of lower gravitational field and thus gets red-shifted, while it gets blue-shifted when moving into a region of higher gravitational field.

6) For objects moving at radial velocities (along r) such as in the example shown in Figure 4, comprising a source charge q_1 moving along r at velocity $\mathbf{v}_1$, and a stationary test charge q_2, one can derive the appropriate radial velocity term T_{Dr} using Lorentz Transformations. The term T_{Dr} can be written as [5]:

$$T_{\mathrm{Dr}} = \frac{1}{\gamma^2} = \left(1 - \frac{\mathbf{v}_1^2}{c^2}\right) \tag{66}$$

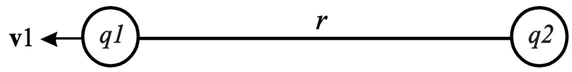

Figure 4 - EM Forces between two Charges – Radial Velocity

By substituting (66) in (57) and letting $T_{\mathrm{D}} = T_{\mathrm{Dr}}$ one can write the G_{QE} equation as follows:

$$G_{\mathrm{QE}} = \frac{e^2 N_{\mathrm{A}}^2}{2\pi\varepsilon_0}\left(1 - \frac{\mathbf{v}_1^2}{c^2}\right)\left(T_{\mathrm{macro}} + T_{\mathrm{micro}}\right) \tag{67}$$

which indicates that gravity in QEG can be influenced by object's radial velocity. Substituting (67) in (55) will make the force decrease as $\mathbf{v}_1$ increases and continues to decrease all the way down to zero (i.e. no gravity) at $\mathbf{v}_1 = c$. If $\mathbf{v}_1 > c$, the first bracketed term in (67) becomes negative which will make gravity change sign and become "repulsive". Equation (67) is expected to have potential implications for the expansion, dynamics and evolution of the universe.

7) The quantum electric gravitational parameter G_{QE} may possibly have another quite interesting behaviour, namely that of temperature sensitivity and effect. Since the total energy in a system is conserved one would expect from (7-9) that any changes in $\mathrm{U_d}$ should alter $\mathrm{U_r}$ and force $\mathbf{F}_{\mathrm{r}}$. An increase in temperature will increase $\mathrm{U_d}$ (thermal expansion), decrease $\mathrm{U_r}$ and decrease distance r, while a decrease in temperature will decrease $\mathrm{U_d}$, increase $\mathrm{U_r}$ and increase distance r. The temperature may alter the "bias" or operating point (p_0, p_1, p_2 .....) on the curve shown in Figure 1 and 2, which effect may produce some nonlinear behaviour that can impact the energy of the system and trade-off. This is expected to have some implications for the expansion and dynamics of the universe as a function of temperature.

8) It is interesting to observe that the "*asymmetrical*" behaviour of the vdW/L-J potential (see Figure 1) is akin to that of a *leaky* Diode Rectifier commonly used in electrical circuits, which enhances one polarity over another. It appears that, by virtue of its property, matter itself is able to dictate how it can *exploit* the bi-directional EM field (likened to alternating current AC) by rectifying part of its

energy in order to extract some unidirectional (likened to rectified direct current DC) energy and force, again, in a manner reminiscent of electrical circuits.

9) We can use Figure 1 to visualize what happens during object's free fall in gravitational field. The gravitational field will produce tidal forces trying to extend the object by moving the auto-balanced equilibrium point from p_0 to p_1 and d_0 to d_1. In turn this will minutely shorten distance r from r_0 to r_1. The object is now effectively moved slightly closer to a higher gravitational field. The process will now repeat itself leading to progressively shorter and shorter r values until the two objects come into contact. Thus the free fall is driven by a positive feedback chain-reaction that thrives to bring the system into the lowest energy state possible. Here is a summary of the free fall sequences, moving from left to right:

$$\begin{aligned} & r_0 \; > \; r_1 \; > \; r_2 \cdots\cdots \; > \; r_{\mathrm{n}} \\ & d_0 \; < \; d_1 \; < \; d_2 \cdots\cdots \; < \; d_{\mathrm{n}} \\ & p_0 \rightarrow p_1 \rightarrow p_2 \cdots\cdots \rightarrow p_{\mathrm{n}} \end{aligned} \tag{68}$$

10) From QEG's equations presented in this paper, one would expect the QEG force to be valid as long as the structure of charge-neutral entities is preserved. One, therefore, wonders about the ultimate form of matter existing at the extremely high levels of gravity found inside very massive stars, and whether it would be in the form of neutrons, quarks or some other unknown forms. The analysis and investigation of the Tripole Atomic Model (S-5) appears to suggest that, providing the structure and form of charge-neutral entities were to be preserved, the force of gravity inside these massive objects may reach a certain limit imposed by the smallest and most compact attainable form of charge-neutral entities and the distances between them. From our current knowledge it is probable that this limit may lie at the level of neutrons (neutron stars). However, if the form of charge-neutral entities were to ultimately breakdown, QEG would then vanish to unmask the raw EM forces into the realm of the presently unknown world.

9. Conclusion

This paper clearly demonstrated the existence of an indelible scientific link (GE-Link) between gravity and electricity/EM. The GE-Link was founded on some of the strongest fundamental pillars of physics namely, electromagnetic theory and molecular bonding and interactions. The paper also demonstrated how a simple and basic Tripole electric atomic model can so effectively supports, establishes and vindicates the GE-Link. The Tripole was then used to probe further into gravity and eventually lead to reproducing Newton's law of gravity using nothing other than EM theory. This compels one to suggest the existence of a new electric theory of gravity referred to as Quantum Electric Gravity (QEG). It is "quantum" because both EM and molecular interactions are essentially pure quantum electrodynamics phenomena. By combining the hitherto irreconcilable theories of Newton's and quantum mechanics/physics, it is expected that the new understandings brought about by the GE-Link and QEG should provide flexible tools and concepts more able to cope with and handle contemporary intractable gravitational and cosmological issues. It is also hoped that this may provide the missing link between gravity and the other fundamental forces of nature, which should bring the goal of theory of everything closer than have been possible. Lying dormant for over three centuries, the origin and character of the gravitational constant G are beginning to unravel, for the GE-Link is now pointing to its quantum electric origin.

Appendix–A: QED's Force Mediation by Virtual Particles

Quantum Electrodynamics (QED), developed by Feynman [6] and others, extends quantum mechanics to the EM Field. QED is a quantum field theory, and is one of the most precise physical theories that have been extensively confirmed experimentally as in the cases of the Gyromagnetic ratio of the Electron [7], the Lamb's shift and Casimir effect [8]. In QED, virtual particles such as electron-positron pairs can be created by "borrowing" energy ΔE from the vacuum for a brief period of time Δt in accordance with the Heisenberg Uncertainty Principle $\Delta E\,\Delta t \geq \hbar/2$. But shortly afterwards they recombine and annihilate to "pay back" their borrowed energy, and this incessant process of creation and annihilation goes on forever. In QED the EM field is quantised and is represented by particles called photons. QED explains how charge particles (fermions) interact by the exchange of messenger particles or photons (bosons) [7,8,9]. For electric and magnetic forces QED describes such interactions as exchange of force-carrier particles in the form of temporary or virtual particles or virtual photons. These particles are "virtual" because they do not obey energy/momentum relations as do real particles. Unlike real photons which transport EM wave, virtual photons mediate the electric and magnetic forces [7,8]. QED also addressed the ambiguous concept of action-at-a-distance as originally envisaged by Newton, and replaced it with the exchange of messenger particles between charge entities. In addition, the quantum vacuum is teeming with virtual particle pairs such as electron-positron pairs that are constantly being created and annihilated. These virtual particle pairs will get polarized when in the neighbourhood of charge entities, through a process known as vacuum polarization [22].

Appendix–B: Atoms as Charge-Neutral Entities

Since neutral atoms contain equal amount of positive and negative charge, one may consider them as charge-neutral entities. A summary of the properties of charge-neutral entities includes:

i) The most striking feature is that they can interact with other charge entities via two types of electromagnetic/QED fields and forces: attractive and repulsive. So, they can exert push and pull forces on all other charge entities, whether single charge or charge-neutral entities.
ii) The absolute magnitudes of positive and negative charge are identical.
iii) The opposite direction fields and forces in (i) will almost completely cancel each other out and, on average, portray atoms as electrically neutral.
iv) They also include neutrons, which do have internal charge structure capable of interacting with fields and forces.
v) They are the fabric of the universe.

Appendix–C: Atomic Charge Factor A_q – Neutral Atoms

$$\text{Electrons} \quad \rightarrow Z$$

$$\text{Proton quarks} \quad \rightarrow (2u,d)Z$$

$$\text{Neutron quarks} \rightarrow (u,2d)(A-Z)$$

$$A_q\,(\text{positive entities}) \;= 2u\,Z + u(A-Z) = \left(\left(\frac{2}{3}+\frac{2}{3}\right)Z + \frac{2}{3}(A-Z)\right) = \frac{2}{3}(A+Z)$$

$$A_q\,(\text{negative entities}) \;= Z + d\,Z + 2d(A-Z) = \left(\left(1+\frac{1}{3}\right)Z + \left(\frac{1}{3}+\frac{1}{3}\right)(A-Z)\right) = \frac{2}{3}(A+Z)$$

Appendix–D - Binomial Expansions – (Multipole Expansion)

$$\frac{1}{(1\mp x)^2} = (1\mp x)^{-2} = 1 \pm 2\frac{x}{r} + 3\left(\frac{x}{r}\right)^2 \cdots \qquad |x| < 1$$

<u>A) Repulsive Components (23)</u>

$$T_{\text{rep1}} = \frac{1}{r^2}$$

$$T_{\text{rep2}} = \frac{x_{1a}x_{2a}}{r^2}\left(1+\frac{a_1-a_2}{r}\right)^{-2} = \frac{x_{1a}x_{2a}}{r^2}\left(1-2\frac{a_1}{r}+2\frac{a_2}{r}+3\frac{a_1^2}{r^2}+3\frac{a_2^2}{r^2}-6\frac{a_1a_2}{r^2}\cdots\right)$$

$$T_{\text{rep3}} = \frac{x_{1a}x_{2b}}{r^2}\left(1+\frac{a_1+b_2}{r}\right)^{-2} = \frac{x_{1a}x_{2b}}{r^2}\left(1-2\frac{a_1}{r}-2\frac{b_2}{r}+3\frac{a_1^2}{r^2}+3\frac{b_2^2}{r^2}+6\frac{a_1b_2}{r^2}\cdots\right)$$

$$T_{\text{rep4}} = \frac{x_{1b}x_{2a}}{r^2}\left(1-\frac{b_1+a_2}{r}\right)^{-2} = \frac{x_{1b}x_{2a}}{r^2}\left(1+2\frac{b_1}{r}+2\frac{a_2}{r}+3\frac{b_1^2}{r^2}+3\frac{a_2^2}{r^2}+6\frac{b_1a_2}{r^2}\cdots\right)$$

$$T_{\text{rep5}} = \frac{x_{1b}x_{2b}}{r^2}\left(1-\frac{b_1-b_2}{r}\right)^{-2} = \frac{x_{1b}x_{2b}}{r^2}\left(1+2\frac{b_1}{r}-2\frac{b_2}{r}+3\frac{b_1^2}{r^2}+3\frac{b_2^2}{r^2}-6\frac{b_1b_2}{r^2}\cdots\right)$$

Summing up similar repulsive *r*-terms and using $x_{1a} + x_{1b} = 1$ and $x_{2a} + x_{2b} = 1$ (21-22) yield:

$$T_{\text{rep-r2}} = \frac{1}{r^2}\left(1+x_{1a}x_{2a}+x_{1a}x_{2b}+x_{1b}x_{2a}+x_{1b}x_{2b}\right) = \frac{2}{r^2}$$

$$T_{\text{rep-r3}} = \frac{2}{r^3}\left[x_{1a}x_{2a}\left(-a_1+a_2\right)+x_{1a}x_{2b}\left(-a_1-b_2\right)+x_{1b}x_{2a}\left(+b_1+a_2\right)+x_{1b}x_{2b}\left(+b_1-b_2\right)\right]$$

$$= \frac{2}{r^3}\left[-a_1\left(x_{1a}x_{2a}+x_{1a}x_{2b}\right)+a_2\left(x_{1a}x_{2a}+x_{1b}x_{2a}\right)+b_1\left(x_{1b}x_{2a}+x_{1b}x_{2b}\right)-b_2\left(x_{1a}x_{2b}+x_{1b}x_{2b}\right)\right]$$

$$= \frac{2}{r^3}\left(-a_1x_{1a}+a_2x_{2a}+b_1x_{1b}-b_2x_{2b}\right) = \frac{2}{r^3}Y_{\text{r3}}$$

$$T_{\text{rep-r4}} = \frac{3}{r^4}\left(\cdots\cdots\right) = \frac{3}{r^4}Y_{\text{r4}}$$

$$\boxed{T_{\text{Trep}} = +\left(T_{\text{rep-r2}}+T_{\text{rep-r3}}+T_{\text{rep-r4}}+\cdots\right) = 2\left(\frac{1}{r^2}+\frac{Y_{\text{r3}}}{r^3}+\frac{3}{2}\frac{Y_{\text{r4}}}{r^4}+\cdots\right)}$$

B) Attractive Components (24)

$$T_{\text{att1}} = \frac{x_{2a}}{r^2}\left(1-\frac{a_2}{r}\right)^{-2} = \frac{x_{2a}}{r^2}\left(1+2\frac{a_2}{r}+3\frac{a_2^2}{r^2}\cdots\right)$$

$$T_{\text{att2}} = \frac{x_{2b}}{r^2}\left(1+\frac{b_2}{r}\right)^{-2} = \frac{x_{2b}}{r^2}\left(1-2\frac{b_2}{r}+3\frac{b_2^2}{r^2}\cdots\right)$$

$$T_{\text{att3}} = \frac{x_{1a}}{r^2}\left(1+\frac{a_1}{r}\right)^{-2} = \frac{x_{1a}}{r^2}\left(1-2\frac{a_1}{r}+3\frac{a_1^2}{r^2}\cdots\right)$$

$$T_{\text{att4}} = \frac{x_{1b}}{r^2}\left(1-\frac{b_1}{r}\right)^{-2} = \frac{x_{1b}}{r^2}\left(1+2\frac{b_1}{r}+3\frac{b_1^2}{r^2}\cdots\right)$$

Summing up similar attractive *r*-terms and using $x_{1a} + x_{1b} = 1$ and $x_{2a} + x_{2b} = 1$ (21-22) yield:

$$T_{\text{att-r2}} = \frac{1}{r^2}\left(x_{2a}+x_{2b}+x_{1a}+x_{1b}\right) = \frac{2}{r^2}$$

$$T_{\text{att-r3}} = \frac{2}{r^3}\left(x_{2a}a_2-x_{2b}b_2-x_{1a}a_1+x_{1b}b_1\right) = \frac{2}{r^3}Y_{\text{a3}}$$

$$T_{\text{att-r4}} = \frac{3}{r^4}Y_{\text{a4}}$$

$$\boxed{T_{\text{Tatt}} = \left(T_{\text{att-r2}}+T_{\text{att-r3}}+T_{\text{att-r4}}+\cdots\cdots\right) = 2\left(\frac{1}{r^2}+\frac{Y_{\text{a3}}}{r^3}+\frac{3}{2}\frac{Y_{\text{a4}}}{r^4}+\cdots\right)}$$

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