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facing@uta.cl
Universidad de Tarapacá
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Torres-Silva, Héctor
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CHIRAL UNIVERSES AND QUANTUM EFFECTS PRODUCED BY ELECTROMAGNETIC FIELDS

UNIVERSOS QUIRALES Y EFECTOS CUÁNTICOS PRODUCIDOS POR CAMPOS ELECTROMAGNÉTICOS

H. Torres-Silva[1]

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RESUMEN

La estructura aceptada del espacio y el vacío se derivan de los resultados de la cosmología relativística y de la teoría cuántica de campo. Se demuestra que una interfaz quiral entre regiones enantioméricas de un universo cerrado, o un universo derecho y un universo izquierdo, relacionados por un elemento de simetría PCT a lo largo de la interfaz, representa un modelo con todos los atributos requeridos por el vacío teórico. Se desprende que el comportamiento cuántico es entonces visto que es inducido por la interfaz de vacío. La mecánica quántica emerge como un caso especial de la mecánica clásica, más bien que siendo la última un subconjunto de la primera. Esto resuelve el problema observacional mecánico cuántico, explica las coincidencias de los grandes números cosmológicos y toma en cuenta la antimateria en el cosmos.

Palabras clave: Vacío, interfaz quiral, campo cuántico, universo derecho (izquierdo).

ABSTRACT

The accepted structure of space and vacuum derives from the results of relativistic cosmology and quantum field theory. It is demonstrated that a chiral interface between enantiomeric regions of a closed universe, or a (right) R-Universe and (left) L-Universe, related by an element of PCT symmetry along the interface, represents a construct with all the attributes required of the theoretical vacuum, in-so-far as quantum behaviour is then seen to be induced by the vacuum interface. Quantum mechanics emerges as a special case of classical mechanics, rather than the latter being a subset of the former. This removes the quantum-mechanical observational problem, explains the cosmological large-number coincidences, and accounts for the anti-matter in the cosmos.

Keywords: Vacuum, chiral interface, quantum field, R(L)-Universe.

INTRODUCTION

The vacuum is surprisingly hard to fill, despite clear pronouncements from both general relativity and quantum theories. The theory of general relativity concerns the shape of four-dimensional space and fields, whereas quantum field theory details a structured vacuum state and particles.

The logical next step of advancing a model of the physical vacuum, consistent with both theories, is the subject of this paper. This is a basic assignment because of the widely held belief that quantum theory and relativity are essentially incompatible. The problem arises through the presumed non-locality of quantum theory, in direct conflict with the tenets of relativity. The difficulty, first highlighted by Einstein, Podolsky and Rosen, now commonly referred to as the EPR paradox. It will be necessary to return to this dilemma as a crucial test of any proposed vacuum. To establish the necessary background, a brief summary of the implications of relativistic cosmologies and of quantum field theory on the nature of space and the vacuum is presented first. Our conjecture is that quantum theory and general relativity are essentially compatible when the matter is produced

[1] Instituto de Alta Investigación. Universidad de Tarapacá. Antofagasta Nº 1520. Arica, Chile. E-mail: htorres@uta.cl

by electromagnetic fields with $R_{\mu\nu} = 0$ and $T^{em}_{\mu\nu} = 0$ but $\det F^{\mu}_{\nu} \neq 0$. The electromagnetic field theory of matter rises when we have two universes separated by a chiral membrane. This defines the vacuum as an interface, either between two universes or between two regions of opposite chirality in the same universe.

Chiral approach means that our Universe is observable area of basic space-time where temporal coordinate is positive and all particles bear positive masses (energies). The mirror Universe is an area of the basic space-time, where from viewpoint of regular observer temporal coordinate is negative and all particles bear negative masses. Also, from viewpoint of our-world observer the mirror Universe is a world with reverse flow of time, where particles travel from future into past in respect to us. The two worlds are separated with the membrane - an area of space-time inhabited by light-like particles that travel along light-like right or left-handed (isotropic-chiral) spirals. In appendix 1 we show the difference in energy between the interface and the two universes.

QUANTUM FIELD THEORY

The approach that reveals the nature of space and the vacuum is Quantum Field Theory. Dirac produced the first quantum field theory for massive spin half particles. The energy spectrum was found to consist of both positive and negative states, separated by a gap of energy $\Delta E=2mc^2$. This Dirac sea is the vacuum which therefore consists of an infinite number of negative energy electrons, protons, neutrons and all other spin half particles, or fermions. Any vacancy or hole in the Dirac sea, at level -E, can be filled by an electron dropping down from the level at E. An amount of energy 2E is radiated, while both hole and electron disappear into the vacuum. The hole is therefore equivalent to a particle (called a positron) of charge +e and of positive energy E. The mass of the electron-positron pair that disappears produces the radiated photon or energy quantum $h\nu = \Delta E = 2(mc^2)$.

This equation can be obtained from the chiral electrodynamics developed in accompanying papers.

This prediction of anti-particles has been confirmed experimentally for all fermions. The model implies that the vacuum should also support an infinite negative sea of the anti-particles to ensure electrical neutrality. Each electron-positron pair is linked by a photon as, seen in figure 1.

In this (Feynmann) diagram a positron differs from an electron only through the direction of an arrow, and positrons have been described as electrons moving backwards in time, (chiral particle).

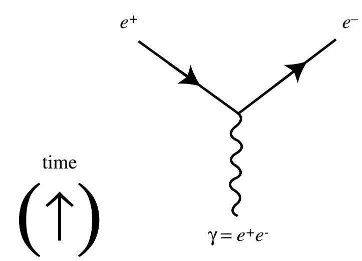

Figure 1. (Feynmann) diagram of an electron and positron produced by a light photon.

The lifetime of virtual particles is proscribed by the uncertainty principle $\Delta E \cdot \Delta t \sim h$. Real particles can be created when the vacuum is polarized by a sufficiently strong chiral field.

The vacuum is assumed to accommodate virtual particle/anti-particle pairs which requires a symmetry between matter and anti-matter worlds. Particles and anti-particles have the same modulus of mass, equal but opposite charges and magnetic moments, and if they are unstable, the same lifetime. Collectively this is known as charge-parity-time (PCT) symmetry. In appendix 1 we explain the PCT symmetry in our model.

The PCT theorem requires invariance for all fields under this three-way combined operation. This is therefore also the property of the vacuum with all its virtual particles and intermediaries.

In view of the foregoing, the single most vexing, unresolved problem is the imbalance between matter and anti-matter in the observable universe. Speculations that link this problem to the parity violation of weak interactions are clearly at variance with the PCT theorem. Conventional wisdom has it that anti-matter apparently disappeared soon after the big bang, and outlandish suggestions of its whereabouts in the universe abound. Contrary to this we postulate regions of matter (R) and anti-matter (L) separated by a radiation layer of chiral EM.

In Quantum theory we find quantum paradoxes dealing with the quantum-mechanical observational problem, non-locality and the EPR paradox. Quantum theory demands that two systems, once in interaction, remain correlated ever after until a measurement disturbs one of them. This measurement then reveals not only the nature of the system under study but also that of the remote partner still linked to the first by a common wave function; all this despite the absence of causality in the quantum world. This instantaneous communication, through the collapsing wave function, constitutes the non-locality of quantum theory.

The information carried by a wave function is indeterminate until a measurement selects a single result from an infinite set, and changes the course of events irreversibly. All information, however, does not perish when the measurement selects one bit. The wave function persists to allow alternative choices elsewhere. Each measurement, therefore, splits the universe into two, each with independent continued existence. Instead of a single quantum universe, an infinite number of universes is therefore required by the many-worlds quantum theory.

In view of the fact that quantum theory deals in non-commuting operators, illogical conclusions in the system are not unexpected, and are actually provided for in quantum logic, which is based on non-Boolean reasoning. The only problem is that it destroys locality, causality, reality, logicality and other coherent ideas on which a consistent cosmology can possibly be constructed. When postulating a vacuum structure, the real challenge is therefore to account for the unpredictability of quantum events. Massive objects behave classically. Even large molecules behave classically. The behaviour of very small particles, which can be considered as isolated in the vacuum, however, is more erratic and more wave-like. To preserve any notion of reality it is therefore necessary to accept the macroscopic world as the norm. It contains quantum world as a special case, and not the other way around.

Noting that the time evolution of both classical and quantum mechanics merely corresponds to a change of coordinates, it is concluded that neither system can adequately describe irreversible processes. Natural macroscopic processes such as decay and lifetime are therefore outside the scope of quantum mechanics, which appears as a simplified limiting case, useful for the description of microscopic events only. In view of this, the standard argument that the more fundamental quantum theory contains classical theory as a special limiting case cannot be sustained. Prigogine finds that quantum theory is not complete, and suggests irreversibility as another basic element in the description of the physical world. However, when superimposing an entropy operator on quantum mechanics the distinction between classical and non-classical systems disappears. The classical theory with irreversibility therefore contains quantum theory as a special case. That is the model to be accepted here, assuming that classical theory, as it describes the rational world, is universally valid. Quantum phenomena only emerge in systems where interaction with the vacuum produces significant perturbations. The most basic ingredient of a cosmologically reasonable model of the vacuum is therefore an ability to predict quantum behaviour for sub-atomic particles.

THE VACUUM INTERFACE

The minimum statement consistent with all relevant theories is that the physical vacuum represents an element of PCT symmetry in four-dimensional space. Literally this defines the vacuum as an interface, either between two universes or between two regions of opposite chirality in the same universe. The latter more economical situation is the more attractive. The experimentally observed structure of the vacuum would then represent the faint echo of another enantiomeric world from across the interface.

Progressively smaller particles experience, to an increasing extent, the effects of interacting with the hidden world beyond the interface. An observer keeping track of the particle is not aware of this hidden interaction and finds that the motion becomes inexplicably more erratic. The differential equation to model the motion is found to represent a wave packet rather than a classical particle. The mathematical description of the particle's progress is precise, but the physical interpretation is incomplete. The crucial result is that the particle in the quantum region does not behave differently from classical particles. Its progress follows the same logic and causality, but since its equations of motion are formulated with neglect of a vital segment of its total environment, they appear more complicated than necessary. This anomalous behaviour decreases rapidly with increasing aggregation. The genesis of the postulated dual system is like the spontaneous separation of phases that occurs on the cooling of a two-component homogeneous fluid. This happens through symmetry breaking down when the interaction between like entities becomes dominant. The phase separation occurs in four dimensions and three-dimensional observations cannot penetrate the dividing surface. A useful analogy is to consider a bilayer of two-dimensional worlds. They are everywhere in contact but oblivious of each other. The interface provides the contact with the third dimension.

The three-dimensional vacuum is to be visualized in strict analogy with this two-dimensional interfacial surface and there is no freedom of motion, either towards or away from the interface. To cross the interface it is necessary to move into a third dimension, which is not an allowed operation in two dimensions. The only way to detect the presence of the interface is by quantum interaction which has little effect on massive entities, but influences microscopic particles dramatically. Likewise, a massive three-dimensional universe is everywhere in contact with the three-dimensional vacuum interface. In order to cross the interface it is necessary to proceed along a fourth dimension.

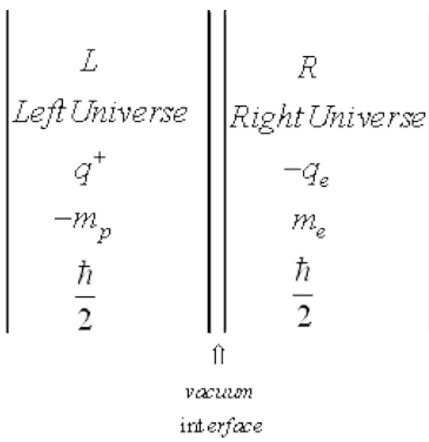

Figure 2. Positron Spin ($\hbar/2$) in L-Universe and Electron Spin ($-\hbar/2$) in a R-Universe or both are in one Universe with two enantiomeric regions.

The exact nature of the difference between the complementary universes makes interesting speculation, but it is useful to think of this as a difference in chirality. It is known from the spontaneous separation of enantiomers how chirality can be the driving force of phase separation. It is well known that objects with two-dimensional chirality can be identical when analysed in three dimensions. Rotations in the plane of these two-dimensional objects can never bring them into coincidence, but a simple rotation about an axis in the plane readily achieves this. The chirality is removed by a three-dimensional operation.

Now consider a row of entities of the L-form only, along the two-dimensional surface of a Möbius strip and with orientation in the surface preserved. A two-dimensional world, populated by objects of the same chirality is obtained. However, the paper can be considered as an interface which separates different worlds on the opposite sides of the sheet.

One finds that it separates enantiomeric forms. The inversion of chirality is brought about by the Möbius twist, which is a three-dimensional operation. The Möbius ribbon is not proposed to represent the true topology of the universe, but is simply used here as an instructive two-dimensional analogue. However, this surface is difficult to visualise as it cannot be embedded in R^3, three-dimensional euclidean space. What is proposed instead is to consider as a model of the physical universe some three-manifold which, like the Möbius strip, is a non-orientable and one-sided elliptical manifold.

The three-dimensional analog requires a four-dimensional twist or curvature of three-dimensional space that closes the universe onto itself and turns left-handed into right-handed objects. Considered as a single universe in three-dimensional space, chirality is preserved throughout. However, the interface created by the curvature separates regions of space with opposite chiralities. This interface cannot be crossed in three-dimensional motion, but allows interaction between entities near the interface to give rise to the quantum effects, (see figure 2 of our universe model). By the principle that the boundary of a boundary is zero, an interface in four-dimensional space has no two-dimensional boundary and the postulated vacuum must be three dimensional as observed.

The present proposal pictures a universe based on the orientable double cover of period 2π. The postulated interface, called the vacuum, is closed in four dimensions with period π, and corresponds to the relativistic hypersurface which is the locus of light signals and populated by bosons only.

The normal to the surface oriented in space is itself oriented in time, the fourth dimension of the present argument. This reduces quantum behaviour to the fluctuation along a time coordinate, between regions of three-dimensional space.

It must be emphasized that this proposed model is nowhere in conflict with either relativistic or quantum theories, and is fully consistent with both. It has the merit of simplicity and provides the logical structure to relate quantum effects directly to the macroscopic physical world, (see appendix 2).

APPLICATION OF THE MODEL

It is of interest to examine how the model deals with some of the vexing problems of quantum theory, like the non-locality embodied in the EPR argument. It is now proposed that the behaviour of the particle remains rational also in the quantum region, near the interface, and hence there must be a persistent causal relationship of both individuals from a correlated pair with their common origin. This relationship persists until the first of the two individuals becomes involved in a unique encounter. Until that point, however, synchronised observation of the pair cannot but reveal correlated behaviour. The degree of correlation is neither a function of their separation nor dependent on an exchange of information.

The model also provides a simple account of the missing anti-matter. It is not difficult to identify anti-matter with the enantiomeric matter introduced above. This means that the vacuum separates the material and anti-material worlds. However, exploration of the universe never reveals the gradual change in chirality along the curvature in four dimensions, and all matter is perceived to be of the same chirality. Encounters across the vacuum interface brings matter into violent contact with anti-matter, and a stable universe is therefore only possible if it is in strict equilibrium with itself. To have a cosmic potential on opposite sides of the interface in balance would certainly require well-tuned characteristics of certain relevant physical parameters. It probably requires a specific value of the fine-structure constants, and could be at the root of the famous large number coincidences. This mercifully eliminates concepts like the anthropic principle and many-world theories. It neatly places radiation in the vacuum where it belongs, between matter and anti-matter. As across any other interface that separates phases in equilibrium, constant seepage must occur. This provides a plausible origin of cosmic rays as chance excursions across the interface, and could also account for the isotropic 3K microwave background.

It is also necessary to consider the time-reversibility of quantum theory and the arrow of time in the macroscopic world. To jump into time it is necessary to cross the vacuum interface, in either direction. Because of the curvature of space, any displacement in the three-dimensional universe is a small step in the same direction, and hence a positive displacement in time. A time axis always points directly into the interface and time flows towards the site directly on the other side. The two-dimensional world model assists to demonstrate how this argument defines the arrow of time. Unfortunately, it also shows how time travel is self-destructive through an encounter with anti-matter. The quantum particle makes a small hop into time, but bounces back with time-reversal and random perturbation of its space coordinates. In contra-distinction to classical particles it therefore manages a displacement in space without an inevitable time advancement. It can even appear to be in two places at the same time as in two-slit diffraction experiments. Time-reversibility and uncertainty principle are implied at the same time. That is the price for not seeing the other side.

The vacuum, considered as an interface, is empty. It is no longer required that it accommodates all the Dirac oceans of negative quantum states. These states are on the opposite side of the interface and they need not be filled. As an example, the negative states for electrons occur in the positron-rich world on the other side of the vacuum interface. Electrons from this side are prevented from dropping down into their negative-energy states by the interfacial surface potential. Photons at the interface can still be considered as representing electron-positron pairs as before. The same holds for the rest of the quantum field entities. The two individuals of a virtual pair are now actually associated with different, symmetry-related time regimes, giving substance to the definition of an anti-particle as a particle moving backwards in time.

The most significant result of the model is perhaps the way it distinguishes between weak and electromagnetic interactions. In order to demonstrate the difference it is noted again that quantum behaviour is a function of aggregation. A massless photon at the interface interacts equally with the material and anti-material worlds. It is the archetype of a non-classical particle: its interaction with exactly one half of its total environment is of necessity ignored by any observer, and it appears to propagate like a harmonic wave, without being a wave. The particulate nature of the photon is demonstrable in experiments where forced confrontation with matter so dominates its behaviour that the influence of the anti-matter is effectively masked. The photoelectric effect illustrates this well.

Its interaction with the other side is scaled down. It is not at the interface in the same sense as a photon and coexists with the positron, its reflection across the interface. It moves like a wave-packet and interacts more strongly with its own matter. The vector boson that mediates the weak interaction also has mass, of about 100 GeV and, unlike the photon, is therefore not identical with its anti-particle and reflects across the vacuum interface that contains the element of PCT symmetry. The weak interaction likewise has reflection symmetry only across the vacuum interface, manifesting itself asymmetrically on both sides of the interface. This requires β-decay to be unsymmetrical.

It remains to explain why the vacuum interface is stable, yet separates two interactive states of matter. The answer is that the three-dimensional interface, postulated here, separates the two layers in time rather than space. This prevents macroscopic interaction, provided the equilibrium is maintained. Interaction between the opposite sides is confined to quantum events which represent penetration of rarefied particles into the time barrier and into the domain of influence of the world beyond. In the appendix 2 and 3, we examine the cosmological implications of this vacuum.

CONCLUSION

The implications of the vacuum interface model have striking parallels with gauge theory. Local gauge invariance, under an appropriate symmetry group, implies a transformation that links an internal property like the phase of a wavefunction or isotropic spin to a gauge field. Breaking of the gauge symmetry has important physical consequences. This locks the phases of the wavefunctions together over macroscopic distances and destroys the gauge symmetry. Gauge theory is presently being extended successfully to incorporate the strong interaction. The quest is to find that symmetry group which contains all the necessary subgroups to define the gauge symmetry of each force separately. The full symmetry occurs only at the grand unification energy, which is so high that all forces are equivalent. At lower energy the symmetry breaks spontaneously and the different forces separate into different symmetry species, as observed.

In the formalism of the present argument a free particle at the vacuum interface has a gauge connection with the quantum potential. The symmetry group of this gauge field contains the unified quantum and classical theories. The contiguous worlds that meet at the interface, like the atomic lattice at superconductivity, provide the mechanism to create a Higgs field which breaks the symmetry and produces the massive worlds of classical theory, with lower symmetry.

Rigorous formulation of this theory requires definition of the full symmetry group, containing also the symmetry subgroups of the known forces of nature. Progressive symmetry breaking produces each of the forces in turn until, at the lowest level of mass separation, gravitational effects appear for the first time. The model therefore contains not only the seeds of grand unification, but also the mechanism for spontaneous separation of matter and anti-matter into different time domains. The three stronger forces are defined in quantum-mechanical terms and gravitation follows classical mechanics.

Quantum effects are proposed to have their origin in the gradient at the vacuum interface. As the curvature of space-time is distorted by large masses, so would the gradient be enhanced, and quantum effects are predicted to become more pronounced in the vicinity of high-density material. Likely candidates are neutron stars, pulsars, quasars and black holes. The effect would manifest itself through a higher value of h, and hence more pronounced quantum-mechanical uncertainty. More massive particles will show quantum behaviour, and in the limit of infinite gradient, the interface is punctured and uncertainty becomes total ($\Delta E \cdot \Delta t \geq h$). This situation corresponds to a black hole. At an intermediate level, an increased h would also produce radiation of constant energy quanta at lower frequency. This represents an intrinsic red shift of the type observed for quasar.

APPENDIX 1:A NEW INSIGHT INTO THE NEGATIVE-MASS AND THE ACCELERATING CHIRAL UNIVERSE

The discovery of acceleration of the universe expansion in recent astrophysics research prompts the author to think that Newton's gravitation law can be generalized to accommodate the antimatter: While the force between matters (antimatters) is attractive, the force between matter and antimatter is a repulsive one. A paradox of negative-mass in gravity versus a basic symmetry ($m \to -m$) based on quantum mechanics is discussed in sufficient detail so that the new postulate could be established quite naturally. Corresponding modification of the theory of general relativity is also proposed. If we believe in the symmetry of particle and antiparticle as well as the antigravity between them, it might be possible to consider a new scenario of the expansion of universe which might provide some new insight into the interpretation of cosmological phenomena including the accelerating universe observed.

Symmetry of space-time inversion

Starting from RQM, we consider the wavefunction (WF) of a freely moving (along x axis) particle:

$$\psi \sim \exp\ [i(p\ \ x - E\ \ t)/\hbar], \tag{1.1}$$

where p is the momentum and $E(>0)$ the total energy. But what is the WF ψ_c of an antiparticle? Before 1956, it was assumed to be a consequence of the operation of a so-called charge-conjugate transformation C which can bring a charged particle (say an electron with charge $-e$) to its antiparticle (say the positron with charge e) [2]:

$$\psi_c = C\psi \sim \psi^* \sim \exp\ [i(-p\ \ x + E\ \ t)/\hbar]. \tag{1.1*}$$

We see that the negative-energy $-E<0$ emerges immediately due to the basic operators in quantum mechanics (QM):

$$\hat{p}_R = -i\hbar\frac{\partial}{\partial x},\ \hat{E}_R = i\hbar\frac{\partial}{\partial t}. \tag{1.2}$$

The negative-energy difficulty at the level of QM was remedied to some extent by the so-called "hole theory for positron" (which is obviously impossible for the Klein-Gordon particle) and solved formally at the level of quantum field theory (QFT) by the redefinition of creation (annihilation) operators.

Since the discovery of parity violation, i.e., the violation of space-inversion $P(x \to -x)$ symmetry in 1956-1957, physicists realize that not only P but also C transformations are not conserved in the weak-interaction processes. So Eq. (1.1) is not applicable in general and the WF of antiparticle should be redefined as:

$$\psi_c = CPT\psi \sim \exp\ [-i(p\ \ x - E\ \ t)/\hbar], \tag{1.3}$$

where the so-called "time-reversal transformation" T is defined as:

$$\psi \to T\psi = \psi^*(x,-t) \sim \exp\ [i(-p\ \ x - E\ \ t)/\hbar]. \tag{1.4}$$

Note that: First, the name "time-reversal" is actually a misnomer [3, 4]. What the transformation (1.4) means is merely a reversal of motion $(p \to -p)$. Second, the correctness of definition of antiparticle WF (1.3) depends on the validity of the CPT theorem which in turn is ensured by basic principles of SR and QFT. Third, as the complex-conjugate operations in C and T cancel each other, what a combined CPT transformation in (1.3) means is merely a sign change of coordinates (x, t) in comparison with Eq. (1) [1, 2]. But the original meaning of C, P and T implies that Eq. (1.3) should describe an antiparticle with the same p and $E(>0)$ as that of the particle described by (1.1). Hence for antiparticles, we should forget the "hole theory" and use the following operators instead of (1.2):

$$\hat{p}_L = i\hbar\frac{\partial}{\partial x}\ ,\ \hat{E}_L = -\ i\ \ \hbar\frac{\partial}{\partial t}\ . \tag{1.5}$$

In fact, Eq. (1.5) had been proven to be the direct and unique outcome of the full solutions to the EPR paradox and Klein Paradox [4-6].

Fourth, once we accept Eqs. (1.3) and (1.5), the CPT theorem becomes a new fundamental postulate, i.e., a basic symmetry which can be stated in the following form:

Under the (newly defined) space-time inversion denoted by PT, meaning merely $x \to -x$, $t \to -t$, the theory of RQM remains invariant with its concrete solution, e.g., a particle WF transforming to its antiparticle WF (denoted by C) automatically. It means that our postulate reads:

$$\mathrm{PT} = \mathrm{C} \tag{1.6}$$

For example, the Schrodinger equation is nonrelativistic. But the following coupled Schrodinger like equation

$$\begin{cases} i\hbar\frac{\partial}{\partial t}\ \ \varphi = mc^2\varphi - \frac{\hbar^2}{2m}\ \ \nabla^2\ \ (\varphi+\chi), \\ i\hbar\frac{\partial}{\partial t}\ \ \chi = -mc^2\chi + \frac{\hbar^2}{2m}\ \ \nabla^2\ \ (\chi+\varphi), \end{cases} \tag{1.7}$$

is just the relativistic Klein-Gordon equation

$$(i\hbar\frac{\partial}{\partial t})^2\ \ \psi = -\ \ c^2\hbar^2\nabla^2\ \ \psi + m^2c^4\psi, \tag{1.8}$$

with relation first pointed out by Feshbach and Villars in 1958:

$$\begin{cases} \varphi = (\psi + i\ \ \hbar\ \ \dot{\psi}/mc^2)/2, \\ \chi = (\psi - i\ \ \hbar\ \ \dot{\psi}/mc^2)/2. \end{cases} \tag{1.9}$$

Now we see that under the space-time inversion $(x \to -x, t \to -t)$ and the transformation:

$$\varphi(-x,-t) \to \chi(x,\ t),\ \ \chi(-x,-t) \to \varphi(x,\ t), \tag{1.10}$$

the Eq. (1.7) does remain invariant while a particle WF (1.6) with $|\varphi|>|\chi|$ (due to E<0, see (1.8) turning to its antiparticle WF (1.9)) with $|\chi_c|>|\varphi_c|$ (due to, $E<0$, $E_c = -E>0$, see (1.9)).

Symmetry of mass inversion

Alternatively, we can restate the above basic symmetry in the following way: Under the mass inversion:

$$m \to -m,\ \ \varphi(x,\ t) \to \chi(x,\ t),\ \ \chi(x,\ t) \to \varphi(x,\ t), \tag{1.11}$$

the theory, e.g., Eq. (1.6), remains invariant. Although transformation (1.6) is equivalent to transformation (1.11), they share different advantages. The former is relevant to unobservable coordinates (x, t) and so is more essential in RQM and equivalent to even more abstract symmetry of i versus $-i$ (see Eq. (1.1) versus (1.3)), while the latter is relevant to observable mass m and so is easily to be generalized to the case of classical theory.

Here, we'd better use the following working rule: to deal with particle (matter) and antiparticle (antimatter) on an equal footing, a classical theory must be invariant under the mass-inversion transformation $m \to -m$. Note that: First, m is always positive. Second, being the external field, the electric-(magnetic) field strength $E(B)$ undergoes no change in the transformation. Third, in RQM like (1.7) or (1.8), the motion equation for antiparticle is the same one as that for particle. This is because each particle state like (1.1) contains its hidden antiparticle field under the condition $|\phi|>|\chi|$ whereas an antiparticle state like (1.3) contains its hidden particle field under the condition $|\chi_c|>|\phi_c|$. Fourth, to clarify further why we prefer the new postulate (1.6) instead of C transformation and CPT theorem, we wish to emphasize an important difference between a postulate (law) and a theorem. All quantities in a theorem must be defined in advance separately and unambiguously and the outcome of the theorem is actually contained in its premise implicitly. For example, the definitions of C, P and T are all clear in mathematics and the validity of CPT theorem is ensured by the basic principles of SR and QFT. Once C, P and T are not conserved in experiments, they cease to be meaningful as physical transformations. In this situation, the CPT theorem immediately exhibits itself as a new postulate (1.12) in which the definition of transformation of particle to antiparticle is just contained in the same equation. In general, a postulate or law can often (not always) accommodate a definition of physical quantity, and the validity of the postulate (law) together with the definition must be verified by experiments. Hence the establishment of a law is a process "from particular to general" or an outcome of "analysis and induction method". By contrast, to prove a theorem from well-established theories is a process "from general to particular" or a consequence of "deduction method".

For example, the definition of gravitational mass m is contained in the gravitational law. The definition of inertial mass m is contained in Newton's law. What we have done is a similar thing - the definition of particle-antiparticle transformation C is contained naturally in a new postulate (1.6) - not one that comes from elsewhere.

Generalization of Einstein field equation in general relativity

Consider a positronium and an atom of matter. If Newton Equation is correct, there will be no gravitational force between them. This means that the gravitational mass m (grav.) of positronium is zero! However, the energy or the relevant inertial mass m (inert.) of positronium is definitely nonzero. Hence we see that in the case of coexistence of particles and antiparticles, the equivalence principle (EP) in the (weak) sense that [8]

$$\text{m (grav.)} = \text{m (inert.)} \tag{1.12}$$

cannot be valid.

As is well known, the EP served as a starting point in establishing the theory of general relativity (GR). The possible invalidity of EP in the presence of antimatter implies that GR is dealing with the gravitation of pure matter without the coexistence of antimatter. Indeed, let us look at the Einstein field equation [9]:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -8\pi G T_{\mu\nu} \tag{1.13}$$

On the left side, the Ricci tensor $R_{\mu\nu}$, curvature scalar R and the metric tensor $g_{\mu\nu}$ are all functions of coordinates x_μ. While on the right side, the energy-momentum tensor $T_{\mu\nu}$ is introduced to describe the existence of matter in the vicinity (a macroscopic small volume) of x_μ. Then under a transformation of mass inversion $m \to -m$ to reflect that of matter to antimatter, $T_{\mu\nu}$ should change its sign due to its proportionality to the mass m. Hence Eq. (1.13) changes sign on the right side whereas not on the left side. This reflects the fact that GR is a classical field theory and so cannot treat the matter and antimatter on an equal footing.

To keep Eq. (1.13) invariant under the mass inversion, we manage to modify its right side by a generalization as:

$$T_{\mu\nu} \to T_{\mu\nu}^{eff} = T_{\mu\nu} - T_{\mu\nu}^{c}, \tag{1.14}$$

(where the superscript c means antimatter,) since under the mass inversion, $T_{\mu\nu} \to -T_{\mu\nu}^{c}$ and $T_{\mu\nu}^{c} \to -T_{\mu\nu}$. Notice that the form of the energy-momentum tensor is the same for both matter and antimatter. We stress once again that the distinction between m and $-m$ is merely relative, not absolute. So in the whole universe (matter+antimatter) we have $T_{\mu\nu}^{eff} = T_{\mu\nu} - T_{\mu\nu}^{c} \equiv 0$ and the Einstein equation is

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \equiv 0 \tag{1.15}$$

APPENDIX 2: THE COSMOLOGICAL CONSTANT PROBLEM

Let's outline shortly the cosmological constant problem.
Consider Einstein equation with Δ -term ($\hbar = c = 1$):

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu} \tag{2.1}$$

Here $T_{\mu\nu}$ is energy-momentum tensor of the matter and Λ is some constant parameter having the dimension [cm^{-2}]. In the used unit system the Newtonian gravitational constant

$$G \sim l_P^2 \sim 2{,}5 \cdot 10^{-66}\, cm^2 \qquad (2.2)$$

and according to experimental data the mean energy density today is of the order

$$T_{\mu\nu} \sim \rho_1 \sim 10^8\, cm^{-4} \to 8\pi G T_{\mu\nu} \sim 5 \cdot 10^{-57}\, cm^{-2} \qquad (2.3)$$

and

$$\Lambda \sim 10^{-56}\, cm^{-2} \qquad (2.4)$$

Thus, if Einstein equation (1) is used for description of the today dynamics of our R-Universe, the quantities in its right hand side are of the same order indicated in (2.3) and (2.4). In our model, for the L-Universe, we have $T_{\mu\nu} < 0$, $\Lambda < 0$.

Now let us estimate the possible value of the right hand side of Eq. (2.1) in the framework of canonical quantum field theory. For simplicity consider energy-momentum tensor in quantum electrodynamics in flat spacetime:

$$T_{\mu\nu} = -\frac{1}{4}(F_{\mu\lambda}F_{\nu}^{\lambda} - \frac{1}{4}\eta_{\mu\nu}F^2) + \frac{i}{2}(\bar{\psi}\gamma_{(\mu}\nabla_{\nu)} - \bar{\nabla}_{(\nu}\bar{\psi}\gamma_{\mu)}\psi) \qquad (2.5)$$

Casimir effect, predicted in [1] and experimentally verified in [2], shows for reality of zero-point energies. Moreover, the attempts to drop out zero-point energies by appropriate normal ordering of creating and annihilating operators in energy-momentum tensor fail for many of reasons (the discussion of this problem see, for example, in [3]). Thus, at estimating vacuum expectation value of energy-momentum tensor (2.5), it should not be performed normal ordering of creating and annihilating operators in (2.5). Thus we obtain for vacuum expectation value of tensor (5) in free theory:

$$\left\langle T_{\mu\nu}\right\rangle_0 = \int \frac{d^3k}{(2\pi)^3}\left(\frac{k_\mu k_\nu}{k^0}\bigg|_{k^0=|k|} - 2\frac{k_\mu k_\nu}{k^o}\bigg|_{k^0=\sqrt{m^2+k^2}} \right) \qquad (2.6)$$

Here m is the electron mass. The first item in (2.6) gives the positive contribution but the second item gives the negative contribution since these items give the boson and fermion contributions to vacuum energy, respectively. If integration in (2.6) is restricted by Planck scale, $k_{\max} \sim l_P^{-1}$, then from (2.6) and (2.2) it follows:

$$8\pi G\left\langle T_{\mu\nu}\right\rangle_0 \sim l_P^{-2} \sim 10^{66}\, cm^{-2} \sim \Lambda_P \qquad (2.7)$$

In the vacuum interface (see figure 2), the Einstein equation is described by

$$R_{\mu\nu} = 8\pi G T_{\mu\nu}^{em} + \Lambda_P g_{\mu\nu} \qquad (2.8)$$

It is clear that the interaction of fields doesn't changes qualitatively the estimation (2.7). From (2.7) and (2.3) we see that the contribution to the right hand side of Eq. (2.1) estimated in the framework of canonical quantum field theory is larger about 10^{120} times in comparison with the experimental estimations.

APPENDIX 3: COSMOLOGICAL IMPLICATIONS

It is instructive to examine some of the cosmological implications of the present proposal. When light traverses intergalactic space it displays a Doppler frequency shift, invariably interpreted in terms of receding sources, and therefore assumed to imply an expanding universe. This interpretation is not inconsistent with the present model, but neither is it a necessary consequence. Curvature of three-dimensional space along a time coordinate implies that a distant source is separated from an observer in both space and time. During transit, the photon moves towards an observer ahead of it in time and therefore appears to lag as if its source was receding. The observed red shift, as before, is a function of separation, but the proportionality constant does not necessarily relate distance to rate of recession, but rather to a time separation interval, Δt, Δt, $zc = rH = r\left[1/t - 1/(t+\Delta t)\right]$, where t=r/c. Hence: $z = 1 - t/(t+\Delta t)$.

This formulation allows the calculation of a Hubble radius rather than a Hubble age of the universe. As $\Delta t \to \infty$, $H \to 1/t_0 = c/r_0$, where the maximum value of the interval $r_0 = ct_0$ is interpreted as an upper bound to some radius of the universe. This effective radius corresponds to $4 x 10^9$ parsec. Converted to a dimensionless distance, one has

$$N_1 = r_0 m_e c^2/e^2 = t_0 m_e c^3/e^2 \approx 10^{40}.$$

Using this value with the dimensionless mass, or number of baryons, of the universe, $N_3 = 10^{80}$, a mass density of $\rho = N_3/N_1^{\,3} = 10^{-40}$ is calculated. This matches the third large number

$$N_2 = e^2/(4\pi\varepsilon_0 G m_p m_e) = 2.3 \times 10^{39},$$

the gravitational coupling constant, as required by Mach's principle, without invoking anthropic principles. There is no reason why any of these large numbers should change with time.

The foregoing does not demand a static universe. As time flows, observers move along the interface and therefore experience a gradually changing curvature. Time evolution amounts to the threading of the interface through the universe, and the consequent changes in configuration are like pseudo-rotation, which increases the isotropic appearance of the universe. The resulting relative motion would probably be not unlike that of an expanding universe.

In-so-far as an abstract surface like P^2 does not exist in less than four dimensions, the vacuum interface must likewise be four-dimensional. Its three-dimensional aspect differentiates between the chiral forms of matter, and by analogy, the four-dimensional vacuum could conceivably differentiate between opposite directions in time. A closed journey along the interface would gradually turn positive into negative time flow as was shown for the chirality of matter, suggesting that time has no unique beginning. The same conclusion is reached by modern quantum cosmologies. Hawking's idea that the universe is finite but has no boundary in imaginary time, may indeed be fully consistent with the four-dimensional chiral structure arrived at here.

The model of the universe with two chiral spaces

The model of the homogenous and isotropic universe with two spaces is considered. The background space is a coordinate system of reference and defines the behaviour of the universe. The other space characterizes the gravity of the matter of the universe produced by electromagnetic waves. In the presented model, the first derivative of the scale factor of the universe with respect to time is equal to the velocity of light. The density of the matter of the universe changes from the Plankian value at the Planck time to the modern value at the modern time. The model under consideration describes the whole universe from the Planck time to the modern time and avoids the problems of the Friedmann model such as the flatness problem and the horizon problem.

As known [14, 15], the Friedmann model of the universe has fundamental difficulties such as the flatness problem and the horizon problem. These appear to be a consequence of that the space of the Friedmann universe, on the one hand, is defined by the gravity of the matter of the universe, and on the other hand, is a coordinate system of reference. The solution of the problem is to introduce the background space as a coordinate system of reference. In this case, the background space defines the behaviour of the universe, and the other space characterizes the gravity of the matter of the universe.

Let us consider the model of the homogenous and isotropic universe with two chiral spaces. Let us introduce the background space as a coordinate system of reference. Then the evolution of the universe is described as a deformation of the background space. Let us take the homogenous and isotropic background space, with the spatial interval of its metric is given by

$$ds^2 = \frac{a^2 dl^2}{\left[1 + \frac{kl^2}{4}\right]^2} \tag{3.1}$$

Suppose that the background space is defined by the total mass of the universe including the mass of the matter and the energy of gravity produced by electromagnetic waves

$$G_{ik} = T_{ik}^{tot} = T_{ik}^{em} = T_{ik} + t_{ik}. \tag{3.2}$$

Let us consider the case when the total mass of the universe is equal to zero. It means that the Maxwell tensor vanishes, $T_{ik}^{em} = 0,$ but with $\det F_i^k \neq 0$.

$$T_{ik}^{tot} = T_{ik} + t_{ik} = 0 \tag{3.3}$$

Then eq. (3.2) take the form

$$G_{ik} = 0. \tag{3.4}$$

The solution of the equations (3.4) gives

$$\frac{d^2 a}{dt^2} = 0 \tag{3.5}$$

$$\frac{da}{dt} = c. \tag{3.6}$$

Thus the second derivative of the scale factor of the universe with respect to time is equal to zero, and the first derivative of the scale factor is equal to the velocity of light. It should be noted that the scale factor of the universe coincides with the size of the horizon

$$a = ct. \tag{3.7}$$

In the model (3.4), the laboratory coordinate system is synchronous. In the laboratory coordinate system, the background space is described by the flat metric

$$ds^2 = c^2dt^2 - a^2dl^2. \tag{3.8}$$

Thus we arrive at the Milne model [16] in which the size of the universe being the maximum distance between the particles coincides with the scale factor of the universe and coincides with the size of the horizon. In the universe with one space, the Milne model is derived from the condition that the density of the matter tends to zero $\rho \to 0$. Here the Milne model describes the background space of the universe, with the total mass of the universe being equal to zero $m_{tot} = 0$.

Let us determine the relationship between the lifetime of the universe and the Hubble constant. Since the Hubble constant is

$$H = \frac{1}{a}\frac{da}{dt}, \tag{3.9}$$

so from (3.6), (3.7), (3.9) one can obtain

$$t = \frac{1}{H}. \tag{3.10}$$

Let us estimate the size of the universe at the Planck time and at present. Remind that the size of the universe coincides with the scale factor of the universe. According to (3.7), at the Planck time $t_{Pl} = (\hbar G / c^5)^{1/2}$, the scale factor of the universe is equal to the Planck length $T_{Pl} = l_{Pl} = (\hbar G / c^3)^{1/2}$. According to (3.7), (3.9), for the modern Hubble constant $H_0 \approx 3 \cdot 10^{-18}$ c^{-1}, the modern scale factor of the universe is $a_0 \approx 10^{28}$ cm.

Let us determine the relationship between the mass of the matter and the scale factor of the universe at t = const. The total mass of the universe is equal to zero, given the mass of the matter is equal to the energy of its gravity

$$m = \frac{Gm}{c^2a}. \tag{3.11}$$

Allowing for (3.7) and (3.10), from (3.11) it follows that the mass of the matter changes with time as

$$m = \frac{c^2a}{G} = \frac{c^3t}{G} = \frac{c^3}{GH}, \tag{3.12}$$

and the density of the matter, as

$$\rho = \frac{3c^2}{4\pi Ga^2} = \frac{3}{4\pi Gt^2} = \frac{3H^2}{4\pi G} \tag{3.13}$$

According to (3.12), growth of the mass of the matter takes place during all the evolution of the universe. At the Planck time t_{p1}, the mass of the matter is equal to the Planck mass $m_{Pl} = (\hbar c / G)^{1/2}$. At present, the mass of the matter is $m_0 \approx 1.4 \cdot 10^{56}$ g, and the density of the matter is $\rho_0 \approx 3.2 \cdot 10^{-29}$ g cm^{-3}. Thus the model of the universe (3.3)-(3.6) provides growth of the mass of the matter from the Plankian value to the modern one.

We have considered the model of the homogenous and isotropic universe with two spaces, with the behaviour of the universe is defined by the background space. Unlike the Friedmann model, the presented model gets rid off the flatness and horizon problems.

Remind [14, 15] that the horizon problem in the Friedmann universe is that two particles situated within the horizon at present were situated beyond the horizon in the past. In the universe under consideration, all the particles are situated within the horizon during all the evolution of the universe, since the size of the universe being the maximum distance between the particles coincides with the size of the horizon. Hence the presented model avoids the horizon problem.

Remind [14, 15] that the essence of the flatness problem in the Friedmann universe is impossibility to get the modern density of the matter starting from the Planck density of the matter at the Planck time. In the presented theory, the density of the matter of the universe changes from the Planckian value at the Planck time to the modern value at the modern time. Hence the flatness problem is absent in the presented theory.

In order to resolve the above problems of the Friedmann universe an inflationary episode is introduced in the early universe [14, 15]. Since the presented model describes the universe from the Planck time to the modern time and avoids the above problems of the Friedmann universe, there is no necessity to introduce the inflationary model.

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