# The Corkscrew Model

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**Abstract**

*This short paper presents an alternative mechanism to explain the wave-particle phenomenon characteristic of the motion of elementary particles. It is shown that there is a particular mechanism, namely the corkscrew mechanism, which can explain the so-called wave-particle behavior. It is shown that in addition to presenting an acceptable dynamical process, the proposed theory extends the underlying physics of Planck's constant, expanding the meaning of the parameters involved in its definition. The Compton wavelength and the Schrödinger equation are also derived within the framework of the present theory. Particularly important is the diffraction pattern explained with the corkscrew motion.*

**Keywords**: Wave-particle, kinetic energy, corkscrew dynamics, Planck constant, Compton wavelength, diffraction, Schrödinger equation, particles.

## INTRODUCTION

The dynamics of very small particles has been challenging scientists for a long time. Particularly the diffraction patterns observed with a beam of particle and the double slit experiment strongly suggests that particles behave like waves. The solution to this peculiar behavior was proposed by De Broglie [1] at the beginning of the last century and remains the cornerstone for most current developments in quantum mechanics. Almost all authors refer to De Broglie's hypothesis to deal with the so-called wave-particle dynamics, which is of fundamental importance to build the theoretical framework of modern physics. As there is no suitable explanation for that peculiar phenomenon with an acceptable set of laws, as is common in classical physics, the solution was to focus on the effect leaving the causes in a black box. Most of the physics textbooks present the wave-particle behavior as a natural phenomenon that does not require a specific explanation. It is remarkable that Serway and Jewett in the excellent textbook Principles of Physics: A Calculus-Based Text [2] clearly state that the particle-wave behavior must be accepted, even without an adequate set of physical laws. R. Feynman [3] and D. Bohm [4] among others, did not fully agree with the wave-particle model commonly adopted to explain the wave behavior of elementary particles and presented alternative models. Anyway, all solutions leave open the basic phenomenological context needed to explain some of the experimental results related to the motion of elementary particles. This difficulty, however, did not prevent the development of research in quantum physics. The difficulty of finding an adequate explanation for the peculiar dynamics of elementary particles, suggested by very careful experiments, did not held up theoretical advancements. Indeed, the wave-particle hypothesis opened a very rich way to strengthen statistical physics in the domain of modern physics.

This paper proposes an alternative mechanism to explain the singular behavior of elementary particles displacing along a straight path. In principle, it applies to the motion of very small particles subject to the laws of classical mechanics, except for one critical detail that relates the wavelength to the particle's radius of gyration, as explained in the next section.

The dynamical model for elementary particle proposed here is the composition of a motion in a linear trajectory coupled to a rotation around an axis coinciding with this linear trajectory. The linear velocity of the particle coincides with the tip velocity of an ideal corkscrew. The rotation of the particle with respect to the inertial frame can vary within two limiting values, namely, the same angular velocity of the corkscrew tip and no rotation at all. In the first case, the particle is assumed to be fixed at the tip of the corkscrew, and in the second case the particle is free to rotate with respect to the tip. Partial connection to the tip is also admissible. Particle motion is always referred to the inertial frame of reference, but frequently described in a distinct frame fixed to the tip of the corkscrew. Note that the helical motion of the corkscrew couples the linear displacement with rotation and this is the detail that justifies the adoption of the corkscrew motion as a satisfactory model for analyzing the dynamics of very small particles. In fact, the interconnection between linear displacement and rotation leads to a space-time relationship suitable for describing wave propagation phenomena. It is also remarkable that the derivation of the kinetic energy of the particle excited with the corkscrew motion leads to a generalized definition of Planck's constant.

The designation "corkscrew" was used because it closely represents the expected motion of a particle in the context of the present paper.

### *The Corkscrew Model*

Let's assume a particle being transported at the tip of a corkscrew so that it moves along a straight path (Fig.1). Additionally, the particle can rotate around the support at the tip of the corkscrew. For an elementary angular displacement $\delta\theta$ of the corkscrew with respect to the inertial frame and an angular displacement $\delta\varphi$ of the particle with respect to the corkscrew the angular displacement of the particle with respect to the inertial frame of reference is given by:

$$\delta\Phi = \delta\theta - \delta\varphi$$

Now let $\bar{\lambda} = \lambda/2\pi$ where $\lambda$ is the pitch of the helical path, that is, the displacement of the corkscrew tip after a complete turn $2\pi$ (Fig.1). We call $\bar{\lambda}$ the specific pitch of the corkscrew. The linear displacement of the tip after an elementary turn $\delta\theta$ is:

$$\delta x = \bar{\lambda}\,\delta\theta$$

Therefore, the total angular displacement of the particle with respect to the inertial frame of reference is:

$$\delta\Phi = \frac{\delta x}{\bar{\lambda}} - \delta\varphi$$

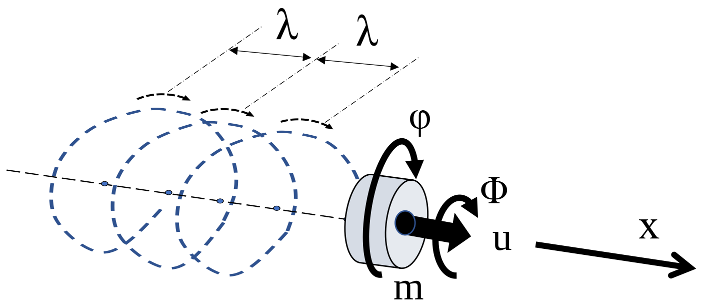


Fig.1. The corkscrew motion. Linear displacement λ along the x axis is correlated with rotation Φ. The linear displacement after one complete turn, Φ =2π is equal to 2πλ. The angle φ represents the rotation of the particle with respect to the corkscrew.

Now let $\delta\varphi = \omega\delta t$ where $\omega$ is the angular velocity of the particle with respect to the corkscrew tip and $\delta x = u\delta t$ where $u$ is the linear velocity of the corkscrew tip. The equation above then reads:

$$\delta\Phi = \left(\frac{u}{\bar{\lambda}} - \omega\right)\delta t$$

The angular velocity of the particle with respect to the inertial frame of reference is:

$$\frac{\delta\Phi}{\delta t} = \frac{u}{\bar{\lambda}} - \omega \qquad (1)$$

The particle is assumed to follow the corkscrew tip along the straight path and can rotate about an ideal support at the corkscrew tip [Fig.1]. Throughout this text we will call $\partial\Phi/\partial t$ the angular velocity instead of frequency, which is already a classical terminology for the ratio $u/\lambda$. If $\omega = 0$ the angular velocity is $u/\bar{\lambda} = 2\pi f$ where $f$ is the well-known designation for the frequency $u/\lambda$.

The motion of a single particle in the inertial frame can therefore be described with the triplet $[u, \lambda, \omega]$ or $[u, \lambda, \Psi]$ with $\partial\Phi / \partial t = \Psi$. The triplet characterizes the motion composed of the linear velocity $u$, the corkscrew specific pitch $\bar{\lambda}$ and $\omega$ the particle angular velocity with respect to the corkscrew tip.

Now consider the particle moving along a line with velocity $u$. The motion of the particle at the corkscrew tip admits two limiting cases depending on its connection to the support.

1. The particle is attached to the tip of the corkscrew so that the angular velocity of the particle with respect to the inertial frame is the same as the corkscrew itself, that is, $\omega = 0$.
2. The particle is free to rotate with respect to the support at the corkscrew tip so that its angular velocity with respect to the inertial frame cancels out, $\partial\Phi/\partial t = 0$.

Consider the first case. Since $\omega = 0$ from (1) it is immediately obtained $\partial\Phi/\partial t = u/\bar{\lambda}$. This is the angular velocity of the particle with respect to the inertial frame. The kinetic energy corresponding to rotation is therefore:

$$E_R = \frac{1}{2} I \left(\frac{\partial\Phi}{\partial t}\right)^2$$

Now with $I = m\rho^2$ where $\rho$ and $m$ are the radius of gyration and the mass of the particle respectively, the equation above gives:

$$E_R = \frac{1}{2} m\rho^2 \frac{u^2}{\bar{\lambda}^2}$$

Now define $\bar{h} = m\rho u$ the generalized Planck's constant, $\partial\Phi/\partial t = \bar{f} = u/\bar{\lambda}$ the corkscrew angular velocity and $k = \rho/\bar{\lambda}$ to obtain:

$$E_R = \frac{1}{2}\overline{hf}k \tag{2}$$

***The principle of Planck parameter invariance:*** *The angular momentum of a particle driven by the corkscrew dynamics is constant, that is,* $L = mu\rho$ *is constant where* $m$ *and* $u$ *are the mass and linear velocity of the particle, respectively, and ρ the corresponding radius of gyration.*

This principle applies for very small particles. For large particles, massive bodies with $m$ large enough and, consequently, large radius of gyration $\rho$, the condition requiring $L$ equal constant would impose an extremely low linear velocity $u$. This is not impossible but it is beyond the scope of this paper. Therefore, let us consider the application of the theory exposed here focused on the atomic and sub-atomic levels. This means, as will be seen in the next sections, that the wave-particle behavior will here be restricted to very small particles, which is consistent with experimental observations. It is also important to observe that the correlation between the generalized Planck's constant with the radius of gyration requires careful consideration about the mass distribution as will be seen later.

Let us derive the energy corresponding to the translational motion imposed by the corkscrew angular displacement:

$$E_T = \frac{1}{2}mu^2 = \frac{1}{2}mu\rho\frac{u}{\bar{\lambda}}\frac{\bar{\lambda}}{\rho}$$

With $\bar{h}$ and $\bar{f}$ as defined above we obtain:

$$E_T = \frac{1}{2}\overline{hf}\frac{1}{k} \tag{3}$$

The total kinetic energy can now be written combining equations (2) and (3):

$$E = \overline{hf}\frac{1}{2}\left(k + \frac{1}{k}\right) \tag{4}$$

**The minimum energy principle**: *The kinetic energy of a particle moving with linear and angular velocities as imposed by a corkscrew motion converges to a minimum.*

The value of $k$ in the equation (4) to match the minimum principle is clearly equal to 1. Therefore, the ratio $k=\rho/\bar{\lambda}$ is equal to one, $k=1$. This condition imposes a peculiar property on the mass distribution of particles, namely, the mass of a particle is not encapsulated in a box with a fixed contour. This is a necessary condition imposed by the minimum principle requiring that $\rho=\bar{\lambda}$ or $\rho=\lambda/2\pi$. That is, the mass distribution varies with the wavelength. Furthermore, the order of magnitude for the radius of gyration admissible for very small particles is approximately one sixth of the corresponding wavelength. A very important consequence of the equivalence between radius of gyration and wavelength is that $\bar{h}=\hbar$ the reduced form of the classical Planck constant $\hbar=h/2\pi$ Another remarkable consequence of the equivalence between the radius of gyration and the wavelength is that, keeping the linear velocity $u$ constant, decreasing radius of gyration implies increasing rotation speeds as given by the relation $\Psi=u/\bar{\lambda}$. Now as $\rho=\bar{\lambda}$ the radius of gyration decreases if the spin increases. This type of motion is clearly observed in ice skating performance when the skater brings the arms close to the body to increase the speed of rotation.

With the Plank parameter invariance principle proposed above, it is possible to write $2\pi u\rho = c_0\lambda_0$ where $c_0$ is the velocity of the particle and $\lambda_0$ the respective wavelength. Now with $\rho/\bar{\lambda}=1$ as given by the minimum principle the above relation reads $u\lambda = c_0\lambda_0$. The wavelength, or the corkscrew specific pitch, varies in the opposite direction as compared to the particle velocity or the corkscrew tip velocity. This means that the wavelength, or the corkscrew specific pitch in our model, decreases as the speed of the particle increases. Since the particle speed is limited, consequently the corkscrew specific pitch has a lower limit for each radiation type which is the corresponding wavelength. This relation is in agreement with the classical theory and introduces the role of the radius of gyration in the particle dynamics at very small scales. With the principles introduced above the equation (4) may be rewritten leading to the well-known energy equation expressing the energy stored in an elementary particle.

$$E=hf \tag{5}$$

Consider now the second case. The particle is connected to the corkscrew tip but free to rotate with respect to the support. That is, the particle is transported by the corkscrew along the x-axis but doesn't rotate with respect to the inertial frame $\partial\Phi/\partial t=0$. For this case only the linear velocity contributes to the kinetic energy. From equation (1) it is immediately obtained $u=\omega\bar{\lambda}$ and the corresponding kinetic energy $\bar{E}_T=mu^2/2$. It is however convenient, for a unified development of the theory, to express the kinetic energy in terms of rotation.

As seen earlier in corkscrew dynamics, translation is coupled to rotation through the corkscrew pitch $\lambda$. Therefore, instead of $u$ let us express the energy as a function of the rotation $\omega$. With $mu\rho = \bar{h}$ and $\omega = u/\bar{\lambda} = \bar{f}$ the kinetic energy reads:

$$\bar{E}_T = \frac{1}{2}mu^2 = \frac{1}{2}\bar{h}\bar{f} \tag{6}$$

Where it was assumed as previously $\rho/\bar{\lambda} = 1$. The energy is expressed in terms of an ideal particle with the same mass rotating with angular velocity $\vec{f}$.

Now consider the general case corresponding to a particle propelled by a corkscrew with specific pitch equal to $\lambda$ and with angular velocity relative to the corkscrew equal to $\omega$. The particle angular velocity with respect to the inertial frame is given by equation (1). The kinetic energy is:

$$E = \frac{1}{2}mu^2 + \frac{1}{2}m\rho^2\left(\frac{u}{\lambda} - \omega\right)^2$$

Now with $k = \rho/\bar{\lambda}$ $r = \omega/(u/\bar{\lambda})$ $f = u/\lambda$ , $h = mu\lambda$ and $0 \le r \le 1$,

$$E = hf\left[\frac{1}{2}\left(k + \frac{1}{k}\right) + \frac{k}{2}r(r-2)\right] \tag{7}$$

The parameter $r$ represents the inverse of the degree of detachment of the particle from the corkscrew tip. That is, if $r$ is low the biding efficiency of the particle support to the corkscrew tip is high. Therefore, if $r = 0, \omega = 0$ the particle is fixed at the tip and if $r = 1$ the particle is free to rotate with respect to the tip pf the corkscrew. Now as it was shown before $k = 1$ and the above equation can be written:

$$E = hf\left[1 + -\frac{1}{2}r(2-r)\right] \tag{8}$$

This is the fundamental energy equation for our theory. The term $\left[r(2-r)/2\right]$ can be interpreted as controlling the stored energy. If the particle is attached to the corkscrew tip $\omega = 0$ and therefore $r = 0$, there is no energy stored in the system. If $\omega = \bar{f}$ then the particle is free to rotate with respect to the corkscrew, $r = 1$ and the energy stored in the system is given by $hf/2$. Therefore, if energy is added to a particle moving with the speed of light, it will be used to activate the rotation of the particle in the inertial frame. That is, according to the model, it will be used to fix the particle on the tip of the corkscrew. There is no prevailing source of energy considering the total energy possibly carried by a particle. Note that, within the scope of the present proposal, it is possible for a particle to move without rotation, but it is not possible for a particle to simply rotate.

### The Mass Distribution Hypothesis

In the previous section it was shown that the corkscrew dynamics leads to a very important conclusion, namely, the wavelength and the radius of gyration are of the same order. This relation imposes that the volume enclosing the mass increases as the wavelength increases. We propose two geometries that satisfies this requirement, [Fig.2].

First, assume that the mass contained in the particle is uniformly distributed in the space. In order to keep the density approximately constant as the wavelength and correspondingly the radius of gyration increase, the mass must be redistributed along the thickness of a hollow sphere [Fig.2(a)]. This hypothesis would impose a continuous interference of decelerating particles in a chaotic universe. Therefore, it is not an acceptable solution for our problem.

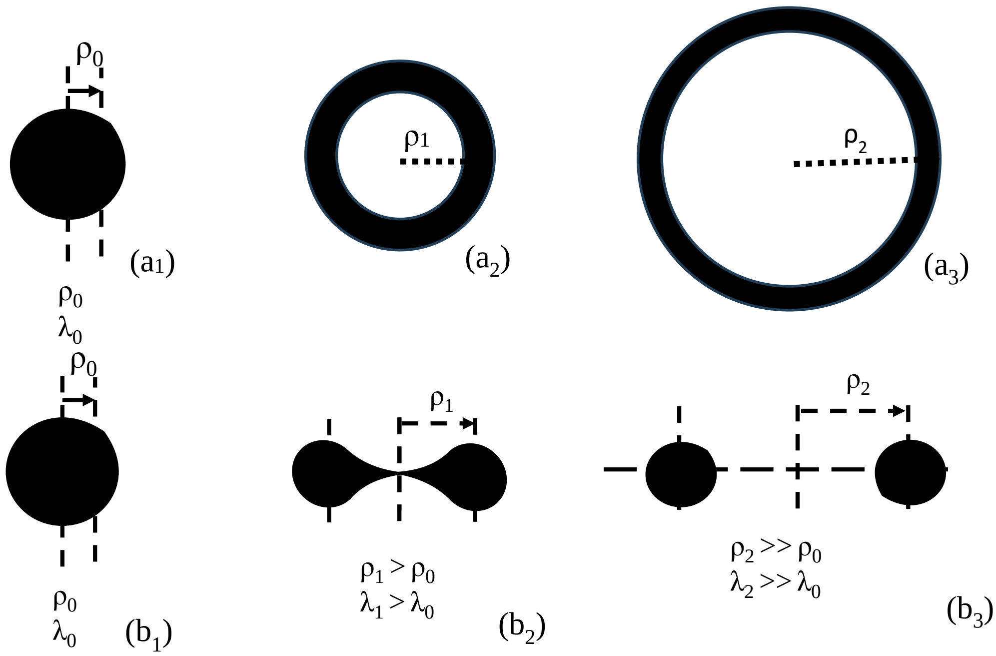


Fig.2. Two hypotheses for the mass distribution for particles moving with different wavelengths. (a) uniformly distributed mass; (b) mass divided into two equal portions

A second solution is to admit that beyond a certain radius of gyration and the corresponding wavelength the particle splits into two similar unities. The new configuration is composed by a pair of similar particles turning around the corkscrew axis following a helical path. They keep a constant distance from each other with the respective centers remaining at a distance equal to $2\rho$. We will call this system the twin particle configuration [Fig.2(a)]. Therefore, the idea that a particle is a single object, as is usually assumed, is discarded and the twin-particle model is taken as the real configuration. The twin configuration is sustained provided that the centers of the two units remain at a distance $d > 2\rho$ where $d$ is the diameter of the particle. Therefore, the critical wavelength $\lambda_{crit}$ is of the order of $d/2$ where $d$ is the diameter of the particle. If the particles come close together, they will collapse, merging into a single unit. Hence, there is a critical limit for the wavelength $\lambda_{crit}$ or correspondingly for the radius of gyration $\rho_{crit}$ such that for all $\lambda > \lambda_{crit}$ and $\rho > \rho_{crit}$ the twin configuration prevails, otherwise the particle collapses into a single-particle mode, [Fig.3(b)]. Note that the energy intensity as a function of wavelength is well known [5].

In the twin configuration, the particles remain in opposite positions in relation to the center of a circle with radius equal to $\rho$ [Fig.3(a)]. The center of the circle coincides with the tip of the corkscrew and moves attached to it with a velocity equal to $u$ [Fig.3(a)]. Note that the particles in the twin configuration always remain symmetrically arranged with respect to the corkscrew tip O, but the orbital radius $\rho$ may vary as a function of the wavelength [Fig.3 (a)]. Summarizing the above ideas, the following principle is proposed:

**The mass bifurcation principle:** *Particles travel as a single unit for frequencies above a critical limit or correspondingly for wavelengths bellow a critical value* $\lambda < \lambda_{crit}$. *If* $\lambda > \lambda_{crit}$ *the total mass assumes the twin configuration with orbital radius proportional to the radius of gyration* $2\pi\lambda = \rho$.

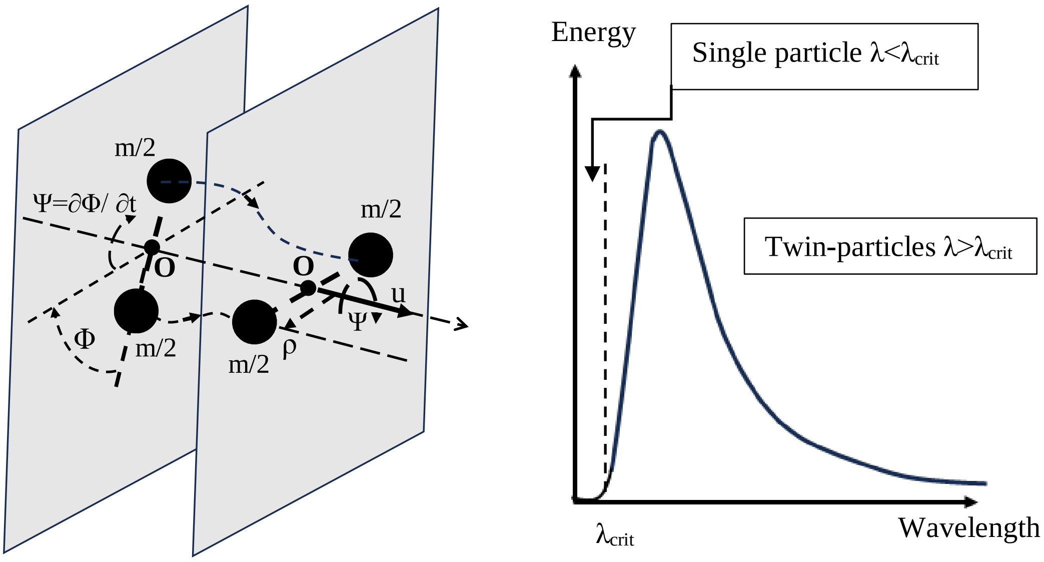


Fig.3. (a)The twin particle model subjected to corkscrew motion. (b) The critical wavelength shown in the black body energy spectrum.

For the purposes of the present paper the main argument in favor of this model is that it explains the observed diffraction pattern for numerous types of radiation as we will see in the next section. Therefore, the twin particle model will be adopted as the standard model in this paper.

### *The Schrödinger Equation*

Now consider the function $\psi(x,t)=\exp\left(i\left(2\pi/\lambda-\Psi t\right)\right)$ where $\Psi=\partial\Phi/\partial t$, the rotation speed of the particle with respect to the inertial frame, is constant. Clearly the function $\psi(x,t)$ belongs to the class of harmonic functions and consequently satisfies the wave equation [6]:

$$\frac{\partial^2\psi}{\partial x^2}+\frac{1}{\overline{c}^2}\frac{\partial^2\psi}{\partial t^2}=0 \tag{9}$$

Where $\overline{c}=\lambda\Psi/2\pi$. Now since $\partial\psi/\partial t=-i\Psi$ the equation (9) reads:

$$\frac{\partial^2\psi}{\partial x^2}-i\Psi\left(\frac{2\pi}{\Psi\lambda}\right)^2\frac{\partial\psi}{\partial t}=0 \tag{10}$$

The kinetic energy of the particle corresponding to rotation is a function of $\Psi = 2\pi(1-r)u/\lambda$, where $r = \omega\lambda/2\pi u$. Let us impose that the angular velocity of the particle with respect to the corkscrew, that is $\omega$, is limited to the interval $0 < r \leq 1$. This means that no external energy is introduced into the particle-corkscrew system. Consequently, the maximum kinetic energy of the particle corresponding to the rotation is reached when the particle is tightly attached to the corkscrew tip $r = 0$ and $\Psi = 2\pi u/\lambda$. If $r = 1$ and therefore $\Psi = 0$, the particle is free to rotate with respect to the corkscrew tip but doesn't rotate with respect to the inertial frame. The equation (10) can now be written as:

$$\frac{\partial^2\psi}{\partial x^2} - i\left(\frac{1}{1-r}\right)\frac{2\pi}{\lambda u}\frac{\partial\psi}{\partial t} = 0$$

Or with $\bar{h} = mu\lambda/2\pi$ we have the Schrödinger equation in a more general form suitable to the present approach:

$$(1-r)\, i\frac{\bar{h}}{m}\frac{\partial^2\psi}{\partial x^2} + \frac{\partial\psi}{\partial t} = 0 \qquad (11)$$

The parameter $r$ controls the particle rotation speed with respect to the inertial frame. If $r = 1$ the function $\psi$ is constant in time, there is no wave motion associated with the particle. The particle moves along a linear path with velocity $v = u$ where $u$ is the velocity of the corkscrew tip. There is no connection between particle and corkscrew transferring the angular motion of the corkscrew to the particle, that is the particle do not rotate in the inertial frame.

If $r = 0$ we have the other limiting motion. The particle is attached to the corkscrew tip, it moves with translation and rotation imposed by the corkscrew tip. The particle moves with linear and angular velocities, $u$ and $2\pi u/\lambda$ respectively.

We can now impose a partial binding of the particle to the corkscrew tip, so that only a fraction of the corkscrew angular motion is transferred to the particle, as explained above with $\Psi = 2\pi(1-r)u/\lambda$. If we take $r = 1/2$, that is the angular velocity of the particle with respect to the inertial fame is half of the angular velocity of the corkscrew tip, we obtain the classical Schrödinger equation:

$$i\frac{\bar{h}}{2m}\frac{\partial^2\psi}{\partial x^2} + \frac{\partial\psi}{\partial t} = 0 \qquad (12)$$

### *The Particle Hitting a Plane Wall*

Let us now consider the result obtained with the corkscrew model for the analysis of a classical problem. Consider a particle hitting a wall under the angle α (Fig.3).

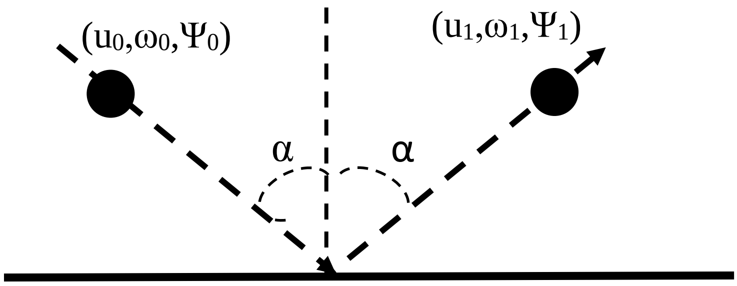


Fig.3. Particle hitting a plane

Let us assume that the trajectory after the impact is symmetrical in relation to the incident trajectory considering the normal at the point of impact. Let the triplets $[u_0, \omega_0, \Psi_0]$ and $[u_1, \omega_1, \Psi_1]$ define the motion before and after the impact. For this case it is reasonable to assume that the angular and linear velocities, $\Psi$ and $u$ remain constant, that is $\Psi_0 = \Psi_1$ and $u_0 = u_1 = u$. This condition comes from the energy conservation principle applied to the translation and rotation motions. The pair $(\lambda, \omega)$ can however vary being different in the incident and reflected trajectories. From the condition $\Psi_0 = \Psi_1$ we obtain:

$$u\overline{\lambda}_1 - u\overline{\lambda}_0 = \overline{\lambda}_0\overline{\lambda}_1\left(\omega_0 - \omega_1\right)$$

With the difference $\Delta\overline{\lambda} = \overline{\lambda}_0 - \overline{\lambda}_1$ we may write:

$$\Delta\overline{\lambda} = -\frac{1}{u}\overline{\lambda}_0\overline{\lambda}_1\left(\omega_0 - \omega_1\right) \tag{13}$$

And with $\Delta\omega = \omega_0 - \omega_1$ we have:

$$\Delta\overline{\lambda} = -\overline{\lambda}_0\left(\overline{\lambda}_0 - \Delta\overline{\lambda}\right)\frac{\Delta\omega}{u}$$

$$\Delta\bar{\lambda}\left(1-\frac{1}{\bar{f}}\Delta\omega\right)=-\frac{\bar{\lambda}_0^2}{u}\Delta\omega \qquad \bar{f}=\frac{u}{\bar{\lambda}_0}$$

Now with $u=c_0$ and $\bar{f}=\bar{f}_0=c_0/\bar{\lambda}_0$ we have:

$$\Delta\bar{\lambda}=-\frac{\bar{\lambda}_0^2\bar{f}_0}{c_0}\frac{\Delta\omega}{\bar{f}_0-\Delta\omega}$$

Now we have from the definition of the Planck's constant:

$$\bar{\lambda}_0^2=\frac{\bar{h}}{m\bar{f}_0}$$

Therefore $\Delta\bar{\lambda}$ reads:

$$\Delta\bar{\lambda}=-\frac{\bar{h}}{mc_0}\frac{\omega_0-\omega_1}{\left(\bar{f}_0-\omega_0\right)+\omega_1}$$

But $\bar{f}_0-\omega_0=\bar{f}_1-\omega_1$ as assumed initially, therefore:

$$\Delta\bar{\lambda}=\frac{\bar{h}}{mc_0}\frac{\omega_1-\omega_0}{\left(\bar{f}_1-\omega_1\right)+\omega_1}=\frac{\bar{h}}{mc_0}\left(\frac{\omega_1}{\bar{f}_1}-\frac{\omega_0}{\bar{f}_1}\right)$$

Noting that $\bar{h}/\Delta\bar{\lambda}=h/\Delta\lambda$ the equation above reads:

$$\Delta\lambda=\frac{h}{mc}\frac{\omega_1}{\bar{f}_1}\left(1-\frac{\omega_0}{\omega_1}\right)$$

Now suppose that the angular velocity of the particle relative to the inertial frame after the collision is equal to zero, ie $\Psi=d\Omega/dt=0$. That is, the particle is free to rotate with respect to the tip of the corkscrew. In this case $\bar{f}_1=\omega_1$ which means that the angular velocity of the particle with respect to the inertial frame vanishes. Therefore, the above expression reads:

$$\Delta\lambda=\frac{h}{mc}\left(1-\frac{\omega_0}{\omega_1}\right) \tag{14}$$

The parameter $h/mc$ is the well-known Compton wavelength. It is reasonable to assume that the corkscrew pitch and, correspondingly, the wavelength decrease after the shock. Therefore $\Delta\lambda > 0$. According to the dynamics proposed in the present approach, the corresponding frequencies increase, that is $\omega_1 > \omega_0$, which is consistent with equation (13). Now since $0 < \omega_0 / \omega_1 < 1$, $\Delta\lambda$ is always positive and less or equal to $h/mc$. According to the present approach, the maximum possible deviation of the wavelength after the collision of the particle against a rigid wall is the Compton wavelength. This is the case if the particle is attached to the corkscrew tip before the collision, that is $\omega_0 = 0$, and released from the support at the tip of the corkscrew after the collision. For this limiting case the speed of rotation of the particle relative to the support after the impact is $\omega_1 = u\left(1/\bar{\lambda}_0 - 1/\bar{\lambda}_1\right)$.

The large electron hypothesis proposed by Compton can be reviewed in the context of the present theory [7] [8]. In fact, the standard model assumes the particle as a single unit with a variable diameter; our proposal splits the particle into two identical units orbiting around each other, for wavelengths beyond a critical value. Thus, the large electron is not an object, but is in fact the trajectory of two objects orbiting around a common center.

***The Double-Slit Experiment***

Diffraction is possibly the most important experiment for detecting the presence of waves propagating through a medium, but in principle, diffraction is not expected to show wave patterns associated with particles being expelled simultaneously through two slits. However, careful experiments show that elementary particles do actually behave like waves and exhibit the corresponding diffraction pattern [9 [10]. As will be shown below, this peculiar behavior can be explained with the particular motion of elementary particles proposed in this paper. The first necessary condition for the development of diffraction patterns associated with two streams of particles simultaneously exiting two slits, is that the particles move in the twin state [Fig.4]. This condition suggests that, after exiting the slits the particle's wavelength increases together with the radius of gyration. Note that particles are assumed bounce off after colliding on the BB wall [Fig.5].

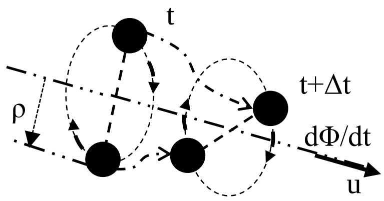

Fig.4. Particles moving in the twin configuration.

Consider particle moving in the twin state. Let us analyze two typical cases:

1. Particles move with maximum angular deviation. The corresponding configuration is that the angular displacement between two particles is an odd number of a quarter of a turn $\Delta\Phi = (2n - 1)\pi/4$.
2. Particles move in line with each other. For this case the angular displacement between two particles is an even number of a quarter of a turn $\Delta\Phi = 2n(\pi/4)$.

Suppose that two particles leaving the two slits in the wall AA with an appropriated time shift arrive almost simultaneously at the wall BB [Fig.5]. If they are in phase they will clash and will disperse randomly. Possibly only a small number of particles will be reflected from BB not enough to make it visible. The region corresponding to this event will remain black [Fig. 5(a)]. The reason is that the leading particle reflects from the wall BB and collides very close to the wall with the incoming particle. As the direction of rotation is reverted after the shock, the interaction is catastrophic. Now, if the particles hit the BB wall in phase opposition, as they are in the twin configuration it is possible for them to cross without colliding [Fig. 5(b)]. In this case the particles reflect back from the wall BB leaving the corresponding region bright t.

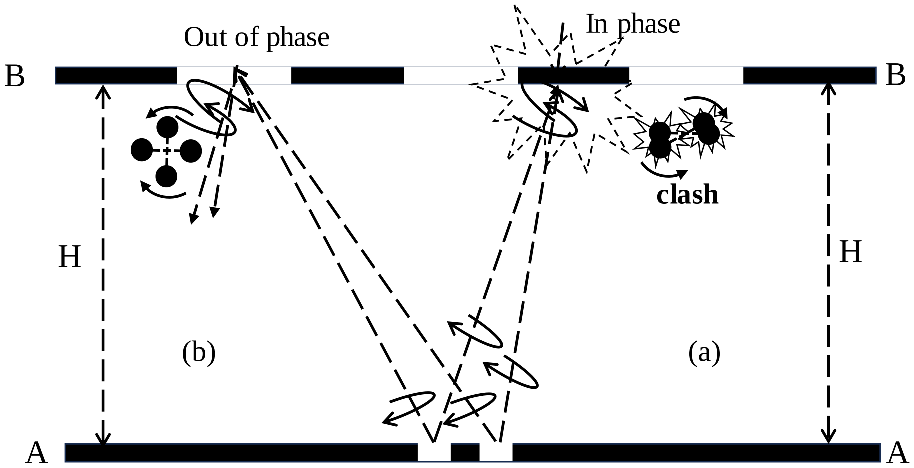


Fig.5. The double-slit experiment. (a) Particles moving in phase causing a catastrophic event near wall BB; (b) Coherent motion, particles reflect back from the wall BB.

It is remarkable how the angular position of the corkscrew trajectory determines the conditions of interaction between the particles leading to a smooth reflection or a catastrophic process blocking all possible reflection. Although the underlying phenomenological process is quite different from wave propagation, the respective result of the double slit experiment is equivalent.

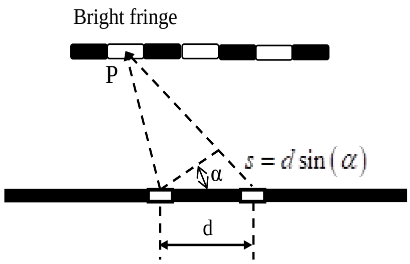


Fig.6. Position of the fringes in the diffraction experiment

With these assumptions, the interference conditions follow the classical approach. The difference between the trajectories of the particles that leave the A-A wall slit and arrive simultaneously at the wall B-B is given by $d\sin(\alpha)$ [Fig.6]. Since the particles travel with velocity equal to *u*, the corresponding time shift is:

$$\Delta t = \frac{d\sin(\alpha)}{u}$$

Now, by equation (1), the time required for a particle to complete an angle of rotation $\Delta\Phi$ is:

$$\Delta t = \frac{1}{u}\frac{\lambda}{1-\omega\lambda/u}\Delta\Phi$$

From the above equations sin(α) is immediately obtained:

$$\sin(\alpha) = \frac{\lambda}{d}\frac{1}{1-\omega\lambda/u}\Delta\Phi \tag{15}$$

Now if the particles arrive in-phase at the B-B wall then $\Delta\Phi$ can be written as $\Delta\Phi = n\pi/2$, n integer. So, we get:

$$\sin(\alpha) = \frac{\lambda}{d}\frac{1}{1-\omega\lambda/u}\frac{n\pi}{2} \qquad n=1,2,3\ldots \text{ black fringes}$$

If the particles are in phase opposition, then the corresponding angle α is given by:

$$\sin(\alpha) = \frac{\lambda}{d}\frac{1}{1-\omega\lambda/u}(2n-1)\frac{\pi}{4} \qquad n=1,2,3\ldots \text{ bright fringes}$$

Clearly, for the fundamental case with the particle attached to the tip of the corkscrew, $\omega = 0$, the above equations reduce to the classical expressions:

$$\sin(\alpha) = \frac{\lambda}{d}\frac{n\pi}{2} \quad \text{and} \quad \sin(\alpha) = \frac{\lambda}{d}(2n-1)\frac{\pi}{4} \quad \text{with } n=1,2,3\ldots$$

corresponding to the black and bright fringes respectively.

Equation (15) leads to a remarkable conclusion. For very small values of $\omega$, the angular shift given by $\sin(\alpha)$ is acceptable. But if the angular velocity of the particle relative to the corkscrew increases, the values obtained for $\sin(\alpha)$ become unacceptable. This means that if the particle is allowed to rotate freely with respect to the corkscrew, then no interference pattern can be observed.

Particles leaving the slits without rotation with respect to the inertial reference frame do not present diffraction patterns. Only particles with vortex motion will produce the diffraction fringes as observed in the experiments.

One of the most important conclusions obtained with the present approach is that a necessary condition for the formation of the diffraction pattern is that particles must be in the twin configuration moving with linear velocity $u$ and angular speed $\Psi$ about an axis parallel to $u$. Note that two particles are needed to induce the diffraction phenomena as proposed in this paper.

**Diffraction patterns for elementary particles**. *Elementary particles in the twin-configuration moving simultaneously with translation and rotation at very high speeds can exhibit diffraction patterns like those observed in wave motion.*

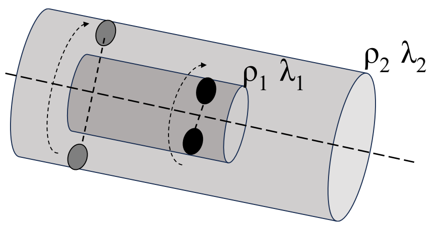


Fig.7. Particles moving in the twin state with different gyration radii.

Additionally, the model proposed here suggests a plausible solution for the annihilation of the diffraction phenomenon when an instrument to detect the motion of particles is coupled to one of the slits. As stated earlier, the particles coming out of the slits are in the twin configuration. The instrument interacts with the particles coming out of the corresponding slit and breaks the symmetry. The gyration radius of the particles in the two beams are no longer equal [Fig.7]. Therefore, the probability of particles in the twin state interacting is very low. The diffraction phenomenon is broken, and the corresponding pattern is no longer observed.

The diffraction phenomenon described above consider the interference of particles reflected off a wall. If the particle after the collision remains stuck to the wall, the diffraction pattern could be reversed. Segments of the wall where particles arrive in phase tend to be bright due to superposition of shocks at the same location. The regions where the impact occurs randomly do not show any particular change.

## FINAL COMMENTS

The corkscrew kinematics introduced in the previous sections is actually a classical approach to rigid body dynamics. The corkscrew is a single mechanism with two degrees of freedom, namely a translation $x$ and a rotation $\theta$. These two motions are not independent, in fact they are coupled through the corkscrew pitch $\lambda$. If we place a particle on the tip of the corkscrew and let it rotate with respect to the corkscrew, a new degree of freedom will be introduced that we call $\varphi$. It was shown that the dynamics analysis of a particle attached to the tip of the corkscrew, that is with $\varphi = constant$, leads to the generalization of Plank's parameter. With the classical definition of energy $E = hf$ it is immediately obtained $\rho = \overline{\lambda}$. This relation is of capital importance for the dynamics of particles. It also implies that the kinetic energy of a particle moving as if it were attached to the tip of a corkscrew converges to a minimum. The particle dynamics proposed in the first sections of this paper is in accordance with the theoretical foundations of the non-relativistic classical quantum mechanics.

Clearly, the equivalence between wavelength and radius o gyration leads to the conclusion that particles at low speeds, correspondingly large wavelengths, must have a proportionally large radius of gyration. This condition leads to an impossible mass distribution pattern if the particle is considered as a single body. The solution to settle the dependence of the radius of gyration with the velocity was to consider the particle as consisting of two similar units symmetrically arranged at the ends of the diameter of the circle whose radius is the radius of gyration. It is the twin particles configuration that is a new geometry proposed here. It is remarkable that this configuration in addition to solving the issue of mass distribution is, I would say, a necessary condition to explain the diffraction phenomenon observed in the classical experiments.

The theory presented in this paper does not contradict the basic phenomenological observations or the main theoretical developments supporting the scientific achievements in quantum mechanics. It is, however, a model that can better explain the characteristic patterns observed in the classical diffraction experiments. Indeed, diffraction patterns can be explained with the particle rotation which is a key component of corkscrew dynamics. Rotation associated with the twin configuration can generate the necessary positive or negative interference processes to explain the bright and dark fringes obtained in diffraction experiments. Particularly important is the annihilation of the diffraction effect when a detector is connected to one of the slits. The twin configuration presents a consistent solution for this event. Note that the explanation for the observed "diffraction patterns" in particle dynamics cannot be attributed strictly to wave motion. Particle dynamics reproduce the diffraction patterns obtained with phenomenon that behave like waves, but particles are not waves. That is, diffraction cannot be attributed exclusively to wave motion, as is commonly admitted. The term wave-particle commonly used in particle dynamics should be avoided, particles are not waves, particles are simply particles. Particles and waves can reproduce similar outputs in some specific experiments, but they keep their own identity.

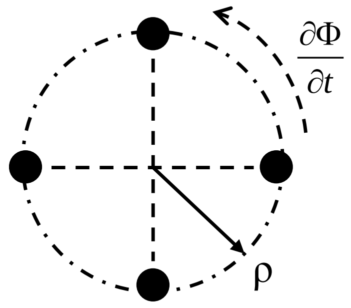


Fig.8.Original particle splits into four sub-particles

In the previous sections, we have assumed that the mass splits into two particles, but there is no difficulty in assuming that mass splits into more than two elements (Fig.8). The density of each sub-particle can, however, increase or decrease depending on the geometry of the new configuration. So far, we have found no convincing reason to say that the density will increase or decrease. Note that the four sub-particles configuration does not present any additional difficulty to the explanation proposed for the formation of diffraction patterns. It is also possible that for a given critical value of the radius of gyration $\rho_{crit}$ each sub-particle assumes an independent path. In this case the new particles can be classified into an appropriate category. If we generalize this idea and admit that up to a given limit the division process can be reproduced, possibly the different categories of particles all or almost all have a single origin, a mother particle existing at the beginning of our universe.

The theoretical framework proposed in this paper suggests that, for a stationary universe, all the mass would be displaced at very large distance from the center, generating a "symmetrical universe". The universe would turn into a huge number of massless skeletons, each bounded by two huge stationary concentration of cold mass at zero degrees Kelvin. Similar reasoning applies to kinetic energy, except that the energy would be concentrated in only one place for each pair of cold masses. Possibly, both dark matter and dark energy are compatible with the model proposed in this paper.

The corkscrew dynamics introduced here provide a solid basis for developing a statistical approach to particle physics. Certainly, there are some phenomena that still need to be analyzed using the corkscrew dynamics. But it is always important to present some basic results before expanding the theory. As explained in the appendix B, it is possible to imagine an experimental setup that can test the correlation between the radius of gyration and the wavelength. Certainly, such an experiment could definitely decide whether the present approach represents what is actually happening at very small scales. Although this paper is about hundred years behind schedule, I hope that the ideas presented here can spark meaningful discussions about how particles move, with special attention to wave motion.

## ACKNOWLEDGEMENTS

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**Appendix A**

The relation between $\rho$ and $\lambda$ can also be derived following a different path. Let $\omega = 0$ with equation (1) it is immediately obtained $\partial\Phi/\partial t = u/\bar{\lambda}$. This is the angular velocity of the particle relative to the inertial frame. The kinetic energy corresponding to rotation is given by:

$$E_R = \frac{1}{2} I \left( \frac{\partial\Phi}{\partial t} \right)^2$$

Now with $I = m\rho^2$ where $\rho$ and $m$ are the radius of gyration and the mass of the particle respectively, the equation above gives:

$$\bar{E}_R = \frac{1}{2} m\rho^2 \frac{u^2}{\bar{\lambda}^2}$$

Or

$$\bar{E}_R = \frac{1}{2} m\lambda u \frac{u}{\lambda} \left( \frac{\rho}{\bar{\lambda}} \right)^2 = \frac{1}{2} hf \left( \frac{\rho}{\bar{\lambda}} \right)^2$$

Now with $h = m\lambda u$ the Planck's constant, $f = u/\lambda$ the corkscrew angular frequency and $k = \rho/\bar{\lambda}$ we obtain:

$$\bar{E}_R = \frac{1}{2} hfk^2 \qquad (1.a)$$

Let us derive the energy corresponding to the translation motion imposed by the corkscrew angular displacement:

$$\bar{E}_T = \frac{1}{2} mu^2 = \frac{1}{2} mu\lambda f = \frac{1}{2} hf \qquad (2.a)$$

The total kinetic energy can now be written combining equations (1.a) and (2.a):

$$\bar{E}_T + \bar{E}_R = \frac{1}{2} hf \left(1 + k^2\right)$$

But $hf = E$, according to De Broglie's proposal, and since $\bar{E}_T + \bar{E}_R = E$ it is immediate that k=1 that is $\bar{\lambda} = \rho$ or $\lambda = 2\pi\rho$

**Appendix B**

The corkscrew model suggests possible mechanisms for selecting different colors through an adequate design of "color-cells". Roughly speaking, it would be a mechanism similar to the one used to detect different sound frequencies. Two types of design are presented, both supported by the same principle. Cells interacting with incoming radiation may be able to detect the respective radius of gyration, as shown in Fig. (B-1). Each segment of the membrane

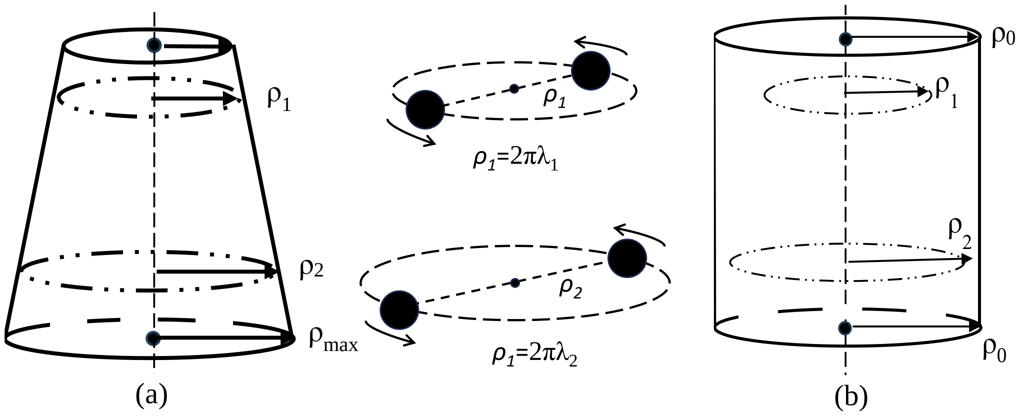


Fig.B-1. (a) Conical membrane. This geometry allows for detecting all radiations with gyration radius $\rho_{min}<\rho<\rho_{max}$ (b) No radiation can be detected all particles go through the tunneling geometry of the membrane.

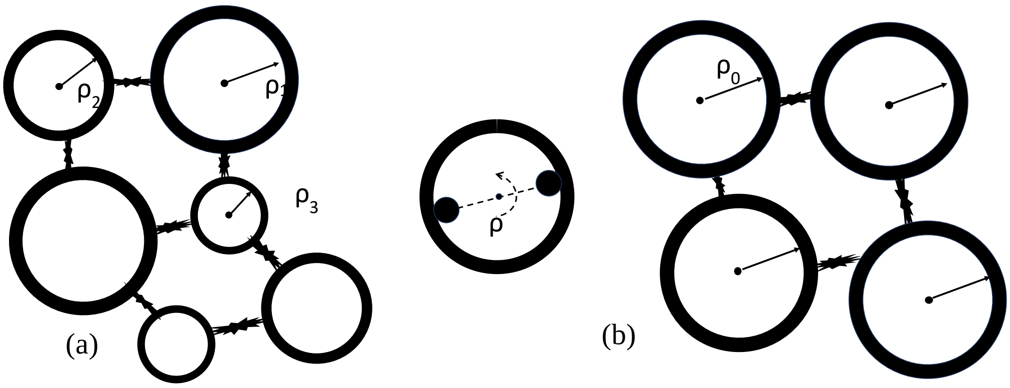


Fig.B-2. (a) Detectors network. This geometry allows for detecting all radiations with gyration radius $\rho_{min}<\rho<\rho_{max}$ (b) No radiation can be detected all particles go through all detectors. No interaction is possible.

responds to a specific dimension of the radius of gyration, that is, to a specific color. A conical membrane may be suitable to perform the required function. A cylindrical membrane would allow the radiation to travel without any interaction. No color could be detected. Other types of configurations are also possible as shown in Fig.B-2. Individual cells with different diameters. Each one is capable of detecting a specific color, that is, a certain radius of gyration. If, however, all cells have the same diameter, then only a specific color could be detected or no color at all if $\rho_0$ is greater than all radii of gyration corresponding to the incident particles.

The above discussion refers to possible geometries and clusters sensitive to the geometry of the particles as proposed here. They could be possibly found in living organisms. If it were possible to build suitable artificial membranes as proposed above, the present theory could be tested.