

A Semi-Classical Model of the Elementary Process Theory Corresponding to Non-Relativistic Classical Mechanics

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Abstract — Currently there are at least four sizeable projects going on to establish the gravitational acceleration of massive antiparticles on earth. While general relativity and modern quantum theories strictly forbid any repulsive gravity, it has not yet been established experimentally that gravity is attraction only. With that in mind, the Elementary Process Theory (EPT) is a rather abstract theory that has been developed from the hypothesis that massive antiparticles are repulsed by the gravitational field of a body of ordinary matter: the EPT essentially describes the elementary processes by which the smallest massive systems have to interact with their environments for repulsive gravity to exist. In this paper we model a non-relativistic, one-component massive system that evolves in time by the processes as described by the EPT in an environment described by classical fields: the main result is a semi-classical model of a process at Planck scale by which a non-relativistic one-component system interacts with its environment, such that the interaction has both gravitational and electromagnetic aspects. Some worked-out examples are provided, among which the repulsion of an antineutron by the gravitational field of the earth. The general conclusion is that the semi-classical model of the EPT corresponds to non-relativistic classical mechanics. Further research is aimed at demonstrating that the EPT has a model that reproduces the successful predictions of general relativity.

1 Introduction

There is a basic principle of science, which Richard Feynman put as follows into words in one of his *Lectures on Physics*:

“experiment is the sole judge of scientific truth” [1]

It is therefore that currently no one can claim to *know* how a system made up of massive antiparticles will behave in the gravitational field of a system of ordinary matter: this has simply not yet been established experimentally. However, at CERN there are three sizeable projects going on that aim to measure the gravitational acceleration \bar{g} of antihydrogen \bar{H} on earth: the AEGIS experiment aims to measure \bar{g} by measuring the vertical displacement of a beam of \bar{H} atoms with a Moiré deflectometer [2]; the ALPHA experiment and the GBAR experiment, on the other hand, aim to measure \bar{g} using \bar{H} atoms that are initially at rest, each by a different method [3, 4]. In addition, the MAGE

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collaboration aims to measure the gravitational acceleration of muonium at the PSI [5]. As a preliminary result it has been reported that \bar{g} must lie between $-65g$ and $110g$ [3]; the aim, however, is to establish \bar{g} with an accuracy of 1%.

That being said, if we depart from Feynman's principle and we start using widely accepted theories of modern physics as a criterion of truth, then it is impossible that the aforementioned experiments will measure anything else than $\bar{g} = g$. A matter-antimatter repulsive gravity is namely not only fundamentally incompatible with general relativity (GR), but also fundamentally incompatible with quantum electrodynamics (QED) and quantum chromodynamics (QCD). The arguments are well-known [6], but we can briefly go through them. Firstly, the basic idea underlying GR is the equivalence principle (EP), introduced by Einstein in 1907 [7]. According to the EP, the acceleration of a massive system in a gravitational field is independent of the nature of its components, so systems made up of matter particles and systems made up of antiparticles should behave similarly in a gravitational field; see Fig. 1 for an illustration.

Secondly, a matter-antimatter repulsive gravity implies that a massive particle and its antiparticle have the same inertial mass but opposite gravitational masses [8]. But if we force these properties to hold for electrons and positrons, then virtual electron-positron pairs inside an atom will contribute to the atom's inertial mass but not to its gravitational mass: modern quantum theories then predict that in that case there has to be an observable difference in the ratio between inertial and gravitational mass of different chemical elements. This difference, however, is not observed: that is the main quantum-theoretical argument against a matter-antimatter repulsive gravity, first published by Schiff [9]. These two fundamental incompatibilities with theories of modern physics have led prominent physicists such as 't Hooft and Krauss to publicly express their dislike of pursuing the idea of repulsive gravity [10, 11].

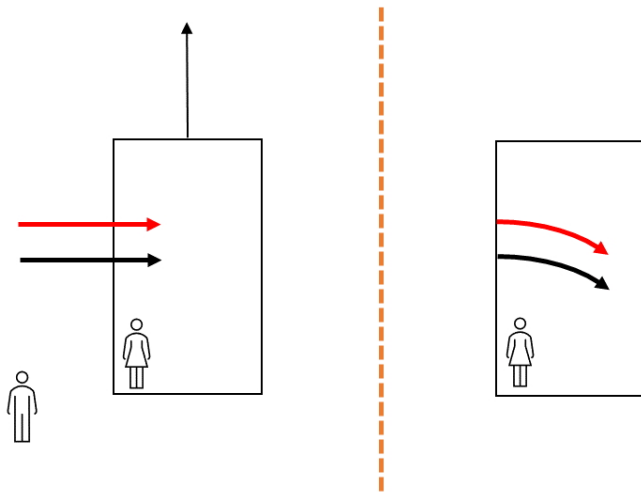


Figure 1: Illustration of the EP. On the left of the dotted line is a force-free environment in outer space. The male icon is Bob, an observer at rest in this environment: he sees a massive system made up of particles and a massive system made up of antiparticles in uniform rectilinear motion, as respectively depicted by the black and red arrows. The female icon is Alice, an observer at rest in a laboratory (depicted by the square) that accelerates uniformly with $1g$ perpendicular to the motion of the systems, and upwards for Alice. To the right of the dotted line is what Alice sees: she will see both massive systems fall down in her laboratory. According to the EP, this is equivalent to what will be observed by an observer at rest in a gravitational field where the gravitational acceleration is $1g$. Ergo, massive particles and massive antiparticles both fall down on earth.

Notwithstanding the foregoing, as long as repulsive gravity is not experimentally refuted, we can still do one of the aforementioned experiments in our thoughts and let it have the outcome that $\bar{g} = -g$. But since this is at odds with theories of modern physics, it is clear beforehand that something big has to go if we want to identify the fundamental principles that would have to be in place for a matter-antimatter repulsive gravity to be a fact of nature. In recent research, which led to the development of the Elementary Process Theory (EPT) [12], that “something big” was not only Einstein’s idea that gravity can be reduced to motion on geodesics of a curved spacetime: in addition, the whole idea that interactions take place by exchanging mediating particles, which is incorporated in modern quantum theories, has been rejected as well. That means that the position was taken that the processes considered in QED—for example the process for electron-electron scattering represented by the Feynman diagram in Fig. 2—do **not** take place in reality. The basic

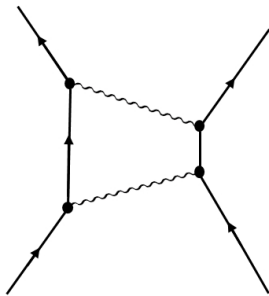


Figure 2: Feynman diagram with four vertices for electron-electron scattering; time is vertical. The electrons scatter by the exchange of two photons.

idea is then that the processes by which all interactions **do** take place are described by the EPT. However, the EPT has not led to much understanding among physicists, which we can blame on the four-dimensionalistic interpretation of the formalism—here the adjective ‘four-dimensionalistic’ refers to four-dimensionalism, the doctrine that objects have temporal parts; for a review, see e.g. [13]. To elaborate, we can say that there are two pairs of glasses through which we can look at the world: *three-dimensionalist glasses* and *four-dimensionalist glasses*. If we look through three-dimensionalist glasses, we see the outside world in terms of *continuants*—a continuant is an object that continuously exists throughout an extended period of time but that is wholly, i.e. in its entirety, present at any point in time at which it exists. E.g. classical particles, leptons, quarks, and bosons are all continuants. If we look through four-dimensionalist glasses, on the other hand, we see the outside world in terms of *occurrents*—an occurrent is an object that has a time span and that is not wholly present at a proper subset of its time span. E.g. the life of a free neutron, from its creation to its decay, is an occurrent. The EPT now describes the physical world not in terms of *elementary particles and interactions* but in terms of *atomic occurrents and transitions*; the atomic occurrents in the EPT are called *phase quanta*. In [12] it has not been explicitly mentioned that these are four-dimensionalistic objects, and that might have been a shortcoming since viewing the world in terms of four-dimensionalistic objects is counterintuitive to most who are not familiar with it, as the following quote by Galton illustrates:

“The four-dimensionalist view is probably coherent ... but you have to make many adjustments to ordinary language, or at least to how it is understood, to talk coherently about it. This is not always appreciated, and I have the impression that many people who are drawn to four-dimensionalism are not fully aware of just what a wrenching disruption to our everyday world-view it entails.” [14]

That being said, the purpose of this paper is twofold:

- (i) to give an interpretation of the formalism of the EPT in the more accessible language of systems theory, at least for the processes by which (in this view) interactions take place with only gravitational and/or electromagnetic aspects;
- (ii) to present a semi-classical model of the EPT, which shows how a one-component massive system, whose temporal evolution is governed by the process-physical principles of the EPT, interacts with its environment when that environment can be described by classical mechanics.

The next two sections successively treat the topics (i) and (ii). The final section discusses the results and their shortcomings, and presents the conclusions.

2 The EPT in the language of systems theory

Below we will develop a version of the EPT in a number of propositions. This version of the EPT will serve as the basis for our semi-classical model.

Proposition 1. *In the universe of the EPT, elementary processes are primary: all massive systems evolve in time by these processes.* ■

For the present purposes we assume that all massive systems are **monadic**, that is, are made up of one massive component. The monadic system is then a systems-theoretic analogue of an elementary particle. In addition, we only consider processes by which an interaction with only gravitational and/or electromagnetic aspects takes place between a monadic system and its environment. In that case, all elementary processes are **simplest**:

Proposition 2. *The essence of a simplest elementary process, by which an interaction with gravitational and/or electromagnetic aspects takes place between a monadic system and its environment, is the following:*

- (i) *the process starts with the monadic system in a ground state, which we may think of as a particle state;*
- (ii) *by the first event the monadic system transforms from the ground state to a transition state, which we may think of as a wave state;*
- (iii) *the monadic system absorbs energy from its environment during the time span it is in a transition state;*
- (iv) *by the next event the monadic system transforms from the transition state to an excited state, which we may think of as a particle state;*
- (v) *by the final event the excited particle state decays into a new ground state plus emitted radiation;*
- (vi) *by emitting the radiation at the final event, the monadic system receives an impulse;*
- (vii) *the monadic system in the new ground state marks the beginning of a new process.*

Throughout a process, a monadic system carries a set of invariant properties. (This set is called a ‘monad’ in the language of the EPT: a system carries one monad for each component, so a monadic system is a system that carries just one monad.) ■

These elementary processes are thus a series of state transitions. The fact that these are primary then has the consequence that ‘motion’ is a derived concept: from the fundamental point of view there is no such thing as motion—there is only a succession of states. Only *after* we have fitted the vacuum with a coordinate system and have assigned positions to particle states, we can start talking about ‘motion’. We will now develop a symbolic description of such a simplest process. The key to the symbolic description is to start viewing the life of a monadic system in a certain state as *one object*.

Proposition 3. *There are countably many monadic systems, so that we can assign a counting number to a monadic system. Each monadic system evolves in time by countably many elementary processes, so that we can index its evolution by real-valued degrees of evolution: we can associate consecutive integer-valued degrees of evolution to the initial events of consecutive processes in the temporal evolution of a monadic system. ■*

Proposition 4. *For any k and any n ,*

- (i) *the life of the k^{th} monadic system in the ground state at the n^{th} degree of evolution is designated by $^{EP}\varphi_k^n$;*
- (ii) *the life of the k^{th} monadic system in a transition state, created at the n^{th} degree of evolution, is designated by $^{NW}\varphi_k^n$;*
- (iii) *the life of the k^{th} monadic system in the excited state at the $(n + 1)^{\text{th}}$ degree of evolution is designated by $^{NP}\varphi_k^{n+1}$;*
- (iv) *the life of the radiation emitted at the $(n+1)^{\text{th}}$ degree of evolution by the k^{th} monadic system is designated by $^{LW}\varphi_k^{n+1}$;*
- (v) *the set of invariant properties carried by the k^{th} monadic system is designated by M_k .*

■

Proposition 5. *Mathematically,*

- (i) *each designator \mathfrak{S} that refers to an object as in clauses (i)-(iv) of Prop. 4 is assumed to be an abstract mathematical constant, meaning that it comes with a mathematical axiom*

$$\exists\alpha : \alpha = \mathfrak{S} \tag{1}$$

saying that there is a thing α in the mathematical universe which is identical to \mathfrak{S} .

- (ii) *each designator M_k that refers to a set of properties as in clause (v) of Prop. 4 is assumed to be an abstract nonempty set, meaning that it comes with a mathematical axiom*

$$\exists\alpha\exists\beta : \alpha = M_k \wedge \beta \in \alpha \tag{2}$$

saying that there are things α and β in the mathematical universe such that α is identical to M_k and β is an element of α .

■

So, it has to be clear from the *typography* to which object a designator refers. The existing typography has been developed with an interpretation in terms of *phase quanta* in mind. For the simplest processes, however, it is much easier to work with Prop. 4, which uses the language of systems theory—we will have to accept, alas, that the formalism is then not an elegant fit, but it's still adequate. Furthermore, we will have to consider sums of constants referring to objects, like ${}^{EP}\varphi_k^n + {}^{NW}\varphi_k^n$, to formalize our process-physical principles. The easiest way to do that is to use a semigroup structure.

Proposition 6. *The semigroup $(G^*, +)$ is the free semigroup on the set A of abstract constants, introduced by clauses (i)-(iv) of Prop. 4, under addition. So,*

(i) *if $g \in A$, then $g \in G^*$;*

(ii) *if $g_1 \in G^*$ and $g_2 \in G^*$, then $g_1 + g_2 \in G^*$.*

■

We will now consider a generic process: the elementary process by which the k^{th} massive system evolves from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. This process has already been described by Prop. 2 in the language of systems theory, but now we have all necessary definitions in place to precisely state the process-physical principles that govern this generic process—these hold, thus, for any process described by Prop. 2. Below we thus obtain a watered-down version of the EPT: it only holds for the simplest processes, but it has the enormous advantage that the physical interpretation of the formalism can be expressed in the language of systems theory—for the full version of the EPT no such interpretation exists.

Proposition 7. *The life of the k^{th} massive system in the ground state at the n^{th} degree of evolution exists:*

$$\mathbb{E}{}^{EP}\varphi_k^n \tag{3}$$

Eq. (3) can be viewed as a notation for the \in -relation ${}^{EP}\varphi_k^n \in R_1$ for a unary relation R_1 on G^* . ■

Proposition 8. *By a state transition at the n^{th} degree of evolution, the life of the k^{th} massive system in the ground state transforms into the life of the k^{th} massive system in a transition state:*

$${}^{EP}\varphi_k^n \rightarrow {}^{NW}\varphi_k^n \tag{4}$$

Likewise, Eq. (4) can be viewed as a notation for an \in -relation $({}^{EP}\varphi_k^n, {}^{NW}\varphi_k^n) \in R_2$ for a binary relation R_2 on G^* . ■

Proposition 9. *The life of the k^{th} massive system in a transition state, created at the n^{th} degree of evolution, effects that the life of the k^{th} massive system in the ground state at the n^{th} degree of evolution is succeeded by the life of the k^{th} massive system in the excited state at the $(n+1)^{\text{th}}$ degree of evolution:*

$${}^{NW}\varphi_k^n : {}^{EP}\varphi_k^n \dashrightarrow {}^{NP}\varphi_k^{n+1} \tag{5}$$

Eq. (5) can be viewed as a notation for an \in -relation $({}^{NW}\varphi_k^n, {}^{EP}\varphi_k^n, {}^{NP}\varphi_k^{n+1}) \in R_3$ for a ternary relation R_3 on G^* . The dashed arrow \dashrightarrow is intended to indicate that the corresponding succession does not take place by a single state transition. ■

Proposition 10. *By a state transition at the $(n + 1)^{\text{th}}$ degree of evolution, the life of the k^{th} massive system in the excited state transforms into the life of the k^{th} massive system in the ground state plus the life of radiation emitted at the $(n + 1)^{\text{th}}$ degree of evolution by the k^{th} massive system:*

$${}^{NP}\varphi_k^{n+1} \rightarrow {}^{EP}\varphi_k^{n+1} + {}^{LW}\varphi_k^{n+1} \quad (6)$$

Eq. (6) can again be viewed as a notation for an \in -relation as in Eq. (4). ■

With regard to the generic process, what remains to be done is to link the above propositions to the set of invariant properties that the massive system by Prop. 2 is assumed to be carrying throughout the process. For that matter, the next two propositions introduce new constants, but it will turn out that these are automatically in the semi-group G^* .

Proposition 11. *The life of the k^{th} massive system in the ground state at the n^{th} degree of evolution followed by the life of the k^{th} massive system in a transition state, created at the n^{th} degree of evolution, is an occurrent designated by $\psi_{M_k}^n$, which is created at the n^{th} degree of evolution, and which carries the set of invariant properties M_k .*

$${}^{EP}\varphi_k^n + {}^{NW}\varphi_k^n = \psi_{M_k}^n \quad (7)$$

By Prop. 6 we thus have $\psi_{M_k}^n \in G^*$. ■

Proposition 12. *The life of the k^{th} massive system in the excited state at the $(n + 1)^{\text{th}}$ degree of evolution is identical to the life of its component in the excited state, which carries the set of invariant properties M_k of the k^{th} massive system at the $(n + 1)^{\text{th}}$ degree of evolution, and which is designated by ${}^{NP}\mu_{M_k}^{n+1}$:*

$${}^{NP}\varphi_k^{n+1} = {}^{NP}\mu_{M_k}^{n+1} \quad (8)$$

We thus have ${}^{NP}\mu_{M_k}^{n+1} \in G^*$. ■

Remark 13. We now have a version of the EPT—note that it is expressed without reference to the coordinate system of an observer—that can serve as a basis for our semi-classical model of the interaction between a monadic system and its environment. However, the generalized principle of choice and the principle of formation of space, two axioms of the EPT, do not occur in this version of the EPT.

The reason for omitting the principle of formation of space is that it is not needed for our present purposes: the idea is that this principle can be used for a new approach to the dark energy problem in a relativistic context. This is outside the intended area of application of the present semi-classical model.

The reason for omitting the principle of choice is that the semi-classical model is *deterministic*. We can nevertheless give a statement of the principle, which applies to the semi-classical model. Since it is deterministic, the set θ_k^{n+1} of parallel possible lives of the k^{th} massive system in an excited state at the $(n + 1)^{\text{th}}$ degree of evolution is just the singleton $\{ {}^{NP}\varphi_k^{n+1} \}$. Now let's view the function f_C on the singleton of θ_k^{n+1} given by $f_C : \theta_k^{n+1} \mapsto {}^{NP}\varphi_k^{n+1}$ as a choice function that “chooses” ${}^{NP}\varphi_k^{n+1}$ from the set $\theta_k^{n+1} = \{ {}^{NP}\varphi_k^{n+1} \}$ of possibilities; the principle of choice of the EPT is then trivially represented by

$${}^{NP}\varphi_k^{n+1} = f_C(\theta_k^{n+1}) \quad (9)$$

■

3 Semi-classical model of the EPT

3.1 General considerations

For starts, let all observers be *inertial observers*, and let's assume that all reference frames of our observers are *Galilean reference frames*, which are defined using the definition of Euclidean space.

Definition 14 (Euclidean space, coordinate system).

3D Euclidean space is an affine space, whose elements will be called points, and whose associated vector space is a 3D Euclidean vector space with inner product. An orthonormal set of basis vectors $\{\vec{e}_1, \vec{e}_2, \vec{e}_3\}$ can be constructed by choosing a point O of the affine space as the origin and by choosing three points E_1, E_2 , and E_3 , such that the directed line segments $\overrightarrow{OE_1}$, $\overrightarrow{OE_2}$, and $\overrightarrow{OE_3}$ are mutual perpendicular and have unit length: the directed line segment $\overrightarrow{OE_j}$ is then the basis vector \vec{e}_j and we have

$$\vec{e}_i \cdot \vec{e}_j = \delta_{ij} \quad (10)$$

where δ_{ij} is the Kronecker delta. Any point \mathcal{X} in the affine space can then be viewed as the end point of a directed line segment $\overrightarrow{O\mathcal{X}}$ for which

$$\overrightarrow{O\mathcal{X}} = x^1 \cdot \overrightarrow{OE_1} + x^2 \cdot \overrightarrow{OE_2} + x^3 \cdot \overrightarrow{OE_3} = x^1 \cdot \vec{e}_1 + x^2 \cdot \vec{e}_2 + x^3 \cdot \vec{e}_3 \quad (11)$$

That way, there is a bijection between the points in 3D Euclidean space and the coordinate tuples in \mathbb{R}^3 . A **cartesian coordinate system** for 3D Euclidean space, i.e. a set of coordinate tuples that uniquely determine a point in 3D Euclidean space, can thus be constructed by choosing an origin and constructing an orthonormal set of basis vectors: a coordinate tuple $X = (x^1, x^2, x^3) \in \mathbb{R}^3$ then describes a point \mathcal{X} in 3D Euclidean space. ■

Agreement 15. We will use S.I. units of length, time, and mass. Units will be displayed between square brackets, e.g. as $[kg]$. ■

Definition 16. A **Galilean reference frame** (GRF) of an (inertial) observer \mathcal{O} is a cartesian coordinate system for 3D Euclidean space co-moving with \mathcal{O} , plus a (separate) time scale in S.I. units. The coordinates in space and time in the GRFs of any two observers \mathcal{O} and \mathcal{O}' are related by a Galilean transformation. ■

We now assume **non-relativistic conditions**, so that in the GRFs of any two observers \mathcal{O} and \mathcal{O}' , who use the same units of length and time,

- (i) the duration δt of the time span $[t, t + \delta t]$ between two events in the GRF of \mathcal{O} is the same as the duration $\delta t'$ of the corresponding time span $[t', t' + \delta t']$ between those events in the GRF of \mathcal{O}' ;
- (ii) the distance $d(X, Y)$ between simultaneous events at positions X and Y in the GRF of \mathcal{O} is the same as the distance $d(X', Y')$ between the corresponding positions X' and Y' of those events in the GRF of \mathcal{O}' ;
- (iii) for any monadic system, the distance δs between consecutive ground states divided by the duration δt of the time span between these ground states is negligible compared to light speed c —that is, $\delta s / \delta t \ll c$.

Postulate 17 (Duration of an elementary process).

Under non-relativistic conditions, all elementary process have the same duration of a Planck time in the GRF of any observer \mathcal{O} . For any integer n , an interval $[n, n + 1] \subset \mathbb{R}$ of degrees of evolution can then be identified with a time span $[t_n, t_{n+1}]$. ■

Remark 18. There is no experimental justification for identifying the duration of an elementary process with a Planck time: this has to be taken as a fundamental postulate of (non-relativistic) Planck-scale physics in the framework of the EPT, which is based on nothing but the idea that “the Planck length and Planck time are conceptually linked at a fundamental physical level”.¹ ■

Remark 19. When we say that we are going to model the interaction between a monadic system and its environment, we take the position that there is a distinction between a monadic system and its environment. In the framework of the EPT, that distinction is merely *conceptual*: a monadic system is not *physically* separated from its environment when it is in a wave state. Quite the opposite: when a monadic system is in a wave state, it is *one with its environment* from a physical perspective. ■

Remark 20. In general, there are two sides to an interaction between a monadic system and its environment:

- the environment has an effect on the monadic system;
- the monadic system has an effect on its environment.

To treat the effect of the environment on the monadic system, we assume that its environment can be modeled as follows in the GRF of an observer \mathcal{O} :

- (i) the environment is an open subset $U \subset \mathbb{R}^3$;
- (ii) the gravitational potential Φ_G , the gravitational field $-\vec{\nabla}\Phi_G$, the electric potential Φ_E , the electric field $-\vec{\nabla}\Phi_E$, and the magnetic field \vec{B} in the environment U can be modeled with classical mechanics.

The effect of the interaction on a monadic system is then an effect on its properties (position, velocity, mass, energy): this effect will be described quantitatively. Importantly, as long as the interaction between a massive system and its environment has only gravitational and/or electromagnetic aspects—this is the case when weak interactions and strong interactions are excluded—this effect is independent of any internal structure of a monadic system: it is not relevant whether e.g. the ground state of a monadic system is a ball, a cube, or just a point. Therefore, this internal structure will not be modeled. We simply assume that in each state, a monadic system has a gravitational mass m_g and an electric charge Q , and its center of mass has a position X and a velocity \vec{v} .

In the next section, we will assume that the effect of the monadic system on its environment is negligible. But if we want to consider the scenario that n monadic systems form a larger massive system, the contribution of each of the n monadic systems to the gravitational potential, the electric potential and the magnetic field may be calculated from its gravitational rest mass, its charge, and its velocity as in classical mechanics. ■

Last but not least, we assume that all matter is *inanimate*. This seems trivial to mention, but it’s not: in the framework of the EPT animated observers have a free will. In this semi-classical model of interactions, however, we are not concerned with free will.

¹The quoted statement has been taken from the lemma “Planck units” on Wikipedia.

3.2 Interactions with only a gravitational aspect

A process of interaction will generally have gravitational and electromagnetic aspects, but if the gravitational aspect is *predominant* it can be called a process of gravitational interaction. So, let's focus first on an elementary process in the temporal evolution of a (monadic) system made up of one uncharged component, in which a gravitational interaction takes place between the system and its environment: let this be the process by which the k^{th} monadic system evolves from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution.

For starters, let's begin with the set of invariant properties M_k carried by the monadic system throughout its temporal evolution. For this semi-classical model we assume that this is a set of three properties, and for this process we assume the following:

- (i) the first invariant property is the **characteristic number of normality** c_n , a dimensionless number having the value $+1$ for ordinary matter and -1 for antimatter;
- (ii) the second invariant property is the **rest mass spectrum**, which we assume to be a constant function s that adds a rest mass m_0 to every integer-valued degree of evolution:

$$\forall n : s(n) = m_0 [kg] \tag{12}$$

- (iii) the third invariant property is the **electric charge** Q , which we assume to be zero: $Q = 0 [C]$.

Examples of monadic systems with these properties are a one-neutron system and a one-antineutron system.

So, let this process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution begin at $t = t_n$ when the monadic system exists in a ground state. To this state, we associate

- (i) a spatial position $X_n = (x_n^1, x_n^2, x_n^3)$, which we may view as the position of the center of mass of the system in its ground state;
- (ii) a spatial momentum $\vec{p}_n = (p_n^1, p_n^2, p_n^3)$, which is inherited from the previous process by a law of conservation of momentum;
- (iii) a total energy H_n , the system's Hamiltonian, which is the sum of rest energy, kinetic energy, and potential energy.

Thus speaking, for the system in its normal particle state at $t = t_n$, its inertial mass m_i , gravitational mass m_g , position X , momentum \vec{p} , and Hamiltonian H have the following values (c being the speed of light):

$$\left\{ \begin{array}{l} m_i = m_0 [kg] \\ m_g = c_n \cdot m_i [kg] \\ X = X_n \\ \vec{p} = \vec{p}_n \\ H = H_n = m_i c^2 + \vec{p}_n \cdot \vec{p}_n / 2m_i + m_g \cdot \Phi_G(X_n) [J] \end{array} \right. \tag{13}$$

In this ground state, the system "sees" the gradient of the potential field Φ_G at $X = X_n$: it is thereby determined what the value is of the impulse $\delta\vec{p}_n$ that the system will receive

in this process. This impulse is the difference between the momentum of the current ground state and the next:

$$\delta\vec{p}_n = \vec{p}_{n+1} - \vec{p}_n \quad (14)$$

Its value is then modeled by

$$\delta\vec{p}_n = -m_g \cdot t_P \cdot \vec{\nabla} \Phi_G \quad (15)$$

That is, we model the value of the impulse by a product of a duration and an average force \vec{F}_{av} , the duration being the duration t_P of the process—this is a Planck time—and the average force being the Newtonian gravitational force at $X = X_n$. It is important to understand, however, that the massive system is **not** subjected to a force \vec{F}_{av} throughout an interval with duration t_P : instead, the massive system receives an impulse $t_P \cdot \vec{F}_{av}$ at once at one point in time.

Now that we have established what the impulse is and what its value is, it remains to be established *how* the system receives the impulse. In a sentence, the idea is that the system, which will now go through a cycle of transition state, excited state, and next ground state, receives the impulse by

- (i) absorbing the energy $\delta E_n = |\delta\vec{p}_n| \cdot c$ of a photon with spatial momentum $-\delta\vec{p}_n$ from its surroundings while being in a transition state;
- (ii) emitting a photon with that momentum $-\delta\vec{p}_n$ when it falls back from the subsequent excited state to its next ground state.

Elaborating, at $t = t_n$ the event takes place by which the system transforms from a ground state to a transition state with lifetime t_P ; the life of the ground state thus has a singular time span $[t_n, t_n] = \{t_n\}$. To the transition state at a time $t \in (t_n, t_n + t_P)$, we associate

- (i) an inertial mass $m_i(t) \geq m_0$;
- (ii) a gravitational mass $m_g(t) = c_n \cdot m_i(t)$;
- (iii) a constant velocity $\vec{v}_n = \vec{p}_n/m_0$, inherited from the preceding ground state;
- (iv) a Hamiltonian $H(t) = H_n + \delta E_n(t) = H_n + \frac{t-t_n}{t_P} \delta E_n$.

Any change in inertial mass and gravitational mass is thus due to the absorption of energy. Modeling the Hamiltonian $H(t)$ of clause (iv) requires an additional postulate.

Postulate 21. *The energy $\delta E_n(t)$ that the system has absorbed from its surroundings in the time span (t_n, t) is stored as rest energy, kinetic energy and/or potential energy. ■*

So, $H(t)$ can be written as a sum of rest energy, kinetic energy and potential energy, where the value of the potential energy can be evaluated at $X(t) = X_n + (t - t_n) \cdot \vec{v}_n$:

$$H(t) = m_i(t)c^2 + \frac{1}{2}m_i(t)\vec{v}_n \cdot \vec{v}_n + m_g(t) \cdot \Phi_G(X(t)) \quad (16)$$

Writing $\Phi_G(X(t)) = \Phi_G(X_n) + \delta\Phi_G(t)$, we can solve for $m_i(t)$:

$$\frac{m_i(t)}{m_0} = \frac{c^2 + \frac{1}{2}|\vec{v}_n|^2 + c_n \cdot \Phi_G(X_n) + c(t - t_n)|\vec{\nabla} \Phi_G|}{c^2 + \frac{1}{2}|\vec{v}_n|^2 + c_n \cdot \Phi_G(X_n) + c_n \cdot \delta\Phi_G(t)} \quad (17)$$

We now limit the area of applicability of this semi-classical model to cases satisfying $m_i(t) \geq m_0$. This corresponds to applicability to weak gravitational fields only, where the Hamiltonian H_n satisfies $H_n > 0$.

At $t = t_{n+1} = t_n + t_P$, the next event takes place by which the system transforms from a transition state to an excited state. In this excited state at $t = t_{n+1}$, the system's inertial mass m_i , gravitational mass m_g , position X , momentum \vec{p} , and Hamiltonian H have the following values:

$$\left\{ \begin{array}{l} m_i = m_i^* = \lim_{t \rightarrow t_{n+1}} m_i(t) [kg] \\ m_g = m_g^* = c_n \cdot m_i^* [kg] \\ X = X_{n+1} = X_n + t_P \cdot \vec{v}_n \\ \vec{p} = \vec{p}_{n+1}^* = m_i^* \cdot \vec{v}_n \\ H = H_{n+1}^* = \lim_{t \rightarrow t_{n+1}} H(t) [J] \end{array} \right. \quad (18)$$

Energy is conserved: $H_n + \delta E_n = H_{n+1}^*$. Still at $t = t_{n+1}$, the final event of the process takes place: the system emits a photon with energy δE_n and momentum $-\delta \vec{p}_n$, thereby transforming to the next ground state; the life of the excited state thus has a singular time span $[t_{n+1}, t_{n+1}] = \{t_{n+1}\}$. To understand what happens at this final event, it is important to understand that first the photon is emitted: what happens thereafter requires an additional postulate.

Postulate 22. *At $t = t_{n+1}$, upon emitting the photon with energy δE_n and spatial momentum $-\delta \vec{p}_n$ the remaining Hamiltonian of the system $H_{n+1} = H_{n+1}^* - \delta E_n$ is instantly divided between a new rest energy, a new kinetic energy, and a new potential energy. ■*

So, in the new ground state at $t = t_{n+1}$, the system's inertial mass m_i , gravitational mass m_g , position X , momentum \vec{p} , and Hamiltonian H have the following values:

$$\left\{ \begin{array}{l} m_i = m_0 [kg] \\ m_g = c_n \cdot m_i [kg] \\ X = X_{n+1} \\ \vec{p} = \vec{p}_{n+1} = \vec{p}_n + \delta \vec{p}_n = m_0 \cdot \vec{v}_{n+1} \\ H = H_{n+1} = m_i c^2 + |\vec{p}_{n+1}|^2 / 2m_0 + m_g \cdot \Phi_G(X_{n+1}) = H_n [J] \end{array} \right. \quad (19)$$

Energy is conserved: $H_{n+1}^* - \delta E_n = H_n$. The monadic system in the new ground state then marks the beginning of a new elementary process in its temporal evolution.

Remark 23. We lead ourselves astray if we demand that a law of conservation of momentum has to hold in this semi-classical model at the final event. It is, namely, in general not true that the momentum of the excited state and the momentum of the emitted photon add up to the momentum of the new ground state, as in

$$\vec{p}_{n+1}^* - \delta \vec{p}_n \stackrel{?}{=} \vec{p}_{n+1} \quad (20)$$

This final event is better understood as an event that comes with an internal shift in energy $H_{n+1}^* \rightarrow H_{n+1} + \delta E_n$ —that is, a shift

$$m_i^* \left[c^2 + \frac{1}{2} |\vec{v}_n|^2 + \Phi_G(X_{n+1}) \right] \rightarrow m_0 \left[c^2 + \frac{1}{2} |\vec{v}_{n+1}|^2 + \Phi_G(X_{n+1}) \right] + \delta E_n \quad (21)$$

whereby the energy δE_n is emitted as a photon and the energy H_{n+1} remains as the ground state. The law of conservation of momentum is $\vec{p}_{n+1} = \vec{p}_n + \delta \vec{p}_n$. ■

3.3 Interactions with gravitational and electromagnetic aspects

To model a process in which an interaction takes place with gravitational and electromagnetic aspects, we have to drop the assumption that the electric charge of the monadic system is zero. So, we make the following assumptions for the characteristic number of normality c_n , the rest mass spectrum s , and electric charge Q :

$$\begin{cases} c_n \in \{-1, +1\} \\ s(n) = m_0 [kg] \\ Q = q [C] \end{cases} \quad (22)$$

Modelling a (non-relativistic) free (anti)particle as a monadic system is then a matter of choosing the right values for these three invariant properties.

For our model of the interaction processes, some changes have to be made to the model of the previous section. For starters, a term accounting for electric potential energy has to be added to the Hamiltonian H_n of the monadic system in its initial ground state at $t = t_n$, to the Hamiltonian $H(t)$ of the monadic system at a point in time $t \in (t_n, t_{n+1})$ when it is in a transition state, and the Hamiltonian H_{n+1}^* of the monadic system in its excited state at $t = t_{n+1}$:

$$H_n = m_i c^2 + \frac{1}{2} m_i |\vec{v}_n|^2 + c_n m_i \Phi_G(X_n) + q \Phi_E(X_n) [J] \quad (23)$$

$$H(t) = m_i(t) c^2 + \frac{1}{2} m_i(t) \vec{v}_n \cdot \vec{v}_n + m_g(t) \cdot \Phi_G(X(t)) + q \Phi_E(X(t)) [J] \quad (24)$$

$$H_{n+1}^* = m_i^* c^2 + \frac{1}{2} m_i^* \vec{v}_n \cdot \vec{v}_n + m_g^* \cdot \Phi_G(X_{n+1}) + q \Phi_E(X_{n+1}) [J] \quad (25)$$

These replace the Hamiltonians H_n , $H(t)$, and H_{n+1}^* as given in the previous section.

Furthermore, the impulse $\delta\vec{p}_n$ that the system receives can still be written as a product of average force \vec{F}_{av} and the Planck time t_P , but it now depends also on the electric and magnetic fields at $X = X_n$:

$$\delta\vec{p}_n = t_P \cdot \vec{F}_{av} [kgm/s] \quad (26)$$

$$\vec{F}_{av} = -c_n m_i \vec{\nabla} \Phi_G(X_n) - q \vec{\nabla} \Phi_E(X_n) + q \cdot \vec{v}_n \times \vec{B}(X_n) [kgm/s^2] \quad (27)$$

It remains the case that the energy $\delta E_n = c |\delta\vec{p}_n|$ of a photon with momentum $-\delta\vec{p}_n$ is absorbed from the environment during the time span of the life of the monadic system in a transition state, and that a photon with momentum $-\delta\vec{p}_n$ is emitted by the monadic system at the final event of the process.

Remark 24. Process-wise nothing has changed: a process in which an interaction takes place with gravitational and electromagnetic aspects is *the same* as a process in which an interaction takes place with only a gravitational aspect. That is, in this framework it is **absolutely not** the case that instead of a single process for one interaction with gravitational and electromagnetic aspects we have two separate processes taking place—one for a gravitational interaction and one for an electromagnetic interaction. On the other hand, the modern idea that interactions take place by exchanging mediating particles inevitably leads to two separate elementary processes for electromagnetism and gravitation. This may indicate how the EPT is intended as a unifying scheme (which is not the same as a unification theory). ■

4 Discussion

4.1 Worked-out examples of interaction processes

Example 25 (Neutron in the earth's gravitational field).

Let us consider a system made up of a single neutron that interacts with the gravitational field of the earth, initially moving away from the earth's surface; let us treat this as a monadic system using the semi-classical model of gravitational interaction processes. So, the electric charge Q_n , inertial rest mass m_0 , and characteristic number of normality c_n have the following values:

$$\begin{cases} Q_n = 0 [C] \\ m_0 = 1.67493 \cdot 10^{-27} [kg] \\ c_n = +1 \end{cases} \quad (28)$$

Now let's model this process in the GRF of an observer \mathcal{O} , who is at rest at the earth's surface: let's take the following values for the mass of the earth M_E and the radius R_O of the earth at the origin O of the GRF of \mathcal{O} , located at the surface of the earth at the equator:

$$\begin{cases} M_E = 5.97237 \cdot 10^{24} [kg] \\ R_O = 6,378,137 [m] \end{cases} \quad (29)$$

Let the positive x^3 -axis of \mathcal{O} 's GRF coincide with increasing distance above the earth's surface, and let this process with duration $t_P = 5.391247 \cdot 10^{-44} [s]$ begin at the point in time $t = t_0 = 0$ on \mathcal{O} 's time scale with the neutron located *exactly* 100 [m] above the earth's surface in a normal particle state with a momentum $100 \cdot m_0 [kgm/s]$ directed away from the earth's surface. So, at $t = 0$ properties of the system and its environment have the following values (using $c = 299,792,458 [m/s]$):

$$\begin{cases} X_0 = (0, 0, 100) \\ \Phi_G(X_0) = -G \frac{M_E}{R_O + 100} = -6.24949 \cdot 10^7 [J/kg] \\ \vec{p}_0 = (0, 0, 1.67493 \cdot 10^{-25}) \\ \vec{v}_0 = \vec{p}_0/m_0 = (0, 0, 100) \\ H_0 = m_0 c^2 + \frac{1}{2} m_0 |\vec{v}_0|^2 + m_g \Phi_G(X_0) = 1.505352 \cdot 10^{-10} [J] \end{cases} \quad (30)$$

At this very starting point of the process, it is already determined what the impulse $\delta \vec{p}_0$ will be that the system will receive in this process. For the value of the gravitational field at $X = X_0$ we have

$$-\vec{\nabla} \Phi_G(X_0) = (0, 0, -9.7983) \quad (31)$$

so the field is directed *towards* the earth's surface. Eq. (15) then gives the following value for the component δp_0^3 of the impulse $\delta \vec{p}_0 = (0, 0, \delta p_0^3)$:

$$\delta p_0^3 = c_n m_0 t_P \frac{\partial \Phi_G}{\partial x^3}(X_0) = -8.847827 \cdot 10^{-70} [kgm/s] \quad (32)$$

Thus speaking, at $t = t_0 = 0$ the one-neutron system transforms by a state transition into a wave state with lifetime t_P , and during the time span $(0, t_P) = (0, 5.391247 \cdot 10^{-44})$

the system will absorb an energy δE_0 from its surroundings, which corresponds to the energy of a photon with momentum $-\delta\vec{p}_0$:

$$\delta E_0 = |\delta\vec{p}_0| \cdot c = 2.652312 \cdot 10^{-61} [J] \quad (33)$$

Next, by the event at $t = t_1 = t_0 + t_P = t_p$, the monadic system transforms from a transition state to an excited state at a position $X_1 = X_0 + \delta X_0 = X_0 + t_P \cdot \vec{v}_0$ with Hamiltonian $H_1^* = m_i^* c^2 + \frac{1}{2} m_i^* |\vec{v}_n|^2 + m_i^* \Phi_G(X_{n+1}) = H_0 + \delta E_0$. Now the leading term in the Hamiltonian H_{n+1}^* is $m_i^* c^2$; writing $m_i^* = m_0 + \delta m_i$, we can easily approximate the increase in inertial mass δm_i :

$$\delta m_i \approx \delta E_0 / c^2 = 2.951098 \cdot 10^{-78} [kg] \quad (34)$$

This is thus the amount by which the inertial masses of ground state and excited state differ due to the absorption of energy.

Finally, at $t = t_1$ the system emits a photon with momentum $-\delta\vec{p}_0$, and transforms to the next ground state with momentum $\vec{p}_1 = (0, 0, 1.67493 \cdot 10^{-25} - 8.847827 \cdot 10^{-70})$. So, it would take $1.89304 \cdot 10^{44}$ similar impulses for the neutron to lose its momentum: this takes $10.20585 [s]$, which *exactly* matches the prediction by classical mechanics. The emitted photon is *gravitational Bremsstrahlung*: its wave length is $\lambda = 7.4889234 \cdot 10^{35} [m]$ or, equivalently, a whopping $7.9159675 \cdot 10^{19}$ light years. Needless to say, this goes beyond detection. ■

Example 26. (Antineutron in the earth's gravitational field.)

Let us now see what happens if we replace the neutron with an antineutron, all other things equal as in Ex. 25. So first of all, the electric charge \bar{Q}_n , inertial rest mass \bar{m}_0 , and characteristic number of normality c_n of the system then have the following values:

$$\begin{cases} \bar{Q}_n = 0 [C] \\ \bar{m}_0 = 1.67493 \cdot 10^{-27} [kg] \\ c_n = -1 \end{cases} \quad (35)$$

Importantly, its gravitational mass \bar{m}_g is negative: $\bar{m}_g = c_n \cdot \bar{m}_0 < 0$. We assume that at $t = 0$, with the antineutron in a ground state, the initial properties X'_0 , $\Phi_G(X'_0)$, \vec{p}'_0 , and \vec{v}'_0 of the system and its environment have the same values as their unprimed counterparts in Ex. 25, given by Eq. (30). For the Hamiltonian \bar{H}_0 , however, we have $\bar{H}_0 > H_0$ because the potential energy is *positive* for the antineutron—it is to be interpreted as the gain in kinetic energy when the antineutron accelerates away to infinity. However, $\bar{m}_0 c^2$ is the leading term in \bar{H}_0 so we don't see this difference back in the numerical value: $\bar{H}_0 \approx H_0 = 1.505352 \cdot 10^{-10} [J]$.

Because $\bar{m}_g < 0$, the impulse $\delta\vec{p}'_0$ that the antineutron receives in this process is *the opposite* of that of the neutron: $\delta\vec{p}'_0 = -\delta\vec{p}_0$. For the component $\delta p_0^{3'}$ of the impulse $\delta\vec{p}'_0 = (0, 0, \delta p_0^{3'})$ we obtain

$$\delta p_0^{3'} = \bar{m}_g t_P \frac{\partial \Phi_G}{\partial x^3}(X'_0) = +8.847827 \cdot 10^{-70} [kgm/s] \quad (36)$$

So, the antineutron absorbs an energy $\delta\bar{E}_0 = |\delta\vec{p}'_0| \cdot c = 2.652312 \cdot 10^{-61} [J]$ from its environment in the time span $(t_0, t_1) = (0, t_P)$.

Immediately after getting in the excited state, a photon with momentum $-\delta\vec{p}'_0$ is then emitted *towards earth*, and the one-antineutron system ends up in the next ground state with momentum $\vec{p}'_1 = \vec{p}'_0 + \delta\vec{p}'_0 = (0, 0, 1.67493 \cdot 10^{-25} + 8.847827 \cdot 10^{-70})$. **So, the prediction is that the antineutron accelerates away from earth.** ■

Example 27 (Electron in a uniform strong electric field).

Let's consider a system made up of a single electron, and let's use the GRF of the observer \mathcal{O} of Exs. 25 and 26 to model the main characteristics of a process of its temporal evolution as it moves through a stationary, uniform electric field. With the system in a normal particle state at $t = t_0 = 0$, the initial conditions are the following:

$$\left\{ \begin{array}{l} m_0 = 9.109384 \cdot 10^{-31} [kg] \\ Q_e = -1.602177 \cdot 10^{-19} [C] \\ X_0 = (0, 0, 1) \\ \Phi_G(X_0) = -6.24959 \cdot 10^7 [J/kg] \\ \Phi_E(X_0) = 25 \cdot 10^6 [V] \\ -\vec{\nabla}\Phi_G(X_0) = (0, 0, -9.7985) \\ -\vec{\nabla}\Phi_E(X_0) = (0, 25 \cdot 10^6, 0) \\ \vec{B}(X_0) = (0, 0, 0) \\ \vec{v}_0 = \vec{p}_0/m_0 = (0, 100, 0) \\ H_0 = m_0c^2 + m_g\Phi_G(X_0) + Q_e\Phi_E(X_0) = -3.923571 \cdot 10^{-12} [J] \end{array} \right. \quad (37)$$

Let \vec{e}_2 and \vec{e}_3 be the unit basis vectors in respectively x^2 -direction and x^3 -direction in the GRF of our observer \mathcal{O} ; then the impulse $\delta\vec{p}_0 = -t_P m_g \cdot \vec{\nabla}\Phi_G - t_P Q_e \cdot \vec{\nabla}\Phi_E$ that the system will receive due to the interaction with the gravitational and electric fields in its environment is then, i.e. at the start of this elementary process at time $t = 0$, determined to be

$$\delta\vec{p}_0 = 2.159432 \cdot 10^{-55} \vec{e}_2 - 4.81214 \cdot 10^{-73} \vec{e}_3 \quad (38)$$

The energy of a photon with momentum $-\delta\vec{p}_0$, which has to be absorbed in the time span during which the system is in a transition state, is

$$\delta E_0 = |\delta\vec{p}_0| \cdot c = 6.473817 \cdot 10^{-47} [J] \quad (39)$$

At $t = t_1 = t_0 + t_P$, the one-electron system gets in an excited state with Hamilton $H_1^* = H_0 + \delta E_0$ at position $X = X_0 + t_P \cdot \vec{v}_0$. The gain in electric potential energy is

$$Q_e(\Phi_E(X_1) - \Phi_E(X_0)) = Q_e \frac{\partial\Phi_E}{\partial x^2} \delta x^2 = 2.159433 \cdot 10^{-55} [J] \quad (40)$$

This is much smaller than the amount of energy absorbed:

$$Q_e(\Phi_E(X_1) - \Phi_E(X_0)) \ll \delta E_0 \quad (41)$$

So, the absorbed energy leads to an increased inertial rest mass m_i^* of the system in its excited state; neglecting the increase in electric potential energy, the increase is

$$\delta m_i = m_i^* - m_0 \approx \delta E_0/c^2 = 7.203093 \cdot 10^{-64} [kg] \quad (42)$$

Immediately after getting in the excited state, the one-electron system emits a photon with momentum $-\delta\vec{p}_0$; the monadic system thereby gets in the next ground state at the position $X = X_1$ with the following properties:

$$\left\{ \begin{array}{l} m_i = m_0 + \delta m \approx m_0 = 9.109384 \cdot 10^{-31} [kg] \\ X = X_1 = (0, 5.391247 \cdot 10^{-42}, 1) \\ \vec{v} = \vec{v}_0 + \delta\vec{v}_0 = (0, 100 + 2.37056 \cdot 10^{-25}, -5.28262 \cdot 10^{-43}) \\ H_1 = H_0 \approx -3.923571 \cdot 10^{-12} [J] \end{array} \right. \quad (43)$$

The existence of the monadic system in its new ground state then marks the beginning of the next elementary process. ■

4.2 Limitations of the present model

The semi-classical model describes interactions between a non-relativistic massive system, which evolves in time by elementary processes described by the EPT, and its environment, which is described by classical fields. Obviously, this semi-classical model cannot explain observed relativistic effects. In particular, if we model a rectilinearly moving muon as a monadic system, then this semi-classical model of interactions cannot explain the observed prolonged lifetime of fast muons [15]. The underlying reason is that both in this model and in Newtonian mechanics the rate of passing of time is the same for all observers. In the literature the inconsistency of Newtonian mechanics with observed relativistic effects has been resolved by the development of *Relativistic Newtonian Dynamics* (RND), a modification of Newton's theory [16]. We could, thus, modify our semi-classical model accordingly: the result would then be consistent with the results of RND. However, just like RND, our semi-classical model would still be inconsistent with the outcome of the Hafele-Keating experiment [17], being that the local rate of passing of time depends on the local strength of the gravitational field. An aim for further research is a model of interaction processes that is consistent with all observations: such a model will thus differ *fundamentally* from RND.

Furthermore, this semi-classical model cannot explain observed quantum effects—in particular, observations where microsystems have been found at positions that deviate from the predictions of classical mechanics. However, if we allow the absorption of incoming photons at the first event of a process—which is when the massive system transforms from a ground state to a transition state—then the massive system still evolves in time at Planck scale in a deterministic way, but our knowledge of the whereabouts of the massive system becomes fundamentally probabilistic. So, this yields a deterministic theory underlying quantum mechanics, a topic that has fairly recently been discussed at the metalevel by several authors [18, 19, 20]. Results in this line of research will be presented in a separate paper.

Another obvious limitation is that the present semi-classical model cannot explain observations involving strong or weak interactions (fission, fusion, radioactivity). There are currently no plans for research in that direction: the first aim for further research is a relativistic model of the EPT that can reproduce the experimentally successful predictions of GR, while predicting a matter-antimatter repulsive gravity. After that, the aim is to refine the relativistic model so that it can also reproduce the experimentally successful predictions of relativistic field theory.

4.3 Conclusions

The main conclusion is that the semi-classical model of the EPT introduced in this paper quantitatively demonstrates the view laid down in the EPT on the elementary processes by which fundamental interactions take place. This view entails a departure from the prevailing idea that interactions between massive systems take place by exchanging mediating particles: the basic picture is that a massive system interacts with its environment by going through cycles of ground state, transition state, and excited state, whereby energy is absorbed from the environment while the system is in a transition state and emitted into the environment when the system falls back from an excited state to the next ground state. While the area of applicability of the present semi-classical model is limited to non-relativistic massive systems evolving in an environment described by classical fields, a refinement of the model will not fundamentally change this basic picture.

A general conclusion is that this semi-classical model of the EPT corresponds with non-relativistic classical mechanics. In the framework of non-relativistic classical mechanics, the momentum \vec{p} of a massive system changes continuously in time according to

$$\frac{d\vec{p}}{dt} = \vec{F}(t) \quad (44)$$

where $\vec{F}(t)$ is the net force on the system at the time t . In the framework of the semi-classical model, on the other hand, the momentum of a massive system changes by discrete impulses $\delta\vec{p}$ evenly separated by a Planck time t_P according to

$$\delta\vec{p}_j = t_P \cdot \vec{F}_j \quad (45)$$

where $\delta\vec{p}_j$ is the j^{th} impulse and \vec{F}_j is the net force on the system at the start of the process in which the system receives that j^{th} impulse. The point is that this step size (in time) is so small, that if we consider a massive system with an initial momentum \vec{p}_0 at $t = t_0$ and we want to know its momentum \vec{p}_1 at a time $t = t_1$ after a time difference $\Delta t = t_1 - t_0 = N \cdot t_P$ in the area of application of classical mechanics (e.g. $\Delta t > 1 [\mu s]$, so $N > 10^{37}$), then for all practical purposes the semi-classical model will predict the same momentum \vec{p}_1 as non-relativistic classical mechanics:

$$\vec{p}_0 + \int_{t_0}^{t_1} \vec{F}(t) dt \approx \vec{p}_0 + \sum_{j=1}^N \delta\vec{p}_j = \vec{p}_0 + \sum_{j=1}^N t_P \cdot \vec{F}(t_0 + (j-1) \cdot t_P) \quad (46)$$

On the left of the \approx -sign in Eq. (46) we have the value of \vec{p}_1 predicted by non-relativistic classical mechanics, on the right of the \approx -sign the value of \vec{p}_1 predicted by the semi-classical model. Mathematically, the summation on the right hand side is a discrete approximation of the Riemann integral on the left hand side. Physically, however, the Riemann integral is the approximation: in the framework of the EPT, the momentum of a massive system changes by discrete steps.

Last but not least, it is once more emphasized that we have considered a hypothesis (repulsive gravity) that is highly unlikely from the perspective of theories of modern physics. Should this hypothesis be refuted by any of the ongoing experimental projects, then the present results have no relevance for physics. On the other hand, if the hypothesis is confirmed, then the present results provide support for the idea that the EPT abstractly describes the processes by which interactions take place.

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