# Einstein-Podolski-Rosen Paradox and Stochastic Wheeler-Feynman Absorber Theory

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**Abstract**

The basic idea of the theory developed in a previous paper: the theory of stochastic electrodynamics with classical Wheeler-Feynman absorber theory, the character of the Lorentz invariant zero point radiation and a minimum "emitter-absorber transaction" of Cramer extended to the case where the zero point radiation exists, has been studied.

## Section 1. Introduction.

The purpose of this paper is to give a more comprehensive account of the fundamental concepts underlying the theory developed in a previous paper[1] on the Wheeler-Feynman absorber theory in the context of the stochastic electrodynamics. It intends to give a clear explanation on Cramer's concept of a "transaction" between an emitter and an absorber extended to the case where the Lorenrtz invariant zero point radiation exists.

The Einstein-Podolski-Rosen paradox (EPR paradox) brought two well established fundamental principles of physics: the principle of quantum mechanical inseparability of states once interacted, on the one hand, and the principle of special relativity, i.e., the Einstein locality premise, on the other, into a sharp conflict by the assertion whether the description of quantum mechanics by a wave function is incomplete or the Einstein locality premise is wrong[2].

The Einstein locality premise may be phrased as follows: If $S_1$ and $S_2$ are two systems that have interacted in the past, but are now arbitrarily separated, then, the real situation of the system $S_1$ does not depend on what is done with $S_2$ which is spatially separated from $S_1$ so that only a superluminal signal can reach from $S_2$

to $S_1$ or *vise versa.*

Retaining the locality premise in the theory, many attempts have started to replace quantum mechamics by other theories which aim at a better description than or present a different interpretation of quantum mechanics from what quantum mechanics predicts. Some of them, the "hidden variables theories" which introduce in the theory "hidden variables" on which quantum mechanics knows nothing about and the theories retain the deterministic character as with classical physics and the Einstein locality premise. The other attempts to replace quantum mechanics are, for example, statistical in nature which is based on the interpretation that quantum mechanics is in essence a classical statistical mechanics. Some others are stochastic in nature which interprete quantum phenomena as due to a stochastic process such as a Brownian motion or a zero point fluctuation radiation field filled in the universe causing quantum effect but itself cannot directly be observed.

In 1956, Bell[3)] has derived an inequality, the Bell's inequality, which tells that the prediction of all "local" hidden variables theories whether they are deterministic, statistical or stochastic should satisfy the inequality while that of quantum mechanics does not. The Bell's inequality, thus exposed the validity of all the local hidden variables theories and quantum mechanics under an experimental verdict.

Several experiments, utilizing various phenomena such as $\gamma$-rays from a cascade-photon-decay of an excited atom,[4)] those positronium annihilation[5)] and proton-proton scatterings,[5)] and so on, have been performed to find whether the Bell's inequality relation holds or not. A majority of the experimental results show that Bell's inequality does not hold but support the prediction of quantum mechanics so that the Einstein locality premise was wrong except to certain people who express reservation of their verdict. This leads to the result that all local hidden variables theories were outlawed as being contradictory to the laws of nature. However, as mentioned above some people maintain an opinion that the experimental results in comparison with the prediction of a theory needs an additional assumption through which the comparison of the experimental result with the Einstein localty premise can be made possible. And they think that the experimental results reject only such assumptions but not the "locality" premise itself.

To get round the difficulty, more attempts of experiments using more sophisticated techniques are going on to test the Bell's inequality directly. However, the abandonment of the Einstein locality premise presents a great difficulty to theoretical physics because the Einstein locality premise is closely connected with the basic assumption of the special theory of relativity and the denial of faster than light velocity which is a well established principle since the theory was founded by Einstein more than three quaters of a century ago. It seems that the EPR paradox brought in front the deep-seated contradiction between the non-separability in quantum mechanics and the principle of relativity. However, several experiments such as Freedman-Clauser experiment,[7] and several others, seem to support the non-separability of quantum states against the Einstein locality premise. A clear explanation based on the fundamental principles to resolve the conflict is needed. But it has not been put forward until Cramer[8] came up with a solution on the basis of Wheeler-Feynman theory with an idea of a minimum emitter-absorber "transaction."

With the help of an extension of the Cramer's concept of transaction in the presence of the "zero point fluctuation radiation", postulated in the stochastic electrodynamics[9], we have developed a theory on a basis of stochastic interpretation of quantum phenomena and, instead of using Maxwell-Lorentz electrodynamics, utilized, the Wheeler-Feynman absorber theory in which advanced fields together with Cramer's transaction model are taken into account.

In section 2, we describe the nature of the zero point fluctuation radiation and the stochastic electrodynamics. In section 3, a description is given of the formulation of Wheeler-Feynman absorber theory[10] with the zero point radiation and the Cramer's model of transaction concluded between an emitter and an absorber in the context of Wheeler-Feynman absorber theory. In section 4, an extension of the Cramer's model of a minimum emitter-absorber is made to the case where the zero point radiation exists. The fundamental equation of a simple harmonic oscillator is derived. In section 5, Wheeler-Feynman absorber theory in the presence of the zero point radiation is described.

## Section 2. Zero point fluctuation radiation and stochastic electrodynamics.

In the stochastic electrodynamics, it is postulated that the universe is a "heat bath" filled with the electromagnetic "zero point fluctuation radiation" even in the vacuum, so that any object in the universe undergoes a stochastic process by interacting with the radiation and thus no system can be considered isolated. The zero point radiation has been familiar to physicists since a harmonic oscillator in quantum theory should have even in its ground state: the zero point energy $E = (1/2)h\nu$. In 1916, Nernst[11] had suggested that the universe might contain zero point radiation in agreement with (1/2)h$\nu$ per normal mode proposed by Planck.

Before accepting the existence of the zero point radiation in the actual universe, several apparent contradictions have to be resolued.

(1) The energy of the radiation integrated over all frequency should be finite. (2) Why should the radiation not give rise to any observable frictional force like that due to Brownian motion which causes a frictional force proportional to the velocity of a moving body or other effects.

Even though the zero point radiation appears naturally in the theory, by these difficulties, the existence of the radiation has been denied. However, recently, Marshall, Boyer[9] and others have found that (1) the zero point radiation with the spectrum of $\rho(\omega)=\frac{h\omega^3}{2\pi^2c^3}$ does not give rise to any observable frictional force on an object moving with a constant velocity. (2) The spectrum of the radiation seen from an inertial observer does not change with the velocity of the observer i.e., the spectrum of the radiation is Lorentz invariant. (3) The radiation remains undetectable directly to an intertial observer by its relative velocity, as was shown in ref. (1) and (9).

These facts together with a finite total energy of the radiation makes it possible for a theory to postulate the existence of the radiation. As will be shown later, the effect due to the radiation manifests itself in quantum phenomena and the stochastic electrodynamics postulates that quantum phenomena are due to the effects attributable to that of the zero point radiation. The stochastic electrodynamics is no longer a hidden variable theory in this respect.

Several attempts have succeeded in explaining that quantum phenomena can be explained by the postulate of the zero point radiation in the context of classical physics for such phenomena as Casimir effect[12], Planck's distribution law for black body radiation, the energy levels of a harmonic oscillator and some quantum phenomena which are discussed by several people and are thought to be explained only by quantum mechanics.

It is, however, difficult for the present stochastic electrodynamics to explain the result of Freedman-Clauser experiment and others which invalidate the Einstein locality premise and support quantum mechanical non-locality.

A comprehensive account of the result of Freedman and Clauser experiment and of the failour of the Einstein locality premise has not yet been given. This presents a great difficulty not only to stochastic electrodynamics but also to quantum theory and relativity even though quantum inseparability is a direct consequence of quantum mechanics.

Recently, however, Cramer[8] has presented a clearcut explanation of the result of Freedman-Clauser experiment. The Cramer's explanation, uses Wheeler-Feynman absorber theory instead of Maxwell-Lorentz electrodynamics which utilizes only retarded potentials. By using quantum mechanical Wheeler-Feynman absorber theory, Cramer resolved the Einstein-Podolski-Rosen paradox in the context of quantum mechanics. On the basis of Cramer's model of a minimum emitter-absober transaction, the authors, in a recent paper, have proposed a new solution to the paradox mentioned above: to explain Freedman-Clauser experimental result and of quantum phenomena in the context of Wheeler-Feynman absorber theory with a postulate of the existence of the zero point fluctuation radiation in the universe.

## Section 3. Classical Wheeler-Feynman absorber theory with zero point radiation.

In the usual Maxwell-Lorentz electrodynamics, only retarded fields have to be present in the universe and advanced field is discarded so that advanced fields do not play any part in the physical theory. However, as Cramer has demonstrated, to explain the correlation effects in quantum mechanics, advanced and retarded fields together should equally play the part.

In our theory, a charged particle emitts both the advanced and retarded fields and also the zero point radiation. There are several possible choices in the boundary condition on the solutions of Maxwell's equations for fixing advanced field and retarded field and thus, fixing the outgoing field and the incoming field at both future and past infinities.

In our theory, we have postulated a time symmetric boundary condition for the zero point radiation at both infinities. The zero point radiation comes in at the past infinity and goes to the future infinity with the same spectrum of the radiation. (As to the asymmetrical property of the expanding universe in relation to the past infinity to the future infinity is discussed in ref. (13)). Thus, the boundary condition is expressed as:

(1) $(-F_{in})+F_{out}=0$, at the past as well as the future infinity.

Then, the total field acting on a particle C: $F_{tot}^{(c)}$, by the rest of the particles $(j)$ is expressed as[13]:

$$(2)\quad F^{(c)}_{tot}=\frac{1}{2}\sum_{j\neq c}(F^{(j)}_{ret}+F^{(j)}_{adv})+\frac{1}{2}(F_{in}+F_{out})$$

The difference of our theory to the current stochastic electrodynamics (SED) is that, advanced field $F^{(j)}_{adv}$ is included in our theory while no advanced field appears in the SED.

Equation (2) can be cast in the following form:

$$(3)\quad F^{(c)}_{tot}=\sum_{j\neq c}F^{(j)}_{ret}-\frac{1}{2}\sum_{all\ j}(F^{(j)}_{ret}-F^{(j)}_{adv})+\frac{1}{2}(F^{(c)}_{ret}-F^{(c)}_{adv})+\frac{1}{2}(F_{in}+F_{out})$$

In deriving the above equation, we have used the following equation:

$$(4)\quad \frac{1}{2}(F_{out}-F_{in})=\frac{1}{2}\sum_{all\ j}(F^{(j)}_{ret}-F^{(j)}_{adv})$$

and the third term on the right-hand side of (3) is the radiation damping force term identified by Dirac[14]. We derive the following equation of motion for a charged particle $c$ of mass $m$ and charge $e$ as:

$$(5)\quad m\ddot{x}^{(c)\mu}=e\dot{x}^{\nu}(F^{(j)}_{tot})^{\mu}_{\nu}$$

$$=\gamma[\dddot{x}^{(c)\mu}+\ddot{x}^{(c)\nu}\ddot{x}^{(c)}_{\nu}\dot{x}^{(c)\mu}]+e\dot{x}^{(i)\nu}(\sum_{j}(F^{(j)}_{ret})^{\mu}_{\nu}+(F_{in})^{\mu}_{\nu})$$

where $\gamma=2e^2/3c^3$ and the dot indicates differentiation with respect to the proper time of the particle $c$. As can be seen from (5), the advanced field $F^{(j)}_{adv}$ completely disappeared in it. The advanced field is absorbed partly into the damping term and partly into $F_{in}$.

However, as will be discussed in the next section, the advanced field plays a vital role in the correlation effect of two quantum states once interacted as revealed by Freedman and Clauser experiment. The advanced field affects in the radiation damping term in equation (5) and they manifest themselves in pre-acceleration of an electron.

In the Maxwell-Lorentz formulation, such an effect contradicts the causality law and is discarded. However, as Cramer has shown, the advanced field explains the non-separability aspect of quantum mechanics and is indispensable in resolving the incompatibility of the Einstein locality premise and the quantum non-separability.

## Section 4. Cramer's model of a minimum "emitter-absorber"

The electromagnetic wave equation for a source-free space is given by the second order differential equation: $c^2\triangle\vec{F}=d^2\vec{F}/dt^2$, where $\triangle$ is the Laplacian operator, $\vec{F}$ the wave function representing either the electric field $\vec{E}$ or the magnetic field $\vec{B}$. The differential equation is second order for both time and space variables so that there are two independent time solutions and two independent space solutions. It has been known that these solutions are waves, one is moving in the $\vec{r}$ direction with positive energy and positive momentum and the other, moving in the $\vec{r}$ direction but with negative energy and negative momentum flowing in the negative direction : $-\vec{r}$. The latter wave, a negative energy solution of the wave equation, going backward in time, will arrive at $t=-|\vec{r}|/c<0$ before the instant $t=0$ of its emission, is called an advanced wave. On the other hand, a wave moving with positive energy and momentum is called a retarded field.

Wheeler-Feynman absorber theory utilizes both fields and proposes a time-symmetric boundary condition and asserts that both half-retarded and half--advanced waves are emitted simultaneously by an emitter or an absorber. To explain Freedman-Clauser's experimental result and others, Cramer presented an idea of a "minimum emitter-absorber transaction" for an elementary electromagnetic interaction process.

The important difference of the Cramer's idea of a "minimum emitter-absorber transaction" characterizing the Wheeler-Feynman absorber theory and is absent from Maxwell-Lorentz formulation of electrodynamics is that the former introduces an idea of a "double transaction" which plays a vital role to explain the result of Freedman and Clauser experiment. The Cramer's transaction can be formulated as follows.

By adopting a time symmetic boundary condition in the Wheeler-Feynman absorber theory, an emitter (an absorber) emitts (absorbs) both an advanced wave and a retarded wave, the energy and momentum of which are opposite in sign. These two waves together compensate the energy and momentum so that the emitter (absorber) does not change its energy nor its momentum by the act. Thus, an emitter (an absorber) could emitt such waves at any time to any possible direction experiencing neither recoil nor energy loss or gain in the act of emission. This feature of emission or absorption process clearly contradicts our experience. However, in Wheeler-Feynman absorber theory, when an interaction takes place, and a transaction between an absorber and an emitter is concluded, an emitter (an absorber) emitts (absorbs) a full retarded wave so that the result agrees with observation. The process is called a completion of a transaction between an emitter and an absorber and is described in detail in the following.

An emitter can send out "probe" waves (both advanced waves as well as retarded waves) in various allowed direction without any change of its energy and momentum, for seeking a "transaction" with a potential absorber of the waves in the universe. While an absorber sends out "probe" waves both of advanced and retarded seeking also for a transaction. When one of the probe waves emitted by an emitter suitable for the absorption, matches an absorber, then the absorber sends back a "verifying wave" to the emitter signalling a confirmation of the "transaction" and arranging for the transmission of energy and momentum to the absorber. When a transaction is completed between an emitter and an absorber, the transaction is called "a minimum emitter-absorber transaction". The process of the transaction proceeds as follows. (see Fig. 1)

In a minimum emitter-absorber transaction, the emitter produces a half-amplitude retarded wave: $\frac{1}{2}R_e$ and a half-amplitude advanced wave: $\frac{1}{2}Ae$, where the following condition holds: $\frac{1}{2}R_e+\frac{1}{2}A_e=0$ for an emitter. Therefore, the emission of the waves produces no effect on the emitter. Also, the absorber emitts a half-advanced wave $\frac{1}{2}A_a$ and a half retarded wave $\frac{1}{2}R_a$, the sum of which is zero: $\frac{1}{2}A_a+\frac{1}{2}R_a = 0$. They cancel at the absorber. In order that a transaction to be concluded, the following "matching" condition between the two waves must be

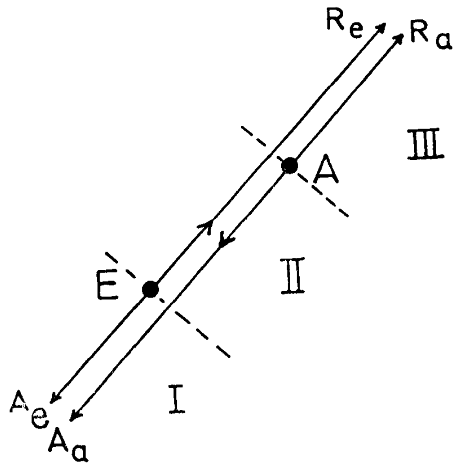


Fig. 1. A simplest emitter-absorber transaction.

For the emitter; $\frac{1}{2}(A_e+R_e) = 0$,

For the absorber: $\frac{1}{2}(A_a+R_a) = 0$.

Transaction condition:

In Region I: $\frac{1}{2}(A_e+A_a) = 0$,

In Region III: $\frac{1}{2}(R_e+\mathrm{R}_a) = 0$,

In Region II: $\frac{1}{2}(R_e-A_a) = R_e$.

satisfied:

(6) $\frac{1}{2}A_e+\frac{1}{2}A_a=0.$ (in region I) (see Fig. 1.)

In the region III, $\frac{1}{2}R_e$ cancels $\frac{1}{2}A_e$ i.e., the "matching" condition holds:

(7) $\frac{1}{2}R_e+\frac{1}{2}R_a=0$ (in region III)

A half retarded wave: $\frac{1}{2}R_a$ enhances the wave: $\frac{1}{2}R_e$ in the region II:

(8) $\frac{1}{2}R_e-\frac{1}{2}A_a=R_e$, (in region II) by virtue of (7).

A transaction is completed and the emitter and the absorber exchange a full retarded wave $R_e$ given by (8), in region II which is passing from the emitter to the absorber with an appropriate recoil to the emitter (and the absorber) during emission (and absorption) but one does not see any waves in regions I and III. (See Fig. 1) Since there is no waves in the regions I and III, no transfer of energy nor momentum from the emitter-absorber system to the outside of the system takes place. The minimum emitter-absorber system as a whole conserves its energy and momentum so that it is considered as an isolated system.

*Double transactions.* Cramer extended the idea of a minimum emitter-absorber to a "double transaction" in which an emitter and two absorbers take part in a transaction to explain the result of Freedman-Clauser experiment.

By a double transaction, an emitter sends out two half-retarded "probe waves" and two half-advanced probe waves anticipating "verifying waves" from two potential absorbers in response to the probe waves.

By the emission of the probe waves, the emitter receives no recoil nor loss or gain of energy and momentum. While two absorbers also emitt two half-advanced waves and two half-retarded waves without any loss or gain of energy and momentum. When the waves emitted from an emitter and two absorbers satisfy the following "matching conditions": (See Fig. 2)

$$(6)\quad \begin{aligned}&\frac{1}{2}R_{ei}+\frac{1}{2}R_{ai}=0,\\&\frac{1}{2}A_{ei}+\frac{1}{2}A_{ai}=0,\end{aligned}\qquad (i=1,2)$$

a double transaction will be completed.

In this case, two half-advanced waves, sent by the two absorbers when they match the condition (6), become the verifying waves to the emitter and the double transaction is concluded between them. (Fig. 2) As in the case of a minimum emitter-absorber system, the system forms a closed system, and the emitter transfers

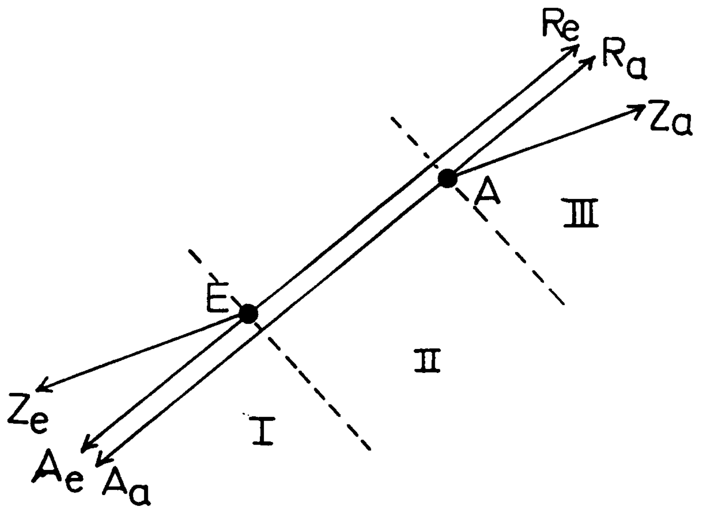


Fig. 2. Transaction in the presence of the zero point radiation.

At the emitter: $Z_e+\frac{1}{2}A_e+\frac{1}{2}R_e=0.$ for a pilot wave.

At the absorber: $Z_a+\frac{1}{2}A_a+\frac{1}{2}R_a=0,$ for a probe wave.

Matching condition:

In region I: $A_e+A_a=0,$

In region III: $R_e+R_a=0,$

Transaction condition:

$Z_a-Z_e=0.$

two waves to two absorbers so that the emitter-absorber system does not emitt or absorb, any waves when seen by an outside obserber.

Cramer has demonstrated that, applying the concept of double transaction to two successive emission of $\gamma$ rays in a double photon decay of an excited Calcium atom to show the polarization correlation between the two $\gamma$ rays. The correlation of the polarization directions of the two photons has been successfully demonstrated by the double transaction model[8]

By the two matching conditions (6), the two photons maintain the polarization correlation between them when they are absorbed by two different absorbers in a spatial position. Because even in a spatially separated position of the two absorbers, the matching condition (6) establishes the correlation of the spin direction of the two photons when they are absorbed by different absorbers. If a verifying advanced wave from an absorber should reach another absorber over a spatial distance the double transaction condition imposes the matching condition in the absorption process. Unless the matching conditions are satisfied, no double $\gamma$-ray transmission should take place. Thus, the correlation of polarization of the two photons is established.

## Section 5. Wheeler-Feynman absorber theory in the presence of the zero point radiation.

It seems that, without the help of Wheeler-Feynman absorber theory, it is difficult for the stochastic electrodynamics to explain the result of Freedman and Clauser experiment.

In a previous paper, we have introduced Wheeler-Feynman absorber theory into the stochastic electrodynamics and extended the idea of an emitter-absorber transaction to the case where the zero point radiation is present. The extended idea of the "transaction" is as follows.

An emitter (an absorber), by the influence of zero point radiation $Z_e$ emitts an advanced wave $\frac{1}{2}A_e(\frac{1}{2}A_a)$ and a retarded wave $\frac{1}{2}R_e(\frac{1}{2}R_a)$ in such a way that the sum of them is zero:

$$(9)\quad \begin{aligned} &Z_e+\frac{1}{2}(A_e+R_e)=0, \text{ for an emitter,} \\ &Z_a+\frac{1}{2}(A_a+R_a)=0, \text{ for an absorber.} \end{aligned} \qquad \text{(See Fig. 3)}$$

By the act of emission (or absorption), neither the emitter nor the absorber receives any recoil. An emitter (an absorber) can send out probe waves in any allowed directions with any allowed frequency without any recoil by the act unless a transaction is completed between the emitter and the absorber.

The condition for a transaction is

$$(10)\quad \begin{aligned} &\frac{1}{2}A_e+\frac{1}{2}A_a=0, \text{ in the region I,} \\ &\frac{1}{2}R_e+\frac{1}{2}R_a=0, \text{ in the region III.} \end{aligned}$$

As the result of a transaction, an emitter absorbs a zero point radiation $Z_e$ and emitts a full retarded field $R_e$. While the absorber absorbs a full retarded field $R_e$ and emitts the zero point radiation which the emitter absorbed. From equations (9) and (10), we obtain the following condition (transaction condition):

$$(11)\quad Z_a-Z_e=0.$$

This process is illustrated in Fig. 3.

To a distant observer, the zero point radiation appears as if it bypasses the emitter-absorber system without producing any influence on the system. However, the allegation does not prove correct for a system consisting of absorbers and emitters of more than two. For example, in the case of a double transaction, is shown in Fig. 3.

In this case, the energies and momenta of the exchanged two photons fluctuate

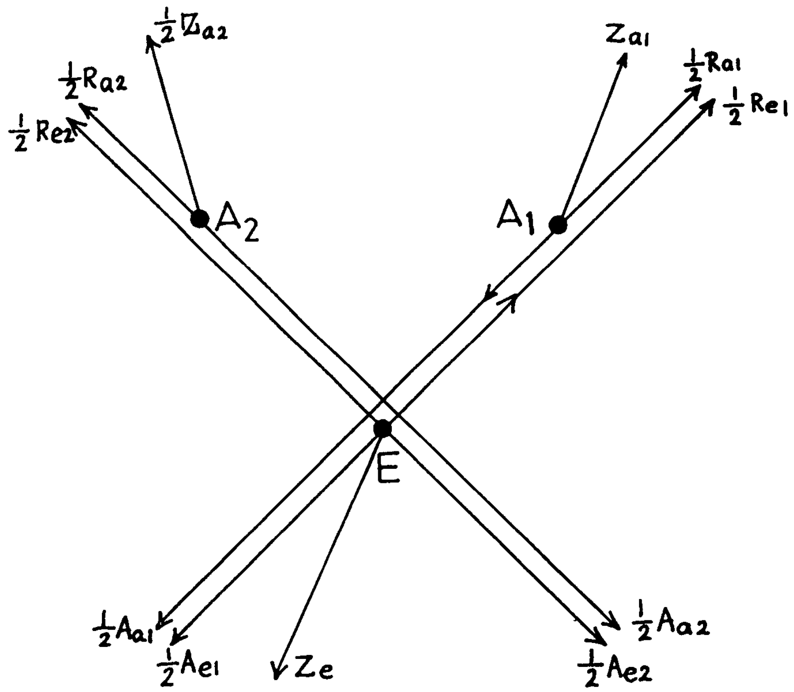


Fig. 3. Condition for an emission or an absorption:

At the emitter: $Z_e+\frac{1}{2}A_{e1}+\frac{1}{2}A_{e2}+\frac{1}{2}R_{e1}+\frac{1}{2}R_{e2}=0$,

At the absorber 1:
At the absorber 2: $Z_{ai}+\frac{1}{2}A_{ai}+\frac{1}{2}R_{ai}=0$, $(i=1, 2)$.

Matching condition:

In regions I and II: $\frac{1}{2}A_{ei}+\frac{1}{2}A_{ai}=0$, $i=1, 2$.

In region III: $\frac{1}{2}R_{ei}+\frac{1}{2}R_{ai}=0$, $i=1, 2$.

Transaction condition: $Z_{ei}+R_{ai}=0$, $i=1, 2$.

because the condition for a transaction given by the equation:

(10) $Z_{in}+Z_{a1}+Z_{a2}=0$.

However, the sum of the energies and that of momenta emitted by the emitter and absorbed by the two absorbers are zero so that the emitter-absorber system, conserves energy and momentum. The above idea has been used for the explanation of EPR paradox in the last paper.

In using this idea of transaction and the equation of motion of a charged particle given by equation (5): the motion of a simple harmonic oscillator, leads to the energy levels $E=(n+\frac{1}{2})h$, The discussion of the finiteness of the total energy of the zero point radiation, the effect of the expansion of the universe on the future-past asymmetry on the boundary condition in the Wheeler-Feynman absorber theory have been given in the last paper and do not discuss them here.

The basic idea developed in a recent paper and described above is useful for SED to explain quantum phenomena in the context of classical Wheeler-Feynman absorber theory with the zero point radiation.

For further application and extension of our theory will be given in future.

In conclusion, our theory has a definite advantage over the current stochastic electrodynamics which cannot explain satisfactorily the quantum non-separability while our theory can cope with the difficulty and will also give an insight into the measurement theory in quantum mechanics which will be discussed shortly in future.

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