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3D Numerical Experiments with the Double Slit Geometry Using Neutral Dipole Particles

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Abstract

In a previous simulation by the author, the path of charged particles were shown to acquire wave properties like diffraction, interference and total reflection when singly shot through a wall of charged particles containing slits and when such paths are collected over time. This is caused by a temporary bound state between the randomly shot charged particles and those of the fixed and charged particles of the wall. In this study we extend the simulation to 3D and consider neutral (dipole) particles instead when shot at a neutral wall and show that a similar wave behavior occurs and within a condition of coherence. The neutral particles are made of two oppositely charged particles connected with a spring. The wall is made of fixed alternating charged particles with a total charge of zero, to simulate the random firing of dipoles at a wall of fixed dipoles, or the double slit experiment for neutral particles. Particles are assumed to interact under an inverse square law of forces and with the bullet dipoles further interacting internally under a spring force law that is derivable from an inverse square law. The numerical method used in the present analysis is simple and basic and can further be used to analyze other related problems like energy modes in molecules and crystals and the problems of focusing of beams of atoms .

Keywords: Double slit, wave-particle duality, inverse square

1 Introduction

From the very early days of modern physics evidence pointed to perplexing facts indicating that particles behave as waves in some physical interactions and as particles in others. That is: particles follow the laws of classical mechanics embodied in Newton's laws of motion sometimes and the laws of wave mechanics as given by the classical theory of waves pioneered by Huygens at others. The 'wave-particle duality principle' phrase was coined as a result of such observations, (See [1] for an interesting discussion of this and other related concepts).

In a previous study by this author [2] it was shown that the wave behavior in particles is true in general, but not necessarily an inherent one. Rather, it is a manifestation of a bound state phenomenon occurring between charged bodies interacting under the classical inverse square law of forces (the Coulomb force in the present case). The inverse square law changes to the spring law of force (Hook's law) if some of the interacting particles are fixed (or hardly moving) and there is a near balance of the different forces coupled with energy exchange. This is the same mechanism that creates waves in fluids within bounded regions. The molecules of a fluid and those of the walls are all governed by the Coulomb force or some of its derivatives like the spring force or the Van-der-Wall force [3]. In effect, a non-moving boundary isolates a small region from the rest of space, and as such replica regions can be added to this region producing a periodic structure and a corresponding periodic solution. Alternatively, one can think of a fixed boundary as one that folds the space changing it from flat and open to closed and circular and a periodic representation follows as a result.

Another observation that contributed to the perplexing behavior of a double-slit experiment is that when particles are shot one at a time and collected over a longer time, they too produce a wave behavior of diffraction and interference- normally associated only with group interactions of particles (a flux of particles). In the words of some, '*how does a single particle know where to land on a screen in order to produce the overall interference patterns collected over time*?'.

The explanation to this phenomenon as given in [2] is that it is simply the result of keeping a fixed geometry of a wall and slits common to all interactions- a spatial filter effect phenomenon. This is like a case of throwing balls or sand particles on a set of vertical compartments in a binomial theorem demonstration experiments of statistics, or as in ray optics wherein an image on a screen out of a fixed optical lens could be imagined as made up of the superposition of individual rays that need not be present at the same time or have any systematic order, provided the screen has long enough memory in adding everything up. In fact we shall see in the present results that a lens behavior is very much apparent here, producing results similar to those corresponding to positive and negative focusing- as observed in concave and convex lenses and mirrors. As is well known, ray optics is derivable from the full theory of waves. Naturally if the position of the collecting compartments or the display screen position or geometry or the initial particle velocity are made to change randomly by a small amount, the coherence is lost either partially or totally and the sought wave behavior disappears.

For purely neutral particles with no charge or a dipole moment and a wall-bullet relation that is only of the go-no go type, the pattern after a wall with a slit is expected to be the simple single line image of that slit. This would change if we are to model scattering and reflection of the beam from the edges of a slit. At most this will add fuzzy boarders to the shadow. In the present work we assume, instead, paired charged particles (i.e. zero total charge or electric dipoles) for our bullet particles. The constituents of these dipoles interact with the wall, but not with the slit part which is to be composed of particles with zero charges. The number of particles removed to make a slit must therefore be even to ensure that the wall with a slit remains neutral. Theoretically this arrangement is an approximation to the interaction of electric (or magnetic) dipoles as the distances in between a pair of charges of any one dipole is made very small [4]. Handling single electric charges, as we do here, is much simpler to model and more basic and easier to understand and check.

For the interaction between the bullet particles and the wall particles we use the simple inverse square relation (Coulomb's law) in addition to the classical second law of motion of Newton. The two component particles of the bullet dipole is additionally connected with a spring to keep them tied together at all times. The spring is not physical and can be thought as the result of some internal atomic Coulomb forces [2]. The use of masses and springs to model atoms and molecules is well known and frequently used in physics to predict atomic and molecular behavior and this is normally called a 'space oscillator'.

2 Theory

For a case of equal masses and unit charges interacting under a central force system, the acceleration of the j^{th} particle due to interactions with all the other i particles, can be written as;

$$\mathbf{a}_j = \frac{d\mathbf{v}_j}{dt} = \sum_i k_{ij}\mathbf{h}_{ij} \ ; \ i, j = 1, 2, \ldots n, \ i \neq j \tag{1}$$

Here $\mathbf{h}_{ij} = \mathbf{r}_{ij}/r_{ij}^3$ for the inverse square force and $\mathbf{h}_{ij} = \mathbf{r}_{ij}$ for a spring force or space oscillator. k_{ij} is the total scalar coupling constant between the two particles i and j. The units for k_{ij} ($=k_m$) are m^3/s^2 for an inverse square force and $k_{ij} = (k_d)$ is s^{-2} for a spring force. $\mathbf{a}_j$ is the resultant acceleration which can be positive/negative for repulsive/attractive interactions.$\mathbf{v}_j$ is the velocity, $r_{ij} = |\mathbf{r}_{ij}|$, $\mathbf{r}_{ij} = \mathbf{r}_j - \mathbf{r}_i$ are the scalar and the corresponding vector separation distances from the i to the j positions and n is the total number of particles. When $i = j$ a particle will interact with itself and this is not allowed.

Equation (1) is a set of simultaneous ode's that must be integrated over a small step (dt) once to find $\mathbf{v}_j(t)$ and twice to find the position $\mathbf{r}_j(t)$ giving;

$$\mathbf{r}_j = \mathbf{r}_{j0} + (dt)\mathbf{v}_{j0} + (dt)^2\mathbf{a}_j \ \ ; \ i, j = 1, 2, \cdots n, \ i \neq j \tag{2}$$

If we know the initial position $\mathbf{r}_{j0}$, the initial velocity $\mathbf{v}_{j0}$, the initial acceleration $\mathbf{a}_j$ from (1) and choose a time step (dt), we can find the next position of the bullet $\mathbf{r}_{j1}$. This is then repeated for different initial velocities and/or positions and the resulting trajectories are collected over time and plotted. Care is not taken for the values of the various parameters to correspond to particular physical values, but rather chosen to accentuate the resulting picture and make it clearer. The ranges of values used in the plots are (in mks units); $d_0 = [5 - 500 \times 10^{-9}]; d_{ym} = [1 - 10^{-6}]; v_0 = [0.5 - 50]; k_m = [0 - 1]; k_d = [5 - 50 \times 10^{+}7]$; single slit=[4 - 6 positions]; double slit=[3 + 3 positions].

A simple numerical one-step method was chosen for the numerical integration to find the velocity and displacement of every particle in order to avoid possible erroneous contributions from the extra terms contained in more refined procedures. Despite this, the solution is quite robust as can be deduced from the absence of any leakage of momentum from one direction to the other, or any deformation in the path of motion when the forces causing such effects are absent, and despite the long integration time needed to follow each particle to complete its journey.

The wall is placed along the (vertical) y-direction and all the bullet particles start with the same horizontal velocity along the (horizontal) x-axis. Either the vertical position or the vertical component of the velocity can then be changed randomly by a small amount in order to cover a wide area of the barrier. The initial direction of the dipole of the bullet particles is also randomized through the random choice of the angle it made with the x-direction θ and with the y-direction α. The axial velocity component must remain constant in each case otherwise coherence is lost and with it the wave behavior.

Because the dipole bullets are fired one at a time, there is no chance of them interacting with each other and can interact only with the fixed dipoles of the wall. An exchange of energy occurs between the various components. In results the wave behavior appears clearly in the path as the bullets travel from the source through the barrier wall and beyond. Slits in the wall are introduced by making the coupling constant zero when evaluating the interaction between the dipole bullets and those of the fixed wall.

3 Results

In the results a large collection of figures together with the necessary comments and conditions are given. Many of the characters of a wave phenomenon like diffraction, total and partial reflection and, above all, interference are observed under coherence conditions. Interference is generally regarded as purely wave phenomenon since it involves positive and negative addition of amplitudes leading to zero totals at some places- the nodes. Particles are supposed to produce only constructive interference because there are no negative particles.

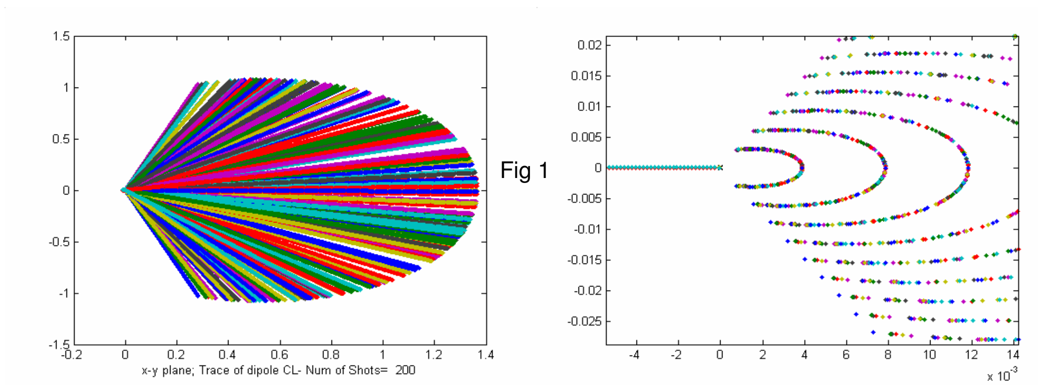


Fig 1

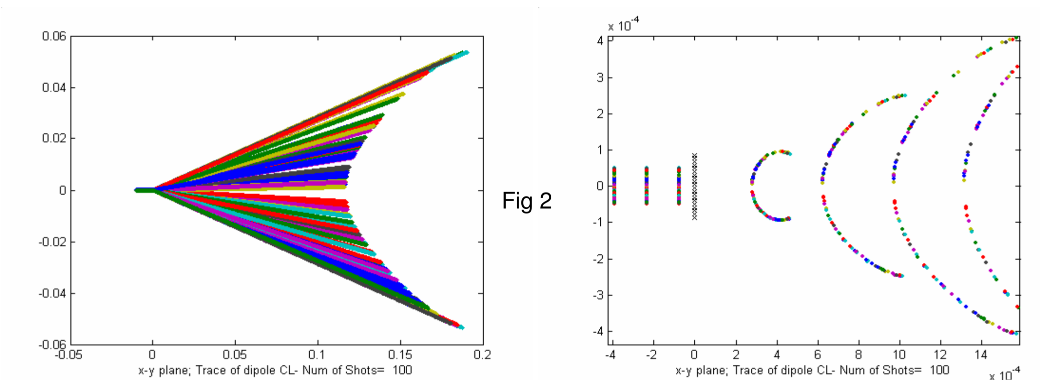


Fig 2

What is made clear in the present results is that such wave behavior can still be produced by real particles interacting under the inverse square law. This law becomes a spring force law due to the bound state brought about by the fixed particles of the wall, producing proper wave behavior - exactly as in a mass spring system. The particle path as a result prefers some positions to others dictated by such interactions and resulting in a crowding or thinning of particle existence at different positions and appearing as constructive or destructive interference. The main factors affecting this are the dipole strength and dimensions, the position of the slit and the position and the approach velocity of the bullets. The role played by the wall is spatial filtering similar to that played by the vertical compartments in the statistical demonstration of the binomial distribution using balls or sand particles dropped on vertically stacked compartments, or by a lens in ray optics as mentioned above.

In Figs 1-11, the right hand side figures are a magnification of the central part of the left hand figures. In Fig 1 we see a beam of particles experiencing diffraction and a change of the wave front from plane to convex. We note again that the various paths making a beam are collected over time and can not interact as they are computed one after the other- that is after one dipole reaches its end of journey the next dipole starts. The velocity in the horizontal x-direction is fixed for every figure but can change from one run to the other.

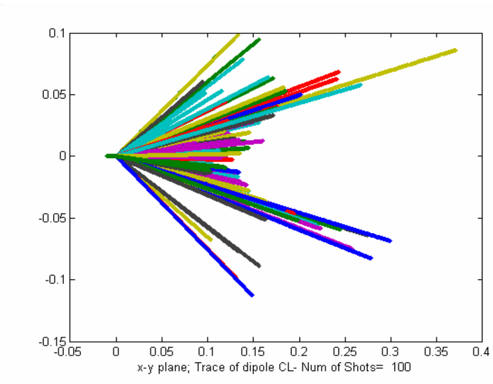
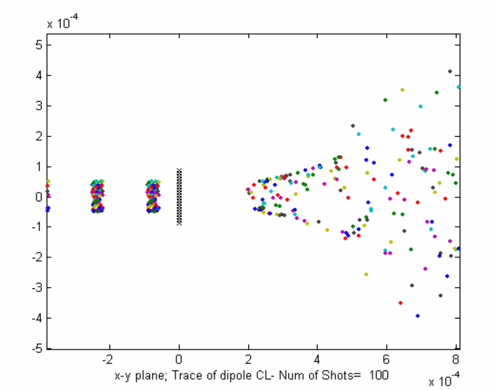


Fig 3



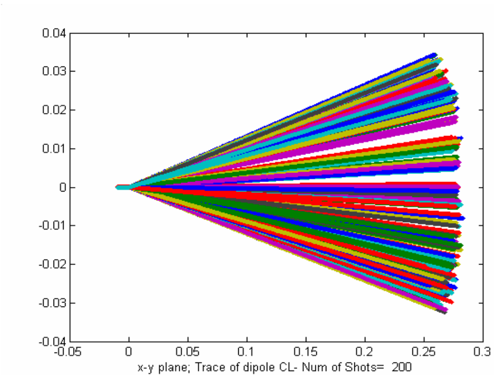
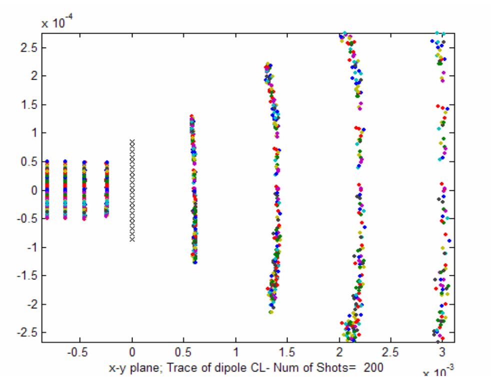


Fig 4



The strength of the coupling constants of the dipole spring k_d and that between the wall and dipole particles k_m, the initial separation distance between the dipole charges d_0, the distance between the wall dipoles d_m, are all fixed for any one single case. The vertical position and orientation of the dipoles, on the other hand, are varied randomly for each path inside any one run to cover the beam width and produce the required random selection and accumulation of results.

In Fig 2 a change from plane to concave wave-front results when the initial velocity takes a new value. It is noted here that 'similar shapes' can be achieved by a change in either the initial velocity or the coupling strength between the particles. The distance between the wall dipoles also have a similar effect to a change in the coupling constant, since all these factors can change the forces affecting the motion of the bullet dipoles. At intermediate settings between the concave and convex profiles, it is possible to obtain a flat wave-front (Fig 8 below).

In Fig 3 randomness is added to the axial velocity of the bullets resulting in a considerable corruption of the wave picture due to a loss of coherence in the phase of the incoming wave front introduced by such randomness. In Fig 4 the initial and random spin of the dipole is increased considerably. There is no marked change in the general picture other than introducing fuzziness at

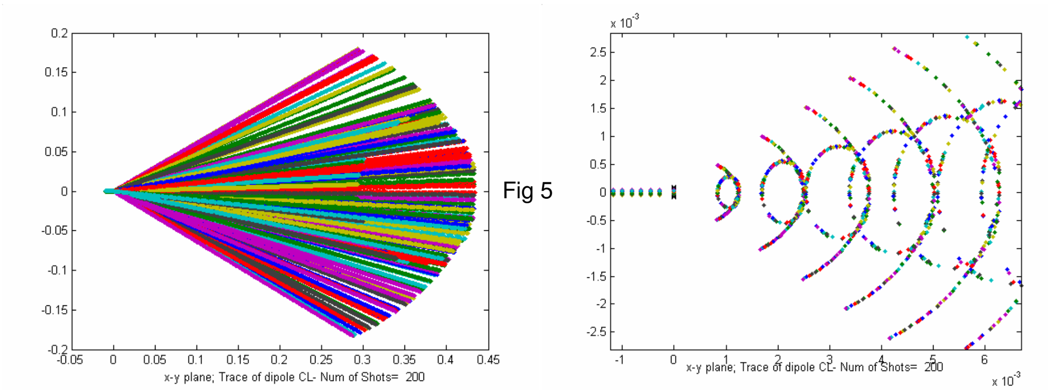


Fig 5

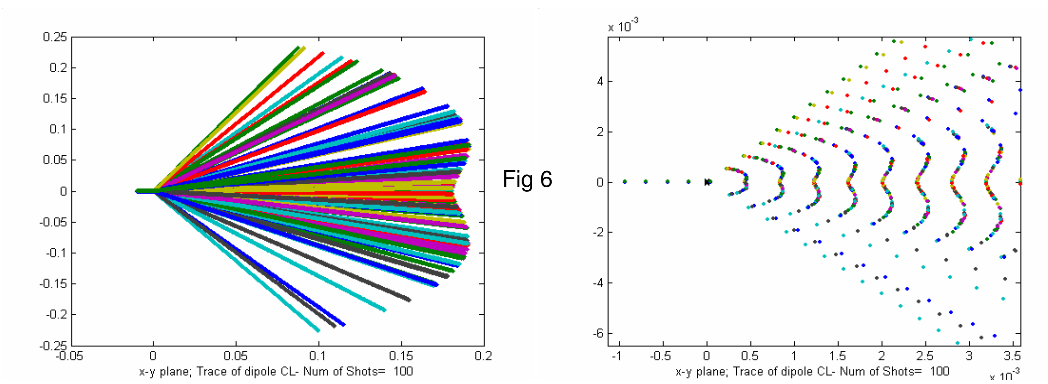


Fig 6

the position of the particle path due to the randomness of the initial direction of the bullet dipoles- a partial loss of coherence.

Fig 5 shows interference patterns caused by a single slit and Figs 6,7 show interference patterns caused by the presence of double slits in the wall of dipoles for the two cases of convex and concave wave fronts. It is possible to see destructive as well as constructive interference if we concentrate on these picture along any one vertical line. Clearly the destructive positions can not be caused by annihilation but rather by a situation of a balance of forces that strongly push the path of particles away from passing through such regions. The wave appearance is a result of such balance of forces. Since the wall with slits has fixed geometry and it is common to all bullets, a chance is presented for the particles to take only specific path shapes.

As in double slit experiments, the interference pattern can disappear if phase coherence is lost between the interfering beams. In the present case this happened when a small random component was imparted to the axial velocity of the bullets. If the randomness is increased, the wave behavior can disappear completely.

In Fig 8 we see a flat wave front before and after the wall. For certain settings of the wall coupling strength (k_m), the beam can be focussed and the focal length can be changed too. In Figs 9, 10, 11 we achieve total and

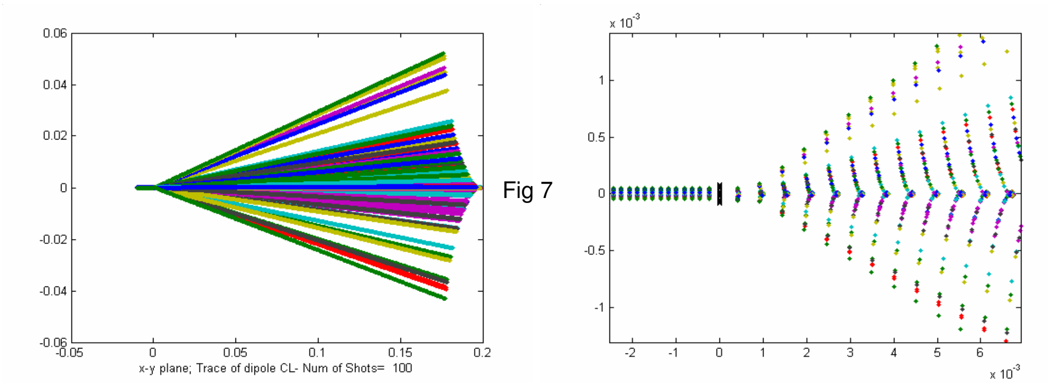


Fig 7

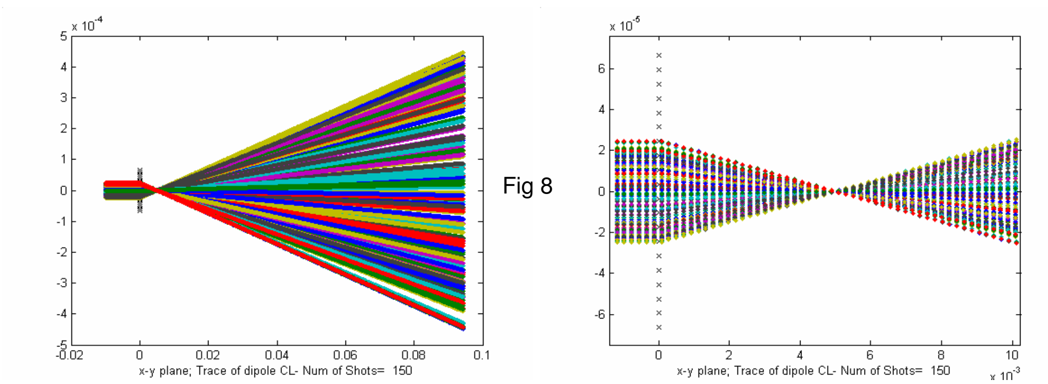


Fig 8

partial reflection of the bullet particles. Interference can also be observed for the case of total reflection from a wall with slits. 'Total reflection' is a distinct wave behavior as the wall is not solid but made of separate particles. In wave mechanics, only when the wave length is larger than the screen spacings we get total reflection. This could be made use of in shielding applications against particles.

In Figs 12,13 samples of the x-y and z-y planes trace for one bullet particle showing the path of the two charges making one dipole. A resonance state sets in the dipole caused by the forces of the wall and also by the internal energy processes within the mass spring system of the dipole. The path of the center of mass is taken to represent the path of the dipole in all the previous results. As the masses are equal, the center of mass is the simple geometrical center.

4 Conclusion

In conclusion we observe that the classical inverse square law is capable of interpreting the wave particle duality phenomenon of physics. As discussed in [5], this law has a geometric origin and is a result of superposition and similarity in the path of motion of particles in a 3D Euclidian space and this could be

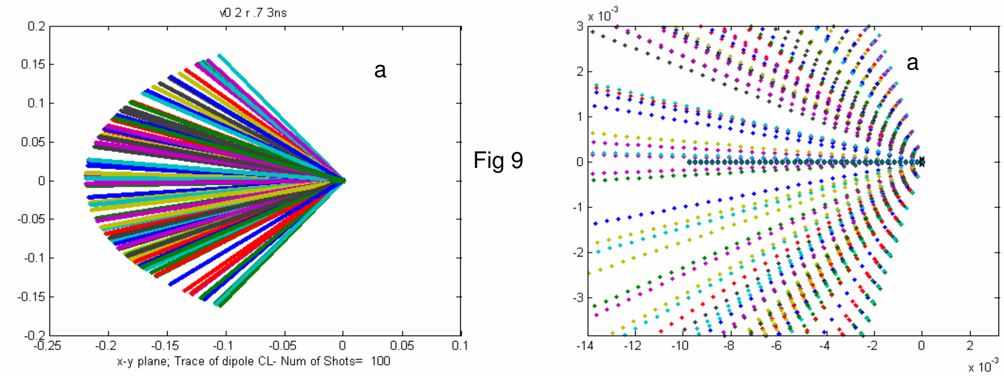


Fig 9

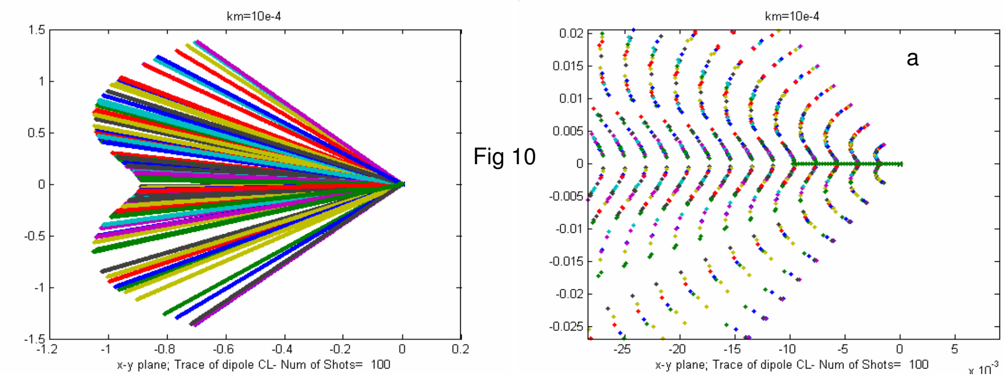


Fig 10

the reason why even the most accurate physics experiments failed to detect a deviation in the action of this law. Also it is not commonly appreciated that this law takes other forms like the Van-de-Wall or Hook's (spring) force forms when a large number of particles of different charges interact with each other within a small space or where the motion of some particles are restricted. An inverse square, a fixed boundary, and an energy exchange are all that is needed to produce the wave phenomena observed in double slit type experiments and others. A fixed boundary is a result of the presence of a large number of particles in a small region making the group of a much larger mass (compared to other distant single particles) and hence a much smaller range of movement.

The fact that singly shot particles can show the same wave behavior expected only in a flux of interacting particles is caused by the fixed geometry of wall and slits in all the shots of the bullet particles creating in effect a spatial filter that makes accumulation of particle paths in time similar to accumulation in space. The need for coherence to produce the observed wave behavior appears here as a need to have the same axial approach velocity (phase) and dipole axis direction (polarization) for all the particles. This clearly must have a close connection with the measuring equipments used and the timing coordination of the experiment.

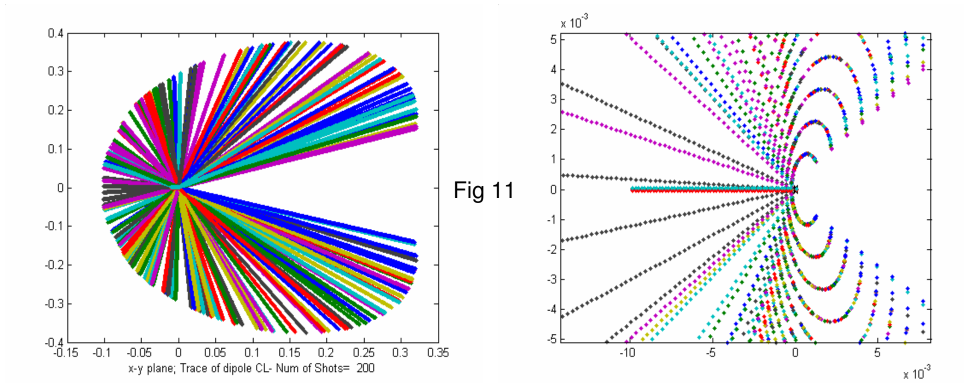


Fig 11

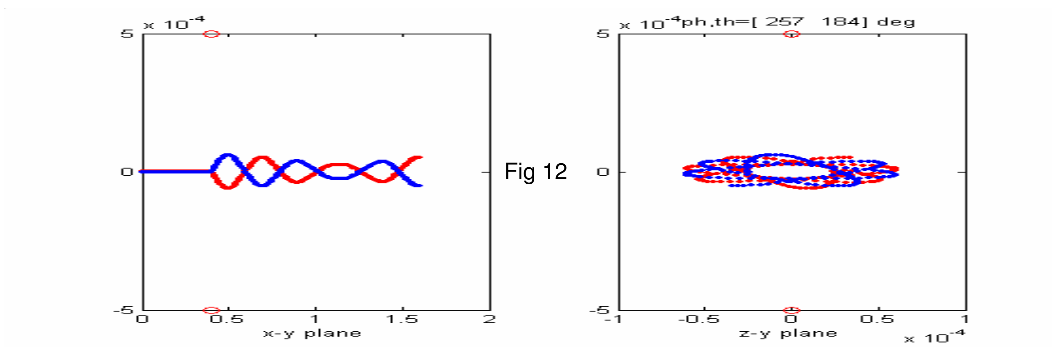


Fig 12

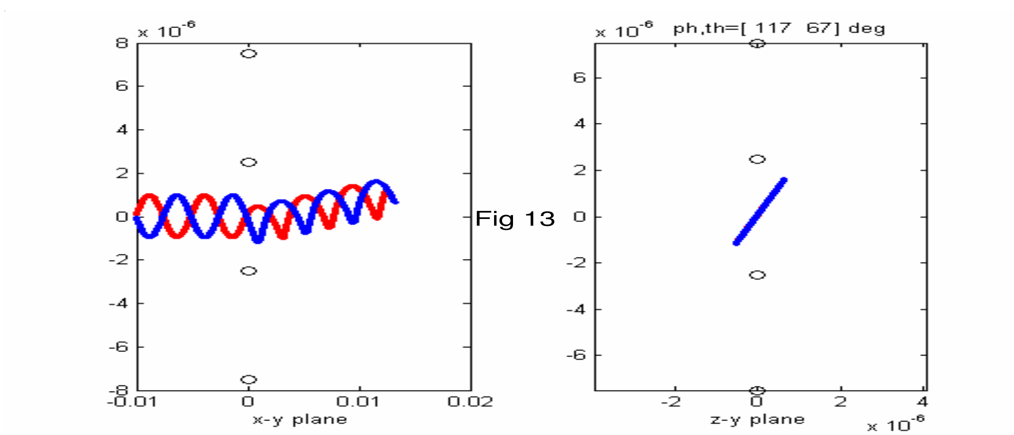


Fig 13

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