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Evidence of Repulsive and Attractive Force between 2 Arrays of Neutral Gold Atoms from Electrostatic Calculations

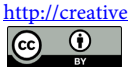
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Abstract

Electrostatic equations in 3 dimensions were set up for the interaction between 2 arrays of neutral atoms. The residual force at small distance from gold neutral atoms was found not negligible. Three atom-thick structures were used: atom, plate and wire. Two structures were set aligned in front of each other, one was considered fix (not moving) and the other was free to move under the action of the force between them. The calculations showed evidence of attraction and repulsion depending on the separation distances between them. Evidence of Poisson-Arago spot appeared when a gold atom was shot to the center of one of the side of a gold plate. The spot appeared just before touching the center of the plate. The results obtained here could find potential applications in nano-electric generators and nano-antennas and also on predicting the Poisson-Arago spot using structured and heavy projectiles like gold atoms which extends particle diffraction to a significant greater range on the projectile mass.

Subject Areas

Nuclear Physics, Nuclear Technology

Keywords

Casimir Effect, Diffraction, Poisson-Arago Spot

1. Introduction

In February of 1948, Casimir and Polder published a paper dealing with the impact of the retardation on the London-van der Waals forces between an atom and a perfectly conducting plane and between 2 neutral atoms using electrodynamics to describe the attractive interaction [1].

In May 1948 Casimir communicated, at a mathematics meeting, the results of his research on the attractive force between 2 conducting plates [2] based on the electromagnetic zero point energy.

Ref. [3] formulated and computed the Casimir effect without referencing to the zero point energy, instead a relativistic quantum force between charges and currents was formulated which yields the Casimir force per unit area when the fine structure goes to zero.

This work set up electrostatic equations in 3 dimensions for the interaction between 2 arrays of neutral gold atoms with the hope that the residual force at small distance from metallic neutral atoms is not negligible as was demonstrated before in diffraction calculations related with the Poisson arago spot [4]. Three atom-thick structures were used: atom, plate and wire. Two structures were set aligned in from of each other (atom-atom, plate-plate, wire-wire), one is considered rigid (not moving) and the other is free to move under the action of the force between them. The results of the calculations show evidence of attraction and repulsion depending on the separation distances between them. Additionally, evidence of Poisson-Arago spot appeared when a gold atom with a speed of 500 m/s was shot to the center of one side of a gold plate, the spot appeared just before touching the center of the plate as obtained when shooting electrons to 1 atom thick gold plate in [4].

2. Electrostatic Model for 2 Sets of Neutral Metallic Atoms (One of the Sets Is Rigid) but Both Have Bound Motionless Atomic Electrons

The electrostatic force exerted by a rigid atom of one set on a free atom of another set is written as:

$$F_{mp-m,x} = k\left((Ze)^2 \frac{x_{m.p}(t) - x_m}{r_{mp-m}^3} - 2Ze^2 \sum_{i=1}^{Z} \frac{x_{m.p}(t) - (x_m + \Delta x_i)}{r_{mp-m,i}^3} + e^2 \sum_{i.p=1}^{Z} \sum_{i=1}^{Z} \frac{(x_{m.p}(t) + \Delta x_{i.p}) - (x_m + \Delta x_i)}{r_{m.i.p-,m,i}^3} \right) \tag{1}$$

$$F_{mp-m,y} = k\left((Ze)^2 \frac{y_{m.p}(t) - y_m}{r_{mp-m}^3} - 2Ze^2 \sum_{i=1}^{Z} \frac{y_{m.p}(t) - (y_m + \Delta y_i)}{r_{mp-m,i}^3} + e^2 \sum_{i.p=1}^{Z} \sum_{i=1}^{Z} \frac{(y_{m.p}(t) + \Delta y_{i.p}) - (y_m + \Delta y_i)}{r_{m.i.p-,m,i}^3} \right) \tag{2}$$

$$F_{mp-m,z} = k\left((Ze)^2 \frac{z_{m.p}(t) - z_m}{r_{mp-m}^3} - 2Ze^2 \sum_{i=1}^{Z} \frac{z_{m.p}(t) - (z_m + \Delta z_i)}{r_{mp-m,i}^3} + e^2 \sum_{i.p=1}^{Z} \sum_{i=1}^{Z} \frac{(z_{m.p}(t) + \Delta z_{i.p}) - (z_m + \Delta z_i)}{r_{m.i.p-,m,i}^3} \right) \tag{3}$$

where,

$$r_{m.p-m} = \sqrt{\left(x_{m.p}(t) - x_m\right)^2 + \left(y_{m.p}(t) - y_m\right)^2 + \left(z_{m.p}(t) - z_m\right)^2}$$

$$r_{m.p-m,i} = \sqrt{\left(x_{m.p}(t) - \left(x_m + \Delta x_j\right)\right)^2 + \left(y_{m.p}(t) - \left(y_m + \Delta y_i\right)\right)^2 + \left(z_{m.p}(t) - \left(z_m + \Delta z_i\right)\right)^2}$$

$$r_{m.i.ip-m,i} = \sqrt{\left(\left(x_{m.p}(t) + \Delta x_{j.p}\right) - \left(x_m + \Delta x_j\right)\right)^2 + \left(\left(y_{m.p}(t) + \Delta y_{i.p}\right) - \left(y_m + \Delta y_i\right)\right)^2 + \left(\left(z_{m.p}(t) + \Delta z_{i.p}\right) - \left(z_m + \Delta z_i\right)\right)^2}$$

where,

F_x, F_y, F_z: Force exerted by all atoms of one data set on all the atoms of the other data set in their respective spatial coordinates x, y, z

mp, m, ip, i: Indexes representing a particular projectile and target atom and particular projectile and target atomic electron

k; Coulomb constant. $k = \dfrac{1}{4\pi\varepsilon_0}$ ε_0: Permittivity of free space (vacuum)

Z: Projectile/Target atomic number

e: Absolute value of the electron charge

$x_{m.p}, x_m$ $y_{m.p}, y_m$ $z_{m.p}, z_m$; Spatial coordinates of the projectile (p) and target (m)

Δx, Δy, Δz: Electron spatial coordinates relative to the nucleus position in question

$r_{m.p-m}$: Separation distance between the projectile atom and the target atom

$r_{m.p-m,i}$: Separation distance between the projectile nucleus and the target atomic electron

$r_{m,i.p-m,i}$: Separation distance between the projectile atomic electron and the target atomic electron

Note that the 1st term of the equations above represent the forces among the nuclei of different sets, the 2nd term are the forces among the target/projectile atomic electrons and the projectile/target nuclei (2 terms) and the 3rd term are the forces among the target atomic electrons and the projectile atomic electrons. Note also that all nuclei and atomic electrons of the projectile move together without any relative movements among them (their trajectories are parallels to each other). That is why the projectile atomic electron positions ($\Delta x_{j.p}$, $\Delta y_{j.p}$, $\Delta z_{j.p}$) are written without any reference to time despite they do have a time dependent trajectory.

Note that by using the relation between the fine structure constant (α) and the electron charge ($\alpha = \dfrac{e^2}{4\pi\varepsilon_0 \hbar c}$), the equations above can be expressed in term of the Planck constant and the speed light, which indicates a link among QM, electromagnetism (EM) and electrostatic as a special case of EM.

The total force on each axis considering all atoms of the 2 datasets is calculated as:

$$F_x = \sum_{mp=1} \sum_{m=1} F_{mp-m,x} \quad F_y = \sum_{mp=1} \sum_{m=1} F_{mp-m,y} \quad F_z = \sum_{mp=1} \sum_{m=1} F_{mp-m,z} \tag{4}$$

The magnitude of the total force on the free-to-move dataset is therefore

$F = \sqrt{F_x^2 + F_y^2 + F_z^2}$

Note that all atoms of the free dataset are assumed to be moving together forming different shapes like spheres, discs, plates, etc. Similarly, all atoms of the rigid (non-moving) dataset could also be of different shapes.

Note that just because Equations (1) through (3) are written for 2 electrically neutral atoms the total force is not necessarily negligible for very small distance between the 2 structures (see next section for specific results).

Acceleration discretization:

$$a_x = F_x(t)/M \quad a_y = F_y(t)/M \quad a_z = F_z(t)/M \quad a = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{5}$$

where,

a : Magnitude of the total acceleration of the free dataset

M : Mass of the free dataset

$$\left(v_x(t+\Delta t) - v_x(t)\right)/\Delta t = a_x \quad \left(v_y(t+\Delta t) - v_y(t)\right)/\Delta t = a_y$$
$$\left(v_z(t+\Delta t) - v_z(t)\right)/\Delta t = a_z$$

Solving for the projectile speed at $t + \Delta t$:

$$v_x(t+\Delta t) = v_x(t) + a_x \Delta t \quad v_y(t+\Delta t) = v_y(t) + a_y \Delta t \quad v_z(t+\Delta t) = v_z(t) + a_z \Delta t \tag{6}$$

Discretization of speed components ($v_x = \mathrm{d}x/\mathrm{d}t \quad v_y = \mathrm{d}y/\mathrm{d}t \quad v_z = \mathrm{d}z/\mathrm{d}t$):

$$\left(x(t+\Delta t) - x(t)\right)/\Delta t = v_x(t) \quad \left(y(t+\Delta t) - y(t)\right)/\Delta t = v_y(t)$$
$$\left(z(t+\Delta t) - z(t)\right)/\Delta t = v_z(t)$$

Solving for the projectile spatial coordinate (location):

$$x(t+\Delta t) = x(t) + v_x(t)\Delta t \quad y(t+\Delta t) = y(t) + v_y(t)\Delta t \quad z(t+\Delta t) = z(t) + v_z(t)\Delta t \tag{7}$$

Once this new free-dataset-spatial coordinates are obtained, the force values are updated and the algorithm is continued (using Equations (1)-(7)) until desired.

If the free dataset is relativistic the initial speed (in the case that what is known is the kinetic energy (E_k)) should be calculated using special relativity as

$$v = c\sqrt{1 - 1/\gamma^2} \tag{8}$$

where,

$$\gamma = 1 + E_k/\left(mc^2\right)$$

c : The usually called speed of light in vacuum

The acceleration should also be corrected for relativistic free-dataset, for example, as

$$a_c = a\left(1 - \beta^2\right)^n \tag{9}$$

where,

$$\beta = v/c$$

$n = 0$: Newtonian acceleration.

$n = 3$. Yields the correct perihelion precession of the planets in the solar system [5].

The traditional correction of special relativity could also be considered.

3. Numerical Results and Analysis

Neutral gold atoms were chosen to demonstrate the Casimir effect based on electrostatics since gold has been used in many experiments related with particle diffraction and has also been specifically used in the experimental demonstration of the Casimir effect.

For convenience and lack of detail knowledge, the electrons were not radially located following any specific quantum mechanical atomic model (e.g. Bohr, Sommerfeld, and Schrodinger), and neither were them considered to have significant kinetic energy. Instead, the electrons in each shell were distributed symmetrically around the nucleus on the x-y plane (all located at z = 0 in the rigid set) and at equally spaced shell radius as in [4] (2, 7, 18, 32, 18, 1: electrons per shell for increasing shell number). The 2 electrons of shell 1 were positioned on the x axis. The last electron (shell 6: 79th electron) was positioned on the positive x axis at the edge of the atom (144 pm).

Tables 1-5 show the results of the calculations for 2 structures of atoms: 2 atoms and 2 parallel plates of one-atom thickness. The MKS unit system was used for the reported variables (spatial coordinates, the force and the acceleration).

Table 1 shows the results of the calculations for 2 atoms (one free to move and the other fix at z = 0) separated by 1 nm. The results show a clear repulsive effect since the z variable increases with time. Note that the x and y variable significantly depart from zero so the net movement does not happen only on the z direction. Note the linear dependency of z vs. time as seen from the reported fitting using the data with boldface fonts.

Table 1. Two atoms repulsion at a separation distance of 1 nm.

t	x	y	z	f	a
1.000E−12	−9.512E−09	6.458E−09	**3.394E−09**	3.842E−09	1.174E+16
2.000E−12	−1.901E−08	1.291E−08	**5.782E−09**	4.189E−12	1.280E+13
3.000E−12	−2.852E−08	1.936E−08	**8.170E−09**	5.465E−13	1.671E+12
4.000E−12	−3.802E−08	2.581E−08	**1.056E−08**	1.641E−13	5.016E+11
5.000E−12	−4.752E−08	3.226E−08	**1.295E−08**	6.966E−14	2.130E+11
6.000E−12	−5.702E−08	3.871E−08	**1.533E−08**	3.580E−14	1.094E+11
7.000E−12	−6.652E−08	4.516E−08	**1.772E−08**	2.077E−14	6.349E+10
8.000E−12	−7.602E−08	5.161E−08	**2.011E−08**	1.310E−14	4.005E+10
9.000E−12	−8.552E−08	5.806E−08	**2.250E−08**	8.789E−15	2.687E+10
1.000E−11	−9.502E−08	6.451E−08	**2.488E−08**	6.179E−15	1.889E+10
1.100E−11	−1.045E−07	7.096E−08	**2.727E−08**	4.508E−15	1.378E+10

Continued

1.200E−11	−1.140E−07	7.741E−08	**2.966E−08**	3.389E−15	1.036E+10
1.300E−11	−1.235E−07	8.386E−08	**3.204E−08**	2.612E−15	7.985E+09
1.400E−11	−1.330E−07	9.031E−08	**3.443E−08**	2.055E−15	6.283E+09
1.500E−11	−1.425E−07	9.676E−08	**3.682E−08**	1.646E−15	5.033E+09
1.600E−11	−1.520E−07	1.032E−07	**3.921E−08**	1.339E−15	4.093E+09
1.700E−11	−1.615E−07	1.097E−07	**4.159E−08**	1.104E−15	3.374E+09
1.800E−11	−1.710E−07	1.161E−07	**4.398E−08**	9.203E−16	2.813E+09
1.900E−11	−1.805E−07	1.226E−07	**4.637E−08**	7.755E−16	2.371E+09
2.000E−11	−1.900E−07	1.290E−07	**4.876E−08**	6.595E−16	2.016E+09
z = 2387.4t + 1E−09					
R^2 = 1					

Table 2. Two atoms attraction at a separation distance of 10 nm.

t	x	y	z	f	a
1.000E−12	−9.356E−12	6.470E−12	**1.000E−08**	3.721E−12	1.138E+13
2.000E−12	−2.807E−11	1.941E−11	**1.000E−08**	3.721E−12	1.138E+13
3.000E−12	−5.614E−11	3.882E−11	**1.000E−08**	3.721E−12	1.138E+13
4.000E−12	−9.356E−11	6.470E−11	**9.999E−09**	3.721E−12	1.138E+13
5.000E−12	−1.403E−10	9.705E−11	**9.999E−09**	3.722E−12	1.138E+13
6.000E−12	−1.965E−10	1.359E−10	**9.997E−09**	3.723E−12	1.138E+13
7.000E−12	−2.619E−10	1.811E−10	**9.995E−09**	3.724E−12	1.138E+13
8.000E−12	−3.367E−10	2.328E−10	**9.992E−09**	3.727E−12	1.139E+13
9.000E−12	−4.208E−10	2.910E−10	**9.987E−09**	3.730E−12	1.140E+13
1.000E−11	−5.142E−10	3.556E−10	**9.981E−09**	3.735E−12	1.142E+13
1.100E−11	−6.168E−10	4.265E−10	**9.973E−09**	3.742E−12	1.144E+13
1.200E−11	−7.287E−10	5.039E−10	**9.962E−09**	3.752E−12	1.147E+13
1.300E−11	−8.496E−10	5.875E−10	**9.948E−09**	3.764E−12	1.151E+13
1.400E−11	−9.796E−10	6.774E−10	**9.930E−09**	3.779E−12	1.155E+13
1.500E−11	−1.119E−09	7.735E−10	**9.908E−09**	3.798E−12	1.161E+13
1.600E−11	−1.266E−09	8.757E−10	**9.882E−09**	3.822E−12	1.168E+13
1.700E−11	−1.423E−09	9.840E−10	**9.851E−09**	3.850E−12	1.177E+13
1.800E−11	−1.588E−09	1.098E−09	**9.814E−09**	3.883E−12	1.187E+13
1.900E−11	−1.761E−09	1.218E−09	**9.770E−09**	3.922E−12	1.199E+13
2.000E−11	−1.943E−09	1.343E−09	**9.719E−09**	3.966E−12	1.213E+13
$z = -7E+54t^6 + 4E+44t^5 - 1E+34t^4 + 1E+23t^3 - 7E+11t^2 + 1.6602t + 1E-08$					
R^2 = 1	**Z monotonously decreases with time**				

Table 2 shows the results for the same structure of Table 1, but with a separation of 10 nm. From that table can be seen an attractive effect since z decreases with time. A polynomial fitting of 6 degree explains the data without any oscillation of the fitting curve.

Table 3 shows the results of the calculations for 2 plates made of 100 atoms in the x and y direction separated by 1 nm (one free to move and the other fixed at z = 0). A linear repulsive effect is manifested by the fitting results. Note that as in the case of the 2 atoms, the plate motion does not happen only on the z direction so a simultaneous attraction and lateral displacement happened. The reason for that asymmetry could be related with the atomic electron distribution and/or precision/accuracy of the compiler and/or of the CPU. No matter the reason for that, it indicates a potential impact on the making of nanotechnology devices.

Table 4 shows the results for the same structure of Table 3, but with a separation

Table 3. Two plates repulsion at a separation distance of 1 nm.

t	x	y	z	f	a
1.000E−12	−9.512E−09	6.458E−09	**3.394E−09**	3.842E−05	1.174E+16
2.000E−12	−1.902E−08	1.292E−08	**5.788E−09**	1.161E−09	3.550E+11
3.000E−12	−2.854E−08	1.937E−08	**8.181E−09**	5.717E−10	1.748E+11
4.000E−12	−3.805E−08	2.583E−08	**1.057E−08**	3.157E−10	9.651E+10
5.000E−12	−4.756E−08	3.229E−08	**1.297E−08**	1.906E−10	5.826E+10
6.000E−12	−5.707E−08	3.875E−08	**1.536E−08**	1.231E−10	3.764E+10
7.000E−12	−6.658E−08	4.520E−08	**1.776E−08**	8.389E−11	2.564E+10
8.000E−12	−7.609E−08	5.166E−08	**2.015E−08**	5.960E−11	1.822E+10
9.000E−12	−8.560E−08	5.812E−08	**2.254E−08**	4.380E−11	1.339E+10
1.000E−11	−9.511E−08	6.458E−08	**2.494E−08**	3.311E−11	1.012E+10
1.100E−11	−1.046E−07	7.103E−08	**2.733E−08**	2.562E−11	7.832E+09
1.200E−11	−1.141E−07	7.749E−08	**2.972E−08**	2.022E−11	6.182E+09
1.300E−11	−1.236E−07	8.395E−08	**3.212E−08**	1.624E−11	4.963E+09
1.400E−11	−1.332E−07	9.041E−08	**3.451E−08**	1.323E−11	4.044E+09
1.500E−11	−1.427E−07	9.686E−08	**3.691E−08**	1.092E−11	3.338E+09
1.600E−11	−1.522E−07	1.033E−07	**3.930E−08**	9.118E−12	2.787E+09
1.700E−11	−1.617E−07	1.098E−07	**4.169E−08**	7.691E−12	2.351E+09
1.800E−11	−1.712E−07	1.162E−07	**4.409E−08**	6.546E−12	2.001E+09
1.900E−11	−1.807E−07	1.227E−07	**4.648E−08**	5.617E−12	1.717E+09
2.000E−11	−1.902E−07	1.292E−07	**4.887E−08**	4.856E−12	1.484E+09
z = 2393.7t + 1E−09					
R^2 = 1					

Table 4. Two plates attraction at a separation distance of 10 nm.

t	x	y	z	f	a
1.000E−12	−9.356E−12	6.470E−12	1.000E−08	3.721E−08	1.138E+13
2.000E−12	−1.817E−11	1.318E−11	1.000E−08	2.182E−09	6.670E+11
3.000E−12	−2.643E−11	2.012E−11	9.999E−09	2.181E−09	6.666E+11
4.000E−12	−3.415E−11	2.729E−11	9.998E−09	2.179E−09	6.662E+11
5.000E−12	−4.133E−11	3.470E−11	9.997E−09	2.178E−09	6.658E+11
6.000E−12	−4.796E−11	4.235E−11	9.995E−09	2.177E−09	6.655E+11
7.000E−12	−5.405E−11	5.023E−11	9.994E−09	2.176E−09	6.652E+11
8.000E−12	−5.959E−11	5.834E−11	9.992E−09	2.175E−09	6.650E+11
9.000E−12	−6.459E−11	6.669E−11	9.989E−09	2.175E−09	6.648E+11
1.000E−11	−6.904E−11	7.527E−11	9.986E−09	2.174E−09	6.646E+11
1.100E−11	−7.295E−11	8.408E−11	9.983E−09	2.174E−09	6.645E+11
1.200E−11	−7.631E−11	9.312E−11	9.980E−09	2.174E−09	6.645E+11
1.300E−11	−7.913E−11	1.024E−10	9.976E−09	2.174E−09	6.645E+11
1.400E−11	−8.140E−11	1.119E−10	9.973E−09	2.174E−09	6.645E+11
1.500E−11	−8.313E−11	1.216E−10	9.968E−09	2.174E−09	6.645E+11
1.600E−11	−8.431E−11	1.316E−10	9.964E−09	2.174E−09	6.647E+11
1.700E−11	−8.494E−11	1.418E−10	9.959E−09	2.175E−09	6.648E+11
1.800E−11	−8.503E−11	1.522E−10	9.954E−09	2.175E−09	6.650E+11
1.900E−11	−8.457E−11	1.629E−10	9.948E−09	2.176E−09	6.652E+11
2.000E−11	−8.356E−11	1.738E−10	9.943E−09	2.177E−09	6.655E+11

$z = 4E{+}54t^6 - 3E{+}44t^5 + 7E{+}33t^4 - 8E{+}22t\text{^}3 + 3E{+}11t^2 - 0.9622t + 1E{-}08$

$R^2 = 0.9995$ Z monotonously decreases with time

of 10 nm. From that table can be seen an attractive effect since z decreases with time. A polynomial fitting of 6 degree explains the data without any oscillation of the fitting curve.

Since for 1 nm a repulsion effect appeared and for 10 nm an attraction effect is manifested, additional calculations were made to find a separation distance where both effects could be expected to appear.

Table 5 shows the results for a separation of 4 nm. Note the transition from repulsion to attraction at about 8 picoseconds.

Out of curiosity calculations were made for 2 wires of 1 atom thickness separated on the z axis by a finite amount (the wires were the mirror of each other). For 1 nm the repulsion effect appeared but for 10 nm unexpected oscillations of z vs. time appeared (see Figure 1), indicating not only cycles of attractions and repulsions but also the crossing of the atoms of the movable wire through the atoms of the fixed wire.

Table 5. Two plates repulsion/attraction at a separation distance of 4 nm.

t	x	y	z	f	a
1.000E−12	−1.463E−10	1.011E−10	**4.001E−09**	5.818E−07	1.779E+14
2.000E−12	−2.919E−10	2.024E−10	**4.001E−09**	2.561E−09	7.828E+11
3.000E−12	−4.368E−10	3.040E−10	**4.002E−09**	2.528E−09	7.727E+11
4.000E−12	−5.810E−10	4.059E−10	**4.002E−09**	2.495E−09	7.628E+11
5.000E−12	−7.245E−10	5.080E−10	**4.002E−09**	2.463E−09	7.530E+11
6.000E−12	−8.673E−10	6.103E−10	**4.002E−09**	2.432E−09	7.435E+11
7.000E−12	−1.009E−09	7.129E−10	**4.002E−09**	2.402E−09	7.341E+11
8.000E−12	−1.151E−09	8.157E−10	**4.001E−09**	2.371E−09	7.249E+11
9.000E−12	−1.292E−09	9.187E−10	**4.001E−09**	2.342E−09	7.159E+11
1.000E−11	−1.432E−09	1.022E−09	**4.000E−09**	2.313E−09	7.071E+11
1.100E−11	−1.571E−09	1.125E−09	**4.000E−09**	2.285E−09	6.984E+11
1.200E−11	−1.710E−09	1.229E−09	**3.999E−09**	2.257E−09	6.898E+11
1.300E−11	−1.848E−09	1.333E−09	**3.998E−09**	2.229E−09	6.815E+11
1.400E−11	−1.986E−09	1.437E−09	**3.997E−09**	2.202E−09	6.732E+11
1.500E−11	−2.123E−09	1.541E−09	**3.996E−09**	2.176E−09	6.652E+11
1.600E−11	−2.259E−09	1.645E−09	**3.994E−09**	2.150E−09	6.572E+11
1.700E−11	−2.395E−09	1.750E−09	**3.993E−09**	2.124E−09	6.494E+11
1.800E−11	−2.530E−09	1.854E−09	**3.991E−09**	2.099E−09	6.418E+11
1.900E−11	−2.664E−09	1.959E−09	**3.990E−09**	2.075E−09	6.343E+11
2.000E−11	−2.798E−09	2.064E−09	**3.988E−09**	2.051E−09	6.269E+11

$z = 3E{+}54t^6 - 2E{+}44t^5 + 3E{+}33t^4 - 3E{+}22t^3 + 6E{+}10t^2 + 0.4887t + 4E{-}09$

$R^2 = 0.9968$ z vs. time shows a maximum

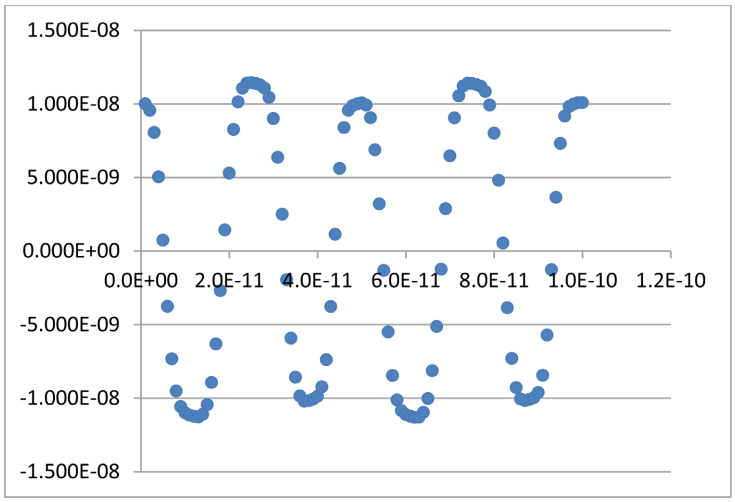


Figure 1. z (m) vs. time (sec.) profile for 2 wires in front of each other separated by 10 nm.

The reason for the apparent asymmetry could here also be related with the atomic electron distribution and/or precision/accuracy of the compiler and/or of the CPU. No matter the reason for that, it indicates a potential impact on the making of nanotechnology devices.

Even though the gravitational force strength is negligible when compared to the electric force it was thought that because the terms of the force equation are not of the same sign, a very small residual electric force could result which compared to the attractive gravitational force in all terms could impact the net result, but calculations results for few cases indicated that the residual electric force is still significantly large than the attractive gravitational force appearing in all terms of Equations (1) through (4).

In ref [4] was suggested that using electrostatics, the interaction of a structured projectile with a neutral metallic structure could be described and it could lead to a potential Poisson-Arago spot. Table 6 shows an example of the veracity of that prediction using the equations described in the present work. That Table shows the results of shooting a neutral gold atom to the center of one of the edges of a square gold plate of 10 micron side and 1-gold atom thick. The projectile speed, position and angle were 500 m/s, 1.5 m, 90 degree (perpendicular to the plate). The intersection of the x axis trajectory with the z axis trajectory occurred at about 0.01 mm away from the plate (between the projectile initial location and the plate). No spot was found after the plate for the few attempts tried using speed changes of no less than 1 m/s around 500 m/s.

Additional calculations showed that oscillatory (cycles of attraction/repulsion) behavior also appears when extending significantly the total time of the calculation for atom-atom interactions.

Table 6. One-gold atom projectile directed at the center of one side of a gold atom plate.

t	x	y	z	f	a
4.000E−05	−1.538E−16	1.064E−16	1.480E+00	3.823E−32	1.169E−07
		Printing jump			
3.000E−03	**−1.059E−10**	7.321E−11	**−1.171E−13**	1.613E−26	4.930E−02
3.040E−03	**1.038E+00**	3.590E−01	**−2.000E−02**	2.245E−16	6.864E+08
3.080E−03	**2.076E+00**	7.180E−01	**−4.000E−02**	1.393E−31	4.259E−07
3.120E−03	**3.114E+00**	1.077E+00	**−6.000E−02**	1.742E−32	5.324E−08
3.160E−03	**4.152E+00**	1.436E+00	**−8.000E−02**	5.161E−33	1.578E−08
3.200E−03	**5.190E+00**	1.795E+00	**−1.000E−01**	2.177E−33	6.655E−09
3.240E−03	**6.228E+00**	2.154E+00	**−1.200E−01**	1.115E−33	3.407E−09
3.280E−03	**7.266E+00**	2.513E+00	**−1.400E−01**	6.451E−34	1.972E−09
3.320E−03	**8.303E+00**	2.872E+00	**−1.600E−01**	4.062E−34	1.242E−09
3.360E−03	**9.341E+00**	3.231E+00	**−1.800E−01**	2.721E−34	8.319E−10

Continued

3.400E−03	**1.038E+01**	3.590E+00	**−2.000E−01**	1.911E−34	5.843E−10
3.440E−03	**1.142E+01**	3.949E+00	**−2.200E−01**	1.393E−34	4.259E−10
3.480E−03	**1.246E+01**	4.308E+00	**−2.400E−01**	1.047E−34	3.200E−10
3.520E−03	**1.349E+01**	4.667E+00	**−2.600E−01**	8.063E−35	2.465E−10
3.560E−03	**1.453E+01**	5.026E+00	**−2.800E−01**	6.342E−35	1.939E−10
3.600E−03	**1.557E+01**	5.385E+00	**−3.000E−01**	5.078E−35	1.552E−10
3.640E−03	**1.661E+01**	5.744E+00	**−3.200E−01**	4.128E−35	1.262E−10
3.680E−03	**1.764E+01**	6.103E+00	**−3.400E−01**	3.402E−35	1.040E−10
3.720E−03	**1.868E+01**	6.462E+00	**−3.600E−01**	2.836E−35	8.670E−11
3.760E−03	**1.972E+01**	6.821E+00	**−3.800E−01**	2.389E−35	7.303E−11
3.800E−03	**2.076E+01**	7.180E+00	**−4.000E−01**	2.031E−35	6.210E−11
3.840E−03	**2.180E+01**	7.539E+00	**−4.200E−01**	1.742E−35	5.324E−11
3.880E−03	**2.283E+01**	7.898E+00	**−4.400E−01**	1.505E−35	4.599E−11
3.920E−03	**2.387E+01**	8.257E+00	**−4.600E−01**	1.309E−35	4.000E−11
3.960E−03	**2.491E+01**	8.616E+00	**−4.800E−01**	1.145E−35	3.501E−11
4.000E−03	**2.595E+01**	8.975E+00	**−5.000E−01**	1.008E−35	3.081E−11
	$z = -0.0193x + 1.04E-05$				
	$R^2 = 1.00$				

4. Summary and Concluding Remarks

Electrostatic equations in 3 dimensions were set up for the interaction between 2 arrays of neutral atoms. The residual force at small distance from gold neutral atoms was found not negligible. Three atom-thick structures were used: atom, plate and wire. Two structures were set aligned in front of each other, one considered fix (not moving) and the other was free to move under the action of the force between them. The calculations showed evidence of attraction and repulsion depending on the separation distances between them. Evidence of Poisson-Arago spot appeared when a gold atom was shot to the center of one side of a gold plate. The spot appeared just before touching the center of the plate.

Calculations were made for 2 wires of 1 atom thickness separated on the z axis by a finite amount (the wires were the mirror of each other). For 1 nm the repulsion effect appeared but for 10 nm unexpected oscillations of z vs. time appeared indicating not only cycles of attractions and repulsions but also the crossing of the atoms of the movable wire through the atoms of the fixed wire.

No matter the reason for those oscillations, it indicates a potential impact on the making of nanotechnology devices. These results could find potential applications on nano-electric generators and nano-antennas if the 2 wires (or any other conceived structures) are set up intentionally misaligned (or even being aligned,

but with oscillatory cycles of attraction repulsion without atoms crossing, in this case the equations set up in this work will be even more applicable)

When comparisons with experiments are to be made, the impact of the atomic electron structure model on the results should be assessed so it is suggested to use different electronic structures to determine which one is the most adequate from accuracy and efficiency point of view.

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Conflicts of Interest

The author declares no conflicts of interest.

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