Vacuum Fluctuations and the Creation of Particles and their Shadow Antiparticles

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Abstract: The authors after showing that the confined helical wave structure of electron is a viable one proposes that its confinement is effected by the interactions with a virtual shadow antiparticle created by the vacuum fluctuations that could be explained on the basis of the uncertainty principle. It is suggested that the two negative energy solutions of the Dirac equation pertains to this shadow particle. These interactions allow vacuum to act like a thermal bath with the confined helical wave attaining a state of equilibrium. It is shown that this equilibrium is not destroyed even when it is in uniform translational motion. This invariance of the equilibrium to the velocity transformation is another way of looking at the theory of relativity. He suggests that other particles may be formed by the confinement of corresponding composite waves which have oscillations in the appropriate fields. This would allow us to generalize the approach based on the confined helical wave to cover all particles.

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1 Introduction

It was earlier shown that the plane wave which represents the electron could be formed by the confinement of the plane polarized half frequency electromagnetic wave (possessing spatial amplitude) after it acquires spinning motion of the same frequency [1]**.** It was observed that such a confined wave acquires mass. The space dependent component of the confined helical wave when given translational velocity was seen to get converted into the amplitude wave that gets compacted into the internal space while the time dependent part transforms into the plane wave defined in the laboratory coordinate system. It has been shown that the confined helical wave structure of electron while accounting for its half spin and the electric charge explains why it satisfies the Pauli's exclusion principle [1][2]. Such a structure was seen to be quite compatible with the Dirac equation [2][3].

We saw the forward and the reverse components of a confined left handed helical wave (positive helicity) oriented along z-axis can be expressed as

$$\phi^{L_1}(\eta) = \eta_1\{\mathbf{j}\cos[E(z'-vt')/\hbar c]+\mathbf{i}\sin[E(z'-vt')/\hbar c]\}e^{-i\hbar^{-1}(Et-\text{þz})}, \quad (1)$$

$$\phi^{L_2}(\eta) = \eta_2\{\mathbf{j}\cos[E(z'-vt')/\hbar c]-\mathbf{i}\sin[E(z'-vt')/\hbar c]\}e^{-i\hbar^{-1}(Et-\text{þz})}. \quad (2)$$

We may obtain the right handed one by changing the sign before the unit vector **i**. Here the cosine and the sine terms which represent the amplitude wave are defined in the internal coordinates while the exponential factor which represents the plane wave is defined in the external coordinates. We know that in the relativistic quantum mechanics, the plane wave may be taken as the eigen function of the four momentum in the coordinate representation. Therefore, when we attribute an inner structure to the plane wave based on the confined helical wave approach, we are actually attributing an inner structure to the eigen state. We shall be expanding this approach further in a separate paper where a re-interpretation of the basic postulates of quantum mechanics will be attempted in the light of the above findings.

In the approach followed by us, the artificial construct of a pair of mirrors facing each other was introduced to confine the helical wave. Now we have to find out which natural phenomenon actually plays the role of the mirrors. Needless to say this role has to be played by waves or particles which are not observable directly. Therefore the obvious choice falls on the vacuum fluctuations. This is because vacuum fluctuations while interacting with particles, are themselves not observable. To begin with we shall examine the nature of vacuum in some detail.

In this paper we shall use the term helical wave to denote the helical wave possessing half spin formed by the plane polarized electromagnetic waves after acquiring half spin. The term confined helical wave will be used to describe the system of standing waves formed by the confinement of the half helical wave between two reflecting mirrors kept facing each other. Such a system represents a particle state when it is moving forward in time and antiparticle state when it is travelling backward in time. Note that a photon also is formed by a train of circularly polarized electromagnetic waves which have helical structure in space. But we shall not use the term helical wave to denote such circularly polarized electromagnetic waves. It will be used solely to denote the half spin helical wave which on confinement creates a particle like electron.

2 Nature of Vacuum

According to quantum field theory, vacuum can be thought as a system of interconnected balls and springs with the strength of the field at any point proportional to the displacement of the ball at that point from its ground state. The vibrations may be propagating based on the wave equation applicable to the particular field in question. The second quantization of the quantum field theory demands that each such ball-spring combination be quantized. Canonically, a simple harmonic oscillator represents the field at each point in space and when we quantize this oscillator we are effectively introducing a quantum harmonic oscillator at each point in space. This allows us to treat the elementary particles as the excitation of the corresponding field. In this approach vacuum is a dynamic system where energy quanta keep bubbling up continuously [4] within the ambit of the uncertainty principle. This is the basic structure of vacuum on which quantum field theory is built.

Such a vacuum is the repository of the zero point energy and this assumption appears to be confirmed by the experiments on the lamb shift [5] and Casimir effect [6]. Take the case of the Casimir effect. If two metallic plates having almost perfect reflecting surfaces are brought very close to each other with the distance separating in microns, then the plates should be acted upon by a force from the outer surfaces which forces them to come closer. While the vacuum fluctuations of electromagnetic waves of all wave lengths could exist outside, only those waves which could form standing waves between the two plates could exist between the two plates. This would mean that the outer sides of the plates are hit by more number of waves than the inner sides and this creates a force bringing the two plates closer. This experiment was actually carried out and such a force was found to exist [6]. This shows that vacuum is full of energy which does not find a way to express itself. In other words, vacuum is not an inert medium, but a dynamic one and it interacts with a particle continuously in a virtual fashion.

3 Vacuum Fluctuations and the Creation of the Shadow Particle

We saw that vacuum could be treated as a dynamic state due to the bubbling up of the vacuum fluctuations of electromagnetic waves. The uncertainty principle

$$\Delta E \, \Delta t \quad \geq \quad h \qquad and \qquad \Delta þ \, \Delta x \quad \geq \quad \tfrac{1}{2} h \tag{3}$$

plays a very important role here. If the period Δt is long, then the fluctuations in the energy of the electromagnetic field would become almost zero. We know from the quantum field theory that in spite of the fluctuations, vacuum is to be taken as the ground state. Any fluctuation in the energy which follows the relation $\Delta E \, \Delta t < h$, will be virtual by nature. We may now attribute the confinement of the helical wave to such fluctuations in the vacuum.

From the earlier discussion [1], it is clear that we may take the plane wave as the confined helical wave. We may now attribute the fluctuations in the energy of the confined helical wave as caused by its interactions with the virtual electromagnetic waves. Note that vacuum can lend or borrow energy and momentum for a short duration so long as the uncertainty principle is not violated. Needless to say, the fluctuations in the energy and momentum of the confined helical wave can be quite large. But if we take a train of such confined helical wavelets occupied successively, then, the net fluctuation in the energy and momentum will be much lower. This is because the cumulative variations in the energy and momentum of the group of the confined helical wave states will nearly cancel each other out. The cancellation will be complete if the number of such states forming the group is infinitely large. Let us assume that the plane wave is formed by a large, but not infinitely large number of wavelets. Therefore, the variations in the energy-momentum of plane wave state will be small, but not negligible.

A very interesting way to picture this interaction is to go back to the plane polarized half frequency wave from which the particle-antiparticle system is created. It is now possible to imagine that a virtual half frequency wave is created during the same period. Of course the requirement is that $\Delta E\ \Delta t < h$ which in the limit we could take it to $\Delta E\ \Delta t = h$. This means that by the time a real particle-antiparticle system is formed by real electromagnetic waves by the process already discussed [1], a particle-antiparticle system can also be formed side by side in a virtual manner. Here the reverse wave of the virtual antiparticle may transfer its momentum to the forward wave of the real particle causing its reflection. Similarly, the forward wave of the virtual antiparticle may transfer its momentum to the reverse wave of the real particle making it undergo further reflection resulting in its confinement. Note that in this process, the virtual forward and the reverse wave (constituting the virtual antiparticle) also gets confined. It is not difficult to imagine a similar set of interactions between the forward and reverse waves of the real antiparticle and those of the virtual particle which results in the confinement of each other.

In the description given above we have four sets of particles. Of these two are real and can be identified with electron and positron. We now see that an electron will always be accompanied by a virtual positron. This positron should not be confused with the real positron produced in the pair production. The virtual positron which facilitates the confinement of the electron is a shadow particle. We can imagine a similar situation in the case of the antiparticle also. For the real positron, the accompanying shadow particle will be a virtual electron. In a separate paper we shall show that ψ^* which appears in the probability postulate actually refers to this shadow particle. It is obvious that the energy and momentum of the real antiparticle created at the moment of pair production will not in any way be coupled with those of the real particle except at the initial moment. On the other hand the energy and momentum of the shadow antiparticles will have the same values just as in the case of the real particle. This means that the solutions of the Dirac equations represent the state of a single particle. In the conventional interpretation, they represent four different states of a particle and we saw that such an interpretation leads to serious contradictions [4].

Let us take the case of the real forward helical wave travelling from A to B (see fig.1). At B the vacuum fluctuation can be assumed to throw up a virtual reverse helical wave travelling in the opposite direction along CQ′B. As a result of the exchange of momentum the original wave APB gets reflected back along BQA by the virtual reverse helical wave CQ′B also gets reflected along BP′C. By the time the virtual wave reaches back at C, it vanishes as based on the uncertainty principle the maximum period for which the fluctuation can be sustained is one period of the oscillation. Therefore, in the limit the period of the oscillation $T_o = \Delta t = h/\Delta E$ (here we are taking the lower limit of the inequality representing the uncertainty principle). Taking $\Delta E = E_o$, the energy of the virtual wave which is generated in the fluctuation, we obtain

$$\Delta t = h/E_o = T_o \tag{4}$$

where T_o is the period of the virtual wave. Now a similar interaction at A will convert the reverse wave into the forward wave. Note that the virtual helical wave created by the vacuum fluctuations also will get

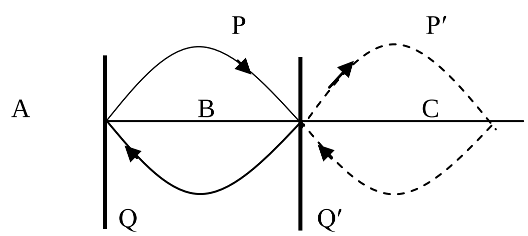

Fig. 1. The original helical wave APB gets reflected to BQA on encountering the virtual reverse helical wave CQ′B at B which in turn gets reflected back to BP′C resulting in the formation of the real and virtual confined helical wave

confined forming the virtual antiparticle. In this manner, the helical waves created by the vacuum fluctuations can play the role of the reflecting mirrors.

4 Confinement of the Helical wave and its Zitterbewegung

In the above analysis we assumed that the energy of the virtual helical wave created by the vacuum fluctuations is exactly equal to that of the real helical wave. Actually, this need not be true. The energy and momentum of the virtual helical waves which interact with the real helical wave themselves may undergo fluctuations. But if we take long enough time interval such that the number of interactions undergone by the real helical wave is large, then based on the uncertainty principle it can be easily seen that fluctuations in the average value of the energy and momentum will become negligibly small. In other words, the rest energy of the particle created by the confinement of the helical wave will be sharply defined.

In the above discussion, for the sake of simplicity we assumed that the magnitude of the momentum of the virtual forward helical wave and the virtual reverse helical wave are equal. Actually this also need not hold good. Even if the energy of the virtual forward helical wave were more than the virtual reverse helical wave it will still be permitted so long as the uncertainty principle is not violated. This means that $\Delta E \Delta t < h$, where ΔE denotes the energy of the forward or reverse wave and Δt, its period of existence. In such a situation, the corresponding energy and momentum of the real forward and reverse helical waves also will show similar variations. Let us assume that the energy of the real forward helical wave becomes E_1 while that of the reverse helical wave becomes E_2 where $E_2 < E_1$. The energy of the confined helical wave will be given by $E = \frac{1}{2}[E_1+E_2]$ and its translational momentum will be given by $\frac{1}{2}(E_1-E_2)/c$. This means that depending on the energy of the virtual helical wave, the real helical wave will undergo random translational motion. We should remember that these states of random motion undergo quantum superposition. In this manner, we may treat the energy of the particle as having contribution from various translational momentum states. But here also, if we take a large number of states, these variations will cancel out and the average value of energy will have a sharply defined value which can be identified with the rest energy of the particle represented by the confined helical wave.

In the situation discussed above, we observe that the rest energy of the particle has two components. One component pertains to the energy of the confined wave and the other component pertains to the energy of the translational motion. If $E_1 > E_2$ such that

$$E_1 \quad = \quad E_2 + \Delta E \tag{5}$$

Then it is obvious that this will result in the confined wave undergoing a translational motion with a net momentum þ given by

$$þ \quad = \quad (E_1 - E_2)/c \quad = \quad \Delta E / c \tag{6}$$

This means that the particle has a rest energy E_2 and translational momentum þ. In spite of these fluctuations, the average value of the rest energy of the particle represented by the confined wave will be E_o which was the energy of the helical wave formed from the half frequency electromagnetic wave after acquiring spinning motion. Therefore the confined helical wave is not to be pictured as a static system, but instead it has to be treated as a system of confined helical wave having different rest energies which undergo to and fro motion or what is usually called the “zitterbewegung” or “zitter” for short.

In the case of a free particle, the region within which it is localized is very large. As a result, the confined helical wave may undergo zitter of longer duration which means that their translational momentum will be lower. If we take N states of confined helical wave, then it may contain certain states where the rest energy is quite high which undergo high frequency zitter. It may also contain certain states with low rest energy undergoing low frequency zitter. In short, out of N states occupied by the confined helical wave, the rest energy may range from very high to very low values. Here we assume that any observation will involve a group of N such states where N can be a large number. Therefore, the only the average value of these N states become the observable quantity. We have to keep in mind that this range of values is created by the vacuum fluctuations. When the helical wave gets confined into a small region, the low energy states will be replaced by those with higher energy. This results in a situation where the rest mass keeps on increasing as the region of confinement becomes smaller and smaller. This approach allows us to view mass as being distributed in concentric shells. But this will not lead to the problem of infinity because the probability for occupying such high energy states will be infinitesimally small. Almost the entire contribution will come from states crowding around the average value. The situation is similar to what we observe in the case of thermodynamic system like an ideal gas. The micro states of the gas have a delta function like probability distribution around the average value. This may explain why the rest energy of the particle cannot be infinite. In quantum field theory it was necessary to introduce an arbitrary cut off in the momentum states in order to avoid the problem of infinity [5]. In this approach the cut off emerges naturally without any arbitrariness. For full explanation of this problem of the infinite self energy it will be necessary to introduce a few other concepts. This will be done in a separate paper.

5 Vacuum Fluctuations and the Theory of Relativity

We saw that the confinement may be attributed to the shadow particle created by the vacuum fluctuations. For a particle at rest, these interactions may be taken as isotropic and for the same reason, the confined helical wave may occupy all possible directions. But as discussed earlier [2], when we introduce translational velocity, then only the confined helical wave in the direction of motion needs to be considered since their amplitude in all other directions can be taken as zero. We know that it is more convenient to replace the interactions with the shadow particle by the artificial construct of two perfect mirrors facing each other as the set up that causes the confinement of the helical wave. Note that the force acting upon the

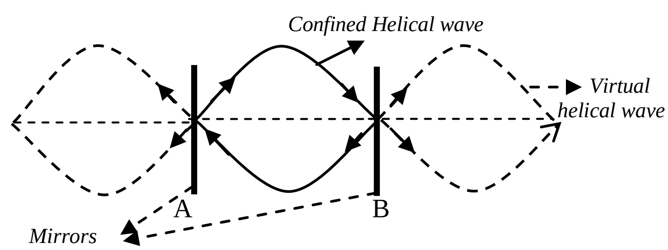

Fig.2. Two perfect mirrors A and B reflect the helical wave back and forth confining it. The force acting on the mirrors from the inner side is balanced by the virtual helical waves which impinge on the mirrors on the outer side where they get reflected back.

mirrors from the inside on reflection of the helical wave will be balanced by the force acted upon by the virtual helical waves (of the shadow particle) from the outside (figure.2). In other words, the reflecting mirrors act like a vessel containing a one dimensional gas in a heat bath and this can be taken as the case where the confined helical wave is in equilibrium with the virtual waves created by the vacuum fluctuations.

Let us now take a stationary particle A. Let B be another particle having uniform velocity, v with regard to A (figure.3 a). According to an observer on A, the energy of the virtual helical waves interacting

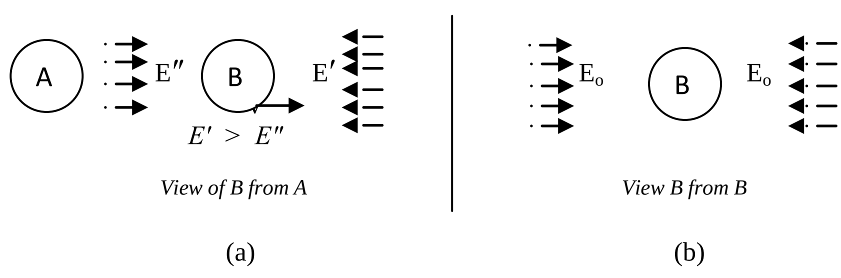

Fig.3. *(a) For an observer on particle A, particle B will be hit with more force in the front than on the reverse due to the Doppler shift in the energy of the virtual helical waves.(b)But to an observer on B same interactions will appear symmetric as the particle is at rest for him.*

with B from the forward direction will be more than that from the reverse direction forcing it to come to a standstill after some time. On the other hand, for an observer on B, its interactions with virtual helical waves will appear isotropic because for him B is at rest. This may at first glance appear as a paradox. A will assume that the helical waves hitting B is anisotropic due to the difference in the Doppler shift in the frequencies of the waves interacting with it in the front compared to those in the reverse.

Let us now take the case of the observer on B. We know that for the observer on B the energy, E_o and the magnitude of momentum, p_o of the forward and the reverse helical waves constituting B will be the same. However, for the observer on A, B will be having uniform velocity v (say, along the z-axis). Therefore, as far as A is concerned, the energy of the forward helical wave of B will get Doppler shifted to a higher value while that of the reverse wave will get Doppler shifted to a lower one. Let us now study the effect of uniform velocity on the helical wave. We should keep in mind that by the time the forward helical

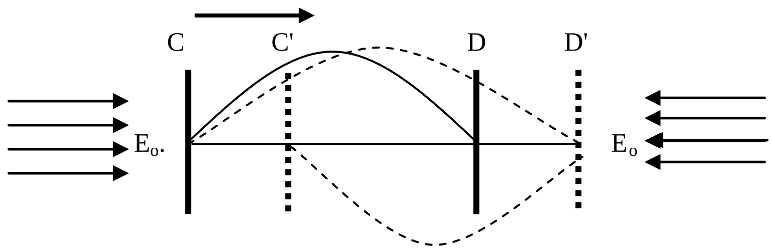

Fig.4. For an observer on A, by the time the forward wave of B moves from C to D, D would have moved to D' thereby stretching the forward wave. On the other hand, the reverse wave would get compressed by the movement of C to C'.

wave moves from C to D (figure.4), D would have traveled to D′ a distance $\frac{1}{2}vT_1$, where T_1 is the period of the forward helical wave. This means that, for observer A, the forward helical wave will get effectively stretched and the effective wave length of the forward wave will be given by

$$\tfrac{1}{2}\lambda_1' \quad = \quad \tfrac{1}{2}\lambda_1 + \tfrac{1}{2}\mathbf{v}T_1 \quad = \quad \tfrac{1}{2}\lambda_1(1+\mathbf{v}/c) \quad = \tfrac{1}{2}\lambda_o\sqrt{1-\mathbf{v}^2/c^2} \tag{7}$$

since $\lambda_1 = \lambda_o\sqrt{(1-\mathbf{v}/c)/(1+\mathbf{v}/c)}$. Here λ_o is the wave length of the confined wave in the rest frame while λ_1 stands for the Doppler shifted wave length where the source is moving in the direction of the wave propagation. Note that (7) expresses the relativistic contraction of the distance between the two mirrors. Likewise, the effective wave length of the reverse wave will be given by

$$\tfrac{1}{2}\lambda_2' \quad = \quad \tfrac{1}{2}(\lambda_2 - \mathbf{v}T_2) \quad = \quad \tfrac{1}{2}\lambda_2(1-\mathbf{v}/c) \quad = \quad \tfrac{1}{2}\lambda_o\sqrt{(1-\mathbf{v}^2/c^2} \tag{8}$$

Here λ_2 stands for the Doppler shifted wave length where the source is moving in a direction opposite to that of the wave propagation. These results are quite logical as the length of the standing wave has to adjust itself to be equal to the separation between the mirrors which undergoes relativistic contraction.

In the case of uniform motion, the momentum of the forward helical wave hitting the mirror D from the inner side will be equal to

$$p_1' \quad = \quad h/\lambda_1' \quad = \quad \gamma\, h/\lambda_o \quad = \quad \gamma\, p_o \ . \tag{9}$$

In the case of the reverse wave the corresponding momentum will be given by

$$p_2' \quad = \quad h/\lambda_2' \quad = \quad \gamma\, h/\lambda_o \quad = \quad \gamma\, p_o \ . \tag{10}$$

Note that the momentum of the virtual helical wave interacting with B from the forward direction will also undergo Doppler shift similar to what happened to the reverse wave as given in (10) and as a result, the momentum of the wave interacting with B head on at D ′ will be given by $p'_2 = \gamma p_o$. This means that the momentum hitting the wall D′ from the inside and that hitting it from the outside balance out. It can be easily seen that a similar balancing of momentum takes place on the reverse mirror C’ also. This explains why the virtual helical waves do not act as a drag on the particle and why it moves forward with a uniform velocity.

Here one may ask why vacuum should not remain inert for accelerated motion also. Why is the uniform motion different from the accelerated motion? As already discussed, as an electron moves with uniform velocity, the forward wave and the reverse wave constituting it are in perfect equilibrium with the vacuum fluctuations. In other words, the vacuum neither lends nor borrows energy from the electron and therefore acts like an inert medium. But when we increase the velocity of the electron from v to v', then it moves from one state of equilibrium with vacuum to another state of equilibrium which has got higher energy. The observer will find that the energy of the virtual helical waves interacting with the forward wave increases from one instant to another while that on the reverse direction decreases proportionately.

6 Vacuum Fluctuations as a Thermal bath

The above discussion shows that a particle in uniform motion is in a thermodynamic state having a certain internal energy and is in a state of equilibrium with vacuum. When the particle is accelerated, the system is shifted from one thermodynamic state with a certain internal energy to another one with a higher internal energy. It is as if the system has undergone adiabatic compression which results in higher temperature and higher internal energy. This may sound like stating the obvious. However, thermodynamic representation of a particle may provide us with a new insight into the nature of inertial mass and the role played by the vacuum fluctuations in the form of virtual helical waves in it.

We saw that a particle in uniform motion is always in thermal equilibrium with the vacuum fluctuations. Therefore, in the thermodynamic sense the principle of relativity represents the fact that the equilibrium with vacuum is independent of the velocity of the particle. When a particle absorbs kinetic energy in an interaction, this equilibrium is disturbed and it has to gain velocity to reach a new equilibrium with the vacuum fluctuations of higher energy and momentum. Note that there is a very important difference between the thermal bath formed by the vacuum fluctuations and the conventional thermal bath used in the laboratory. In the conventional thermal bath, the energy (and also the momentum) of the molecules of the thermal bath have well defined average values. But in the case of the thermal bath formed by the vacuum fluctuations, the energy of the interactions with a particle depends on the energy of the particle itself. A particle with higher energy will be interacting with vacuum fluctuations of higher energy. This is the reason why we have particles with different rest energies existing side by side in vacuum in equilibrium. In a conventional thermal bath it is not possible to have two systems with different intrinsic internal energy to be in equilibrium with it.

7 Conclusion

In the approach followed in this paper, the confinement of the helical wave which results in the formation of the particle is effected by the virtual helical waves created by the vacuum fluctuations. We know that this confinement directly leads to the creation of mass and the electric charge [1],[2]. Here we should keep in mind that the particle under study was electron as it interacts with the virtual helical waves formed by the electromagnetic waves created in vacuum fluctuations. But if we consider particles like quarks, the same virtual helical waves created by the vacuum fluctuations may not be able to effect the confinement. But then we should remember that a quark may have to be thought of as created by the confinement of a composite wave which has oscillations not only in the electromagnetic field but also in other fields which could account for their properties like color and charm [7]. Note that for particles like quarks also the proposed mechanism of confinement using the virtual vacuum waves will be equally effective. The time dependent part of the confined helical wave will transform to plane wave while the space dependent part which accounts for the internal structure of the particle will get compacted into the internal coordinates. This means that whatever be the interactions confining the composite helical wave, it will continue to be represented by the plane wave in the laboratory coordinate system. All other field which interacts with the system confining it will affect only its inner structure.

The concept of the vacuum fluctuations that acts like a thermal bath needs to be studied in depth. It should be noted here that the interactions with the vacuum thermal bath should be understood in terms of the quantum superposition principle which allows a particle to occupy a large number of states at the same time. Needless to say the present approach which is based on the wave mechanical approach to quantum mechanics will have to be expressed in the formalism of quantum field theory for greater clarity. This will be attempted in due course in separate papers.

Since a confined helical wave is in equilibrium with the sub-quantum thermal bath it will be occupying a range of states having specific values for energy and momentum. This group of states can be treated as a gas which may be called the “primary gas”. Therefore, it should be possible to treat a particle as a thermodynamic system possessing properties like temperature, internal energy, entropy etc. and these thermodynamic properties may be related to the corresponding mechanical properties of the particle. In the next paper it will be shown how a particle can be treated as a gas and how its mechanics can be derived from its thermodynamics.

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