# Elementary Process Theory

**VRIJE UNIVERSITEIT BRUSSEL**

**FACULTEIT DER LETTEREN EN WIJSBEGEERTE**

# Elementary Process Theory: axiomatic introduction and applications

**Marcoen J.T.F. Cabbolet**

Proefschrift ter verkrijging van de graad van Doctor in de Wijsbegeerte

Akademiejaar 2010-2011

Promotor: Jean Paul van Bendegem

ISBN 978-90-5972-521-8

Uitgeverij Eburon
P.O. Box 2867
NL-2601 CW Delft
The Netherlands
tel.: +31-(0)15-2131484 / fax: +31-(0)15-2146888
info@eburon.nl / www.eburon.nl

Cover design: Larisa Gubska

Front cover image: Crab Nebula
Source: archive ESA
Credit: NASA/ESO, Allison Loll, Jeff Hester (both Arizona State University)
Acknowledgement: Davide De Martin (ESA/Hubble)

Back cover image: Constellations Ursa Maior and Ursa Minor
Source: archive ESA
Acknowledgement: Akira Fujii

**DEDICATED**

**TO**

**SERGEY SANNIKOV**

## CONTENTS

# PREFACE

This dissertation is about the foundations of physics, but *not* about the foundations of contemporary theories. Instead, an entirely new ontology is presented that consists of a physically complete set of ultimate constituents of the universe that are referred to by mathematical symbols, and of a physically complete set of first principles – called: the Elementary Process Theory (EPT) – that are formulated mathematically by means of these symbols and that are intended to describe the individual processes taking place in the universe in terms of its ultimate constituents: this ontology is *potentially* applicable as a foundational framework for physics.

Thus far, much dispute has arisen over the question whether this work now has to be seen as physics, or as philosophy, or as mathematics, or as something else. This preface is to settle that dispute.

The philosopher Alfred North Whitehead defined speculative philosophy as follows[*]: “Speculative Philosophy is the endeavor to frame a coherent, logical, necessary system of ideas in terms of which every element of our experience can be interpreted.” This endeavour includes a search for first principles, which was the essential activity in this PhD research: as such, the present works seems at first glance to fall under speculative philosophy in this Whiteheadian sense. The point is, however, that the set of first principles that was found – the EPT – is formalized in mathematical language and is in principle experimentally testable by the scientific method of Lakatos: because of these two features of the EPT, this dissertation transcends the borders of *pure philosophy* – it is thus not metaphysics.

A further point is that the EPT, as a consequence of the newness of the ontology, is built from very different elements than the axioms of Quantum Mechanics (QM) or Geneneral Relativity (GR): it is a completely different theory and it should thus not be mistaken for an attempt to unify QM and GR. As such, this dissertation

[*] *Process and Reality: an Essay in Cosmology*, corrected edition, edited by David Ray Griffin and Donald W. Sherburne. New York: The Free Press, 1978, p. 3.

falls outside the realm of *contemporary physics*, i.e. the physics based on QM and/or GR. But not only that: although it is understood what happens at object level in the universe governed by the EPT and although examples of observed phenomena have been formalized in the framework of the EPT, due to the degree of abstractness of the formalism in which the EPT is written it is not yet understood how *any* of the known laws of nature emerges from this new ontology. While the latter provides a challenge for further research, at the moment it implies that this dissertation falls outside the entire realm of *natural science*, which is broader than just the physics based on GR and QM.

And last but not least, it is true that the foundation of mathematics in terms of Zermelo-Fraenkel set theory has been generalized in order to develop the formalism in which the EPT is written, but this new generalized foundation is not at all intended as an advancement in pure mathematics; the same is also true for the EPT. That places this dissertation also outside the realm of *pure mathematics*, although it can certainly be viewed as *applied mathematics* on the basis of its rigorously formalized content.

To settle the dispute, this dissertation is thus neither physics, nor pure philosophy, nor pure mathematics: it is an *interdisciplinary* topic with a delicate balance between philosophical, physical and mathematical aspects[*]. As such, it would fit perfectly in a *centrale interfaculteit*[†], as meant by Evert Willem Beth and Gerrit Mannoury in the 1950's. Since the Center for Logic and Philosophy of Science at the Vrije Universiteit Brussel is in the spirit of such a *centale interfaculteit*, it seems to be an appropriate place to submit this dissertation.

---

[*] To additionally indicate the degree of scientificness, the EPT would currently have to be classified as *protoscience*. The EPT thus remains protoscience until it is falsified and becomes *obsolete*, or until it is confirmed by enough experimental results to call it *science* – in which case it would fall under *mathematical physics*, that is, physics in a rigorous mathematical framework.

[†] In English, this would translate as a "department of interdisciplinary studies".

## ACKNOWLEDGEMENTS

Counted from the day that the original inspiration was put in writing for the first time to the day that this PhD thesis has been publicly defended, more than fourteen years have passed. On the one hand this is much longer than the "average" time for the development of a result, but on the other hand it can be called a miracle that it got to a PhD defense at all. Therefore I would like to use this section to mention a few people, without whom this PhD defense would not have taken place.

First and foremost, I would like to thank dr. Sergey Sannikov of the Institute of Theoretical Physics, a department of the Kharkov Institute of Physics and Technology (Ukraine), not only for the prolonged constructive discussion about the most fundamental assumptions in physics and mathematics that led to exactly formulated ideas for the results in this PhD thesis, but also for the attitude as a physicist that he passed on to me – an attitude that in some respects is the opposite of the "shut up and calculate!!" attitude, that, having blown over to Europe from the USA, is usually being taught to physics students at western universities these days. The reception during the working visits in Kharkov was always hospitable; my stays at Sannikov's place have allowed me to experience the Russian culture *directly*, which is still something different than from a hotel. The whole collaboration with Sergey Sannikov was a unique experience, which I recall to mind with incredibly great pleasure. What I remember in particular was the discussion we had in a busy tramway in Kharkov about the formal differences between a set and a matrix. Here Sannikov suddenly began to write equations on the steamed windows of the tramway. I wrote my answer underneath, which on its turn was followed by a reply from him, and so forth: this way the basis of set matrix theory was in the shortest time written out in front of a highly surprised public on the steamed windows of a busy tramway in the morning peak of Kharkov in the year 2000. After a long disease, Sergey Sannikov died on the 25th of March 2007; to his commemoration the appendix "*IN MEMORIAM*" is included, and this PhD thesis is dedicated to him.

In the second place, I would like to thank *prof. dr.* Harrie de Swart of the University of Tilburg (the Netherlands) for the extra-ordinarily rigorous peer review process by which the main results have been realized in its final form. Under the supervision of Harrie de Swart – for which, by the way, never a formal contract has been written – first the finishing touch was put on set matrix theory, which is presented in its final form in chapter three. Thereafter, the elementary process theory, which up till then was formulated as a so-called first-order theory, was edited and formalized within the newly defined mathematical-logical framework of set matrix theory; the result is presented in chapter four. The mathematical rigor, on which Sannikov had been hammering for years, has become a fact by this "informal" collaboration with Harrie de Swart: the last-named made me, as they say in Dutch, *put the dots on the i* in that respect. Although the elementary process theory still has a higher degree of abstractness than quantum mechanics and general relativity, its current formalization within a mathematical-logical framework – as opposed to a formalization as "just" a first-order theory – has greatly benefitted the readability and with that the accessibility of the results: so if after reading the technical part of this PhD thesis a feeling of understanding would remain in your case, then that is by large thanks to the efforts of Harrie de Swart.

In the third place, I would like to thank the promotor *prof. dr.* Jean Paul van Bendegem for offering the possibility to obtain a doctorate on the basis of this work. And this is not just a mere "thanks for the offer": I am deeply indebted to *prof. dr.* Van Bendegem, not only because this work questions the universal applicability of some widely accepted assumptions, but because in addition this "Dutch alliance of pseudoskeptics" has risen that has blocked a PhD graduation in the Netherlands and that has both publicly ánd behind the scenes tried to discredit this work and everyone connected to it[*] – although their arguments are bogus, it still requires courage to take a stance against them. So notwithstanding the fact that

[*] e.g. Gerard 't Hooft, 2008, *Elementaire-procestheorie allang achterhaald*, Natuurwetenschap & Techniek **76**(9), 65 (in Dutch); Frank van der Duyn Schouten, 2008, *De kwestie Cabbolet*, Cursor **50**(19), 9 (in Dutch)

I have heard it said that there is less academic freedom these days than in the Middle Ages at the time of the Inquisition, the fact that the present research results were allowed to be published in the form of a PhD thesis *despite this previous history* proves that it is not the case that there is no academic freedom *at all* these days – quite a reassurance  when thinking about further research.

Furthermore, I would like to thank all those people who made this research financially possible, all the more because a regular financing by NWO (the Netherlands Organisation for Scientific Research) in practice turned out to be impossible within the limits of the regulations at the time. In the beginning it had been quite an enterprise to come up with a legal construction enabling a finance for a full-time commitment to a research under the supervision of Sergey Sannikov, but finally I could, as an employee of the state-funded Pluspunt Eindhoven BV, be detached to the Foundation Liberalitas – which I founded myself – to conduct a scientific investigation in collaboration with the Kharkov Institute of Physics and Technology in Ukraine. I would like to thank my colleague-governors of the Foundation Liberalitas at that time, to say: Anton Lenders (in the beginning), Ernst-Jan Pulles and Peter Pijpers, for doing/signing all necessary formalities; in addition, I would like to thank all donors to the Foundation Liberalitas – of which I especially would like to mention Tour de Ville Fietskoeriers from Eindhoven – for donating together the required costs of detachment. Further I would explicitly like to thank my contact person at Pluspunt Eindhoven BV, Dorette Kipperman: she has personally arranged that I could work full-time at this research not for *two* but for *four* years, that I could buy all necessary books, and that I could twice yearly go on a monthlong working visit to Kharkov. This all has been essential to obtain the results presented in this PhD thesis.

Moreover, I would like to thank the many academics from various countries for their constructive criticism to the letter that I sent in 1997 to various physics departments all over the world; these correspondences have at the time significantly contributed to the decision, that it made sense to continue and to have the initial inspiration followed by a serious investigation – which turned into a PhD research. I would like to mention two of them by name. In particular, I would like to thank Werner Benger, at the time connected to the University of Innsbruck (Austria), for the profound correspondence in 1997 about the possibilities and impossibilities to substantiate the hypothesis (Section 1.3) in the light of existing ideas and established facts in the field of gravitation. Also I am much obliged to dr. David Maker, at the time employed in a not-to-be-named large American space travel agency, among other things for checking and confirming (also in 1997) that my point of view was new.

During the fourteen-and-a-half years that this research lasted my path was strew with roses all the time, but nevertheless there have been moments when I felt nothing but the thorns. Therefore, last but not least, I would like to thank a number of people from my own private circle who have supported me morally in this period: Rogier, Flavio, Alex & Alex, Evgeny, Victor, my brother Jeroen, his girlfriend Shiro, my father Ferdi, my mother Trees, and my girlfriend and wife Larisa.

Marcoen Cabbolet

# 1

## INTRODUCTION

> "The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction", Albert Einstein (1918).

In this introduction the work will be put in a broad context, and it will be made clear under which condition the results would be potentially applicable to physics.

### 1.1 The fundamental questions of physics

Ever since Thales of Miletus in the $7^{th}$ century B.C started wondering whether there could be a rational explanation for natural phenomena, it has intrigued people how physical reality can be explained. Commenting on Democritus' philosophy of nature that the physical world is made up of atoms moving in a void, the Roman philosopher Cicero wrote already around 50 B.C. in his work *De finibus bonorum et malorum* that "in the study of Nature there are two questions to be asked, first, what is the matter out of which each thing is made, second, what is the force by which it is made". Slightly reformulating these two questions and adding a third gives the following three questions: What is the universe made of? How does it function? What is its origin? These – and no other – are the fundamental questions of physics.
The current state of affairs is that contemporary theories do not provide an adequate answer to the above questions. It has been established that there are four types of fundamental interactions in nature (gravitational, electromagnetic, weak and strong), and for each of these interactions there is a theory available: the Standard Model, a series of theories based on Quantum Mechanics (QM), can be applied to

explain observations at microscopic scale involving the electromagnetic, strong or weak interaction, and General Relativity (GR) can be applied to explain observations involving the gravitational interaction at macroscopic scale, where planets can be viewed as particles. But the point is that these interaction theories do not form a coherent whole, because the cornerstones of modern physics, that is, QM and GR, correspond with mutually exclusive world views. Modern physics thus lacks a foundational theory that can be applied to all four fundamental interactions. The next section gives an exact definition of this foundational problem.

## 1.2 The foundational problem of physics in historical perspective

Historically, the Greek philosopher Pythagoras (±572 – ±500 B.C.) was the first to propose that a correct description of physical reality had to be in the form of mathematical formulas. Heraclitus of Ephesus (±550 – ±480 B.C.), another Greek philosopher, was the first to put forward the notion of laws of nature as the logic to which all change is subjected.

The first actual attempt to explain physical reality in terms of mathematically formulated laws of nature can be identified with the publication in 1687 of Newton's laws, that were obtained starting from experimental data. The consistency of Newton's laws with experimental results lasted some 200 years, but came to an end in 1887. In that year, in their now historic experiment the physicists Michelson and Morley failed to detect the absolute motion of earth in a static aether, which was predicted using Newton's laws. In 1905 Einstein formulated special relativity (SR), in which the idea of an absolute frame of reference, such as a static aether, was rejected. SR was consistent with the result of the Michelson-Morley experiment: this contributed to the rejection of Newton's laws as universal laws of physics. The subsequent scientific revolution had by the mid-1920's yielded two results: GR and QM, still the the cornerstones of modern-day physics.

In the framework of GR, the classical concept of a particle, i.e. a material body whose dimensions can be neglected in describing its motion, is embraced, as well as the classical idea that a particle moves on a continuous trajectory. But contrary to Newton's idea of the gravitational interaction as action at a distance, GR includes the idea that massive objects such as planets "warp" the space surrounding them, and that the resulting curvature affects the trajectories of particles moving through these surroundings, thus causing gravitation. At a macroscopic level, where celestial bodies can be treated as particles, GR was found to be more accurate than Newton's laws and Newtonian gravitation.

In the framework of QM, on the other hand, the classical notion of a particle is rejected. Instead, a purely mathematical wave function $\psi \in C^X$ is assigned to every physical microsystem; here $X$ is the set of all positions and $C$ the set of complex numbers. It is not the case that this wave function describes the microsystem itself: instead, $\psi$ can be used to compute the probabilities of possible outcomes of measurements on the microsystem; an example is given just below. This corresponds with the position that individual processes are probabilistic of nature, so that a statistical explanation is all that can be given of the microcosmos. QM predicts that a particle, once set off at a given position, can be found in places away from the trajectory predicted by classical mechanics. At the subatomic level, where gravitational aspects play no significant role, QM was found to be more accurate than Newton's laws and classical electromagnetism.

In the context of two consecutive measurements, whereby an electron is observed first at position $\underline{x}_a$ and next at position $\underline{x}_b$, the radical difference between QM and GR comes to expression in the difference between the two views on how the electron has got from $\underline{x}_a$ to $\underline{x}_b$. In the worldview based on GR, the electron has moved on a continuous trajectory $\underline{x}(t)$ from $\underline{x}_a$ to $\underline{x}_b$, whereby the electron at every point of the trajectory was in a particle state; see figure 1.1 below for a graphical illustration of this classical concept of continuous motion. In the worldview based on the Copenhagen[1] interpretation of QM, however, the electron wasn't really anywhere in between the two measurements: instead, at every intermediate time $t$ the electron had in every region U of the whole space $X$ a possibly nonzero probability

[1] There are other interpretations of QM, such as the ontological interpretation and the many worlds interpretation, that give rise to a different worldview.

$p$(U) of being found there; for a region U this real valued probability $p$(U) can then be calculated using the wave function $\psi_t$ of the electron at the time $t$ and the formula

$$p(\mathrm{U}) = \int_{\mathrm{U}} \psi_t(\underline{x})\, \psi_t(\underline{x})^* d\underline{x} \tag{1.1}$$

where $\underline{x}$ is a position vector, $\psi_t(\underline{x})$ the complex valued image of $\underline{x}$ under $\psi_t$, and $\psi_t(\underline{x})^*$ its complex conjugate. See figure 1.2 below for a graphical illustration of this accepted concept of wave motion. So from this quantum-mechanical point of view there is no such thing as the trajectory of the electron: it had a definite position only at $\underline{x}_a$ and $\underline{x}_b$, and had these *because of* the acts of measurements – it were these acts of measurement that "forced" the electron to assume the definite positions $\underline{x}_a$ and $\underline{x}_b$[2].

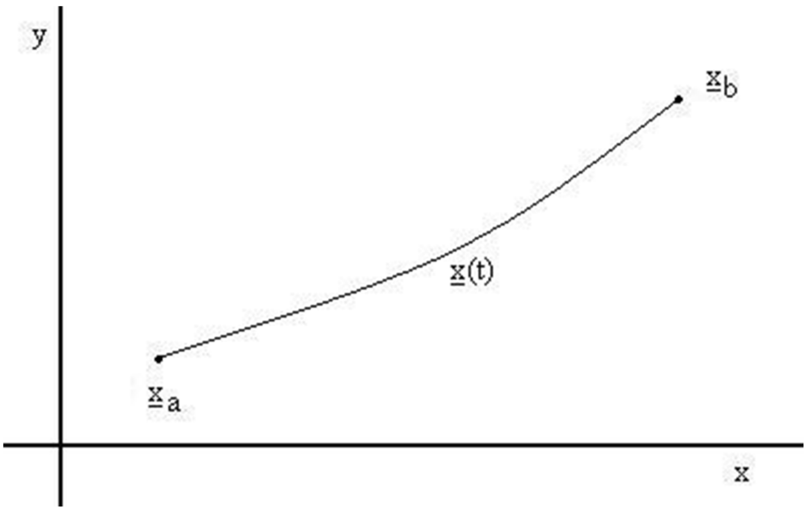


*Figure 1.1: graphical illustration of the concept of motion in GR. In an xy-plane the points $\underline{x}_a = (x_a, y_a)$ and $\underline{x}_b = (x_b, y_b)$ where the electron was observed are shown, and the trajectory $\underline{x}(t)$ along which the electron has moved as a particle according to GR.*

---

[2] Thus speaking, in the framework of QM a microsystem is *never* in a definite state in absence of measurement, but upon measurement a microsystem is *always* in a definite state. The standard explanation hereof is that the state vector of a microsystem evolves continuously in time according to the Schrödinger-equation in absence of measurement, but upon measurement discontinuously collapses into a definite state.

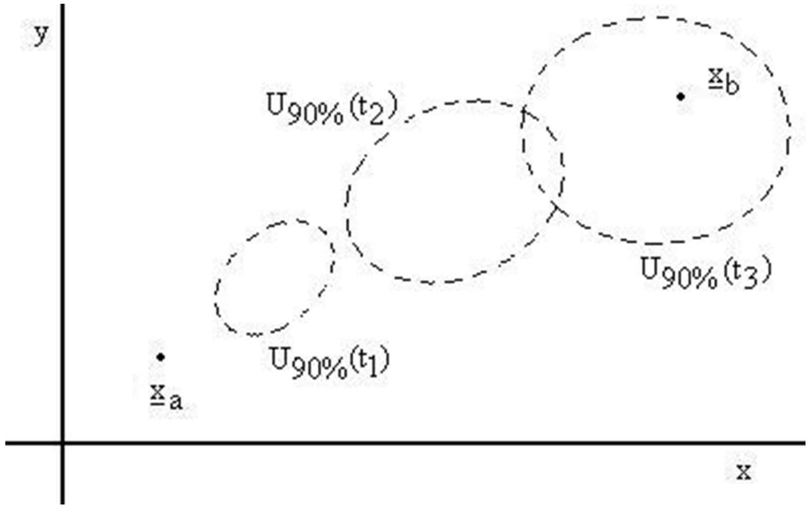


*Figure 1.2: graphical representation of the concept of motion in QM. In an xy-plane the points* $\underline{x}_a = (x_a, y_a)$ *and* $\underline{x}_b = (x_b, y_b)$ *where the electron was observed are shown, as well as three regions* $U_{90\%}(t_i)$ *for intermediate points in time* $t_i$ *with* $t_a < t_1 < t_2 < t_3 < t_b$. *Each region* $U_{90\%}(t_i)$ *represents an area U with a probability of* $p(U) = 90\%$ *of finding the electron within that area at that time* $t_i$ *according to QM.*

The above demonstrates that QM and GR yield very different answers to the first two of the three fundamental questions of physics; for an extensive discussion on the differences of QM and GR see the literature, e.g. (Sachs 1988). The foundational problem of modern physics is then easily laid bare by a logical analysis. First of all, a theory *merges* QM and GR if and only if it is a coherent set of well-formed formulas Σ, written in a formal language *L*, such that for any axioms $A_{QM}$ of QM and $A_{GR}$ of GR the following two conditions are satisfied for the translations $A^*_{QM}$ and $A^*_{GR}$ of $A_{QM}$ and $A_{GR}$ respectively in *L*:

$$\Sigma \vdash A^*_{QM} \tag{1.2}$$

$$\Sigma \vdash A^*_{GR} \tag{1.3}$$

A theory can thus not be said to merge GR and QM if it does not satisfy (1.2) and

(1.3): such a claim would be an overstatement, a misuse of the word ‘merge’. However, let $X_{GR} = \{x_1, x_2, x_3, \ldots\}$ be the set of outcomes of position measurements done for the verification of GR; this set $X_{GR}$ is a countable subset of the set $X$ of all positions: $X_{GR} \subset X$. Because particles move on timelike geodesics in GR, it is then for every position measurement the case that the position $x(t)_n \in X$ of the observed particle approaches to $x_n$ at times $t$ just before $t_n$, the time of that measurement:

$$\forall x_n \in X_{GR} (\lim_{t \to t_n} x(t)_n = x_n) \tag{1.4}$$

On the other hand, let $Y_{QM} = \{y_1, y_2, y_3, \ldots\}$ be the set of outcomes of position measurements done for the verification of QM; this set $Y_{QM}$ is a countable subset of the set $Y$ of all positions: $Y_{QM} \subset Y = X$. Because the universe is probabilistic in the framework of QM, it is then not at all the case that for every position measurement the expectation value $\langle\, y(t)_\mathrm{n} \,\rangle \in Y$ of the position of the observed particle approached to $y_n$ at times $t$ just before $t_n^*$, the time of that measurement:

$$\neg \forall y_n \in Y_{QM} (\lim_{t \to t_n^*} \langle y(t)_n \rangle = y_n) \tag{1.5}$$

If the formulas (1.4) and (1.5) represent *true* knowledge, then they have to hold for *all* position measurements, which would mean quantification over at least the union of sets $X_{GR} \cup Y_{QM}$. But that means that a theory $\Sigma$ satisfying conditions (1.2) and (1.3) is *necessarily* inconsistent. That is, if $\Sigma$ satisfies (1.2) and (1.3), then there is at least one formula $\Phi$ in the language $L$ of $\Sigma$ such that

$$\Sigma \vdash \Phi \wedge \neg\Phi \tag{1.6}$$

For example, if $\Phi$ is the translation of (1.4) in the language $L$ of $\Sigma$, such that it holds for all position measurements, then $\neg\Phi$ follows from the translation of (1.5) in the language $L$ of $\Sigma$: according to (1.4) an electron approached the position where it was found on a timelike geodesic, but according to (1.5) it didn’t – this inconsistency is necessarily reflected in $\Sigma$.

This logical analysis demonstrates that it is *not possible* to develop a unitary, consistent foundational theory $\Sigma$ that merges QM and GR, that is, a consistent theory $\Sigma$ that incorporates QM and GR in their entirety as two true theories of one and the same universe: thát is the foundational problem of modern-day physics.

As most research on Kaluza-Klein theory, which merges GR with classical electrodynamics by assuming a curled-up fifth spatial dimension, was terminated by the 1980's (Witten 1985), there is currently virtually no research activity aimed at a complete foundation of physics on the basis of GR: at present the mainstream research programs, aimed at eliminating the foundational problem, work towards a complete foundation of physics on the basis of QM. The next section gives an overview of the current state of affairs in three of the main approaches, as well as the motivation for a new approach.

## 1.3 Motivation for the present investigation

The currently most popular approach to the foundational problem of physics is the research program aimed at a mathematical formulation of string theory, which is believed "to incorporate all four of nature's forces … and all types of matter in a single quantum-mechanical framework"[3]; the idea of additional spatial dimensions that are curled-up, which was used in Kaluza-Klein theory, is also being used in this research program. Although quite some authors suggest that string theory will "merge" QM and GR, see e.g. (Rovelli 2003; Green 2004; Doplicher 2006), the previous section has demonstrated that a merger of QM and GR in their entirety is beyond the epistemic limits of the research program: string theory can thus *at most* yield an eclectic theory that merges QM with aspects of GR. It is then one thing to develop a purely mathematical construct that incorporates all this *without adding something new*, but quite some authors suggest that string theory will yield *new physics*, cf. e.g. (Rovelli 2003; Green 2000; Casanova & Spallucci 2006). A weak point is then the way that progress has been made: in the research program on string theory, namely, physical ideas were sought to match the mathematics just developed (Witten 1988); a decade later, Duff reported that "physicists are glimpsing only small corners of M-theory; the big picture is still lacking" (1998). This methodological aspect, that the theory is developed without clear mental picture, makes

[3] Quote taken from the entry 'string theory' in Encyclopædia Britannica (2011). Retrieved from http://www.britannica.com/EBchecked/topic/574576/string-theory.

this research program susceptible to the Kantian critique that true knowledge is *not possible* without a clear mental picture. So even if a string theory would be formulated that satisfies the principle of correspondence, then from the Kantian perspective still at most the biblical term "cleverly invented story" (2 Peter 1:16) applies. To the defense of string theory one might argue that Dirac, on the other hand, mentioned that "to work from the mathematical basis" is one of "two main procedures for a theoretical physicist", but he too added that "in any region of physics where very little is known, one must keep to the experimental basis if one is not to indulge in wild speculation that is almost certain to be wrong" (1968): this latter *Sollsatz* is violated by the assumption of additional curled-up spatial dimensions. An advancement of knowledge about the fundamental workings of the universe is thus beforehand almost certainly beyond the epistemic limits of the research program on string theory, and added to that the current state of affairs in the research program is reported to be the following: "in fact, there is no [string] theory so far – just a set of hunches and calculations suggesting that a theory might exist. And, even if it does, this theory will come in such a bewildering number of versions that it will be of no practical use" (Holt 2006).

Another leading approach is the research program on loop quantum gravity (LQG): the aim here is to develop a quantum-mechanical theory of gravitation by a quantization of GR, as a result of which "volume is discrete at Planck length" (Rovelli 2003). Together with the already existing Standard Model, LQG would yield a physically complete body of theories based on QM – *without* the assumption of extra spatial dimensions as in string theory. The current state of affairs in LQG is stated by one of its main proponents as follows: "the theory yields a definite physical picture of quantum spacetime and definite quantitative predictions, but a systematic way of extracting physical information is still lacking. Experimentally, there is no support for the theory, neither direct nor indirect" (Rovelli 2008).

A third approach is the research program aimed to extend the Standard Model with a quantum-mechanical theory of gravitation by applying the conventional methods of quantum field theory, which have already been applied successfully in the various theories that make up the Standard Model. Although all seemingly obvious ways to develop a quantum-mechanical theory of gravitation this way have failed (De Witt 1967), this is still an active field of research. Recent progress in this research program has been reported by Toms (2010), but it has to be added that Veltman's remark, that there is no consensus about what gravitation is from this point of view (2003), is still valid to date.

Although there are other approaches that are not mentioned here, the above overview covers the majority of the mainstream research activity in theoretical physics at present. The conclusion is then that the foundational problem of physics exists already for over eight decades, that all research programs aimed to eliminate it by developing a complete foundation of physics on the basis of GR or QM have thus far not yielded the desired output, and that the mainstream research programs are not expected to yield a solution in the nearby future: that is in itself a motivation to look at things in another way.

An undeniable observation is then that in virtually all mainstream research programs in modern physics it is *assumed* that gravitation is attraction only, but this is not *known*: it is currently, namely, not known whether antimatter is repulsed or attracted by the gravitational field of the earth – direct measurements on, for example, antiprotons are extremely difficult if not downright impossible because of the larger electromagnetic couplings, and the production and manipulation of neutral antimatter, in particular anti-hydrogen, requires further perfection before a measurement of the coupling between antimatter and gravitation is possible; the earliest experiments of the $AE\bar{g}IS$ project are expected to take place in 2013.

In this PhD research, this widely accepted assumption was questioned: what if gravitation isn't attraction only? What if antimatter is the gravitational antipole of matter? One ought to realize that the true answers to the fundamental questions of physics will differ in an essential way from those implied by contemporary theories, if antimatter were repulsed by the gravitational field of the earth. It is clear that mainstream research programs in physics will experience great difficulties in incorporating the experimental results if such a repulsion would be observed: contemporary theories of physics are then namely falsified as the true foundations for physics, so that a new framework for physics would then be required.

The purpose of this PhD research was thus to search for an answer – as rigorous and complete as possible – to the following **research question**:

> Which elementary principles might underlie the hypothesis that antimatter such as positrons, antiprotons and antineutrons has positive rest mass, but will be repulsed by the gravitational field of the earth?

The relevance of this research question for science is thus that identifying fundamental laws underlying gravitational repulsion of matter and antimatter could lead to an elimination of the foundational problem from physics and to an advancement of knowledge about the fundamental workings of the universe. Naturally, a *necessary* condition for any research result to apply to physics is that this gravitational repulsion has to be observed: if a gravitational attraction of matter and antimatter is observed, then the result is developed from a falsehood and has to be discarded.

The outline of the remainder of this PhD thesis is as follows. Chapter two discusses the method – a dialectic process – by which the final result, the Elementary Process Theory (EPT), was developed. The next three chapters present the results: chapter three introduces the mathematical language in which the EPT is written; chapter four axiomatically introduces the EPT; chapter five presents some applications of the EPT to real world problems. The final two chapters are preserved for a discussion of the results (chapter six) and the conclusions (chapter seven). The main result, the EPT, has also appeared in a journal publication, cf. (Cabbolet 2010).

# 2

# METHODOLOGY

This chapter elaborates on the general methodology by which the EPT has been developed. The first Section, 2.1, gives an overview of the whole process, while the Sections 2.2, 2.3, and 2.4 deal with specific phases in the process. All in all, the key steps in the development of the EPT are described, but the subject is not treated exhaustively: the position is taken that the merit of the EPT, like that of any other theory, is to be found by testing its correspondence to reality, and not in an endless elaboration of all the thinking steps that lead to the EPT – all the more because the notion of proof does not apply since the EPT has not been deduced by means of formal deduction.

## 2.1 General methodology

The EPT has been developed in a dialectical process, which went through a finite sequence of theses, antitheses and syntheses. The tacit assumption, that this leads to knowledge of the physical world, then entails acceptance of Hegel's thesis, that the truth can be attained by a finite dialectical process. During this dialectical process, the four rules of René Descartes for the development of true knowledge, which he described in part II of his *Discours de la Méthode*, were adhered to as guidelines:

- do not accept anything for true which is not presented to the mind so clearly and distinctly that all grounds of doubt are excluded;
- analyse the difficulty under examination and divide it into parts if necessary;
- starting with the objects the simplest to know, ascend step by step to the knowledge of the more complex;
- be so complete and general that it is sure that nothing is omitted.

That being said, the development of the EPT can – in retrospect – be divided in three phases:

- a foundational phase in which a starting point for true knowledge is formulated on the basis of an analysis of a clear and distinct idea;
- a destructive phase in which existing knowledge is rejected on the basis of contradiction with that starting point for true knowledge;
- a constructive phase in which the system is extended to completeness.

In his *Meditations on First Philosophy*, René Descartes goes through the same three phases for the development of his system, but in a different order: for Descartes, his "*cogito ergo sum*" was the only truth that remained áfter radically doubting existing knowledge, while in the present PhD research existing theories were doubted áfter the hypothesis of Section 1.3 had been formulated.

During the dialectical process in the second and third phase, heuristic guidance, including assistance by putting forward antitheses, was provided by dr. S.S. Sannikov (Institute of Theoretical Physics, Kharkov Institute of Physics and Technology, National Science Center, Ukraine). All antitheses were based on established foundational theories or on established experimental results.

At the end of the constructive phase, when the theory already had taken shape in the dialectic process, the axiomatic method was applied. In the present case this means that primitive notions were formalized in mathematical language but without reference to any concrete mathematical structure, that derived notions were defined in terms of primitive notions using a monoid structure, that axioms were formulated as well-formed closed expressions in mathematical language using the newly defined formalism, and that interpretation rules were defined which translate the formal axioms into elementary physical principles underlying the hypothesis. Guidance has been provided by prof.dr. H.C.M. de Swart (Group of Logic, University of Tilburg, the Netherlands).

## 2.2 On the foundational phase

The ultimate source for the EPT is a mystical experience, which is neither an experience of the senses nor an act of reasoning: for any perceiving subject, a mystical experience is a very intense event in which the subject feels united with its environment and perceives insight in the all.

Historically, the position that a mystical experience can be a source of knowledge is known at least since Plotinus (±204 – 270), who was a proponent of the idea that such an experience is even the *only* source of knowledge. However, in this PhD research an epistemological mysticism was embraced during the development of the EPT: a mystical experience is *necessary* for true knowledge about the universal elementary laws of nature, but *not sufficient*: a communicable form of such knowledge, that is, the explicit, mathematical formulation of it, hás to be developed using reasoning, and empirical data as well.

The *necessity* of the mystical experience can be substantiated with Kant's position, that no true knowledge is possible without a clear mental image. The development of knowledge of the fundamental laws of nature requires a clear mental image, but because the microcosmos is hidden from direct observation this clear mental image cannot be obtained from experience of the senses, and because reasoning without observation is empty it can neither be obtained from reasoning or intuition: a mystical experience is thus a necessary source for true knowledge of the world beyond the observable. Now Kant made a distinction between the 'noumenal world' and the 'phenomenal world': the noumenal world is the world as it is in itself, and the phenomenal world is the mental image that is attained from perception of the noumenal world – a process that depends on sensory input. Thus speaking, according to Kant man can only develop knowledge of the phenomenal world, because knowledge of the noumenal world would require cognitive access to that noumenal world without sensory observation, which – according to Kant – is impossible. In this PhD research this Kantian inaccessibility of the noumenal world was rejected: the mystical experience is thus accepted as a source of knowledge of Kant's *noumenal* world. In the remainder of this text, the term 'noumenon' will be used in its Kantian sense as a thing in itself, but without any relation to the limits of human knowledge. As far as it concerns the development of knowledge of the fundamental laws of nature, both (strict) empiricism, i.e. the view that true knowledge can only be based on experience of the senses, and (strict) rationalism, i.e. the view that true knowledge can only be based on reasoning, are thus rejected.

That the mystical experience is *not sufficient* can be substantiated by general criticism of Schopenhauer on the mystical experience and the assertions based on such an experience: "nothing of this is communicable except the assertions that we have to accept on his word; consequently he is unable to convince" (1844). Reformulating this in the framework of the justified-true-belief definition of knowledge, Schopenhauer argues thus that the assertions made on the basis of a mystical experience do not satisfy the justification condition of knowledge. To meet this criticism, the communicable set of assertions that form the EPT must thus be able to satisfy this justification condition: that means that the communicated version of the EPT must be testable by the scientific method. Positive results then at some point yield convincing evidence, that is, sufficient evidence so that the justification condition for knowledge is objectively satisfied. The crux is then that reasoning and empirical data are required to develop such communicable version of the EPT.

The clear and distinct idea that resulted from the mystical experience cannot be expressed in usual language, but its essence is captured in these two sentences:

- if a coin has fallen down from one's hand onto the table, then in opposite time-direction an anticoin has fallen upwards from the antitable into the antihand;
- this tendency to "fall upwards" is preserved in antimatter that exists in "our" time-direction.

Following Descartes' rules, this idea was further analyzed in classical terms of *inertial* and *gravitational* mass. Inertial mass $m_i$ is defined as the resistance of a particle to its state of motion as laid down in Newton's second law

$$F = m_i \cdot a \qquad (2.1)$$

where $a$ is the acceleration; *rest mass* $m_0$ is then the inertial mass of a particle in rest. Experimentally, it has already been established that both matter and antimatter particles have a positive rest mass. The assumed tendency to “fall upwards” will manifest itself in the observation that an antimatter particle, set off above the earth’s surface, will accelerate away from earth: as the only force at work is the gravitational force, on account of (2.1) this gravitational force is thus also directed away from earth. Gravitational mass $m_g$, on the other hand, is defined as the ‘charge’ of a particle for the gravitational force according to the formula

$$F_g = G\frac{m_{g(1)} \cdot m_{g(2)}}{r^2} \tag{2.2}$$

While the gravitational mass of ordinary matter particles is positive, the observable gravitational mass of antimatter particles has thus necessarily to be *negative:* only then, namely, the observable gravitational force (2.2) is negative on earth, i.e. pointed away from the earth’s surface. Note that negative gravitational mass is then an *observed* property of antimatter: no statement has been made at this point on whether this is a primary or a secondary property as meant by Locke[4]. That is, no statement has been made on whether negative gravitational mass is also a property of the thing in itself in the noumenal world, or only a property of the observed phenomena that is not present in the thing in itself.

On this basis, the original hypothesis was formulated that antimatter such as antiprotons, antineutrons and positrons has positive rest mass but will be repulsed by the gravitational field of the earth, that is, have negative gravitational mass. Including possible relativistic corrections, this hypothesis would imply that, mathematically, the following relation holds between rest mass $m_0$ and gravitational mass $m_g$ in case of antimatter (e.g. antiprotons):

$$-m_g \geq m_0 > 0 \tag{2.3}$$

Before this inequality for antimatter was accepted as a starting point for true knowledge, it was checked against impossibility arguments: theoretical studies on the interplay of antimatter and gravitation have namely been performed since the 1950’s, and since then various theoretical arguments *against* a mutual repulsion of

[4] In the remainder of the text, the terms ‘primary property’ and ‘secondary property’ will be used in the sense of Locke.

matter and antimatter have been discussed in the scientific literature; for an extensive review see (Nieto & Goldman 1991, 1992).

The perhaps most compelling argument against a gravitational repulsion of matter and antimatter is that it would violate the law of conservation of energy, which Morrison inferred from a Gedankenexperiment, cf. (Morrison 1958). Nieto and Goldman, however, showed that Morrison's Gedankenexperiment does not forbid a gravitational repulsion outside the framework of Einstein's GR (1991, 1992); in addition, Chardin and Rax have shown that Morrison's idea doesn't even forbid gravitational repulsion inside the framework of GR (1992). Another argument that was initially thought to rule out anomalous gravitational behavior of antimatter is that of Schiff, who stated that such is impossible on quantum field-theoretic grounds (1958; 1959). However, Nieto and Goldman showed that Schiff's renormalization procedure is invalid, and that the argument is thus inconclusive (1991, 1992). A third argument is that Good inferred from the decay of neutral $K_0$ mesons that the gravitational interaction of antimatter cannot possibly deviate from that of matter (1961). However, Good's argument is criticized for using absolute potentials, and Chardin and Rax showed that, when using relative potentials, "CP violation in the kaon system may be explained by antigravity" (1992). In short, the arguments of Morrison, Schiff and Good have been refuted; the inequality (2.3) was thus considered acceptable as a starting point for true knowledge.

It is emphasized once more that the ultimate source for this starting point for true knowledge is a mystical experience: if the inequality (2.3) is falsified experimentally, that is, if it is experimentally confirmed that matter and antimatter attract each other gravitationally, then this result automatically disqualifies the mystical experience as a undoubtable source of knowledge.

### 2.3 On the destructive phase

In a sentence, the Cartesian criterion for the rejection of existing knowledge was applied: all theories were rejected that could be doubted on the basis of the inequality (2.3). That is, widely accepted theories were rejected not because they could be proven to be false, but because there was reason to doubt them.

The principle of equivalence in Einstein's GR equates gravitational mass $m_g$ and inertial mass $m_i$ for all particles. In the framework of GR, inertial mass is not just identical to rest mass $m_0$ as in nonrelativistic Newton's theory, but depends on the momenta in $x$-, $y$-, and $z$-direction according to $m_i = \sqrt{m_0^2 + p_x^2 + p_y^2 + p_z^2}$ . In GR, the following relation thus always holds for any particle having rest mass:

$$m_g \geq m_0 > 0 \tag{2.4}$$

From the quantum-mechanical point of view no theory of gravitation exists; however, TCP-invariance of the Standard Model, which is based on QM, predicts the same mass for a particle and its antimatter counterpart. Thus, on the basis of the Standard Model there is no reason to believe that the gravitational mass $m_{g,\bar{p}}$ of an antiproton $\bar{p}$ would have the opposite sign of the gravitational mass $m_{g,p}$ of a normal proton $p$. In other words:

$$m_{g,\bar{p}} = m_{g,p} \geq m_0 > 0 \tag{2.5}$$

Obviously, both (2.4) and (2.5) are in direct contradiction with (2.3). However, the equivalence principle of GR has not been tested in the realm of antimatter: formulas (2.4) and (2.5) are no 100% guarantees. In addition, given that there is no evidence at all that GR or the Standard Model are applicable at the supersmall scale (Will 1993; 2001; Fuchs & Peres 2000), and given that modern physics is in a crisis (Section 1.2), it cannot be excluded that both GR and the Standard Model are wrong: it can thus absolutely not be excluded that the actual interactions causing gravitational and quantum effects occur at a much smaller scale than the areas of application of GR and the Standard Model, so that GR and the Standard Model are not fundamental but merely emergent in their area of application. On that basis both GR and the Standard Model were rejected *in their entirety*. That is, not just the aforementioned aspects of these theories were rejected, but the beliefs that GR and the Standard Model are universally true were rejected as false.

In fairly recent literature a repulsion of antimatter moving in the gravitational field of matter has been predicted, cf. (Santilli 1999), but a classical approach was used. This was not accepted, because it has already been established experimentally that, for example, electrons exhibit non-classical behavior: positrons, the antimatter counterparts of electrons, then also exhibit such behavior.

Thus, inequality (2.3) provided the starting point for the development of new universal principles. It was thus tacitly assumed that there is a physical universe, independent of whether or not anyone may be perceiving it in one way or another, and that the true nature of this noumenal universe can be laid down in abstract first principles; this view is similar to what Sachs called 'abstract realism' (1988). The idea, however, that these first principles representing the true nature of the universe have to be equations, i.e. formal expressions of the type $t_1 = t_2$, was abandoned.

## 2.4 On the constructive phase

In this phase, the general principle of relativity, that the elementary laws of the universe have to be the same for all observers, was to be applied. This general principle of relativity is not formulated exactly, that is, word for word, the same as the general principle of relativity formulated by Einstein: "the laws of physics must be of such a nature that they apply to systems of reference in any kind of motion" (Einstein 1916); but because of the similarity in intended meaning, the same name was given to the present principle.

As a solution towards laws of physics which underlie (2.3), the case was considered that rest mass $m_0$ and gravitational mass $m_g$ are characteristics of *different* physical states: then, namely, $m_0$ and $m_g$ do not necessarily have to be the same in sign or in absolute value. Having taken into account that motion of electrons is proven to have wavelike aspects, this led to the development of a concept of stepwise motion, according to which nonzero rest mass entities (protons, electrons, neutrons, their antimatter counterparts, etc.) move from one particlelike state, which is absolutely at rest, to a next in a wavelike state. In the period after Newton, the idea for stepwise motion has been suggested by Van Dantzig, who wrote (1937):

*“ ... matter could be considered as discontinuous in time as well as in space. Let us see to what consequences this would lead. Using the usual illustration in spacetime, a particle would not be represented by a curve (worldline) but by a sequence of world-points, which will be called ‘flashes’.”*

This “more or less vague suggestion” of Van Dantzig (as he called it himself) was, however, never developed further to a mathematical representation. In the present case, rest mass $m_0$ then is a characteristic of the particlelike state, and gravitational mass $m_g$ a characteristic of the wavelike state. In the end, cf. Section 6.3, this turned out to give the following relation between rest mass $m_0$ and gravitational mass $m_g$:

$$|m_g| \geq m_0 > 0 \tag{2.6}$$

The special case for antimatter, (2.3), is then consistent with the general case for all rest-mass-having matter, (2.6). The research was then focused on identifying principles according to which nonzero rest mass entities would transform from a particlelike state to a wavelike state, and back into a similar particlelike state.

However, it became clear very soon that such principles could not be formulated in the framework of QM[5]. In orthodox QM, namely, the quantum state of a nonzero rest mass entity – say, an electron – is *represented* by a wave function, but it is not the case that the electron in question *is* a wave. In the present case, however, the electron *is* a wave, at least temporarily, in the process of stepwise motion. It has got into a wavelike form by a discrete transition, which is certain to happen regardless whether one is observing the electron or not. That is, the actual state of the wavelike form may be influenced by the observation, but the discrete transition, by which the electron transforms from a particlelike into a wavelike form, takes place independent of observation. Because such a transition is discrete and not continuous, it cannot be described by the Schrödinger equation; and because the transition does not necessarily require a measurement it would be inappropriate to describe it as a discontinuous collapse into a definite state upon a measurement. Thus, continuing towards principles governing such discrete transitions would necessitate a departure from orthodox QM. It therefore turned out that principles governing gravitational repulsion could not be described in terms of wave functions and operators: it

[5] In the destructive phase, the Standard Model had been rejected, but not QM itself.

was necessary to introduce some new concepts, in particular the concept of a ‘phase quantum’.

It is, however, the case that a mathematical model of the supersmall level has to be nonlocal in order to do the same predictions as QM on subatomic level, as was shown by Bell (1964). As a solution towards elementary laws of nature that are in accordance with this result, the case was considered that the wavelike states, in which nonzero rest mass entities move from one particlelike state to the next, are nonlocal, that is, have their spatial extension instantaneously.

In addition, it was considered that in the ontological interpretation of QM by Bohm, all particles are accompanied by a wave which guides the particles’ motion, cf. (Bohm 1952[a,b]). It is, however, not the case that the wave function of an electron is interpreted as a real wave such that the electron *is* the wave at any point: it is merely the case that the electron moves on a continuous trajectory governed by the quantum potential, an object that is ontologically a different object than the electron and that derives from the wave function of the electron. Thus, because in the present case the electron *is* a wavelike object during its motion, and because motion is stepwise and not continuous, any fundamental principles underlying this stepwise motion clearly had to formulated outside the framework of Bohmian QM.

Furthermore, the observation was taken into account that that photons are deflected by the gravitational field of the sun, first reported in 1920 – cf. (Dyson, Eddington & Davidson 1920). Assuming the hypothesis mentioned on antimatter, photons then would have to be an entirely different kind of matter than protons, because photons are identical to antiphotons: it cannot be the case that one and the same photon is both attracted and repulsed by the gravitational field of the sun. The aforementioned observation was therefore not interpreted as a proof that photons are attracted by the gravitational field of the sun, but merely as a proof that the geometry of the vacuum is non-Euclidean. Given that photons travel with the speed of light and are emitted from a source, as a solution towards laws of physics that are in accordance with this observation it was considered that in the process of stepwise motion of a nonzero rest mass entity first a discrete transition occurs from a particlelike state at a definite position (characterized by rest mass) to a nonlocal wavelike state (characterized by gravitational mass), that next a discrete transition (collapse) occurs from the nonlocal wavelike state to a point-particlelike state at a next definite position, and that from there then a photon is emitted as a local wavelike entity: the photon is then a different form of matter and has neither rest mass nor gravitational mass.

Moreover, the observation was taken into account that the universe is expanding, cf. (Hubble 1929). Now the concept of stepwise motion allows the subsequent rest masses of a proton to form a (strictly) decreasing sequence: if energy is to be conserved, then in every step the energy corresponding with a loss of rest mass would thus have to be emitted alongside a photon after the nonlocal wavelike state has collapsed as mentioned in the foregoing paragraph. Towards laws of physics that could in principle explain why the universe is expanding, it was considered that the energy emitted from the point-particlelike states led to the formation of space; a gradual decrease of rest mass of protons might then be the root cause of the expansion of the universe.

What was also considered was that in the modified quantum theory of Ghirardi, Rimini, and Weber (1986) it is postulated that microscopic systems are subjected to spontaneous localization processes at random times. In the present case, however, stepwise motion occurs as the result of a series of *different* transitions, all of which are certain to happen: the chain of transitions together yields a physical process which is quite different from the localization processes suggested by this GRW quantum theory. Thus, any fundamental principles underlying the current concept of stepwise motion would also lie completely outside the paradigm of GRW quantum theory.

It turned out that generalized principles could be formulated: not just principles for motion in a gravitational field, but universal elementary laws that apply regardless of the type of interaction that plays a role. The EPT then entails the view that physical reality is best understood as a process; historically, the Greek philosopher Heraclitus of Ephesus (±550 – ±480 B.C.) was the first to use this approach. In the final stage, when the idea for the EPT already had taken shape, the axiomatic method was applied. In the present case this meant that primitive notions were formalized in mathematical language, but without reference to any concrete mathematical structure; that derived notions were defined in terms of primitive notions using a monoid structure; that axioms were formulated as well-formed closed expressions in mathematical language using the newly defined formalism; and, that interpretation rules were defined which translate the formal axioms into elementary physical principles underlying the hypothesis.

The correspondence of the EPT with reality is thus constructed as follows. The EPT is contained in a formal axiomatic system: its seven laws are formalized as non-logical axioms of the system. In itself, the theorems of the axiomatic system (which, naturally, include the seven elementary principles of the EPT) are just well-formed mathematical-logical formulas. Therefore, interpretation rules have been defined for the terms of the language of the EPT: it is by these interpretation rules that a one-to-one correspondence with physical reality is postulated. The EPT is then a scheme of principles describing the dynamics of individual processes that take place at supersmall scale, that is, at the scale in the universe where distances much smaller than $10^{-10}$ atomic radii play a role. The overall intention is on the one hand that every theorem of the axiomatic system yields a true statement about physical reality, and one the other hand that every process in physical reality can be formalized in the framework of the EPT.

# 3

## MATHEMATICAL FOUNDATION

This chapter is best started by stating what it is *not*: it is *not* to merely prove that the foundations of mathematics can also be formulated on the basis of the notion of a finite matrix with set-valued entries. The point is that one is *compelled* to reject the usual language of mathematics – that of Zermelo-Fraenkel set theory (ZF) – when trying to formalize the EPT; Section 3.1 elaborates on the problems that were encountered. Section 3.2 axiomatically introduces set matrix theory (SMT) as a generalization of ZF: SMT provides the language of mathematics in which the EPT cán be formalized. Sections 3.3, 3.4 and 3.5 discuss the result: Section 3.3 evaluates the relation of SMT with standard set theory (ZF); Section 3.4 demonstrates that SMT indeed solves the problems with the formalization of the EPT; Section 3.5 solves an issue that arises in SMT. In the remainder of the text, the symbol '□' marks the end of a remark, definition, etc. where useful.

### 3.1 Motivation for the introduction of set matrix theory

It is a mathematical fact that Zermelo-Fraenkel set theory (ZF) can be used as foundation for virtually all of modern mathematics. More precisely, mathematics may be viewed as the body of statements, that can be derived within ZF by means of logical reasoning: one can call this a 'philosophy of mathematics'. Corresponding with this view is the adage "everything is a set": every term of every mathematical expression is a set – there are no other terms.

It turned out, however, that the EPT could not be formalized within ZF: the feature of ZF, namely, that everything has to be a set causes complications that are both unavoidable and unsolvable within the framework of ZF. These complications render ZF *inappropriate* as the foundation of the mathematical-logical framework within which the EPT is formalized.

The first complication arises from the truth-condition of knowledge, which is an essential aspect of every theory intended as a foundation for physics. For the EPT, as a formalized theory, to represent knowledge of the physical universe, the condition was set that there had to be a *direct* relation between components of the physical universe and the theoretical terms referring to these components: entities that occur in the ontology for physics had to be designated by mathematical terms that occur as such in the ontology for mathematics. The point is then that in the world view based on the EPT, the physical universe consists of a world and an antiworld; a component of this universe is simultaneously a constituent of a world and a constituent of an antiworld. Thus, in the EPT matrices of the type $\begin{bmatrix} x \\ y \end{bmatrix}$ with set-valued entries $x$ and $y$ (set matrices) had to be applied as designators of components of a universe, consisting of a constituent $x$ of a world and a constituent $y$ of an antiworld. A conflict then arises from the fact that in the framework of ZF, a matrix cannot be considered as something existing in its own right as a square array of entries, because everything has to be a set. Thus, in the framework of ZF a $m \times n$ set matrix has to be formalized as a set, for example, as a function on the Cartesian product $\{1, \ldots, m\} \times \{1, \ldots, n\}$. Thus, a 2×1 set matrix $\begin{bmatrix} x \\ y \end{bmatrix}$ can be defined as a function $f$, given by the following function prescription:

$$f: \langle 1, 1 \rangle \to x \tag{3.1}$$

$$f: \langle 1, 2 \rangle \to y \tag{3.2}$$

Using the set-theoretical definition of a function, this function $f$ as a set is thus given by

$$f = \{\langle\langle 1, 1\rangle, z\rangle\ , \langle\langle 1, 2\rangle, y\rangle\ \} \tag{3.3}$$

The set-theoretical definition of an ordered two-tuple is the following, cf. (van Dalen, Doets, de Swart 1975: 35):

$$\langle a, b \rangle = \{\{a\}, \{a, b\}\} \tag{3.4}$$

Combining (3.3) and (3.4), this gives

$$f = \{\{\{\langle 1, 1\rangle\}, \{\langle 1, 1\rangle, x\}\}, \{\{\langle 1, 2\rangle\}, \{\langle 1, 2\rangle, y\}\}\} \tag{3.5}$$

Concluding, in the framework of ZF set theory, the 2×1 set matrix $\begin{bmatrix} x \\ y \end{bmatrix}$ is thus merely the *notation* for the set $f$ in (3.5): the *actual object* in the set-theoretical universe, namely, is $f$. With regard to the intended application as designators of components of the physical universe, obviously this set $f$ is not a one-to-one designator of the physical component in question: the two constituents, designated by $x$ and $y$, are not at all designated by $f$ but by elements of elements of $f$. This complication does not disappear by defining a 2×1 set matrix $\begin{bmatrix} x \\ y \end{bmatrix}$ otherwise as some set $S$: it remains the case that it is not the *actual mathematical object S* (actual because it exists as such in the universe of sets) that designates the physical object: it is merely *the notation* $\begin{bmatrix} x \\ y \end{bmatrix}$ of the mathematical object $S$ that designates the physical object. Thus, the definition of 2×1 set matrices $\begin{bmatrix} x \\ y \end{bmatrix}$ as (notations for) sets led to mathematical designators that were not in a direct relation with the physical objects they designated. To put this in other words: in the context of the EPT, objects that exist in the physical universe cannot be designated by objects that exist as such in the mathematical universe if matrices have to be defined as sets. This was considered inappropriate; note that this is not a mathematical argument against the definition of matrices as sets.

A second complication arises from the maxim that *every* theorem of the formal axiomatic system containing the EPT has to yield a statement about the physical universe – which is intended to be true – by applying the interpretation rules. The point here is that the EPT contains expressions of the type $\begin{bmatrix} a \\ b \end{bmatrix} : \begin{bmatrix} f \\ g \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} x \\ y \end{bmatrix}$; these are first-order expressions $P\alpha\beta\gamma$ that had to be formalized as well-formed formulas in a mathematical framework. The interpretation rule for such a bidirectional expression is that the component $\begin{bmatrix} a \\ b \end{bmatrix}$ mediates an equilibrium between the components $\begin{bmatrix} f \\ g \end{bmatrix}$ and $\begin{bmatrix} x \\ y \end{bmatrix}$, which is to say that the constituent *a* of the world effects a discrete transition in the world from the constituent *f* to the constituent *x*, while the constituent *b* of the antiworld effects a discrete transition in the antiworld from the constituent *y* to the constituent *g*[6]. In other words, one has to think of two simultaneous but oppositely directed transitions. Now let these bidirectional expressions be formalized in ZF, and let the 2×1 set matrices $\begin{bmatrix} a \\ b \end{bmatrix}$, $\begin{bmatrix} f \\ g \end{bmatrix}$ and $\begin{bmatrix} x \\ y \end{bmatrix}$ be identical to the sets *S*, *T*, and *V*, respectively. Using substitutivity of equality

$$u = t \vdash \Psi(u) \Leftrightarrow \Psi([t/u]) \tag{3.6}$$

it follows that in ZF a formula $S\colon T \overset{\rightarrow}{\leftarrow} V$ can be derived, as in

$$\begin{bmatrix} a \\ b \end{bmatrix} : \begin{bmatrix} f \\ g \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} x \\ y \end{bmatrix} \vdash_{ZF} S\colon T \overset{\rightarrow}{\leftarrow} V \tag{3.7}$$

Thus, if the EPT is formalized in ZF, then such expressions $S\colon T \overset{\rightarrow}{\leftarrow} V$ are theorems of the axiomatic system containing the EPT, but these *cannot* be translated into statements about physical reality because the interpretation rule doesn't apply to such expressions without 2×1 set matrices. The aforementioned maxim is then unattainable and this was considered *unacceptable*. If, on the other hand, a 2×1 set matrix is defined as an object in itself – not identical to any set – then it is not possible to construct such nonsensical expressions of the type $S\colon T \overset{\rightarrow}{\leftarrow} V$ from these expressions of the type $\begin{bmatrix} a \\ b \end{bmatrix} : \begin{bmatrix} f \\ g \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} x \\ y \end{bmatrix}$.

[6] It is emphasized that the words `component', `constituent' and `discrete transition' in this interpretation rule thus all concern the *physical* universe, not the *mathematical* universe.

On these grounds, ZF was rejected as an adequate mathematical foundation for the EPT. Led by the credo "*mathematica ancilla physicae*" (mathematics is the servant of physics) it was therefore decided to develop a foundational theory for mathematics based on matrices of sets instead of sets; a condition was that the resulting theory should not be weaker than ZF, that is, every set that can be constructed in ZF must also be constructible in the framework of the new theory. For that matter, it was decided to merge the primitive notion of a matrix with axiomatic set theory into a new mathematical theory; the resulting theory was called set matrix theory (SMT). The primitive notion used is that of a $m \times n$ matrix, that can be described as an ordered rectangular object, consisting of $m \cdot n$ entries $t_{ij}$ arranged evenly spaced in $m$ rows and $n$ columns within square brackets, as in $\begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & & \vdots \\ t_{m1} & \cdots & t_{mn} \end{bmatrix}$. In SMT, the entries $t_{ij}$ of matrices are allowed to be $p_{ij} \times q_{ij}$ matrices themselves, but in the end every matrix has to consist of a finite number of simple entries (sets). Axioms were identified for the matrices, as well as for sets. The idea was to describe sets axiomatically in such a way, that matrices could be elements of sets. For that matter, generalizations of the axioms of the usual Zermelo-Fraenkel set theory, given e.g. in (van Dalen, Doets & de Swart 1975: 141-153), could be used.

## 3.2 Axiomatic introduction of set matrix theory

*3.2.1 Definition* (*vocabulary*)

The vocabulary for set matrix theory is a first order language with identity, and is defined as follows:

(i) the simple constant Ø

(ii) countably many variables ranging over all sets: $a$, $b$, $c$, ...

(iii) countably many function symbols (see Definition 3.2.4 for their intended interpretation):

the unary function symbol $f_1^1 = f_{1\times 1}$

the 1st binary function symbol $f_1^2 = f_{1\times 2}$

the 2nd binary function symbol $f_2^2 = f_{2\times 1}$

the 1st ternary function symbol $f_1^3 = f_{1\times 3}$

the 2nd ternary function symbol $f_2^3$, with $f_2^3(x, y, z) = f_{1\times 2}(f_{1\times 2}(x, y), z)$

the 3rd ternary function symbol $f_3^3$, with $f_3^3(x, y, z) = f_{1\times 2}(x, f_{1\times 2}(y, z))$

the 4th ternary function symbol $f_4^3$, with $f_4^3(x, y, z) = f_{1\times 2}(f_{2\times 1}(x, y), z)$

the 5th ternary function symbol $f_5^3$, with $f_5^3(x, y, z) = f_{1\times 2}(x, f_{2\times 1}(y, z))$

the 6th ternary function symbol $f_6^3$, with $f_6^3(x, y, z) = f_{2\times 1}(f_{1\times 2}(x, y), z)$

the 7th ternary function symbol $f_7^3$, with $f_7^3(x, y, z) = f_{2\times 1}(x, f_{2\times 1}(y, z))$

the 8th ternary function symbol $f_8^3$, with $f_8^3(x, y, z) = f_{2\times 1}(f_{2\times 1}(x, y), z)$

the 9th ternary function symbol $f_9^3$, with $f_9^3(x, y, z) = f_{2\times 1}(x, f_{2\times 1}(y, z))$

the 10th ternary function symbol $f_{10}^3 = f_{3\times 1}$

the 1st quaternary function symbol $f_1^4 = f_{1\times 4}$

the 2nd quaternary function symbol $f_2^4$, with

$$f_2^4(v, x, y, z) = f_{1\times 3}(f_{1\times 2}(v, x), y, z)$$

and so forth.

(iv) countably many variables ranging over all matrices:

$\alpha, \beta, \gamma \ldots$

(v) the binary predicate symbols $\in$ and $=$

(vi) the usual connectives $\neg, \Rightarrow, \Leftrightarrow, \wedge, \vee$

(vii) the usual quantifiers $\forall, \exists$

*3.2.2 Definition* (*syntax*)

The syntax of the formal language is defined as follows:

(i) if $t$ is a simple constant (set) or a variable ranging over sets, then $t$ is a term

(ii) if $t_1, ..., t_n$ are $n$ terms, and $f_i^n$ is an $n$-ary function symbol, then $f_i^n(t_1, ..., t_n)$ is a composite term

(iii) if $t_1$ and $t_2$ are simple or composite terms and P is one of the binary predicate letters $\in$ or $=$, then $t_1 P t_2$ is an atomic formula (infix notation)

(iv) if $\Phi$ is a formula, then $\neg\Phi$ is a formula

(v) if $\Phi$ and $\Psi$ are formulas, then $(\Phi \Rightarrow \Psi)$, $(\Phi \Leftrightarrow \Psi)$, $(\Phi \wedge \Psi)$, $(\Phi \vee \Psi)$ are formulas

(vi) if $\Phi$ is a formula, Q a quantifier $\exists$ or $\forall$, and $x$ a variable ranging over sets, then $Qx(\Phi)$ is a formula

(vii) if $\Phi(x)$ is a formula in which the variable $x$ ranging over sets occurs not bounded by a quantifier, and if Q is a quantifier $\exists$ or $\forall$, and $\alpha$ is a variable ranging over matrices, then $Q\alpha(\Phi(\alpha))$ is a formula, where $\Phi(\alpha)$ results from $\Phi(x)$ by replacing $x$ everywhere by $\alpha$.

The variables ranging over matrices thus occur only bounded in universal or existential quantifications.

*3.2.3 Remark*

The list 3.2.1.(iii) of function symbols is exhaustive. That is, for every composite term $t$, constructed by applying the clauses 3.2.2.(i) and (ii) finitely many times, there is a term $f_i^n(x_1, ..., x_n)$, of which $x_1, \ldots, x_n$ are interpretable as sets, such that $t = f_i^n(x_1, ..., x_n)$. For example, using the ternary function symbol $f_2^3$ the composite term $f_1^2(f_1^2(x_1, x_2), x_3)$ can also be written as the term $f_2^3(x_1, x_2, x_3)$. This exhaustive enumeration of function symbols is very useful for the formulation of the axioms.

*3.2.4 Definition* (*standard notation*)

The following are standard notations for terms (set matrices) and formulas:

(i) outer parentheses "(" and ")" can be omitted.

(ii) $t_1 \notin t_2$ denotes $\neg t_1 \in t_2$

(iii) $t_1 \neq t_2$ denotes $\neg t_1 = t_2$

(iv) $[\ x\ ]$ denotes $f_1^1(x)$

(v) $\begin{bmatrix} x & y \end{bmatrix}$ denotes $f_1^2(x, y)$

(vi) $\begin{bmatrix} x \\ y \end{bmatrix}$ denotes $f_2^2(x, y)$

(vii) $[x \quad y \quad z]$ denotes $f_1^3(x, y, z)$

(viii) $[\,[x \quad y] \quad z]$ denotes $f_2^3(x, y, z)$

(ix) $[\,x \ [\,y \quad z]\,]$ denotes $f_3^3(x, y, z)$

(x) $\begin{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} & z \end{bmatrix}$ denotes $f_4^3(x, y, z)$

(xi) $\begin{bmatrix} x & \begin{bmatrix} y \\ z \end{bmatrix} \end{bmatrix}$ denotes $f_5^3(x, y, z)$

(xii) $\begin{bmatrix} [x \quad y] \\ z \end{bmatrix}$ denotes $f_6^3(x, y, z)$

(xiii) $\begin{bmatrix} x \\ [y \quad z] \end{bmatrix}$ denotes $f_7^3(x, y, z)$

And so forth.

*3.2.5 Example*

As an example, it is shown how the formula $\exists x \forall \alpha(\alpha \notin x)$ can be constructed:

step 1: from clause 3.2.2.(iii) it follows that "$y \in x$" is an atomic formula for the variables $x$ and $y$ ranging over sets

step 2: from clause 3.2.2.(iv) it then follows that "$\neg y \in x$" is a formula

step 3: from clause 3.2.4.(ii) it then follows that "$y \notin x$" is a formula

step 4: from clause 3.2.2.(vii) it then follows that "$\forall \alpha(\alpha \notin x)$" is a formula

step 5: from clause 3.2.2.(vi) it then follows that "$\exists x \forall \alpha(\alpha \notin x)$" is a formula.

□

*3.2.6 Remark* (*substitution rule*)

The following substitution rule is logically valid for the variables ranging over matrices:

$$\forall\alpha\,(\Psi(\alpha)) \Rightarrow \Psi(\,f_i^n\,(x_1, ..., x_n)) \tag{3.8}$$

Rule (3.8) is valid for any function symbol $f_i^n$ and any $n$ constant sets $x_1$, …, $x_n$; $\Psi(\,f_i^n\,(x_1, ..., x_n))$ is obtained by replacing $\alpha$ in $\Phi(\alpha)$ everywhere by $f_i^n\,(x_1, ..., x_n)$.

*3.2.7 Set Matrix Axiom Scheme*

(i) $\forall x_{11}\,...\forall x_{mn}\,\exists\alpha\,(\alpha = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix})$

(ii) $\forall\alpha_{11}\,...\forall\alpha_{mn}\exists\beta\,(\beta = \begin{bmatrix} \alpha_{11} & \cdots & \alpha_{1n} \\ \vdots & & \vdots \\ \alpha_{m1} & \cdots & \alpha_{mn} \end{bmatrix})$

The Set Matrix Axiom Scheme is a countably infinite scheme. The subscheme (i), consisting of an axiom for every function symbol $f_{m\times n}$, guarantees that for any $m{\cdot}n$ sets there is a corresponding set matrix with these sets as entries; the subscheme (ii), also consisting of an axiom for every function symbol $f_{m\times n}$, guarantees that for any $m{\cdot}n$ set matrices there is a corresponding set matrix having these set matrices as entries.

*3.2.8 Reduction Axiom*

$\forall x\,(\,[x] = x\,)$

The purpose of the Reduction Axiom is to equate set matrices having one set as sole entry with that set itself. Hence, any set $x$ is identical to the set matrix $[x]$ of dimension one by one. For example, the empty set Ø is identical to the one by one set matrix [Ø] containing the empty set Ø as sole entry.

*3.2.9 Omission Axiom Scheme*

$$\forall\alpha_{11}\ldots\forall\alpha_{mn}\left(\left[\begin{bmatrix}\alpha_{11} & \cdots & \alpha_{1n}\\ \vdots & & \vdots\\ \alpha_{m1} & \cdots & \alpha_{mn}\end{bmatrix}\right] = \begin{bmatrix}\alpha_{11} & \cdots & \alpha_{1n}\\ \vdots & & \vdots\\ \alpha_{m1} & \cdots & \alpha_{mn}\end{bmatrix}\right) \qquad m{\cdot}n \geq 2$$

The Omission Axiom Scheme is a countably infinite scheme consisting of an axiom for every function symbol $f_{m\times n}$ with $m{\cdot}n \geq 2$. The Omission Axiom Scheme is to formalize that a matrix $\left[\begin{bmatrix}t_{11} & \cdots & t_{1n}\\ \vdots & & \vdots\\ t_{m1} & \cdots & t_{mn}\end{bmatrix}\right]$, constructed by placing an existing matrix $\begin{bmatrix}t_{11} & \cdots & t_{1n}\\ \vdots & & \vdots\\ t_{m1} & \cdots & t_{mn}\end{bmatrix}$ as sole entry in square brackets "[" and "]", is identical to the existing matrix $\begin{bmatrix}t_{11} & \cdots & t_{1n}\\ \vdots & & \vdots\\ t_{m1} & \cdots & t_{mn}\end{bmatrix}$. It should be noted that this includes the case that the entries $t_{ij}$ are sets: the Reduction Axiom, namely, equates a 1×1 set matrix $[z]$ with the set $z$. Quantification over matrices therefore includes quantification over sets. From the Omission Axiom Scheme it thus follows that the notion of a matrix is different from the notion of a set, because $\{x\} \neq x$ for any set $x$.

*3.2.10 Epsilon Axiom Scheme*

$$\forall\alpha_{11}\ldots\forall\alpha_{mn}\forall\beta_{11}\ldots\forall\beta_{pq}\left(\begin{bmatrix}\alpha_{11} & \cdots & \alpha_{1n}\\ \vdots & & \vdots\\ \alpha_{m1} & \cdots & \alpha_{mn}\end{bmatrix} \notin \begin{bmatrix}\beta_{11} & \cdots & \beta_{1q}\\ \vdots & & \vdots\\ \beta_{p1} & \cdots & \beta_{pq}\end{bmatrix}\right) \qquad \text{for } p{\cdot}q \geq 2$$

The Epsilon Axiom Scheme is a countably infinite scheme consisting of an axiom for every function symbol $f_{m\times n}$ and for every function symbol $f_{p\times q}$ with $p{\cdot}q \geq 2$. The purpose of the Epsilon Axiom Scheme is to formalize that set matrices, consisting of more than one set, have no elements in the sense of the ∈-relation. As a consequence, entries of set matrices of other dimensions than 1×1 are no elements of set matrices in the sense of the ∈-relation. So, for example, for any sets $x$, $y$, and $z$ one gets $[x \quad y] \notin [\,[x \quad y] \quad z]$ and $z \notin [\,[x \quad y] \quad z]$, where the latter follows from the Epsilon Axiom Scheme because $z = [z]$ on account of the Reduction Axiom 3.2.8. So only expressions of the type

$$f_i^n\,(x_1, ..., x_n) \in x \tag{3.9}$$

with a set $x$ to the right of the $\in$-symbol are contingent.

*3.2.11 Division Axiom Scheme*

$\forall x_1 \ldots \forall x_n \forall y_1 \ldots \forall y_m\,(\, f_i^n\,(x_1, ..., x_n) \neq \; f_j^m\,(y_1, ..., y_m))$ for $n \neq m \vee i \neq j$

The Division Axiom Scheme is a countably infinite axiom scheme, consisting of an axiom for every choice of different function symbols $f_i^n$ and $f_j^m$. The purpose of the Division Axiom Scheme is to distinguish between different types of matrices.

*3.2.12 Example*

By the Division Axiom Scheme a 2×1 set matrix $\begin{bmatrix} x \\ y \end{bmatrix}$ having sets $x$ and $y$ as entries is different from any 1×1 set matrix $[z]$, which by the reduction axiom is identical to the set $z$. So concretely, the set matrix $\begin{bmatrix} \{\varnothing\} \\ \varnothing \end{bmatrix}$ is different from any set $z$.

*3.2.13 Remark* (*ordered n-tuples*)

Because matrices are viewed as objects existing in their own right in the framework of set matrix theory, the common notation $\langle x_1, \ldots, x_n \rangle$ for an ordered $n$-tuple of sets can be applied as a special notation for a $1{\times}n$ set matrix:

$$\langle x_1, \ldots, x_n \rangle := [x_1 \quad x_2 \quad \cdots \quad x_n] \tag{3.10}$$

But by the Division Axiom Scheme for any three sets $x_1$, $x_2$, and $x_3$ ,

$$[x_1 \quad x_2 \quad x_3] \neq [\,[x_1 \quad x_2\,] \quad x_3] \tag{3.11}$$

Therefore, accepting a $1{\times}n$ matrix with $n$ sets as entries as the definition of an ordered $n$-tuple requires the rejection of the recursive definition of an ordered $n$-tuple of sets $\langle x_1, ..., x_n \rangle$ given in the literature, cf. (van Dalen, Doets & de Swart 1975: 36):

$$\langle x_1 \rangle := x_1 \tag{3.12}$$

$$\langle x_1, ..., x_{n+1} \rangle := \langle\langle x_1, ..., x_n \rangle, x_{n+1}\rangle \tag{3.13}$$

In the remainder of this text, equation (3.10) will be used.

*3.2.14 Extensionality Axiom Scheme for Set Matrices*

$$\forall\alpha_{11} ...\forall\alpha_{mn}\forall\beta_{11} ...\forall\beta_{mn} \left( \begin{bmatrix} \alpha_{11} & \cdots & \alpha_{1n} \\ \vdots & & \vdots \\ \alpha_{m1} & \cdots & \alpha_{mn} \end{bmatrix} = \begin{bmatrix} \beta_{11} & \cdots & \beta_{1n} \\ \vdots & & \vdots \\ \beta_{m1} & \cdots & \beta_{mn} \end{bmatrix} \Leftrightarrow \right.$$

$$\left. \alpha_{11} = \beta_{11} \wedge ... \wedge \alpha_{mn} = \beta_{mn} \right) \text{ for } m{\cdot}n > 1$$

The Extensionality Axiom Scheme for Set Matrices is a countably infinite axiom scheme, with an axiom for every function symbol $f_{m\times n}$ with $m{\cdot}n > 1$. The purpose of the Extensionality Axiom Scheme for Set Matrices is to formalize that two matrices of the same type are identical if and only if the entries are identical: this reduces the identity of matrices to a conjunction of identities of sets.

*3.2.15 Example*

From the Extensionality Axiom Scheme for Set Matrices it can be derived that

$$\begin{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} & c \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} & z \end{bmatrix} \Leftrightarrow a = x \wedge b = y \wedge c = z \tag{3.14}$$

The Generalized Extensionality Axiom for Sets, cf. 3.2.17, is then to be consulted for the criterion under which the sets are identical.

*3.2.16 Definition* (*subset*)

$\forall x \forall y\ (x \subseteq y \Leftrightarrow \forall\alpha\ (\alpha \in x \Rightarrow \alpha \in y))$

The interpretation of this definition is that a set $x$ is a subset of a set $y$ if and only if every matrix, that is an element of $x$ is also an element of $y$. It should be noted that this includes the case that $x$ and $y$ are sets of sets.

*3.2.17 Generalized Extensionality Axiom for Sets*

$\forall x \forall y\, (x = y \Leftrightarrow x \subseteq y \wedge y \subseteq x)$

The Generalized Extensionality Axiom for Sets is not exactly the same as the extensionality axiom for sets of ZF, because the definition of $x \subseteq y$ is different in the current framework.

*3.2.18 Generalized Axiom of Emptiness*

$\exists x \forall \alpha (\alpha \notin x)$

This axiom formalizes that there is a set $x$, such that no matrix is an element of $x$. Suppose, there were two such sets $x$ and $y$. Then by 3.2.17, $x = y$. Hence there is precisely one set $x$ such that $\forall \alpha (\alpha \notin x)$. This set is called the empty set, denoted by the constant Ø or {}, which by 3.2.8 is identical to [Ø] or [{}].

*3.2.19 Remark*

For all $n > 1$, set matrices $f_i^n(x_1, ..., x_n)$ have no elements on account of the Epsilon Axiom Scheme, but are not identical to the empty set Ø on account of the Division Axiom Scheme. Such set matrices, that is, set matrices $f_i^n(x_1, ..., x_n)$ with $n > 1$, are therefore objects that are not sets.

*3.2.20 Generalized Axiom Scheme of Separation*

$\forall x \exists y \forall \alpha\, (\alpha \in y \Leftrightarrow \alpha \in x \wedge \Phi(\alpha))$

This axiom scheme formalizes that for every set $x$ and for every property $\Phi$ there is a subset $y$ of $x$ made up of precisely those elements of $x$ that have the property $\Phi$. Hereby the symbol $\Phi(\alpha)$ represents any well-formed formula with an occurrence of $\alpha$ not bounded by a quantifier $\forall$ or $\exists$. The fact that every well-formed formula has to be finite implies that such a property $\Phi(\alpha)$ can contain only finitely many function symbols $f_i^n$, of which there are infinitely many. And this implies, that for infinite sets, having elements $f_i^n(x_1, ..., x_n)$ for an infinite number of function symbols $f_i^n$, certain properties cannot be formulated in a single formula $\Phi$. Of such sets, certain subsets, also having elements $f_i^n(x_1, ..., x_n)$ for an infinite number of function symbols $f_i^n$, can thus not be singled out (i.e. constructed) directly by applying the Generalized Axiom Scheme of Separation only once. In Section 3.5 it is set forth how such subsets can be constructed nevertheless.

*3.2.21 Generalized Pair Axiom*

$\forall\alpha\forall\beta\exists x\forall\gamma(\gamma \in x \Leftrightarrow \gamma = \alpha \vee \gamma = \beta)$

The Generalized pair axiom formalizes that for every pair of matrices $\alpha$ and $\beta$ there is a set $x$ such that the matrices $\alpha$ and $\beta$ are precisely the elements of $x$. From the Generalized Extensionality Axiom for Sets 3.2.17 it follows that this set $x$ is unique, and it can be denoted by $x = \{\alpha , \beta\}$. Because 1×1 set matrices $[y]$ and $[z]$ can be taken as value for the matrices $\alpha$ and $\beta$, it follows from the Reduction Axiom that the Generalized Pair Axiom applies to sets $y$ and $z$, yielding $x = \{y , z\}$.

*3.2.22 Set of Matrices Axiom Scheme*

$$\forall x\exists y(\forall\alpha_{11} ...\forall\alpha_{mn} (\alpha_{11}\in x \wedge \ldots \wedge \alpha_{mn}\in x \Leftrightarrow \begin{bmatrix} \alpha_{11} & \cdots & \alpha_{1n} \\ \vdots & & \vdots \\ \alpha_{m1} & \cdots & \alpha_{mn} \end{bmatrix} \in y ) \wedge$$

$$\forall\beta (\beta\in y \Rightarrow\exists\gamma_{11} \ldots \exists\gamma_{mn}(\beta= \begin{bmatrix} \gamma_{11} & \cdots & \gamma_{1n} \\ \vdots & & \vdots \\ \gamma_{m1} & \cdots & \gamma_{mn} \end{bmatrix} \wedge \gamma_{11} \in x \ldots \wedge \gamma_{mn} \in x))$$

The Set of Matrices Axiom Scheme is a countably infinite axiom scheme, with an axiom for every function symbol $f_{m\times n}$. On the one hand, every such axiom guarantees that for every $mn$ elements $\alpha_{11}$ ... $\alpha_{mn}$ of $x$ there is a matrix $\begin{bmatrix} \alpha_{11} & \cdots & \alpha_{1n} \\ \vdots & & \vdots \\ \alpha_{m1} & \cdots & \alpha_{mn} \end{bmatrix}$ in $y$; on the other hand, it guarantees that there are *no other* elements in $y$ since for every element $\beta$ of $y$ there have to be $mn$ elements $\gamma_{11} \ldots \gamma_{mn}$ in $x$ such that the identity $\beta = \begin{bmatrix} \gamma_{11} & \cdots & \gamma_{1n} \\ \vdots & & \vdots \\ \gamma_{m1} & \cdots & \gamma_{mn} \end{bmatrix}$ holds. In every such axiom the set $y$ occurring in it is unique, and can be denoted $M_{m\times n}(x)$, the set of all $m\times n$ matrices with elements of $x$ as entries. The elements of $M_{m\times n}(x)$ are all set matrices.

*3.2.23 Generalized Sum Set Axiom*

$\forall x(\forall\alpha\,(\alpha\in x\Rightarrow\exists u\,(u=\alpha))\Rightarrow\exists y\forall\beta\,(\beta\in y\Leftrightarrow\exists z\,(z\in x\wedge\beta\in z)))$

The Generalized Sum Set Axiom formalizes that for every set of sets $x$ there is a set $y$ made up precisely of the elements of the sets that are in $x$.

Universal quantification over sets of sets is achieved by the restricted quantification $\forall x\,(\forall\alpha\,(\alpha\in x\Rightarrow\exists u\,(u=\alpha))\Rightarrow$, because then only sets $x$ are considered such that for every matrix $\alpha$ in $x$ there is a set $u$ identical to that matrix $\alpha$. From the Generalized Extensionality Axiom for Sets it follows that the sum set $y$ is unique, and it can be denoted by $y=\bigcup x$.

*3.2.24 Example*

Let the set $S$ be given by

$$S=\{\{\varnothing,[\varnothing\ \ \varnothing]\},\{\begin{bmatrix}\varnothing\\ \varnothing\end{bmatrix}\}\} \tag{3.15}$$

The sum set $\bigcup S$ is then the set that contains the elements of the sets $\{\varnothing,[\varnothing\ \ \varnothing]\}$ and $\{\begin{bmatrix}\varnothing\\ \varnothing\end{bmatrix}\}$ in $S$, and is by 3.2.23 thus given by

$$\bigcup S=\{\varnothing,[\varnothing\ \ \varnothing],\begin{bmatrix}\varnothing\\ \varnothing\end{bmatrix}\} \tag{3.16}$$

This set $\bigcup S$, however, is no longer a set of sets, cf. remark 3.2.19. Therefore, it does not follow from the Generalized Sum Set Axiom that there is a set $\bigcup(\bigcup S)$. If the restricted quantification in 3.2.23 would be replaced by a quantification $\forall x_1$ over sets, then one would have $\bigcup(\bigcup S)=\varnothing$, because none of the objects of the set $\bigcup S$ in (3.16) has any elements. However, in this axiomatization is chosen for restricted quantification, because it is senseless to talk about collecting elements of set matrices, of which is already known that they can't have elements in the sense of the $\in$-relation.

*3.2.25 Remark* (*Cartesian product*)

At this point the Cartesian product $x{\times}y$ of two sets $x$ and $y$ can be introduced:

$$\forall\alpha\,(\alpha \in x{\times}y \Leftrightarrow \exists\beta\,\exists\gamma\,(\beta \in x \wedge \gamma \in y \wedge \alpha = [\beta \quad \gamma\,]\,)) \tag{3.17}$$

The set $x{\times}y$ can then be denoted by $\{[\beta \quad \gamma\,] \mid \beta \in x \wedge \gamma \in y\,\}$. The existence of the set $x{\times}y$ is guaranteed by the previous axioms of set matrix theory. Namely, for any two sets $x$ and $y$ the set $\{x, y\}$ exists on account of the Generalized Pair Axiom. The union $x \cup y$ of the sets $x$ and $y$ then exists on account of the Generalized Sum Set Axiom:

$$x \cup y = \bigcup\,\{x, y\} \tag{3.18}$$

The set $\mathrm{M}_{1\times 2}(x \cup y)$ then exists on account of the Set of Matrices Axiom Scheme:

$$\begin{aligned}&\forall\alpha\forall\beta\,(\alpha \in x \cup y \wedge \beta \in x \cup y \Rightarrow [\alpha \quad \beta] \in \mathrm{M}_{1\times 2}(x \cup y)) \wedge \\ &\qquad\qquad \forall\gamma\,(\gamma\ \in \mathrm{M}_{1\times 2}(x \cup y) \Rightarrow \exists\mu\exists\nu\,(\gamma = [\mu \quad \nu] \wedge \mu \in x \wedge \nu \in x))\end{aligned} \tag{3.19}$$

The set $x{\times}y$ then exists on account of the Generalized Axiom Scheme of Separation:

$$\forall\alpha(\alpha \in x{\times}y \Leftrightarrow \alpha \in \mathrm{M}_{1\times 2}(x \cup y)\ \wedge \exists\beta\,\exists\gamma\,(\alpha = [\beta \quad \gamma\,] \wedge \beta \in x \wedge \gamma\ \in y\,)) \tag{3.20}$$

It should be noted that because of the Division Axiom Scheme, the sets $x{\times}y{\times}z$, $(x{\times}y){\times}z$, and $x{\times}(y{\times}z)$, are three mutually different sets.

*3.2.26 Generalized Power Set Axiom*

$\forall x\exists y\ (\forall\alpha(\alpha \in y\ \Rightarrow \exists u(u = \alpha)) \wedge \forall z\ (z \in y\ \Leftrightarrow z \subseteq x\,))$

The Generalized Power Set Axiom says that for every set $x$ there is a set of sets $y$ that is made up precisely of the subsets of $x$. This power set $y$ is unique on account of the Generalized Extensionality Axiom for Sets; notation: $y = POW(x)$. Note that existential quantification over sets of sets is achieved by the restricted quantification $\exists y(\forall\alpha(\alpha \in y \Rightarrow \exists u\,(u = \alpha)) \wedge \ldots$

*3.2.27 Example*

As an example of an application of the notion of a power set in the framework of set matrix theory, below an axiomatization is given of a semi-topological space $[X \quad S]$ as a 1×2 set matrix:

$$S \subseteq POW(X) \tag{3.21}$$

$$\varnothing \in S \wedge X \in S \tag{3.22}$$

$$\forall x(x \subseteq S \Rightarrow \bigcup x \in S) \tag{3.23}$$

The axioms (3.21)-(3.23) are formulated strictly within the formalism of set matrix theory, which demonstrates applicability of the formalism; it can be proven that this axiomatization of a semi-topological space is equivalent to the axiomatization originally introduced by Latecki (1992).

*3.2.28 Definition* (*successor set*)

Given any set $x$, there is a unique successor set with standard notation $\{x\}$ defined by $\forall \alpha\,(\alpha \in \{x\} \Leftrightarrow \alpha = x)$. □

This definition defines for every set $x$ a singleton $\{x\}$, that has the set $x$ as sole element. The singleton $\{x\}$ is unique on account of the Generalized Extensionality Axiom for Sets, and its existence is guaranteed on account of the Generalized Pair Axiom. In the literature, this successor set $\{x\}$ is also denoted by $(x)^+$.

*3.2.29 Generalized Axiom of Countable Infinity*

$\exists x(\varnothing \in x \wedge \forall y\,(y \in x \Rightarrow \{y\} \in x))$

*3.2.30 Remark*

Starting with the empty set Ø, this axiom thus guarantees the existence of an infinite set $N$, defined by

$$N := \{\varnothing, \{\varnothing\}, \{\{\varnothing\}\}, \ldots\} \tag{3.24}$$

The elements of $N$ can then be numbered, using $0 := \varnothing$ and $n{+}1 := \{n\}$, yielding the set of natural numbers $\{0, 1, 2, \ldots\}$. It should be noted that the infinite set $N$, given by (3.24), is not the only infinite set that satisfies the Generalized axiom of countable infinity. For example, the set $\bigcup \{N, \{\begin{bmatrix} \varnothing \\ \varnothing \end{bmatrix}\}\}$ also satisfies 3.2.29.

*3.2.31 Generalized Substitution Axiom Scheme*

$\forall x\, (\forall \alpha\, (\alpha \in x \Rightarrow \exists! \beta\, \Phi(\alpha, \beta)) \Rightarrow \exists y\, (\forall \beta\, (\beta \in y \Leftrightarrow \exists \gamma\, (\gamma \in x \wedge \Phi(\gamma, \beta)))))$

For any set $x$, this axiom scheme formalizes that if every matrix $\alpha$ in $x$ is related to precisely one matrix $\beta$, then there is a set $y$ made up of precisely those matrices $\beta$ that are in relation $\Phi(\gamma, \beta)$ with some matrix $\gamma$ in $x$. The axiom is applicable for any well-formed formula $\Phi(\alpha, \beta)$ that relates every matrix in $x$ with precisely one matrix $\beta$. What has been said of the Generalized Axiom Scheme of Separation applies also here: the fact that every well-formed formula has to be finite implies that such a formula $\Phi(\alpha, \beta)$ can contain only finitely many function symbols $f_i^n$, of which there are infinitely many. This means that for infinite sets, made up of set matrices $f_i^n(x_1, ..., x_n)$ for an infinite number of function symbols $f_i^n$, some relations would require an infinitely long formula $\Phi(\alpha, \beta)$: the Generalized Substitution Axiom Scheme is then not directly applicable. In Section 3.5 this issue is solved.

*3.2.32 Remark* (*function space*)

At this point, the space $y^x$ of all functions from a set $x$ to a set $y$ can be introduced:

$$\forall \alpha\, (\alpha \in y^x \Leftrightarrow \exists f (f := \alpha \wedge f \subseteq x{\times}y \wedge \forall \beta\, (\beta \in x \Rightarrow \exists! \gamma\, (\gamma \in y \wedge [\beta \quad \gamma] \in f)))$$

The set $y^x$ is a subset of the power set of $x{\times}y$, so that its existence is guaranteed by the Generalized Axiom Scheme of Separation.

As an example of an application of the notion of a function space in the framework of SMT, below an axiomatization is given of a semi-group $[S \quad *]$ as a $1{\times}2$ set matrix:

$$* \in S^{S\times S} \tag{3.25}$$

$$\forall \alpha \forall \beta\, \forall \gamma\, \forall \delta\, (\alpha \in S \wedge \beta \in S \wedge \gamma \in S \wedge \delta \in S \Rightarrow \\ ([\,[\alpha{*}\beta \quad \gamma] \quad \delta\,] \in * \Leftrightarrow [\,[\alpha \quad \beta{*}\gamma] \quad \delta\,] \in *)) \tag{3.26}$$

The operation * is thus a set (an element of the function space $S^{S\times S}$); and an element $\mu * \nu$ of $S$ thus denotes the element $\lambda$ for which $[\,[\mu \quad \nu] \quad \lambda\,] \in *$. The axioms (3.25) and (3.26) are formulated strictly within the formalism of set matrix theory to demonstrate applicability of the formalism; it can be proven that this axiomatization of a semi-group is equivalent to the usual one.

*3.2.33 Generalized Foundational Axiom*

$\forall x\,(\exists \alpha\,(\alpha \in x) \wedge \forall \beta\,(\beta \in x \Rightarrow \exists y\,(\beta = y)) \Rightarrow \exists z (z \in x \wedge \forall \gamma\,(\gamma \in z \Rightarrow \gamma \notin x))))$

The Generalized Foundational Axiom formalizes that every nonempty set of sets $x$ has an element $z$, which shares no elements with $x$. This axiom excludes in particular that there is a set $x$ such that $x = \{x\}$. Namely, if $x = \{x\}$ then the set $x$ does not have an element $z$ for which $\forall \gamma\ (\gamma \in z \Rightarrow \gamma \notin x)$. In case $x = \{x\}$, then for every element $z$ of the set $x$ there is a matrix $\gamma = x$ for which $\gamma \in z \wedge \gamma \in x$: this is precisely the contraposition of $\forall \gamma\ (\gamma \in z \Rightarrow \gamma \notin x)$. The case $x = \{x\}$ thus contradicts the Generalized Foundational Axiom, so that no such set $x$ exists.

With the above axiomatization of set matrix theory, there is for every axiom (or axiom scheme) of ZF a corresponding Generalized axiom in set matrix theory. For further comments on the ZF axiom schemes or their meaning, see the literature, e.g. (van Dalen, Doets, de Swart 1975: 141-153).

*3.2.34 Remark* (*philosophy of mathematics*)

Having defined the framework of SMT, the general philosophy of what mathematics is may then be distilled from the most widely accepted point of view on the matter: mathematics is the body of statements that can be derived within the framework of SMT by means of formal deduction.

In the framework of SMT, besides sets also set matrices occur as terms of the mathematical language. These set matrices are in general not sets, so that the adage “everything is a set” of ZF is certainly not valid in the framework of SMT. However, because of the Reduction Axiom 3.2.8, in the framework of SMT every set $x$ is identical to a $1 \times 1$ set matrix $[x]$. As a result, the adage “everything is a matrix” holds in the framework of SMT. Concerning the terms of the language a nominalist position is taken, in the sense that these terms (sets and matrices of sets) in themselves are without any fundament in physical reality – that is, there is no Platonian domain in reality that *is* the universe of SMT.

Furthermore, given that the motivation for the development of SMT lies in physics, the point of view on the position of mathematics in the whole of science is reflected by the adage "*mathematica ancilla physicae*" (mathematics is the servant of physics). This implies the view that mathematics in the first place is meant to provide a language for the natural sciences. □

### 3.3 The relation with Zermelo-Fraenkel set theory

An undeniable observation is that the language $L_{ZF}$ of ZF is properly contained in the language $L_{SMT}$ of SMT. Now let L' be the restriction of the language $L_{SMT}$ by leaving out the function symbols $f_i^n$ with $n > 1$, and let SMT|L' be the restriction of set matrix theory to the language L'. Thus speaking, the only function symbol in L' is $f_1^1$ with $f_1^1(x) = [x]$, and '=' and '$\in$' are the only predicate letters in L', so that the Omission Axiom Scheme 3.2.9, the Epsilon Axiom Scheme 3.2.10, the Division Axiom Scheme 3.2.11, and the Extensionality Axiom Scheme for Set Matrices 3.2.14 do not occur in SMT|L'.

*3.3.1 Theorem*

$\vdash_{\mathrm{SMT}\,|\,\mathrm{L'}} \forall x \exists ! \alpha\, (\alpha = [x]\,) \wedge \forall \alpha\, \exists ! x (\alpha = x\,)$

*Proof*:

In SMT|L' the Set Matrix Axiom Scheme (i) is reduced to

$$\forall x \exists \alpha (\alpha = [x]\,) \tag{3.27}$$

Because of the absence of the other function symbols $f_i^n$ in SMT|L', the variables $\alpha$ range only over these 1×1 set matrices $[x]$. Using this completeness argument and the Reduction Axiom it then follows that

$$\vdash_{\mathrm{SMT}\,|\,\mathrm{L'}} \forall \alpha \exists x (\alpha = x\,) \tag{3.28}$$

Uniqueness in (3.27) and (3.28) follows from symmetry and transitivity of the identity relation. □

*3.3.2 Theorem*

$\vdash_{SMT\,|\,L'}\ \forall\alpha\psi(\alpha) \Leftrightarrow \forall x\psi(x)$

*Proof*:

Theorem 3.3.2 follows from theorem 3.3.1 and substitutivity of equality. This means that in SMT|L' quantification over all matrices is equivalent to quantification over all sets. □

*3.3.3 Theorem*

$\vdash_{SMT\,|\,L'}\ \forall x(\forall\alpha\,(\alpha \in x \Rightarrow \exists y\,(y = \alpha)))$

*Proof*:

In theorem 3.3.1 it has been demonstrated that $\vdash_{SMT\,|\,L'}\ \forall\alpha\exists x(\alpha = x)$. So, in particular, $\vdash_{SMT\,|\,L'}\ \forall\alpha\,(\alpha \in x \Rightarrow \exists y\,(y = \alpha))$. □

Below it will be shown that the axioms of set matrix theory, restricted to the language L', yield precisely the axioms of ZF set theory. Hence, every theorem of ZF is a theorem of SMT|L'.

*3.3.4 Theorem (extensionality axiom of ZF)*

$\vdash_{SMT|L'}\ \forall x\forall y\,(x = y \Leftrightarrow \forall z\,(z \in x \Leftrightarrow z \in y))$

*Proof*:

Theorem 3.3.4 follows from definition 3.2.16, the Generalized Extensionality Axiom for Sets, and theorem 3.3.2. □

*3.3.5 Theorem (empty set axiom of ZF)*

$\vdash_{SMT|L'}\ \exists x\forall y\,(y \notin x)$

*Proof*:

This follows from the Generalized Axiom of Emptiness and theorem 3.3.2. □

*3.3.6 Theorem (separation axiom of ZF)*

$\vdash_{SMT|L'}\ \forall x\exists y\forall z\,(z \in y \Leftrightarrow z \in x \wedge \Phi(z))$

*Proof*:

Theorem 3.3.6 follows from the Generalized Axiom Scheme of Separation and theorem 3.3.2. □

*3.3.7 Theorem (pair axiom of ZF)*

$\vdash_{\mathrm{SMT|L'}}$ $\forall x \forall y\, \exists z \forall u\, (u \in z \Leftrightarrow u = x \vee u = y)$

*Proof*:

This follows from the Generalized Pair Axiom and theorem 3.3.2. □

*3.3.8 Theorem (sum set axiom of ZF)*

$\vdash_{\mathrm{SMT|L'}}$ $\forall x \exists y \forall z\, (z \in y \Leftrightarrow \exists u\, (u \in x \wedge z \in u))$

*Proof*:

This follows from the Generalized Sum Set Axiom and theorems 3.3.2, 3.3.3. □

*3.3.9 Theorem (power set axiom of ZF)*

$\vdash_{\mathrm{SMT|L'}}$ $\forall x \exists y \forall z\, (z \in y \Leftrightarrow z \subseteq x)$

*Proof*:

Theorem 3.3.9 follows from the Generalized Power Set Axiom, theorem 3.3.3, definition 3.2.16 and theorem 3.3.2. □

*3.3.10 Theorem (axiom of countable infinity of ZF)*

$\vdash_{\mathrm{SMT|L'}}$ $\exists x (\emptyset \in x \wedge \forall y\, (y \in x \Rightarrow \{y\} \in x))$

*Proof*:

Theorem 3.3.10 is identical to the Generalized Axiom of Countable Infinity. □

*3.3.11 Theorem (substitution axiom of ZF)*

$\vdash_{\mathrm{SMT|L'}}$ $\forall x\, (\forall y\, (y \in x \Rightarrow \exists! z\, \Phi(y, z)) \Rightarrow \exists u\, (\forall z\, (z \in u \Leftrightarrow \exists y\, (y \in x \wedge \Phi(y, z)))))$

*Proof*:

Theorem 3.3.11 follows from the Generalized Substitution Axiom Scheme and theorem 3.3.2. □

*3.3.12 Theorem (foundational axiom of ZF)*

$\vdash_{\mathrm{SMT|L'}} \ \forall x(\exists y\ (y \in x) \Rightarrow \exists z(z \in x \wedge \forall u\ (u \in z \Rightarrow u \notin x))))$

*Proof*:

Theorem 3.3.12 follows from the Generalized Foundational Axiom 3.2.33, theorem 3.3.3 and theorem 3.3.2. □

*3.3.13 Proposition (relation between set matrix theory and ZF set theory)*

The restriction of set matrix theory to L' is a conservative extension of ZF.

*Proof*:

For every axiom $A$ of ZF, it has now been proven that $\vdash_{\mathrm{SMT|L'}} A$. In other words, it has been proven for every formula $\Psi$ of ZF that if $\vdash_{\mathrm{ZF}} \Psi$, then $\vdash_{\mathrm{SMT|L'}} \Psi$. □

*3.3.14 Remark*

It should be noted, however, that (unrestricted) set matrix theory is not an extension of ZF in the accepted sense of the term 'extension' (Shoenfield 2001: 41). It is namely not the case that every theorem of ZF is a theorem of SMT. For example, it is a theorem of ZF that there is precisely one set which has no sets as elements:

$$\vdash_{ZF} \ \exists! x \forall y\, (y \notin x) \tag{3.29}$$

In set matrix theory, this theorem does not hold. For example, the set $\{\begin{bmatrix}\varnothing \\ \varnothing\end{bmatrix}\}$ has no sets as elements (because its element $\begin{bmatrix}\varnothing \\ \varnothing\end{bmatrix}$ is not a set, cf. remark 3.2.19), but the set $\{\begin{bmatrix}\varnothing \\ \varnothing\end{bmatrix}\}$ is not identical to the empty set on account of the Generalized Extensionality Axiom for Sets 3.2.17. Thus, in set matrix theory there are at least two sets that have no sets as elements, which proves that the formula $\exists! x \forall y\, (y \notin x)$ does not hold in set matrix theory. Thus, set matrix theory is not an extension of ZF.

*3.3.15 Remark*

Instead, SMT is to be viewed as a *generalization* of ZF. As a definition of this notion, the following is suggested: a theory T' (in this case: SMT) is an generalization of a theory T (in this case: ZF) if and only if the following conditions are satisfied:

(i) the language $L_{T'}$ for T' is a proper extension of the language $L_T$ of T;

(ii) the universe for $L_{T'}$ properly contains the universe for $L_T$;

(ii) there is a language L' (in this case $L_{SMT}$ without the function symbols $f_i^n$ with $n > 1$), such that L' is an extension of $L_T$ and $L_{T'}$ is an extension of L', and such that the restriction of T' to L' is a conservative extension of T.

These conditions, namely, are precisely satisfied.

*3.3.16 Remark*

From the point of view of pure mathematics, one has to conclude that SMT is thus not better suited than ZF as a foundation for mathematics. It is true that SMT is not weaker than ZF, as is demonstrated by the fact that a restriction of SMT is a conservative extension of ZF: all sets that can be constructed with ZF can thus also be constructed with SMT. It is also true that SMT yields an incremental improvement, because *n*-ary structures fit more elegantly in the ontology corresponding with the framework of SMT than in the ontology corresponding with the framework of ZF. That is, binary structures such as groups and topological spaces are simply 1×2 set matrices in the framework of SMT, ternary structures such as fields are 1×3 set matrices, etc.: it is not the case that these structures cannot be represented in the framework of ZF, but their representation is less elegant. A group, for example, is a two-tuple $\langle G, *\rangle$ so that strictly speaking a group is a set $\{\{G\}, \{G, *\}\}$ in the framework of ZF set theory. The 1×2 set matrix $[G \quad *]$ is then a more elegant representation of a group than this set $\{\{G\}, \{G, *\}\}$. The crux, however, is that SMT does not make the foundation of mathematics in itself more powerful. That is, the basic set-theoretical questions, that are unsolvable in ZF set theory, remain unsolved in set matrix theory.

### 3.4 Resolving the issues with the formalization of the EPT

The main reason for introducing SMT is that it solves the complications that arise from a formalization of the EPT in the framework of ZF. These have been discussed in Section 3.1. Below, it will be shown that these complications do not exist in the framework of SMT.

First of all, in the framework of SMT the 2×1 set matrices $\begin{bmatrix} x \\ y \end{bmatrix}$ exist as objects *sui generis*: on account of the Division Axiom Scheme these set matrices are not identical to any set. Therefore, such 2×1 set matrices can be used as direct designators of components of the physical universe, consisting of a constituent of a world (designated by the entry $x$ in the first row) and a constituent of an antiworld (designated by the entry $y$ in the second row). Thus speaking, by taking SMT as the mathematical foundation for the EPT, the demand for the truth condition of knowledge can be met that objects that ontologically exist in the physical universe are to be designated by objects that ontologically exist in the mathematical universe: the complication that arises from a formalization of the EPT in the framework of ZF is thus absent in the framework of SMT.

Next, expressions of the type $\begin{bmatrix} a \\ b \end{bmatrix} : \begin{bmatrix} f \\ g \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} x \\ y \end{bmatrix}$ can be formalized in the framework of SMT as a standard notation for a ternary relation $R$:

$$\begin{bmatrix} a \\ b \end{bmatrix} : \begin{bmatrix} f \\ g \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} x \\ y \end{bmatrix} \Leftrightarrow \langle \begin{bmatrix} a \\ b \end{bmatrix}, \begin{bmatrix} f \\ g \end{bmatrix}, \begin{bmatrix} x \\ y \end{bmatrix} \rangle \in R \tag{3.30}$$

Such a formalization is also possible in the framework of ZF, but the point is that the 2×1 set matrices $\begin{bmatrix} a \\ b \end{bmatrix}$, $\begin{bmatrix} f \\ g \end{bmatrix}$, and $\begin{bmatrix} x \\ y \end{bmatrix}$ are not identical to sets $S$, $T$ and $V$ in the framework of SMT because of the Division Axiom Scheme. Thus, in the framework of SMT one gets:

$$\begin{bmatrix} a \\ b \end{bmatrix} : \begin{bmatrix} f \\ g \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} x \\ y \end{bmatrix} \nvdash_{\text{SMT}} S\colon T \overset{\to}{\underset{\leftarrow}{}} V \tag{3.31}$$

Suppose, namely, that $S\colon T \overset{\to}{\underset{\leftarrow}{}} V$ can be deduced. Given expression (3.30), this would imply that $\langle S, T, V \rangle \in R$. But the set $R$ is well-defined in the EPT (see chapter two of this dissertation): it only contains three-tuples of the form $\langle \begin{bmatrix} a \\ b \end{bmatrix}, \begin{bmatrix} f \\ g \end{bmatrix}, \begin{bmatrix} x \\ y \end{bmatrix} \rangle$.

And given the Division Axiom Scheme, such a three-tuple is not identical to a three-tuple of the form $\langle S, T, V\rangle$. Thus, $\langle S, T, V\rangle$ is not in $R$. Contradiction. Thus, the expression $S\colon T \overset{\rightarrow}{\leftarrow} V$ cannot be deduced.

Clearly, expression (3.31) is in contrast with expression (3.7): if SMT is thus taken as the mathematical foundation for the EPT, then the axiomatic system containing the EPT has no theorems of the type $S\colon T \overset{\rightarrow}{\leftarrow} V$, which cannot be translated into a statement about the physical universe and which are thus physically uninterpretable. This shows that also the second complication that arises from a formalisation of the EPT in the framework ZF, is absent in the framework of SMT.

*3.4.1 Remark*

It has been shown in Section 3.1 that a formalization of the EPT in the framework of ZF leads to unsolvable complications, and it has been demonstrated above that SMT resolves these complications by expanding the ontological repertoire of the language of mathematics in the sense that set matrices exist as such in the mathematical universe of SMT. Despite what has been said in remark 3.3.16, SMT is thus better suited than ZF as a foundation for mathematics in the research program on the EPT.

## 3.5 Resolving infinities arising in Separation and Substitution

*3.5.1 Example*

Let the set $N^* = N - \{0\} = \{1, 2, 3, \ldots\}$. Consider the sets $M_{m\times n}(N)$ given by

$$M_{m\times n}(N) = \{ \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \mid x_{11}, \ldots, x_{mn} \in N\} \tag{3.32}$$

Let the set $\{M_{m\times n}(N) \mid m, n \in N^*\}$ be the set of all these sets $M_{m\times n}(N)$, and let the set $S = \bigcup_{m,n\in N^*} \{M_{m\times n}(N)\}$. In words, $S$ is the set of all matrices of all dimensions $m\times n$ with entries from the set of natural numbers $N$. It is then not possible to single out the subset $T$ of all matrices of all dimensions $m\times n$ with entries of the set $2N+1$ of odd natural numbers, $2N+1 = \{1, 3, 5, \ldots\}$, by applying the Generalized Axiom of Separation only once to the set $S$. Namely, the formula

$$\exists y(\begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \in y \Leftrightarrow \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \in \mathrm{S} \wedge x_1, \ldots, x_{mn} \in 2N+1 \qquad (3.33)$$

is not an instance of the Generalized Axiom Scheme of Separation if $m$ and $n$ are undetermined, because the term $\begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$ then cannot be constructed using the clauses of definition 3.2.2. However, for every set $M_{m\times n}(N)$ defined by (3.32) the formula

$$\exists y\ (\begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \in y \Leftrightarrow \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \in M_{m\times n}(N) \wedge x_1, \ldots, x_n \in 2N+1) \qquad (3.34)$$

is a well-formed formula for fixed $m$ and $n$, if the subformula $x_1, \ldots, x_{mn} \in 2N+1$ is as usual viewed as an abbreviation of $x_1 \in 2N+1 \wedge \ldots \wedge x_n \in 2N+1$. The set $y$ is then unique, and $y = M_{m\times n}(2N+1)$. The requested subset $T$ of $S$ is then defined by

$$T = \bigcup \{ M_{m\times n}(2N+1)\} \subset S \qquad (3.35)$$

It thus takes infinitely many applications of the Generalized Axiom of Separation to construct the set $T$ from the set $S$.

*3.5.2 Remark*

The previous example illustrates that the Generalized Axiom of Separation 3.2.20 has less power in the framework of set matrix theory than its counterpart has in the framework of ZF. This is due to the occurrence of the metavariable Φ. The point is that Φ represents a first-order formula, and thus has to be finite: for a set with infinitely many different types of matrices as elements, it thus becomes impossible to formulate certain properties covering all elements in a single finite formula, purely because the starting set is made up of infinitely many different types of matrices.

Below in remark 3.5.4, which uses the next theorem 3.5.3, it will be shown that this loss of power does not lead to an incompleteness in the framework of SMT. But the previous example 3.5.1 illustrates the general case: in the framework of SMT the Generalized Axiom of Separation has to be applied infinitely many times to single out certain subsets of sets, made up of infinitely many different types of set matrices.

*3.5.3 Theorem*

Every set $x$ can be written as the sum of a possibly infinite set of sets $x_i^n$, made up of precisely the elements of $x$ that can be written as terms $f_i^n(x_1, ..., x_n)$ using one and the same function symbol $f_i^n$:

$x = \bigcup \{ x_1^1,\ x_1^2,\ x_2^2,\ x_1^3, \ldots,\ x_{10}^3,\ x_1^4, \ldots \}$

*Proof*:

For any set $x$, these subsets $x_i^n$ of $x$ can be singled out on account of the Generalized Axiom of Separation:

$$\forall x \exists x_1^1 \forall \alpha (\alpha \in x_1^1 \Leftrightarrow \alpha \in x \wedge \exists x_1 (\alpha = [x_1])) \tag{3.36}$$

$$\forall x \exists x_1^2 \forall \alpha (\alpha \in x_1^2 \Leftrightarrow \alpha \in x \wedge \exists x_1 \exists x_2 (\alpha = [x_1 \quad x_2])) \tag{3.37}$$

$$\forall x \exists x_2^2 \forall \alpha (\alpha \in x_2^2 \Leftrightarrow \alpha \in x \wedge \exists x_1 \exists x_2 (\alpha = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix})) \tag{3.38}$$

and so forth. So, $x_1^1$ is the set of all sets in $x$, $x_1^2$ is the set of all matrices in $x$ of the form $[x_1 \quad x_2]$, $x_2^2$ is the set of all matrices in $x$ of the form $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$, etc. Because the list of function symbols $f_i^n$ is complete, cf. remark 3.2.3, every element $\alpha$ of $x$ is in at least one such subset $x_i^n$, and because of the Division Axiom Scheme 3.2.11 every element $\alpha$ of $x$ is in at most one such subset $x_i^n$. This proves theorem 3.5.3.

*3.5.4 Remark*

Having applied theorem 3.5.3 to a set $x$, then for every such subset $x_i^n$ of $x$ properties Φ can be formulated as a finite first-order formula: the elements of $x_i^n$, namely, all use the same function symbol $f_i^n$ so that a term $f_i^n(x_1, ..., x_n)$ of Φ ranges over all elements of $x_i^n$. That way, for every set $x_i^n$ a subset $y_i^n$ can be singled out. Then, using the Generalized Sum Set Axiom, one can collect the elements of the sets $y_i^n$ in a set $y$:

$$y := \bigcup\{\, y_1^1,\ y_1^2,\ y_2^2,\ y_1^3,\ \ldots,\ y_{10}^3,\ y_1^4,\ \ldots\} \tag{3.39}$$

This shows that there is no incompleteness involved with the Generalized Axiom Scheme of Separation: even of a set $x$, that contains elements $f_i^n(x_1, ..., x_n)$ for infinitely many function symbols $f_i^n$, subsets $y$ can be constructed by applying the Generalized Axiom Scheme of Separation.

*3.5.5 Remark*

Similarly to what has been said in remark 3.5.2, also with the Generalized Substitution Axiom Scheme 3.2.31 a loss of power is connected, again because of the occurrence of the metavariable Φ for formulas. In this case, for a set made up of infinitely many different types of matrices some functional relations cannot be formulated with a finite first-order formula Φ, purely because the set is made up of infinitely many different types of matrices. The Generalized Substitution Axiom Scheme is then not directly applicable to construct the image of such a set under a function. However, theorem 3.5.3 comes once more to the rescue: a similar infinite scheme as described above can be applied.

*3.5.6 Example*

Consider once more the set $S$ of all matrices that can be constructed from the set of natural numbers $N$, cf. example 3.5.1. Now for every matrix $\alpha = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & & \vdots \\ t_{m1} & \cdots & t_{mn} \end{bmatrix}$ in

$S$, there is exactly one matrix $\beta$ that is identical to the entry $t_{11}$ in the first row and the first column of $\alpha$. This functional relation, however, cannot be formalized in a finite formula $\Phi$, because there are infinitely many different types of matrices $\alpha$. But applying theorem 3.5.3, the infinite scheme below does formalize the functional relation:

$$\forall x(\ [x] \in S_1^1 \Rightarrow \exists! \alpha (\alpha = x)) \tag{3.40}$$

$$\forall x_1 \forall x_2 ([x_1 \quad x_2] \in S_1^2 \Rightarrow \exists! \alpha (\alpha = x_1 \ )) \tag{3.41}$$

$$\forall x_1 \forall x_2 (\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \in S_2^2 \Rightarrow \exists! \alpha (\alpha = x_1 \ )) \tag{3.42}$$

and so forth. In this scheme, for every set $S_i^n$ a functional relation $\Phi$ is described with a well-formed formula. Thus, according to the Generalized Substitution Axiom Scheme for every set $S_i^n$ a set $U_i^n$ exists, made up of all the top-left entries of the matrices of $S_i^n$. And a set $U = \bigcup \{ U_i^n \}$, which is made up of all elements of all sets $U_i^n$, exists on account of the Generalized Sum Set Axiom. This shows how the Generalized Axiom Scheme of Substitution can be applied to construct an image of a set $x$, that contains elements $f_i^n(x_1, ..., x_n)$ for infinitely many function symbols $f_i^n$.

# 4

## ELEMENTARY PROCESS THEORY

This chapter introduces the EPT; as the EPT is formalized within the framework of SMT, it suffices to introduce the individual constants of the EPT, the axioms that constitute the EPT, and the interpretation rules, by which theorems of the axiomatic system containing the EPT can be translated into statements about physical reality. The predicate symbols '=' and '$\in$', the negation sign '$\neg$', the connectives '$\Rightarrow$', '$\wedge$', '$\vee$', and '$\Leftrightarrow$', as well as the quantifiers '$\forall$' and '$\exists$', which all occur in the EPT, are thus the ones given by the mathematical-logical framework of SMT. In addition, the syntax, the set of rules on how to construct well-formed formulas using all these symbols, is also given by the mathematical logical framework of SMT. Section 4.1 introduces the individual constants of the EPT and the corresponding interpretation rules; Section 4.2 axiomatically introduces the EPT. Section 4.3, the metaphysics, presents some results at the metalevel.

### 4.1 Individual constants and interpretation rules

*4.1.1 Definition (standard notation)*

Some standard notations:

(i) $\forall t \in S(\Phi(t))$ denotes $\forall t(t \in S \Rightarrow \Phi(t))$ for any term $t$ and for any set $S$;

(ii) $\exists t \in S(\Phi(t))$ denotes $\exists t(t \in S \wedge \Phi(t))$ for any term $t$ and for any set $S$.

*4.1.2 Definition* (*difference of sets*)

Let for any sets $X$ and $Y$ the difference be the set $X\backslash Y$, defined by

$$\forall \alpha(\alpha \in X\backslash Y \Leftrightarrow \alpha \in X \wedge \alpha \notin Y) \tag{4.1}$$

That is, $X\backslash Y$ is the set of al elements of $X$ that do not occur in $Y$. □

*4.1.3 Definition (individual constants)*

The language of the EPT contains the following individual constants:

(i) the infinite set of positive integers $Z^+ = \{1, 2, 3, \ldots\}$;

(ii) the finite abelian group $[Z_N \quad +]$ under addition modulo N, with

$$Z_N = \{0, 1, 2, \ldots, N-1\} \tag{4.2}$$

$$(N-1) + 1 = 0 \tag{4.3}$$

(iii) for every $x \in Z_N$ , a section $S_{\omega(x)}$ of positive integers, with

$$S_{\omega(x)} = \{k \in Z^+ \mid k < \omega(x) + 1\} \tag{4.4}$$

(iv) the nonabelian group $[P \quad \circ]$, being the group of permutations on $Z^+$;

(v) the commutative monoid $[M \quad +]$, with a set $G$ of generators made up of:

- for every $x \in Z_N$ and every $k \in S_{\omega(x)}$ one 2×1 set matrix $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix}$;
- for every $x \in Z_N$ and every $k \in S_{\omega(x)}$ one 2×1 set matrix $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^{x} \end{bmatrix}$;
- for every $x \in Z_N$ and every $k \in S_{\omega(x)}$ one 2×1 set matrix $\begin{bmatrix} \beta_k^x \\ \overline{\beta}_k^{x} \end{bmatrix}$;
- for every $x \in Z_N$ and every $k \in S_{\omega(x)}$ one 2×1 set matrix $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix}$;
- for every $x \in Z_N$ and every $k \in S_{\omega(x)}$ one 2×1 set matrix $\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix}$;
- for every $x \in Z_N$ and every $k \in S_{\omega(x)}$ one 2×1 set matrix $\begin{bmatrix} {}^{S}\varphi_k^{x+2} \\ {}^{S}\overline{\varphi}_k^{x+2} \end{bmatrix}$;
- a number $p(x, k)$ of 2×1 set matrices $\begin{bmatrix} {}^{EP}\mu_i^x \\ {}^{EP}\overline{\mu}_i^{x} \end{bmatrix}$ for every constant $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix}$;
- a number $q(x, k)$ of set matrices $\begin{bmatrix} {}^{NP}\mu_j^{x+1} \\ {}^{NP}\overline{\mu}_j^{x+1} \end{bmatrix}$ for every constant $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix}$;

(vi) a subset $M_{\mathrm{E}}$ of $M$, given by $\forall\alpha(\alpha \in M_{\mathrm{E}} \Leftrightarrow \alpha \in M \wedge \Phi_{\mathrm{E}}(\alpha))$, where $\Phi_{\mathrm{E}}$ is a mathematical formalization of the unary predicate letter E (Exists) on $M$;

(vii) for every $x \in Z_{\mathrm{N}}$ and for every $k \in S_{\omega(x)}$, a set $\Theta_k^{x+1}$;

(viii) a function $f_C$ such that $f_C(\Theta_k^{x+1}) = {}^{NP}\varphi_k^{x+1}$ for every $\Theta_k^{x+1}$.

□

*4.1.4 Interpretation rule*

The constants 0, 1, ..., N–1 $\in Z_{\mathrm{N}}$ designate degrees of evolution. □

The degrees of evolution are essential characteristics of the observable process of evolution: a degree of evolution is thus different from a moment in time, because a moment in time is a point on a linear continuum. In the context of the discreteness of the degrees of evolution, it is interesting to quote John von Neumann: “the general opinion in theoretical physics had [in the 1920’s] accepted the idea that the principle of continuity, prevailing in the perceived macrocosmic world, is merely simulated by an averaging process in a world which in truth is discontinuous by its very nature” (1955: 3-4). It should be noted that the invariance of counting implies that all observers will find a structure isomorphic to the group $[Z_{\mathrm{N}}\ \ +]$: a degree of evolution $n \in Z_{\mathrm{N}}$ is therefore an absolute value, that is, the same for all observers.

*4.1.5 Interpretation rule*

The numbers $k \in S_{\omega(x)}$ are to be interpreted as numerical labels of the individual processes from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution; at any degree of evolution $x$, there are, thus, $\omega(x)$ of such individual processes. □

In the universe governed by the EPT, the observable process of evolution emerges from many synchronously running individual processes; to quote Von Neumann: “man generally perceives the sum of many billions of elementary processes simultaneously, so that the leveling law of large numbers completely obscures the real nature of the individual processes” (1955: 4). The term ‘individual process’ is used in its intuitive sense. The numbering of individual processes is not necessarily the same for all observers: there are $\omega(x)$ individual processes from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution, but every observer is free to use any number $k \in S_{\omega(x)}$ to refer to any particular individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution. There is, however, always a permutation in the set $P$ of permutations on $Z^+$, such that the numerical labels of one observer can be transformed into the numerical labels of another observer. In addition, all elementary principles of the EPT turn out to be of the form $\forall k \in S_{\omega(x)}(\Phi(k))$, so the elementary principles are applicable to every individual process, regardless of the value of the variable $k$ which an observer uses to refer to that particular individual process. The point is that the actual numerical value, assigned by an observer to the label $k$ for the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution, is not important for the description of what happens during the individual process: maintaining the same label throughout one such individual process is both necessary and sufficient.

### *4.1.6 Interpretation rule*

An individual constant $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} \in M$ designates a component of the noumenal universe, consisting of the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ occurring in the world at the $x^{\text{th}}$ degree of evolution in the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution, and the conjugated extended particlelike phase quantum ${}^{EP}\overline{\varphi}_k^x$ occurring in the antiworld.

### *4.1.7 Remark (phase quanta)*

A 'phase quantum' is an ultimate substantive constituent of the noumenal world or of the noumenal antiworld; it has to be seen as the smallest possible amount (a quantum) of a phase, that is, of a distinctive portion of matter in a heterogeneous system (a phase) – the universe as a whole is thus seen as a heterogeneous system. In a phase quantum, an amount of energy (the product of a scalar measure and an energetic unit) is distributed over a certain spatial extension. The energy, the energy distribution and the spatial extension are primary properties: these are properties of the phase quantum that are also present in the observed phenomenon. A phase quantum is thus not beyond the limits of human knowledge: it is a noumenon in the sense of a thing in itself, not in the sense of a thing that is unknowable. Loosely speaking, every phase quantum is a form of energy, with 'energy' used as a primitive notion; in this context it is mentioned that the Greek philosopher Anaximander (±610 – ±646 B.C.) contended that all elements consisted of one primary substance, which he called 'apeiron'.

The idea is to model a phase quantum $\varphi$ mathematically as follows as an element of a normed vector space containing functions from the set of all positions $X$ to the field $F$:

$$\varphi = C\cdot\varepsilon\cdot\chi\cdot\psi \tag{4.5}$$

$$||\varphi|| = |\varepsilon| \tag{4.6}$$

Here $\varepsilon \in F$ is a real number representing the amount of energy distributed in the phase quantum $\varphi$, $\chi \in F^X$ is a characteristic function which has the value 1 on a position $\underline{x} \in X$ if and only if the position $\underline{x}$ is an element of the spatial extension of the phase quantum $\varphi$ and the value 0 else, and $\psi \in F^X$ represents the distribution of the energy over the spatial extension $\chi^{-1}(1)$. $C$ is a number ensuring (4.6).

Furthermore, it is always the case that the spatial extensions of the conjugated phase quanta in world and antiworld are one and the same[7]; the phase quantum in the antiworld is what would be observable of the component of the universe if the observer would exist in opposite time-direction. For comparison, Feynman's interpretation of a positron is, that a positron $e^+$ is an electron $e^-$ traveling backwards in time (Feynman 1949): such an electron/positron pair can also be designated by a 2×1 matrix $\begin{bmatrix} e^+ \\ e^- \end{bmatrix}$. In fairly recent literature, the idea that world and antiworld are spatially separated has been suggested by Sannikov (1996). □

[7] That is, the set, containing both the spatial extension of the phase quantum in the world, and the spatial extension of the conjugated phase quantum in the antiworld, is a singleton (as in $\{a, a\} = \{a\}$).

The general rule for the formalism for sets designating phase quanta in world and antiworld is this: the Greek letter $\varphi$ indicates that the constituent designated is a *phase quantum*; the left superscript (e.g. EP in 4.1.6) indicates the type of phase quantum designated; the right superscript ($x$ in 4.1.6) refers to the degree of evolution at which the constituent is formed; the right subscript ($k$ in 4.1.6) refers to the individual process in which the constituent is formed (note that different observers may use different right subscripts); a bar over the symbol $\varphi$ indicates that a constituent of the antiworld is designated – absence of such a bar thus automatically implies that a constituent designated is a constituent of the world.

*4.1.8 Interpretation rule*

An individual constant $\begin{bmatrix} {}^{EP}\mu_i^x \\ {}^{EP}\overline{\mu}_i^{x} \end{bmatrix} \in M$ designates a subcomponent of a component $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix}$, and consists of the extended particlelike matter quantum ${}^{EP}\mu_i^x$ at the $x^{\text{th}}$ degree of evolution in the noumenal world that concerns the $i^{\text{th}}$ monad, and the conjugated extended particlelike matter quantum ${}^{EP}\overline{\mu}_i^{x}$ at the $x^{\text{th}}$ degree of evolution in the noumenal antiworld that concerns the $i^{\text{th}}$ monad. □

The difference between *phase quanta* and *matter quanta* lies in here: there are components $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix}$ that consist of more than one subcomponent $\begin{bmatrix} {}^{EP}\mu_i^x \\ {}^{EP}\overline{\mu}_i^{x} \end{bmatrix}$, but the point is then that these matter quanta ${}^{EP}\overline{\mu}_i^{x}$ are not *substantive*. That is, it is physically not possible to produce one of these matter quanta without the other(s).

The general rule for the formalism for sets designating matter quanta in world and antiworld is the following: the Greek letter $\mu$ indicates that the subconstituent designated is a *matter quantum*; the left superscript indicates the type of matter quantum designated; the right superscript refers to the degree of evolution at which the subconstituent is formed; as opposed to phase quanta, the right subscript index $m$ of conjugated matter quanta ${}^{EP}\overline{\mu}_i^{-x}$ and ${}^{EP}\overline{\mu}_i^{-x}$ does not refer to the $i^{\text{th}}$ individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution, but to the $i^{\text{th}}$ monad; a bar over the symbol $\mu$ indicates that a subconstituent of the antiworld is designated – absence of such a bar thus automatically implies that the subconstituent designated is a subconstituent of the world.

*4.1.9 Remark (monads)*

A monad is an individualized set of *invariant* properties: as such, it is an ultimate, immaterial individual. Its properties manifest themselves in the aforementioned essential properties of phase quanta: the monad is thus not directly observable by the senses, but can be known by reasoning.

It is emphasized that here the concept ‘monad’ does not have the same meaning as the concept ‘monad’ in Leibniz’ monadology or in the work of others (such as Pythagoras) who applied it. The role of present concept ‘monad’ becomes apparent when one tries to translate back and forth between the language of the EPT and existing physical language, in particular when one tries to answer the question “what is an electron in the framework of the EPT?” This question will be addressed further on.

Different observers can number the monads differently, but given any $q$ numerical labels of monads there is always a permutation $\tau \in P$ such that these numerical labels are identical to $\tau(1), \ldots, \tau(q)$.□

*4.1.10 Remark (particlelike matter quanta)*

Of every particlelike matter quantum, the spatial extension is bounded. In addition, it has to be taken that particlelike matter quanta are static, that is, do not move at all. Furthermore, in a subcomponent $\begin{bmatrix} {}^{EP}\mu_i^x \\ {}^{EP}\mu_i^{-x} \end{bmatrix}$ it is always the case that the amount of energy, distributed in the matter quantum ${}^{EP}\mu_i^x$, is positive, while the amount of energy distributed in the conjugated matter quantum ${}^{EP}\overline{\mu}_i^x$ is negative. The amount of energy distributed in the matter quantum ${}^{EP}\mu_i^x$ is the rest mass of the $i^{\text{th}}$ monad at the $x^{\text{th}}$ degree of evolution. Moreover, one should not confuse the notion of a particlelike matter quantum with the classical notion of a particle: the term 'particle' is used in classical mechanics for material bodies whose dimensions can be neglected in describing its motion, while the term 'particlelike matter quantum' is used in the EPT for material entities that are devoid of motion and whose dimensions may not be negligible – which might be the case at the supersmall scale. □

*4.1.11 Interpretation rule*

An individual constant $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M$ designates a component of the noumenal universe, consisting of the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ occurring in the world at the $x^{\text{th}}$ degree of evolution in the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution, and the conjugated nonlocal wavelike phase quantum ${}^{NW}\overline{\varphi}_k^x$ occurring in the antiworld. □

A nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ is a wavelike entity of finite duration, in which an amount of energy is distributed changeably over a continuous spatial extension, while the internal time-direction in the conjugated phase quantum ${}^{NW}\overline{\varphi}_k^x$ is opposite. Here time is a linear continuum, enabling the numbering of the internal wave states in the direction from earlier to later[8]. A nonlocal wavelike phase quantum then has its spatial extension instantaneously, so that the principle of locality, being that an object cannot directly exert influence at a distance, does not hold at such an event: hence the adjective 'nonlocal' in the name of these phase quanta.

[8] In absence of nuclear reaction this bears some resemblance with the notion of time as a numbering of the motion from earlier to later, as proposed by Aristotle.

*4.1.12 Interpretation rule*

An individual constant $\begin{bmatrix} \beta_k^x \\ \overline{\beta}_k^x \end{bmatrix} \in M$ designates a component of the noumenal universe, consisting of the binad $\beta_k^x$ occurring in the world at the $x^{\text{th}}$ degree of evolution in the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution, and the necessarily conjugated binad $\overline{\beta}_k^x$ occurring in the antiworld. □

The concept 'binad' provides a link to existing physical language: what in existing language are states of being of electrons, protons, or neutrons, are electronic, protonic, or neutronic binades in the language of the EPT, see also §6.4.

*4.1.13 Interpretation rule*

An individual constant $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix} \in M$ designates a component of the noumenal universe, consisting of the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ occurring in the world at the $(x+1)^{\text{th}}$ degree of evolution in the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution, and the necessarily conjugated nonextended particlelike phase quantum ${}^{NP}\overline{\varphi}_k^{x+1}$ occurring in the antiworld.

*4.1.14 Interpretation rule*

An individual constant $\begin{bmatrix} {}^{NP}\mu_j^{x+1} \\ {}^{NP}\overline{\mu}_j^{x+1} \end{bmatrix} \in M$ designates a subcomponent of a component $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix}$, consisting of the nonextended particlelike matter quantum ${}^{NP}\mu_j^{x+1}$ preceding the $j^{\text{th}}$ monad at the $(x+1)^{\text{th}}$ degree of evolution in the noumenal world, and the conjugated nonextended particlelike matter quantum ${}^{NP}\overline{\mu}_j^{x+1}$ at the $(x+1)^{\text{th}}$ degree of evolution in the noumenal antiworld. □

In case a particlelike matter quantum (remark 4.1.10) is nonextended, the bounded spatial extension is limited to a single point and has therefore an empty interior. The notion of a nonextended particlelike phase quantum thus bears resemblance with the notion of motionless point-particle in classical mechanics. A difference is that a motionless point-particle in classical mechanics still goes through time, while a nonextended particlelike phase quantum is devoid of motion in a spatiotemporal sense: it exists only at *one* moment in time.

*4.1.15 Interpretation rule*

An individual constant $\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} \in M$ designates a component of the noumenal universe, consisting of the local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ occurring in the world at the ($x$+1)th degree of evolution in the $k$th individual process from the $x$th to ($x$+1)th degree of evolution, and the necessarily conjugated local wavelike phase quantum ${}^{LW}\overline{\varphi}_k^{x+1}$ occurring in the antiworld. □

A local wavelike phase quantum is a wavelike entity of continuously changing spatial extension; the speed of change of the changing spatial extension is identical to the speed of light. One of the fundamental differences with nonlocal wavelike phase quanta is that the local wavelike phase quanta adhere to the principle of locality, that is, do not exert instantaneous influence at a distance.

*4.1.16 Interpretation rule*

A 2×1 set matrix $\begin{bmatrix} {}^{S}\varphi_k^{x+2} \\ {}^{S}\overline{\varphi}_k^{x+2} \end{bmatrix} \in M$ designates a component of the noumenal universe, consisting of the spatial phase quantum ${}^{S}\varphi_k^{x+2}$ occurring in the world at the ($x$+2)th degree of evolution after the $k$th individual process from the $x$th to the ($x$+1)th degree of evolution, and the conjugated spatial phase quantum ${}^{S}\overline{\varphi}_k^{x+2}$ occurring in the antiworld. □

A spatial phase quantum is a constituent of the vacuum that contributes directly to its spaciousness: the spatial phase quanta form space itself. In this context it is mentioned that the concept of the Firmament, which occurs in the Bible (Genesis 1:6-8), also means space itself, but further philosophical-theological research would have to establish whether or not these are the same. The spatial phase quanta are transcended by the nonlocal wavelike phase quanta, and together these two kinds of phase quanta form a homogenous phase, which is observed as a spacetime with non-Euclidean geometry; this homogenous phase acts as a carrier for the local wavelike phase quanta.

*4.1.17 Interpretation rule*

An expression $\begin{bmatrix} x \\ \bar{x} \end{bmatrix} \in M_{\mathrm{E}}$ means that the component $\begin{bmatrix} x \\ \bar{x} \end{bmatrix}$ exists in the universe.

*4.1.18 Interpretation rule*

The additive unit, denoted by $\begin{bmatrix} 0 \\ 0 \end{bmatrix}$, designates physical emptiness.

*4.1.19 Interpretation rule*

For any $\begin{bmatrix} g_1 \\ \bar{g}_1 \end{bmatrix}$, ..., $\begin{bmatrix} g_n \\ \bar{g}_n \end{bmatrix} \in G$, the sum $\begin{bmatrix} g_1 \\ \bar{g}_1 \end{bmatrix} + \ldots + \begin{bmatrix} g_n \\ \bar{g}_n \end{bmatrix}$ designates a component of the noumenal universe that is the superposition of these $n$ subcomponents $\begin{bmatrix} g_i \\ \bar{g}_i \end{bmatrix}$.

*4.1.20 Interpretation rule*

A term $\Theta_k^{x+1}$ designates the set of parallel possible nonextended particlelike phase quanta at the $(x+1)^{\mathrm{th}}$ degree of evolution in the $k^{\mathrm{th}}$ process from the $x^{\mathrm{th}}$ to the $(x+1)^{\mathrm{th}}$ degree of evolution. □

*4.1.21 Remark* (*invariance of the type of phase quanta*)

It is emphasized that different observers will assign the same kind of form to a phase quantum: this is an invariant feature. The total number, five, of kinds of phase quanta corresponds – with respect to that number five – to the philosophy of Aristotle (384 – 322 B.C), who contended that there are five elements of nature: earth, fire, air, water and aether (quinta essentia).

## 4.2 Axiomatic introduction of the EPT

Below, the axioms that together constitute of the EPT are introduced; some additional interpretation rules are given. The axioms are supplemented with a number of postulates: these postulates cannot be formally deduced from the axioms, but are included in the physical meaning of the principles. Using an informal Toulmin scheme the postulates could be substantiated, but this is omitted: the goal here is to build an axiomatic system.

Regarding the commutative monoid [$M$ +], the set of all entries $g$ and $\bar{g}$ of all generators $\begin{bmatrix} g \\ \bar{g} \end{bmatrix} \in G$ also generates a monoid under addition. As a result, any sum in $M$ can be written as follows:

$$\begin{bmatrix} x \\ \bar{x} \end{bmatrix}, \begin{bmatrix} y \\ \bar{y} \end{bmatrix} \in M \Rightarrow \begin{bmatrix} x \\ \bar{x} \end{bmatrix} + \begin{bmatrix} y \\ \bar{y} \end{bmatrix} = \begin{bmatrix} x+y \\ \bar{x}+\bar{y} \end{bmatrix} \tag{4.7}$$

In fact, this set $\{g\ ,\ \bar{g} \mid \begin{bmatrix} g \\ \bar{g} \end{bmatrix} \in G\}$ generates a group under addition when $g + \bar{g} = 0$.

*4.2.1 Postulate*

$$\forall x \in Z_N \forall k \in S_{\omega(x)}\ \exists \sigma \in P \exists p \in Z^+ \left( \begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\bar{\varphi}_k^{x} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^{x} + \ldots + {}^{EP}\mu_{\sigma(p)}^{x} \\ {}^{EP}\bar{\mu}_{\sigma(1)}^{x} + \ldots + {}^{EP}\bar{\mu}_{\sigma(p)}^{x} \end{bmatrix} \right)$$

*4.2.2 Postulate*

$$\forall x \in Z_N \forall k \in S_{\omega(x)}\ \exists \tau \in P \exists q \in Z^+ \left( \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{NP}\mu_{\tau(q)}^{x+1} \\ {}^{NP}\bar{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{NP}\bar{\mu}_{\tau(q)}^{x+1} \end{bmatrix} \right)$$

Postulate 4.2.1 means that an extended particlelike *phase* quantum ${}^{EP}\varphi_k^x$ in the world is *always* a superposition of finitely many particlelike *matter* quanta ${}^{EP}\mu_i^x$. The distinguishability of extended particlelike phase quanta among the existing phases is thus a direct consequence of the locality and the boundedness of the spatial extension of the extended particlelike matter quanta. It is emphasized that if two or more extended particlelike matter quanta form an extended particlelike phase quantum, then these matter quanta are centered at different positions, cf. figure 4.1 for an illustration. Postulate 4.2.2 is similar to postulate 4.2.1 in that it means that every nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ in the world is composed of finitely many nonextended particlelike matter quanta ${}^{NP}\mu_j^{x+1}$.

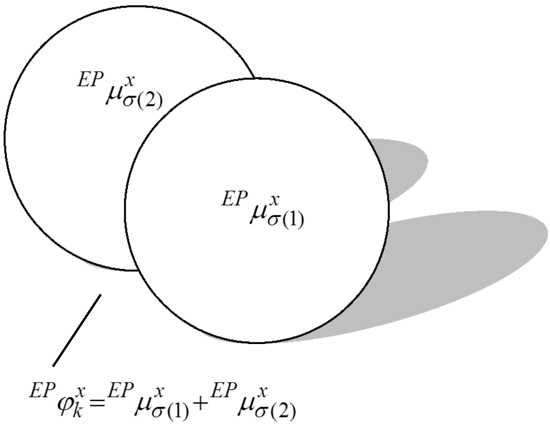


*Figure 4.1: schematic illustration of the idea of an extended particlelike phase quantum ${}^{EP}\varphi_k^x$, composed of two extended particlelike matter quanta ${}^{EP}\mu_{\sigma(1)}^x$ and ${}^{EP}\mu_{\sigma(2)}^x$; these matter quanta cannot be seen as separate phase quanta (consider the case of a deuterium nucleus, composed of a proton and a neutron, cf. 4.2.20).*

*4.2.3 Postulate*

$$\forall\, x\in Z_N \forall k\in S_{\omega(x)} \left( \begin{bmatrix} {}^{\alpha}\varphi_k^x \\ {}^{\alpha}\bar{\varphi}_k^x \end{bmatrix} \in M_E \Leftrightarrow \begin{bmatrix} {}^{\alpha}\varphi_k^x \\ {}^{\alpha}\bar{\varphi}_k^x \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix} \right) \quad \text{for } \alpha = EP, NW, LW, NP, \text{ or } S$$

*4.2.4 Postulate*

$$\begin{bmatrix} x \\ \bar{x} \end{bmatrix} + \begin{bmatrix} x \\ \bar{x} \end{bmatrix} \notin M_E \qquad \text{for any } \begin{bmatrix} x \\ \bar{x} \end{bmatrix} \in M$$

□

*4.2.5 Postulate*

$$\begin{bmatrix} \varphi_1 \\ \bar{\varphi}_1 \end{bmatrix} \in M_E \wedge \ldots \wedge \begin{bmatrix} \varphi_n \\ \bar{\varphi}_n \end{bmatrix} \in M_E \Leftrightarrow \begin{bmatrix} \varphi_1 \\ \bar{\varphi}_1 \end{bmatrix} + \ldots + \begin{bmatrix} \varphi_n \\ \bar{\varphi}_n \end{bmatrix} \in M_E$$

for any $n$ different nonzero generators $\begin{bmatrix} \varphi_i \\ \bar{\varphi}_i \end{bmatrix}$ of the type $\begin{bmatrix} {}^{\alpha}\varphi_k^x \\ {}^{\alpha}\bar{\varphi}_k^x \end{bmatrix}$. □

The postulates 4.2.3, 4.2.4, and 4.2.5 concern the existence predicate. Postulate 4.2.3, which is a scheme of five formulas, just means that any existing component, consisting of a phase quantum in world and a phase quantum in the antiworld, differs from physical emptiness. Postulate 4.2.4, which is a scheme of formulas, asserts that no component exists which is a superposition of that component and itself. Postulate 4.2.5, which is a finite scheme, asserts that if each of $n$ different components, consisting of phase quanta in world and antiworld, exists, then their superposition exists.

*4.2.6 Corollary*

$M_E \neq M$

*Proof*:

Consider any element $\begin{bmatrix} x \\ \bar{x} \end{bmatrix} \in M_E$. On account of 4.1.3/(vi), then also $\begin{bmatrix} x \\ \bar{x} \end{bmatrix} \in M$. On account of postulate 4.2.4, $\begin{bmatrix} x \\ \bar{x} \end{bmatrix} + \begin{bmatrix} x \\ \bar{x} \end{bmatrix} \notin M_E$. However, $\begin{bmatrix} x \\ \bar{x} \end{bmatrix} + \begin{bmatrix} x \\ \bar{x} \end{bmatrix} \in M$, because $M$ is a monoid. Thus, $M_E \neq M$. □

*4.2.7 Corollary*

$\begin{bmatrix} 0 \\ 0 \end{bmatrix} \notin M_E$

*Proof*:

Because $\begin{bmatrix} 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$, this follows directly from postulate 4.2.4. □

Before introducing the axioms, it is reiterated that expressions $\begin{bmatrix} t_1 \\ \bar{t}_1 \end{bmatrix} : \begin{bmatrix} t_2 \\ \bar{t}_2 \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} t_3 \\ \bar{t}_3 \end{bmatrix}$ are formalized as a relation between $\begin{bmatrix} t_1 \\ \bar{t}_1 \end{bmatrix}$, $\begin{bmatrix} t_2 \\ \bar{t}_2 \end{bmatrix}$, and $\begin{bmatrix} t_3 \\ \bar{t}_3 \end{bmatrix}$, see Section 3.4. That is,

$$\begin{bmatrix} t_1 \\ \bar{t}_1 \end{bmatrix} : \begin{bmatrix} t_2 \\ \bar{t}_2 \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} t_3 \\ \bar{t}_3 \end{bmatrix} \Leftrightarrow \langle \begin{bmatrix} t_1 \\ \bar{t}_1 \end{bmatrix}, \begin{bmatrix} t_2 \\ \bar{t}_2 \end{bmatrix}, \begin{bmatrix} t_3 \\ \bar{t}_3 \end{bmatrix} \rangle \in R \tag{4.8}$$

for some set $R \subseteq M \times M \times M$. As a set, the ternary relation $R$ on $M$ is completely determined by the elementary principles of the EPT: a separate definition of $R$ is therefore omitted.

*4.2.8 Axiom* (*Elementary principle of nonlocal equilibrium*)

$\forall x \in Z_N \forall k \in S_{\omega(x)} \left( \begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\varphi_k^{\bar{x}} \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\varphi_k^{\bar{x}} \end{bmatrix} \right)$

*4.2.9 Interpretation rule*

The elementary principle of nonlocal equilibrium means that at every degree of evolution $x$ and in every process from that $x^{\text{th}}$ degree of evolution to the next, an equilibrium occurs between the components $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix}$ and $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix}$, which is not mediated by any existing physical object, but occurs spontaneously. That is, when the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ exists in the world, then a discrete transition ${}^{EP}\varphi_k^x \to {}^{NW}\varphi_k^x$ occurs spontaneously in the world; this is accompanied by a discrete transition ${}^{NW}\bar{\varphi}_k^x \to {}^{EP}\bar{\varphi}_k^x$ in the antiworld. In every nonlocal equilibrium the genuinely new substance ${}^{NW}\varphi_k^x$ is created in the world: every instance of the principle 4.2.8 thus corresponds with an event causation – the transition ${}^{EP}\varphi_k^x \to {}^{NW}\varphi_k^x$ (an event) causes the existence of ${}^{NW}\varphi_k^x$. □

*4.2.10 Axiom* (*Elementary principle of nonlocal mediation*)

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} : \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} \right)$$

*4.2.11 Interpretation Rule*

The elementary principle of nonlocal mediation means that at every degree of evolution $x$ and in every process from that $x^{\text{th}}$ degree of evolution to the next, the component $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix}$ mediates an equilibrium between the components $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix}$ and $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix}$. That is, the phase quantum ${}^{NW}\varphi_k^x$ brings about a discrete transition ${}^{EP}\varphi_k^x \to {}^{NP}\varphi_k^{x+1}$ in the world, while the phase quantum ${}^{NW}\bar{\varphi}_k^x$ brings about a discrete transition ${}^{NP}\bar{\varphi}_k^{x+1} \to {}^{EP}\bar{\varphi}_k^x$ in the antiworld. Physically, in the world the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$, which evolved from the extended particlelike phase quantum ${}^{EP}\varphi_k^x$, collapses into a superposition of a finite number of nonextended particlelike matter quanta ${}^{NP}\mu_j^{x+1}$, which together form the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ occurring in the world at the (x+1)$^{\text{th}}$ degree of evolution in the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to $(x+1)^{\text{th}}$ degree of evolution. The function of the phase quantum ${}^{NW}\varphi_k^{x}$ is thus that it causes the transition from the phase quantum ${}^{EP}\varphi_k^{x}$ to the phase quantum ${}^{NP}\varphi_k^{x+1}$: every instance is thus an agent causation. □

By the collapse of the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^{x}$ the genuinely new substance ${}^{NP}\varphi_k^{x+1}$ = ${}^{NP}\mu_{\tau(1)}^{x+1} + ... + {}^{NP}\mu_{\tau(q)}^{x+1}$ is created in the world by a nonlocal mediation: if $q > 1$, then the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^{x}$ collapses into multiple nonextended particlelike matter quanta ${}^{NP}\mu_{\tau(j)}^{x+1}$ at different positions. In addition, the $q$ nonextended particlelike matter quanta ${}^{NP}\mu_{\tau(1)}^{x+1},...,{}^{NP}\mu_{\tau(q)}^{x+1}$ constituting the phase quantum ${}^{NP}\varphi_k^{x+1}$ have a different spatiotemporal location than the $p$ extended particlelike matter quanta ${}^{EP}\mu_{\sigma(1)}^{x},...,{}^{EP}\mu_{\sigma(p)}^{x}$ constituting the extended particlelike phase quantum ${}^{EP}\varphi_k^{x}$, from which the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^{x}$ originated. See figure 4.2 below for an illustration of the elementary principle of nonlocal mediation, using the case that both particlelike phase quanta involved (${}^{EP}\varphi_k^{x}$ and ${}^{NP}\varphi_k^{x+1}$) are composed of a single matter quantum (so that $p = q = 1$ and $\sigma(1) = \tau(1)$ in this case).

Given postulates 4.2.1 and 4.2.2, in a nonlocal mediation a component $\begin{bmatrix} {}^{NW}\varphi_k^{x} \\ {}^{NW}\bar{\varphi}_k^{x} \end{bmatrix}$ mediates an equilibrium between a component $\begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\bar{\varphi}_k^{x} \end{bmatrix}$, constituted of $p$ subcomponents $\begin{bmatrix} {}^{EP}\mu_{\sigma(i)}^{x} \\ {}^{EP}\bar{\mu}_{\sigma(i)}^{x} \end{bmatrix}$, and a component $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix}$, constituted of $q$ subcomponents

$\begin{bmatrix} {}^{NP}\mu_{\tau(j)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(j)}^{x+1} \end{bmatrix}$. The numbers $p$ and $q$ need not be identical: in case $p \neq q$ a nuclear reaction takes place in the world – all possible nuclear reactions are covered by the principle of nonlocal mediation. If no nuclear reaction takes place, then $p = q$ and $\{\sigma(1), \ldots, \sigma(p)\} = \{\tau(1), \ldots, \tau(q)\}$. Examples where $p \neq q$ will be given in the next sections.

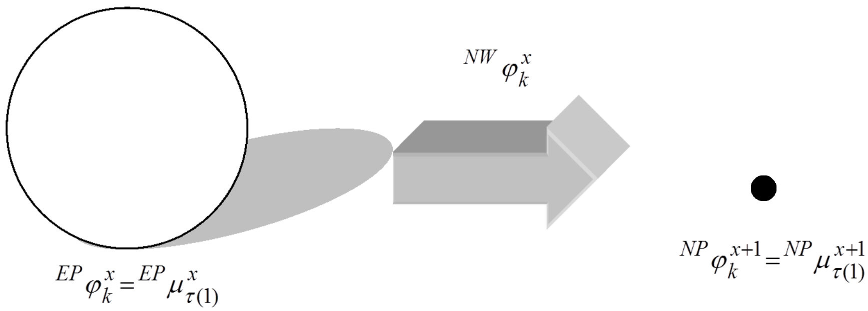


*Figure 4.2: schematic illustration of a nonlocal mediation, by which in the world the nonlocal phase quantum ${}^{NW}\varphi_k^x$ effects a discrete transition from the extended particlelike phase quantum ${}^{EP}\varphi_k^x$, composed of the single matter quantum ${}^{EP}\mu_{\tau(1)}^x$, to the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$, composed of the single matter quantum ${}^{NP}\mu_{\tau(1)}^{x+1}$. The matter quanta ${}^{EP}\mu_{\tau(1)}^x$ and ${}^{NP}\mu_{\tau(1)}^{x+1}$ have different spatiotemporal positions.*

*4.2.12 Axiom* (*Elementary principle of local equilibrium*)

$$\forall x \in Z_N \forall k \in S_{\omega(x)} \left( \begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} \right)$$

*4.2.13 Interpretation rule*

The elementary principle of local equilibrium means that at every degree of evolution $x$ and in every process from that $x^{\text{th}}$ degree of evolution to the next, an equilibrium occurs between the components $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix}$ and $\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\bar{\varphi}_k^{x+1} \end{bmatrix}$, which is not mediated by any existing physical object, but occurs spontaneously. That is, when the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ exists in the world, then a discrete transition ${}^{NP}\varphi_k^{x+1} \rightarrow {}^{LW}\varphi_k^{x+1}$ occurs spontaneously in the world, which has to be taken that ${}^{LW}\varphi_k^{x+1}$ is emitted; this is accompanied by a discrete transition ${}^{LW}\bar{\varphi}_k^{x+1} \rightarrow {}^{NP}\bar{\varphi}_k^{x+1}$ in the antiworld. □

With the sole exception of the case $x$+1 = 0, in a local equilibrium the genuinely new substance ${}^{LW}\varphi_k^{x+1}$ is created in the world: in all these cases the principle 4.2.12 thus corresponds with an event causation in the world, in which the discrete transition ${}^{NP}\varphi_k^{x+1} \rightarrow {}^{LW}\varphi_k^{x+1}$ (an event) causes the existence of ${}^{LW}\varphi_k^{x+1}$. The spatial extension of every such new local wavelike phase quantum then spreads out gradually, that is, with the speed of light. Thus, the principle of locality does hold for such an event: hence the adjective ‘local’ in the name of these phase quanta.

*4.2.14 Axiom* (*Elementary principle of local mediation*)

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \exists \tau \in P \exists q \in Z^{+} \left( \begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\bar{\varphi}_k^{x+1} \end{bmatrix} : \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{EP}\mu_{\tau(q)}^{x+1} \\ {}^{EP}\bar{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{EP}\bar{\mu}_{\tau(q)}^{x+1} \end{bmatrix} \right)$$

*4.2.15 Interpretation rule*

The elementary principle of local mediation means that at every degree of evolution $x$ and in every process from that $x^{\text{th}}$ degree of evolution to the next, the component $\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\bar{\varphi}_k^{x+1} \end{bmatrix}$ mediates an equilibrium between the components $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix}$ and

$\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + ... + {}^{EP}\overline{\mu}_{\tau(q)}^{x+1} \end{bmatrix}$. That is, the local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ causes a discrete transition ${}^{NP}\varphi_k^{x+1} \to {}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1}$ in the world, while the phase quantum ${}^{LW}\overline{\varphi}_k^{x+1}$ causes a transition ${}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + ... + {}^{EP}\overline{\mu}_{\tau(q)}^{x+1} \to {}^{NP}\overline{\varphi}_k^{x+1}$ in the antiworld. The function of the phase quantum ${}^{LW}\varphi_k^{x+1}$ is thus that it causes the transition from the phase quantum ${}^{NP}\varphi_k^{x+1} = {}^{NP}\mu_{\tau(1)}^{x+1} + ... + {}^{NP}\mu_{\tau(q)}^{x+1}$ to a superposition ${}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1}$ of $q$ extended particlelike matter quanta; every instant is thus an agent causation. □

*4.2.16 Definition*

$$\forall x \in Z_N \forall k \in S_{\omega(x+1)} \left( \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix} \in M_A \Leftrightarrow \begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} : \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} 0 \\ 0 \end{bmatrix} \right)$$

Definition 4.2.16 defines a property for generators $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix}$ of $M$ that are elements of a subset $M_A \subset M$; the designated components occur in annihilation reactions that are further described in Section 5.1. The mediation in definition 4.2.16 is to be called an annihilating mediation.

Except for the case that $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix} \in M_A$, by a local mediation the genuinely new substance ${}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1}$ is created in the world. The $q$ extended particlelike matter quanta ${}^{EP}\mu_{\tau(i)}^{x+1}$ then arise at the location of the $q$ nonextended particlelike matter quanta ${}^{NP}\mu_{\tau(i)}^{x+1}$ that make up the phase quantum ${}^{NP}\varphi_k^{x+1}$. That is, contrary to the case of a nonlocal mediation, in a local mediation no displacement occurs. It should be noted that in a local mediation the right subscript indices, occurring in the superposition of matter quanta ${}^{NP}\mu_{\tau(1)}^{x+1}+...+{}^{NP}\mu_{\tau(q)}^{x+1} = {}^{NP}\varphi_k^{x+1}$, are conserved in the superposition of the matter quanta ${}^{EP}\mu_{\tau(1)}^{x+1}+...+{}^{EP}\mu_{\tau(q)}^{x+1}$: the same monads remain involved. For an illustration of the principle of local mediation, see figure 4.3 below.

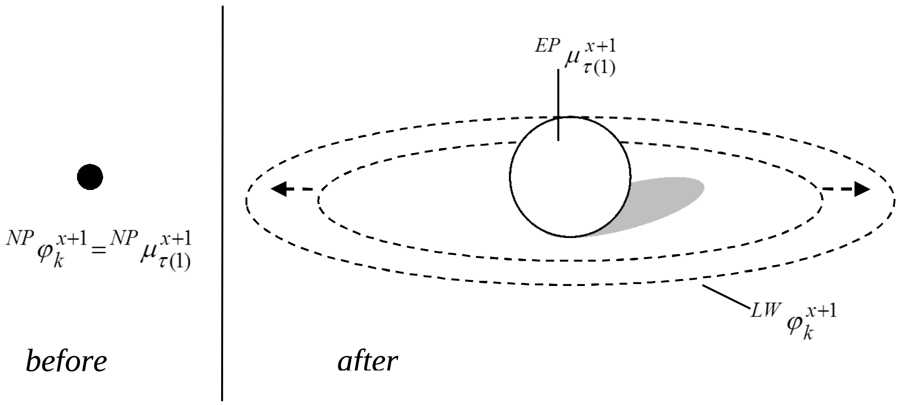


*Figure 4.3: schematic illustration of what happens in the world by a local mediation; to the left the nonextended particlelike phase quantum* ${}^{NP}\varphi_k^{x+1}$*, composed of one matter quantum* ${}^{NP}\mu_{\tau(1)}^{x+1}$*, is shown: this precedes the local mediation. To the right the extended particlelike matter quantum* ${}^{EP}\mu_{\tau(1)}^{x+1}$ *and the local wavelike phase quantum* ${}^{LW}\varphi_k^{x+1}$*, gradually spreading out in space, are shown: these exist áfter the local mediation. It has to be taken that the two matter quanta (before and after) occupy the same position.*

*4.2.17 Postulate*

$$\forall x \in Z_N\ \forall j \in Z^+ \exists l \in S_{\omega(x)} \exists \tau \in P \exists p \in Z^+ \left( \begin{bmatrix} {}^{EP}\mu_j^x \\ {}^{EP}\overline{\mu}_j^x \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix} \Rightarrow \right.$$

$$\left. \begin{bmatrix} {}^{EP}\mu_j^x \\ {}^{EP}\overline{\mu}_j^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^x \\ {}^{EP}\overline{\mu}_{\tau(1)}^x \end{bmatrix} \wedge \begin{bmatrix} {}^{EP}\varphi_l^x \\ {}^{EP}\overline{\varphi}_l^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^x + \ldots + {}^{EP}\mu_{\tau(p)}^x \\ {}^{EP}\overline{\mu}_{\tau(1)}^x + \ldots + {}^{EP}\overline{\mu}_{\tau(p)}^x \end{bmatrix} \right)$$

This postulates means that every physically nonzero matter quantum ${}^{EP}\mu_j^{x+1}$, created by a local mediation, occurs as a (possibly only) component of an extended particlelike phase quantum ${}^{EP}\varphi_l^{x+1}$. From there, the principle of nonlocal equilibrium applies and a new individual process starts (the $l^{\text{th}}$ individual process from the $(x+1)^{\text{th}}$ to the $(x+2)^{\text{th}}$ degree of evolution). It should be noted that the superposition $\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{EP}\mu_{\tau(q)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\tau(q)}^{x+1} \end{bmatrix}$, occurring in the elementary principle of local mediation, does not necessarily form a *single* phase quantum $\begin{bmatrix} {}^{EP}\varphi_l^{x+1} \\ {}^{EP}\overline{\varphi}_l^{x+1} \end{bmatrix}$ for some $l \in S_{\omega(x)}$. Special cases where said superposition does form a single phase quantum are treated in the next chapter.

Furthermore, it follows from the elementary principle of local mediation that a nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ precedes the superposition ${}^{EP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{EP}\mu_{\tau(q)}^{x+1}$ in the process of evolution in the world. In this context, it should be mentioned that in the period after Newton also others came forth with notions of entities preceding usual observable matter, such as for example the notion of ‘hylogeneous momenta’ by Von Helmholtz (1896) and the notion of ‘prematter’ by Sannikov (1978).

*4.2.18 Axiom* (*Elementary principle of formation of space*)

$$\forall x \in Z_{\mathrm{N}} \backslash \{N-2\} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} \in M_{\mathrm{E}} \Rightarrow \begin{bmatrix} {}^{S}\varphi_k^{x+2} \\ {}^{S}\overline{\varphi}_k^{x+2} \end{bmatrix} \in M_{\mathrm{E}} \right)$$

With the sole exception of the case $x+2 = 0$, by the formation of space the genuinely new substance ${}^{S}\varphi_k^{x+2}$ is formed from the phase quantum ${}^{LW}\varphi_k^{x+1}$, which has to be taken as the formation of space itself. The principle 4.2.18 thus determines a law of succession for the world, instances of which cannot be reduced to an event causation (it's a continuing process).

*4.2.19 Axiom* (*Elementary principle of identity of binades*)

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} \beta_k^x \\ \overline{\beta}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} + \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \right)$$

Given the interpretation rules 4.1.6, 4.1.11, 4.1.12, and 4.1.19, the physical meaning of axiom 4.2.19 is straightforward. The next example applies this elementary principle of identity of binads to relate the building blocks of the universe of the EPT to observed objects such as protons, neutrons, electrons, etc.

*4.2.20 Example*

All states of being of electrons, positrons, free[9] neutrons, free antineutrons, free protons, and free antiprotons are binads $\beta_k^x$, of which the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ is simple, i.e. composed of a single extended particlelike matter quantum ${}^{EP}\mu_i^x$. The state of being of a ${}^{10}_{5}B$ boron nucleus is a binad, of which the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ is composite, in this case composed of 10 extended particlelike matter quanta ${}^{EP}\mu_i^x$. The state of being of a ${}^{2}_{1}D$ deuterium nucleus is a binad, of which the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ is composite and composed of two extended particlelike matter quanta ${}^{EP}\mu_i^x$, cf. figure 4.1. □

[9] Free: not bound by the strong force, and not participating in a nuclear reaction.

*4.2.21 Theorem* (*principle of particle/wave duality of the EPT*):

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} \beta_k^x \\ \bar{\beta}_k^x \end{bmatrix} \in M_{\mathrm{E}} \Rightarrow \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \right)$$

*Proof*:

See appendix A. □

Theorem 4.2.21 asserts that without any exception both the particlelike component ${}^{EP}\varphi_k^x$ and the wavelike component ${}^{NW}\varphi_k^x$ of an existing binad $\beta_k^x$ exist. Loosely speaking, the particle/wave dualism of the EPT is thus that at any degree of evolution, the state of being of nonzero rest mass entities such as electrons, protons, and neutrons consists always of a particlelike state of rest and a wavelike state of motion. Because particlelike matter quanta have a definite position, theorem 4.2.21 thus asserts that an electron orbiting a nucleus has countably many times a definite position. Naturally, this also holds for all free protons, antiprotons, neutrons, and antineutrons: all have countably many times a definite position.

In this context it is interesting to mention that that in the philosophy of the Greek stoa in the 3rd century B.C. physical reality is ruled by a passive principle, which is matter, and an active principle, which is also part of the physical world.

Thus speaking, the states of being of an electron, e.g. one orbiting a nucleus, at consecutive degrees of evolution $x(1)$, $x(2)$, …, $x(n)$ are binads $\beta_{k(i)}^{x(i)}$, for which $\beta_{k(i)}^{x(i)} = {}^{EP}\varphi_{k(i)}^{x(i)} + {}^{NW}\varphi_{k(i)}^{x(i)} = {}^{EP}\mu_j^{x(i)} + {}^{NW}\varphi_{k(i)}^{x(i)}$: the right subscript index $j$ of the term ${}^{EP}\mu_j^{x(i)}$, which refers to the $j^{\text{th}}$ monad, is thus conserved. This conservation of the right subscript index allows an observer to say in existing language that these binads $\beta_{k(i)}^{x(i)}$ concern consecutive states of being of *one and the same* electron. Section 6.4 further addresses the question “what is an electron in the framework of the EPT?”; the same then holds for electrons, protons, neutrons and their antimatter counterparts.

*4.2.22 Remark (deduction rule)*

The general deduction rule

$$\begin{bmatrix} x \\ \bar{x} \end{bmatrix} \in M,\ \begin{bmatrix} y \\ \bar{y} \end{bmatrix} \notin M_{\mathrm{A}},\ \begin{bmatrix} z \\ \bar{z} \end{bmatrix} \neq \begin{bmatrix} {}^{LW}\varphi_1^0 \\ {}^{LW}\bar{\varphi}_1^0 \end{bmatrix},\ \begin{bmatrix} x \\ \bar{x} \end{bmatrix} : \begin{bmatrix} y \\ \bar{y} \end{bmatrix} \substack{\rightarrow \\ \leftarrow} \begin{bmatrix} z \\ \bar{z} \end{bmatrix} \vdash \begin{bmatrix} y \\ \bar{y} \end{bmatrix} \in M_{\mathrm{E}} \Leftrightarrow \begin{bmatrix} z \\ \bar{z} \end{bmatrix} \in M_{\mathrm{E}}$$

applies to all degrees of evolution and to all monoid elements $\begin{bmatrix} x \\ \bar{x} \end{bmatrix}$, $\begin{bmatrix} y \\ \bar{y} \end{bmatrix}$, and $\begin{bmatrix} z \\ \bar{z} \end{bmatrix}$.

The case $\begin{bmatrix} y \\ \bar{y} \end{bmatrix} \in M_{\mathrm{A}}$ is discussed in example 5.1.8; the case $\begin{bmatrix} z \\ \bar{z} \end{bmatrix} = \begin{bmatrix} {}^{LW}\varphi_1^0 \\ {}^{LW}\bar{\varphi}_1^0 \end{bmatrix}$ is discussed in Section 5.2.

*4.2.23 Axiom ( Elementary principle of choice)*

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} = \begin{bmatrix} f_C(\Theta_k^{x+1}) \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} \right)$$

*4.2.24 Interpretation rule*

The interpretation of principle 4.2.23 is that every nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$, occurring in the world at the $(x+1)^{\mathrm{th}}$ degree of evolution in the $k^{\mathrm{th}}$ process from the $x^{\mathrm{th}}$ to the $(x+1)^{\mathrm{th}}$ degree of evolution, is a choice of parallel possible phase quanta.

*4.2.25 Lemma* (*elementary choice lemma*)

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} {}^{NW}\varphi_k^{x} \\ {}^{NW}\bar{\varphi}_k^{x} \end{bmatrix} : \begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\bar{\varphi}_k^{x} \end{bmatrix} \substack{\rightarrow \\ \leftarrow} \begin{bmatrix} f_C(\Theta_k^{x+1}) \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} \right)$$

*Proof*:

Lemma 4.2.25 follows from the elementary principle of nonlocal mediation 4.2.10 and the elementary principle of choice 4.2.23 by substitution. □

The elementary choice lemma 4.2.25 explicates that the choice in question is made in a nonlocal mediation by the collapse of the nonlocal wavelike phase quantum

${}^{NW}\varphi_k^x$, that has an internal time-direction in the direction of evolution. Each such choice thus corresponds with an *irreducible* agent causation: the agent, that is, the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$, effects the transition from the initial extended particlelike phase quantum ${}^{EP}\varphi_k^x$ at spatiotemporal position *X* to the non-extended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ at the *chosen* spatiotemporal position *Y*. Assuming the elementary principle of choice means that the ideas of a deterministic universe, which can be traced back to Democritus (± 460 – 370 B.C), and of a probabilistic universe have to be rejected.

*4.2.26 Example*

To illustrate the elementary choice lemma 4.2.25, let the following hold for the $k^{\text{th}}$ process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution:

$$\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^x \\ {}^{EP}\bar{\mu}_{\tau(1)}^x \end{bmatrix} \wedge \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \tag{4.9}$$

At the instant when the discrete transition ${}^{EP}\mu_{\tau(1)}^x \rightarrow {}^{NW}\varphi_k^x$ takes place – and this transition will certainly take place because of the elementary principle of nonlocal equilibrium 4.2.8 – the nonlocal wavelike phase quantum in the world ${}^{NW}\varphi_k^x$ has not yet collapsed. Thus, at said instant the collapse can still happen at every point of the spatial extension of the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$: every possible point of collapse now corresponds with a parallel possible nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ in the set $\Theta_k^{x+1}$. At the instant when the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ collapses, the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$, and thus the component $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix}$, is chosen; see figure 4.4 below for a schematic illustration.

*4.2.27 Remark (causal laws)*

The five principles of action 4.2.8, 4.2.10, 4.2.12, 4.2.14, and 4.2.18 are causal laws: all other causal laws are hereby rejected as invalid at the supersmall level. The elementary principle of identity of binads 4.2.19 and the elementary principle of choice 4.2.23 are not causal laws, but are still synthetic propositions.

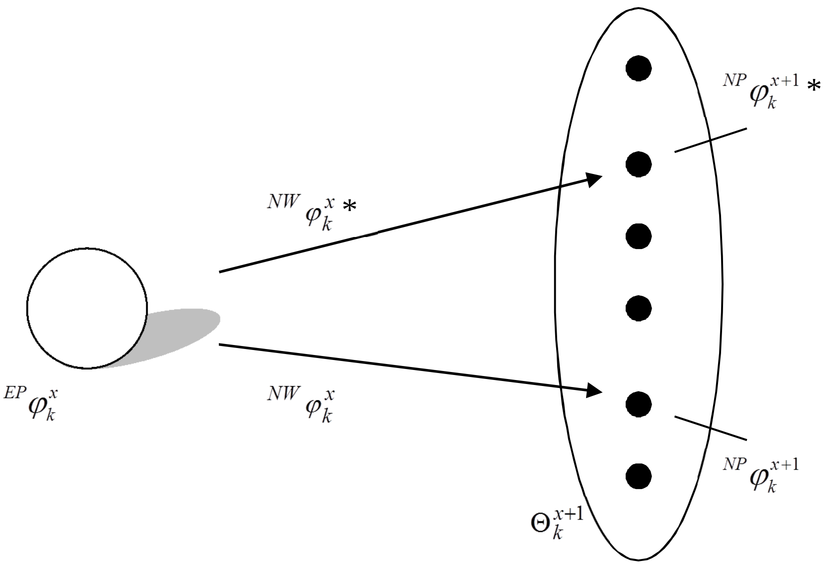


*Figure 4.4: schematic illustration of the elementary choice lemma. To the left, the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ is shown. To the right, the set $\Theta_k^{x+1}$ of parallel possible nonextended particlelike phase quanta is depicted as a Venn diagram; the dots represent elements of the set. The lower arrow indicates the action of the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$: of all parallel possible nonextended particlelike phase quanta, it causes the creation of ${}^{NP}\varphi_k^{x+1}$. The upper arrow indicates that* ***another*** *phase quantum ${}^{NW}\varphi_k^x*$ would have been required to cause the element ${}^{NP}\varphi_k^{x+1}*$ of $\Theta_k^{x+1}$ to come into existence. The phase quantum ${}^{NW}\varphi_k^x*$ can differ from the phase quantum ${}^{NW}\varphi_k^x$ in energy content and distribution. See also remark 4.3.7 on causal exclusion and causal closure in the next section.*

## 4.3 Metaphysics

The term ‘metaphysics’ is used here in its original Greek sense: this is the section that comes after the sections about physics. In this section, some propositions are presented *about* the EPT, that is, at the metalevel. It is, however, not the case that these propositions are conclusions $C$ that follow logically from a finite number of premises $P_1, \ldots, P_n$ as in $P_1, \ldots, P_n \vdash C$. That is, these propositions are not conclusions that are proven logically by *analytic* argumentation, but claims that are justified by *substantial* argumentation – this substantial argumentation is referred to by the term ‘substantiation’. As Toulmin and Habermas have pointed out, the difference is this: in analytical argumentation, the predicate that is affirmed of the subject in the conclusion is already contained in the premises, that is, the conclusion adds nothing new to the premises; in substantial argumentation, however, one starts with given data and arrives at a claim that is not entailed by the data – the claim adds something substantial to the data. Below, the framework of the EPT provides the data, that is, the formalism of the EPT, the axioms of the EPT and the interpretation rules are the given data.

*4.3.1 Proposition*

The EPT is in agreement with the general principle of relativity.

*Substantiation*:

The following four statements hold:

(i) a degree of evolution is the same for all observers;

(ii) the kind of form of a phase quantum is the same for all observers;

(iii) the elementary principles, laid down in the EPT, do not depend on the numbering of the individual processes by an observer;

(iv) the elementary principles, laid down in the EPT, do not depend on the numbering of the matter quanta by an observer.

From this it follows that the EPT is the same for all observers, and hence satisfies the general principle of relativity. □

Note that the clauses (i)-(iv) do not contain any restrictions regarding the position of the observers in space or time. The EPT is thus background-independent, that is, is the same always and everywhere.

*4.3.2 Proposition*

The EPT is conceptually coherent

*Substantiation*:

The concepts introduced for the physical interpretation of the EPT – phase quanta, matter quanta, discrete state transitions – form a coherent whole. It is, for example, not the case that one kind of phase quantum is a form of energy, while another kind of phase quantum is something completely different.

For contrast, consider the theory of evaporation of black holes (Hawking 1974). In this theory, Hawking borrows the concept of a black hole from the framework of GR, and the concept of a quantum fluctuation from the framework of QM: consequently, the theory cannot be called conceptually coherent (which, by the way, does *not* refute the theory!).

*4.3.3 Conjecture*

The EPT is logically consistent.

*Substantiation*:

There is no proof that Zermelo-Fraenkel set theory (ZF) is consistent; consequently, there is no proof that set matrix theory (SMT), which is a generalization of ZF, is consistent. Because the EPT is formalized within the framework of SMT, one can thus *at most* prove that the EPT is consistent *assuming that* SMT is consistent. In appendix B it is outlined how such a proof may be constructed. The universe of the EPT is finite, so the proof itself will be finite – which, by the way, does not mean that it will be short. It is emphasized, however, that appendix B contains only an *outline of* the proof, and *not* the actual proof: conjecture 4.3.3 is thus unproven. In further research, however, logical consistency of the EPT is assumed.

*4.3.4 Proposition*

The EPT is mathematically well-defined.

*Substantiation*:

The mathematical-logical framework of SMT is correctly defined in chapter 3, and the EPT is correctly formalized within this framework: all formulas of the EPT are well-formed formulas. The EPT is therefore mathematically well-defined.

*4.3.5 Proposition*

The EPT is physically complete.

*Substantiation*:

The EPT describes every individual process in the universe governed by the EPT: there are no other processes then those described by the EPT. The EPT is therefore physically complete. Consequently, in the universe governed by the EPT, there are no "deeper" principles that underlie the EPT: the elementary principles of the EPT are the first principles. Furthermore, the EPT describes the creation of every fundamental building block of this universe: it is thus not possible to produce less than a phase quantum in any experimental set up.

It should be noted, however, that this physical completeness does not make the EPT a "Theory Of Everything" (TOE)[10]. For example, it cannot be deduced from the EPT what a living organism is. From the point of view of the EPT, the idea of a TOE has to be rejected as a reductionistic illusion.

*4.3.6 Remark* (*designators*)

Individual constants of the EPT are defined without reference to any concrete mathematical structure, such as the space of all functions from the set $R^3$ to the set of complex numbers $C$. That is, simple constants of the EPT have as value 'a set',

[10] The term `Theory of Everything' refers to the reductionistic idea that there is an ultimate theory that can explain all phenomena ranging from elementary particle physics to, for example, mental disease. Difficulties with this concept are described in (Anderson 1972). So, one has to understand that a "theory of every thing" is not even remotely the same as a "Theory of Everything" (Laughlin & Pines 1978).

without that set further being specified. A crucial point is then that the formal objects, which occur in the axioms of the EPT, are *designators* of material objects, but not *representations* of the state of objects designated. Thus, from the formalism of the EPT it is clear to which component of the (physical) universe a given symbol refers, but mathematically that symbol does not represent the state of the material component in question. Compare the term ‘Downing Street 10, London UK’: it is obvious to which building this term refers, but the description contains no information about the size of the building, the number of floors, the type of roof, etc. As a result, the EPT has a higher degree of abstractness than QM and GR, where representations are used. For example, the quantum-mechanical wave function of an electron is a *representation* of its quantum state: it enables the calculation of the expectation values of position and momentum. This degree of abstractness adds a feature of generality to the EPT: the principles of the EPT apply to the components involved regardless of their position, mass, momentum, etc. In addition, at this degree of abstractness the principles of the EPT are of great simplicity.

*4.3.7 Remark* (*causal exclusion and closure*)
Having rejected the notion of a deterministic universe and the notion of a probabilistic universe on account of the elementary choice lemma 4.2.25, the universe governed by the EPT can thus be defined negatively as non-deterministic and non-probabilistic. However, a positive definition is also possible: the universe governed by the EPT is endowed with volition. This will be demonstrated in the application of the EPT to the mind-body problem in philosophy in Section 5.3.

The point here is that research on free will has yielded two metaphysical principles that are widely held: causal exclusion and causal closure. Causal exclusion can be formulated as follows: “no single event can have more than one sufficient cause occurring at any given time – unless it is a genuine case of causal overdetermination” (Kim 2005: 42). The other principle, causal closure, can be formulated as follows: “if a physical event has a cause that occurs at *t*, it has a physical cause that occurs at *t*” (Kim 2005: 42). Both these principles hold in the EPT at fundamental level. See for example figure 4.4: the lower arrow indicates that the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ causes the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ to come into existence: that could thus not have been brought about by *another* physical cause. Thus, if the amount of energy, distributed in ${}^{NW}\varphi_k^x$ would have been different, or would have been distributed otherwise, then (as indicated by the upper arrow in figure 4.4) *another* of the parallel possible nonextended particle phase quanta from the set $\Theta_k^{x+1}$ would have come into existence.

# 5

## APPLICATIONS

Section 5.1 formalizes a variety of observed physical processes in the framework of the EPT; Section 5.2 formalizes a theory of the Planck era of the universe in the framework of the EPT; finally, Section 5.3 applies the EPT to the mind-body problem in philosophy.

### 5.1 Formalization of observed processes in the framework of the EPT

*5.1.1 Definition*

The $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution is simple if and only if in this $k^{\text{th}}$ individual process the following expressions are true:

$$\begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^{x} + \ldots + {}^{EP}\mu_{\sigma(p)}^{x} \\ {}^{EP}\overline{\mu}_{\sigma(1)}^{x} + \ldots + {}^{EP}\overline{\mu}_{\sigma(p)}^{x} \end{bmatrix} \qquad \text{for some } \tau \in P,\ p \in Z^{+} \tag{5.1}$$

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x} + \ldots + {}^{EP}\mu_{\tau(p)}^{x} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x} + \ldots + {}^{EP}\overline{\mu}_{\tau(p)}^{x} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NW}\varphi_k^{x} \\ {}^{NW}\overline{\varphi}_k^{x} \end{bmatrix} \tag{5.2}$$

$$\begin{bmatrix} {}^{NW}\varphi_k^{x} \\ {}^{NW}\overline{\varphi}_k^{x} \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^{x} + \ldots + {}^{EP}\mu_{\sigma(p)}^{x} \\ {}^{EP}\overline{\mu}_{\sigma(1)}^{x} + \ldots + {}^{EP}\overline{\mu}_{\sigma(p)}^{x} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{NP}\mu_{\tau(p)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{NP}\overline{\mu}_{\tau(p)}^{x+1} \end{bmatrix} \wedge \sigma = \tau \tag{5.3}$$

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{NP}\mu_{\tau(p)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{NP}\overline{\mu}_{\tau(p)}^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} \tag{5.4}$$

$$\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{NP}\mu_{\tau(p)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{NP}\overline{\mu}_{\tau(p)}^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{EP}\mu_{\tau(p)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\tau(p)}^{x+1} \end{bmatrix} \tag{5.5}$$

Here the formulas (5.1)-(5.5) are instants of the elementary principles of nonlocal equilibrium (4.2.8), of nonlocal mediation (4.2.10), of local equilibrium (4.2.12), and of local mediation (4.2.14), respectively. Furthermore,

$$\begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{NP}\mu_{\tau(p)}^{x+1} \\ {}^{NP}\bar{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{NP}\bar{\mu}_{\tau(p)}^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} \tag{5.6}$$

in formula (5.3).□

In a simple individual process no nuclear reactions take place; this property is captured in expression (5.3) by conserving the right subscript index of the matter quanta; if a nuclear reaction takes place, these subscript indices are not conserved (see below for examples). All motion under the influence of long-distance interactions is due to simple processes, regardless whether gravitational or electromagnetic aspects are predominant. A simple individual process can, of course, be succeeded by a new simple individual process. In that case, the superposition emerging from the local mediation (5.5), $\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{EP}\mu_{\tau(p)}^{x+1} \\ {}^{EP}\bar{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{EP}\bar{\mu}_{\tau(p)}^{x+1} \end{bmatrix}$, satisfies for some positive integer $l \in S_{\omega(x+1)}$ the identity $\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{EP}\mu_{\tau(p)}^{x+1} \\ {}^{EP}\bar{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{EP}\bar{\mu}_{\tau(p)}^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{EP}\varphi_l^{x+1} \\ {}^{EP}\bar{\varphi}_l^{x+1} \end{bmatrix}$, while the expressions (5.1)/(5.5) then hold for the $l^{\text{th}}$ individual process from the $(x+1)^{\text{th}}$ to the $(x+2)^{\text{th}}$ degree of evolution.

*5.1.2 Definition*

The $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution is a simplest individual process if and only if this $k^{\text{th}}$ individual process is a simple individual process for which the following expression is true:

$$\begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\bar{\varphi}_k^{x} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_i^{x} \\ {}^{EP}\bar{\mu}_i^{x} \end{bmatrix} \quad \text{for some } i \in Z^{+} \tag{5.7}$$

This is a special case of (5.1), meaning that in the simplest individual processes the extended particlelike phase quantum in the world ${}^{EP}\varphi_k^{x}$ is simple, that is, composed of only a single extended particlelike matter quantum ${}^{EP}\mu_i^{x}$.□

To sketch what happens in the world during a simplest process, let's assume that the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution is a simplest individual process; the starting point is the component $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_i^x \\ {}^{EP}\overline{\mu}_i^x \end{bmatrix}$, cf. formula (5.7). The extended particlelike matter quantum has an observable spatiotemporal position, say, *X*. In this individual process, in the world first spontaneously a discrete transition ${}^{EP}\mu_i^x \to {}^{NW}\varphi_k^x$ takes place, cf. formula (5.2) with $p = 1$, whereby the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ comes into existence. In the antiworld, then the discrete transition ${}^{NW}\overline{\varphi}_k^x \to {}^{EP}\overline{\mu}_i^x$ has happened. Next, in this individual process in the world the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ collapses after a finite amount of time into a nonextended particlelike matter quantum ${}^{NP}\mu_i^{x+1}$, thus in effect bringing about a transition from ${}^{EP}\mu_i^x$ to ${}^{NP}\mu_i^{x+1}$; the right subscript index *i* is preserved in this latter transition. In the antiworld then the opposite has happened in accordance with the elementary principle 4.2.10. Finally, in this individual process in the world the local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ is emitted from the nonextended particlelike matter quantum ${}^{NP}\mu_i^{x+1}$, which immediately brings about the discrete transition ${}^{NP}\mu_i^{x+1} \to {}^{EP}\mu_i^{x+1}$. The extended particlelike phase quantum ${}^{EP}\mu_i^{x+1}$, formed in this last phase of the individual process, has then an observable spatiotemporal position *Y*. In the antiworld then the opposite has happened in accordance with the elementary principles 4.2.12 and 4.2.14.

This individual process has then brought about the stepwise motion from the extended particlelike matter quantum ${}^{EP}\mu_i^x$ at position *X* to the extended particlelike matter quantum ${}^{EP}\mu_i^{x+1}$ at position *Y*. For an observer, who himself is subjected to the same individual processes, this is observed as the motion of, say, and electron from $X$ to $Y$. Two factors have then contributed to the change in observable position $\Delta X = X - X$:

(i) the displacement effected by the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$;

(ii) an intermediate change of the state of the vacuum by the formation of spatial phase quanta.

The surroundings of such a process are a two-phased heterogeneous vacuum: one phase is a curved space composed of spatial and nonlocal wavelike phase quanta, the second phase is carried by the first and composed of local wavelike phase quanta. In such a simplest process then a long-distance interaction takes place having gravitational and electromagnetic aspects: the principle of the gravitational aspect is that the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ interacts with the curved space in the sense that the displacement $\Delta X$ depends on the metric of the curved space (the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ "sees" the metric) and simultaneously the metric of the curved space depends on the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$; the principle of the electromagnetic aspect is that the displacement $\Delta X$ depends on the state of the second phase of the vacuum (the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ "sees" the field of local wavelike phase quanta) and on the intermediate change of state of the vacuum.

*5.1.3 Definition*

The $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution is complex if and only if it is not simple. □

Suppose, for some $\sigma, \tau \in P$, that the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution starts with a component $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^x + \ldots + {}^{EP}\mu_{\sigma(p)}^x \\ {}^{EP}\overline{\mu}_{\sigma(1)}^{x} + \ldots + {}^{EP}\overline{\mu}_{\sigma(p)}^{x} \end{bmatrix}$,

and suppose that in this $k^{\text{th}}$ individual process the nonlocal mediation yields a component $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + \ldots + {}^{NP}\mu_{\tau(q)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + \ldots + {}^{NP}\overline{\mu}_{\tau(q)}^{x+1} \end{bmatrix}$. If the individual process is complex, then the number ($p$) of subcomponents $\begin{bmatrix} {}^{EP}\mu_{\sigma(i)}^{x} \\ {}^{EP}\overline{\mu}_{\sigma(i)}^{x} \end{bmatrix}$ of the component $\begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix}$ is not necessarily the same as the number ($q$) of subcomponents $\begin{bmatrix} {}^{NP}\mu_{\tau(j)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(j)}^{x+1} \end{bmatrix}$ of the component $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\overline{\varphi}_k^{x+1} \end{bmatrix}$. In any complex individual process, the following holds for the right subscript indices of these components:

$$\{\sigma(1), \ldots, \sigma(p)\} \cap \{\tau(1), \ldots, \tau(q)\} = \varnothing \tag{5.8}$$

That is, the extended particlelike matter quanta ${}^{EP}\mu_{\sigma(i)}^{x}$, entering a complex individual process, and the extended particlelike matter quanta ${}^{EP}\mu_{\tau(j)}^{x+1}$, formed in a complex individual process, do not concern the same monads.

### *5.1.4 Example (electron in an electron shell)*

A sequence of the simplest processes applies to any electron orbiting any atomic nucleus in the world. The states of being of the electron at $n$ consecutive degrees of evolution $x$, $x$+1, …, $x$+$n$–1 are then designated by the $n$ corresponding binads $\beta_{k(1)}^{x}$, …, $\beta_{k(n)}^{x+n-1}$, for which the identity 4.2.19 is valid. Here the right subscript index $k(j)$ has not necessarily the same value for every value of $j$, because the successor of the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution is not necessarily the $k^{\text{th}}$ individual process from the $(x+1)^{\text{th}}$ to the $(x+2)^{\text{th}}$ degree of evolution.

Because of (5.7), for these $n$ binads the following holds for some $i \in Z^+$:

- $\beta_{k(1)}^{x} = {}^{EP}\mu_i^{x} + {}^{NW}\varphi_{k(1)}^{x}$
- $\beta_{k(2)}^{x+1} = {}^{EP}\mu_i^{x+1} + {}^{NW}\varphi_{k(2)}^{x+1}$

and so forth. Thus, the right subscript $i$ of ${}^{EP}\mu_i^{x}$ is conserved in a sequence of simple processes to indicate that the $n$ binads concern states of being of *one and the same* electron. Section 6.4 further elaborates on the question: what is an electron in the framework of the EPT?

The equation $\beta_{k(1)}^{x} = {}^{EP}\mu_{i}^{x} + {}^{NW}\varphi_{k(1)}^{x}$ then reads: the binad occurring in the world in the $k(1)^{th}$ individual process from the $x^{th}$ to the $(x+1)^{th}$ degree of evolution consists of the extended particlelike matter quantum concerning the $i^{th}$ monad at the $x^{th}$ degree of evolution and the nonlocal wavelike phase quantum occurring in the world at the $x^{th}$ degree of evolution in that individual process. Thus speaking, in this sequence of simplest processes the electron orbiting an atomic nucleus has consecutively $n$ definite positions $X_x$, $X_{x+1}$, …, $X_{x+n-1}$: these are the positions where the $n$ extended particlelike matter quanta ${}^{EP}\mu_{i}^{x+j}$ for $j = 0$ to $n-1$ happen to find themselves. □

*5.1.5 Example (free neutron gravitating towards earth)*

A sequence of the simplest processes also applies to any free neutron gravitating towards earth. Similarly to the previous example, a sequence of $p$ consecutive binads $\beta_{l(1)}^{y}$, …, $\beta_{l(p)}^{y+p-1}$ then designates the states of being of the neutron at $p$ consecutive degrees of evolution $y$, $y+1$, …, $y+p-1$. To these $p$ binads the following equations apply for some $j \in Z^{+}$:

- $\beta_{l(1)}^{y} = {}^{EP}\mu_{j}^{y} + {}^{NW}\varphi_{l(1)}^{y}$
- $\beta_{l(2)}^{y+1} = {}^{EP}\mu_{j}^{y+1} + {}^{NW}\varphi_{l(2)}^{y+1}$

and so forth. In the process of gravitating towards earth, the neutron then has $p$ consecutive definite positions $Y_y$, $Y_{y+1}$, …, $Y_{y+p-1}$ corresponding with the $p$ extended particlelike matter quanta ${}^{EP}\mu_{j}^{y}$, …, ${}^{EP}\mu_{j}^{y+p-1}$. □

Comparing the last two examples, the $n$ binads $\beta_{k(1)}^{x}$, …, $\beta_{k(n)}^{x+n-1}$ will be very different from the $p$ binads $\beta_{l(1)}^{y}$, …, $\beta_{l(p)}^{y+p-1}$, and the $n-1$ leaps between the $n$

consecutive positions $X_x$, $X_{x+1}$, …, $X_{x+n-1}$ will be very different from the $p$–1 leaps between the $p$ consecutive positions $Y_y$, $Y_{y+1}$, …, $Y_{y+p-1}$. The point is, however, that the elementary principles of action are exactly the same for both processes. That is, at the degree of abstractness of the EPT, there is absolutely no difference between an electron orbiting an atom and a neutron gravitating towards earth: all simplest processes are the same.

*5.1.6 Remark (photons)*

In any sequence of simplest individual processes, the nonzero rest mass entity has a spatial momentum in the world when leaping from the $j^{\text{th}}$ to the $(j+1)^{\text{th}}$ position. Being motionless, the nonextended particlelike matter quantum at the $(j+1)^{\text{th}}$ position has no spatial momentum. The aforementioned spatial momentum is then conserved by a photon: photons are local wavelike matter quanta, that occur in the world in local wavelike phase quanta. Assuming that the $k^{\text{th}}$ individual process at the $x^{\text{th}}$ degree of evolution is a simplest individual process, the component $\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix}$ is then a superposition

$$\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} = \begin{bmatrix} \gamma_k^{x+1} \\ \overline{\gamma}_k^{x+1} \end{bmatrix} + \begin{bmatrix} \xi_k^{x+1} \\ \overline{\xi}_k^{x+1} \end{bmatrix} \tag{5.9}$$

where $\gamma_k^{x+1}$ is the photon emitted in the $k^{\text{th}}$ individual process at the $x^{\text{th}}$ degree of evolution, and $\xi_k^{x+1}$ is another local wavelike matter quantum emitted in this process. The latter local wavelike matter quantum is connected with the conservation of rest mass, see remark 6.3.4 for further comments.

*5.1.7 Example (decay of a neutron)*

To formalize the decay of a neutron in the framework of the EPT, it is first necessary to define the notion of a protonic/electronic/neutronic monad: as an indivualized set of properties, a monad is protonic/electronic/neutronic if and only the properties of the monad manifest themselves in observable properties of binads that are typical for states of beings of protons/electrons/neutrons. At this point it is not important *which* properties that are: it only matters *that* there are protonic, electronic and neutronic monads – the next chapters discusses the properties.

Proceeding, let, for some $\sigma$, $\tau \in P$, the $\sigma(1)^{\text{th}}$ monad be a neutronic monad, the $\tau(1)^{\text{th}}$ a protonic monad, the $\tau(2)^{\text{th}}$ an electronic monad, and let (5.8) hold for $p = 1$ and $q = 2$. Let the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution be determined by the following:

$$\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^x \\ {}^{EP}\overline{\mu}_{\sigma(1)}^x \end{bmatrix} \tag{5.10}$$

$$\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^x \\ {}^{EP}\overline{\mu}_{\sigma(1)}^x \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + {}^{NP}\mu_{\tau(2)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{NP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} \tag{5.11}$$

$$\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + {}^{NP}\mu_{\tau(2)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{NP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + {}^{EP}\mu_{\tau(2)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{EP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} \tag{5.12}$$

In this process, in the world the extended particlelike matter quantum ${}^{EP}\mu_{\sigma(1)}^x$, that concerns a neutronic monad, has decayed in a superposition ${}^{EP}\mu_{\tau(1)}^{x+1} + {}^{EP}\mu_{\tau(2)}^{x+1}$ of two extended particlelike matter quanta, that concern a protonic monad and an electronic monad. This individual process can then be succeeded by two simplest individual processes, the starting points of which are the components $\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} \end{bmatrix}$ and $\begin{bmatrix} {}^{EP}\mu_{\tau(2)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix}$ in accordance with (5.7).

In the individual process described above in the world a decay of a neutron occurs according to the decay reaction $n \rightarrow p^+ + e^- + \nu$ as originally proposed by Wolfgang Pauli (1930). The neutrino $\nu$ is a local wavelike matter quantum, that exists in the local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ emitted in this process:

$$\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} = \begin{bmatrix} \nu_k^{x+1} \\ \overline{\nu}_k^{x+1} \end{bmatrix} + \begin{bmatrix} \gamma_k^{x+1} \\ \overline{\gamma}_k^{x+1} \end{bmatrix} + \begin{bmatrix} \xi_k^{x+1} \\ \overline{\xi}_k^{x+1} \end{bmatrix} \tag{5.13}$$

Here $\nu_k^{x+1}$ designates the neutrino in the world; for the other components, see remarks 5.1.6 and 6.3.4.

*5.1.8 Example (annihilation of a proton/antiproton pair)*

For some $\sigma$, $\tau \in P$, let the $\sigma(1)^{\text{th}}$ monad be a protonic monad, the $\sigma(2)^{\text{th}}$ an antiprotonic monad, and let (5.8) hold for $p$ = 2 and $q$ = 1. Let the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution be determined by the following:

$$\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^x + {}^{EP}\mu_{\sigma(2)}^x \\ {}^{EP}\bar{\mu}_{\sigma(1)}^x + {}^{EP}\bar{\mu}_{\sigma(2)}^x \end{bmatrix} \tag{5.14}$$

$$\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^x + {}^{EP}\mu_{\sigma(2)}^x \\ {}^{EP}\bar{\mu}_{\sigma(1)}^x + {}^{EP}\bar{\mu}_{\sigma(2)}^x \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} \\ {}^{NP}\bar{\mu}_{\tau(1)}^{x+1} \end{bmatrix} \tag{5.15}$$

$$\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\bar{\varphi}_k^{x+1} \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} \\ {}^{NP}\bar{\mu}_{\tau(1)}^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{5.16}$$

In this individual process, in the world a proton and an antiproton are annihilated: such an annihilation process applies to any other pair of nonzero rest mass entities (such as electron/positron, neutron/antineutron, etc.).

The right subscript index $\tau(1)$ in the designator ${}^{NP}\mu_{\tau(1)}^{x+1}$ refers to a monad, which has the property that it immediately decays completely into a local wavelike phase quantum, cf. definition 4.2.16 with $\begin{bmatrix} {}^{NP}\varphi_k^{x+1} \\ {}^{NP}\bar{\varphi}_k^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} \\ {}^{NP}\bar{\mu}_{\tau(1)}^{x+1} \end{bmatrix}$. The annihilating mediation (5.16) is thus a special case of a local mediation, cf. axiom 4.2.14, with $q$ = 1 and $\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} \\ {}^{EP}\bar{\mu}_{\tau(1)}^{x+1} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$.

*5.1.9 Example (formation of deuterium)*

For some $\sigma$, $\tau \in P$, let the $\sigma(1)^{\text{th}}$ monad be a protonic monad, the $\sigma(2)^{\text{th}}$ a neutronic monad, the $\tau(1)^{\text{th}}$ a deuterium-protonic monad, and the $\tau(2)^{\text{th}}$ a deuterium- neutronic monad, and let (5.8) hold for $p$ = 2 and $q$ = 2. Let the $k^{\text{th}}$ individual process be determined by the following:

$$\begin{bmatrix} {}^{EP}\varphi_k^{x} \\ {}^{EP}\overline{\varphi}_k^{x} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^{x} + {}^{EP}\mu_{\sigma(2)}^{x} \\ {}^{EP}\overline{\mu}_{\sigma(1)}^{x} + {}^{EP}\overline{\mu}_{\sigma(2)}^{x} \end{bmatrix} \tag{5.17}$$

$$\begin{bmatrix} {}^{NW}\varphi_k^{x} \\ {}^{NW}\overline{\varphi}_k^{x} \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\sigma(1)}^{x} + {}^{EP}\mu_{\sigma(2)}^{x} \\ {}^{EP}\overline{\mu}_{\sigma(1)}^{x} + {}^{EP}\overline{\mu}_{\sigma(2)}^{x} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + {}^{NP}\mu_{\tau(2)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{NP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} \tag{5.18}$$

$$\begin{bmatrix} {}^{LW}\varphi_k^{x+1} \\ {}^{LW}\overline{\varphi}_k^{x+1} \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} + {}^{NP}\mu_{\tau(2)}^{x+1} \\ {}^{NP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{NP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + {}^{EP}\mu_{\tau(2)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{EP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} \tag{5.19}$$

In this individual process, in the world a proton and a neutron have formed a deuterium nucleus. This complex individual process is then succeeded by a simple individual process, say the $l^{\text{th}}$ individual process from the $(x+1)^{\text{th}}$ to the $(x+2)^{\text{th}}$ degree of evolution, for which $\begin{bmatrix} {}^{EP}\mu_{\tau(1)}^{x+1} + {}^{EP}\mu_{\tau(2)}^{x+1} \\ {}^{EP}\overline{\mu}_{\tau(1)}^{x+1} + {}^{EP}\overline{\mu}_{\tau(2)}^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{EP}\varphi_l^{x+1} \\ {}^{EP}\overline{\varphi}_l^{x+1} \end{bmatrix}$. The free neutrons and protons are different from (that is: concern other monads than) the neutrons and protons bound in deuterium nuclei, because their rest masses add up differently: the rest mass of a deuterium nucleus is different from the sum of the rest masses of a free proton and a free neutron. □

The variety of complex individual processes is far more extended than these examples, but these examples demonstrate that the EPT applies to various nuclear reactions. Other examples of complex processes will be given in the next section.

## 5.2 Theory of the Planck era of the universe

The theory of the Planck era of the universe will be given in the form of a sequence of formulas, describing events that follow one another in the direction of evolution. Every formula is either an assumption of the theory of the Planck era of the universe, or a corollary of a previous assumption and the EPT. The last formula of the sequence identifies a condensed matter field in a nonempty vacuum; technically, the sequence of formulas is a formal deduction of this last formula within the smallest axiomatic system containing the EPT.

*5.2.1 Assumption*

$$\begin{bmatrix} {}^{NP}\varphi_1^0 \\ {}^{NP}\overline{\varphi}_1^0 \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{NP}\varphi_1^0 \\ {}^{NP}\overline{\varphi}_1^0 \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_1^0 \\ {}^{NP}\overline{\mu}_1^0 \end{bmatrix}$$

The interpretation of assumption 5.2.1 is straightforward: initially the component $\begin{bmatrix} {}^{NP}\varphi_1^0 \\ {}^{NP}\overline{\varphi}_1^0 \end{bmatrix}$ exists, while the nonextended particlelike phase quantum ${}^{NP}\varphi_1^0$ is simple, and composed of the one nonextended particlelike matter quantum ${}^{NP}\mu_1^0$, that precedes the first monad. Following the convention of interpretation rule 4.1.13 strictly, ${}^{NP}\varphi_1^0$ is the nonextended particlelike phase quantum occurring in the world in the first (and only) process from the $(N–1)^{\text{th}}$ to the $0^{\text{th}}$ degree of evolution. This one process thus consists of the initial events succeeding the existence of the component $\begin{bmatrix} {}^{NP}\varphi_1^0 \\ {}^{NP}\overline{\varphi}_1^0 \end{bmatrix}$ – to be discussed in this paragraph – and events at a higher degree of evolution that lead back to the initial component $\begin{bmatrix} {}^{NP}\varphi_1^0 \\ {}^{NP}\overline{\varphi}_1^0 \end{bmatrix}$: these events at the higher degree of evolution will then take place at a later time than the initial events. In particular, the nonlocal mediation $\begin{bmatrix} {}^{NW}\varphi_1^{N-1} \\ {}^{NW}\overline{\varphi}_1^{N-1} \end{bmatrix} : \begin{bmatrix} {}^{EP}\varphi_1^{N-1} \\ {}^{EP}\overline{\varphi}_1^{N-1} \end{bmatrix} \underset{\leftarrow}{\rightarrow} \begin{bmatrix} {}^{NP}\varphi_1^0 \\ {}^{NP}\overline{\varphi}_1^0 \end{bmatrix}$ will take place at a later time. The degree of abstractness of the EPT thus enables one to state that it is certain that this mediation will happen, although it is now not known what the actual constitution of the component $\begin{bmatrix} {}^{EP}\varphi_1^{N-1} \\ {}^{EP}\overline{\varphi}_1^{N-1} \end{bmatrix}$ will be: the entries of the matrices are *designators*, not *representations*.

*5.2.2 Assumption*

$$\begin{bmatrix} {}^{LW}\varphi_1^0 \\ {}^{LW}\bar{\varphi}_1^0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

In this initial individual process at the $0^{\text{th}}$ degree of evolution, no local equilibrium takes place; the corresponding elementary principle of local equilibrium 4.2.12 is trivially true. It can be derived from this elementary principle that then a discrete transition ${}^{NP}\mu_1^0 \rightarrow 0$ takes place in the world – that is, nothing is emitted from the initial nonextended particlelike matter quantum ${}^{NP}\mu_1^0$.

*5.2.3 Corollary*

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_1^0 \\ {}^{NP}\bar{\mu}_1^0 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\bar{\mu}_1^0 \end{bmatrix}$$

*Proof*:

Corollary 5.2.3 follows from the elementary principle of local mediation 4.2.14 by universal quantifier elimination. The correct substitution values are given in assumption 5.2.2, and the right hand side of assumption 5.2.1. □

The interpretation of corollary 5.2.3 is that the local equilibrium between the components $\begin{bmatrix} {}^{NP}\mu_1^0 \\ {}^{NP}\bar{\mu}_1^0 \end{bmatrix}$ and $\begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\bar{\mu}_1^0 \end{bmatrix}$ is not mediated by any physical object (that is, by any nonzero component), but occurs spontaneously. Thus, in the world spontaneously a discrete transition ${}^{NP}\mu_1^0 \rightarrow {}^{EP}\mu_1^0$ takes place, and this is accompanied by a discrete transition ${}^{EP}\bar{\mu}_1^0 \rightarrow {}^{NP}\bar{\mu}_1^0$ in the antiworld.

*5.2.4 Corollary*

$$\begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\bar{\mu}_1^0 \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.4 follows from assumption 5.2.1 and corollary 5.2.3 by the general deduction rule 4.2.22. As a side note, the initial process does not involve an annihilation reaction of matter and antimatter, so that in this case $\begin{bmatrix} {}^{NP}\mu_1^0 \\ {}^{NP}\overline{\mu}_1^0 \end{bmatrix} \notin M_{\mathrm{A}}$. Throughout this paragraph, a similar argument remains valid for other cases where the deduction rule 4.2.22 is applied. □

*5.2.5 Corollary*

$$\begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\overline{\mu}_1^0 \end{bmatrix} = \begin{bmatrix} {}^{EP}\varphi_1^0 \\ {}^{EP}\overline{\varphi}_1^0 \end{bmatrix}$$

*Proof*:

Corollary 5.2.5 follows from corollary 5.2.3 and postulate 4.2.17. □

At this point a new individual process begins in the numbering of individual processes, so it has to be taken that $\omega(0) = 1$, so that $S_{\omega(0)} = \{1\}$, cf. definition 4.1.2.(iii). This means that there is one individual process from the $0^{\text{th}}$ to the $1^{\text{st}}$ degree of evolution.

*5.2.6 Corollary*

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\overline{\mu}_1^0 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\overline{\varphi}_1^0 \end{bmatrix}$$

*Proof*:

Corollary 5.2.6 follows from corollary 5.2.5, and the elementary principle of nonlocal equilibrium 4.2.8. □

In this one process from the $0^{\text{th}}$ to the $1^{\text{st}}$ degree of evolution, in the world thus spontaneously a discrete transition ${}^{EP}\varphi_1^0 \rightarrow {}^{NW}\varphi_1^0$ takes place, accompanied by a discrete transition ${}^{NW}\overline{\varphi}_1^0 \rightarrow {}^{EP}\overline{\varphi}_1^0$ in the antiworld.

*5.2.7 Corollary*

$$\begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\overline{\varphi}_1^0 \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.7 follows from corollaries 5.2.4 and 5.2.6, and the general deduction rule 4.2.22. □

The vacuum system in the world at the 0th degree of evolution is solely composed of the nonlocal wavelike phase quantum ${}^{NW}\varphi_1^0$. The suggested duration of the life-time of ${}^{NW}\varphi_1^0$ is a Planck-time, so from here on time comes into existence. There is no such thing as a metric in this early vacuum system.

*5.2.8 Corollary*

$$\begin{bmatrix} \beta_1^0 \\ \overline{\beta}_1^0 \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\overline{\mu}_1^0 \end{bmatrix} + \begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\overline{\varphi}_1^0 \end{bmatrix}$$

*Proof*:

Corollary 5.2.8 follows from corollary 5.2.5 and the elementary principle of identity of binads 4.2.19. □

From corollaries 5.2.4, 5.2.7, 5.2.8 and postulate 4.2.5 it follows that

$$\begin{bmatrix} \beta_1^0 \\ \overline{\beta}_1^0 \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\overline{\mu}_1^0 \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\overline{\varphi}_1^0 \end{bmatrix} \in M_{\mathrm{E}} \tag{5.20}$$

The principle of particle/wave duality, theorem 4.2.21, thus holds already at the 0th degree of evolution.

*5.2.9 Corollary*

$$\begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\overline{\varphi}_1^0 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\overline{\mu}_1^0 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\varphi_1^1 \\ {}^{NP}\overline{\varphi}_1^1 \end{bmatrix}$$

*Proof*:

Corollary 5.2.9 follows from corollary 5.2.5 and the elementary principle of non-local mediation 4.2.10. □

*5.2.10 Assumption*

$$\begin{bmatrix} {}^{NP}\varphi_1^1 \\ {}^{NP}\bar{\varphi}_1^1 \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1 \\ {}^{NP}\bar{\mu}_2^1 + {}^{NP}\bar{\mu}_3^1 + \ldots + {}^{NP}\bar{\mu}_{2K+1}^1 \end{bmatrix} \qquad \text{for some } K \in Z^+$$

*5.2.11 Remark (pre-protons, pre-electrons)*

Substituting assumption 5.2.10 in corollary 5.2.9 yields the formula

$$\begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\bar{\varphi}_1^0 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\bar{\mu}_1^0 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1 \\ {}^{NP}\bar{\mu}_2^1 + {}^{NP}\bar{\mu}_3^1 + \ldots + {}^{NP}\bar{\mu}_{2K+1}^1 \end{bmatrix} \tag{5.21}$$

The interpretation of (5.21) is that the component $\begin{bmatrix} {}^{NW}\varphi_1^0 \\ {}^{NW}\bar{\varphi}_1^0 \end{bmatrix}$ mediates an equilibrium between the components $\begin{bmatrix} {}^{EP}\mu_1^0 \\ {}^{EP}\bar{\mu}_1^0 \end{bmatrix}$ and $\begin{bmatrix} {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1 \\ {}^{NP}\bar{\mu}_2^1 + {}^{NP}\bar{\mu}_3^1 + \ldots + {}^{NP}\bar{\mu}_{2K+1}^1 \end{bmatrix}$. In the world, the nonlocal wavelike phase quantum ${}^{NW}\varphi_1^0$ thus collapses into the superposition ${}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1$ of $2K$ nonextended particlelike matter quanta ${}^{NP}\mu_i^1$, each at a different position. Here $K$ is a large integer, which Sannikov estimated in the order of magnitude of $10^{75}$ (personal communication). The $2K$ corresponding monads, i.e. the monads numbered 2, 3, 4, …, $2K$+1, then, for reasons to be explained below, concern $K$ pre-protonic monads and $K$ pre-electronic monads. The properties of these monads manifest themselves in properties of a composite binad, which in existing language would have to be called a state of being composed of pre-protons and pre-electrons, see further below corollary 5.2.19.□

*5.2.12 Corollary*

$$\begin{bmatrix} {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1 \\ {}^{NP}\bar{\mu}_2^1 + {}^{NP}\bar{\mu}_3^1 + \ldots + {}^{NP}\bar{\mu}_{2K+1}^1 \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.12 follows from corollaries 5.2.4, 5.2.9, assumption 5.2.10, and the general deduction rule 4.2.22. □

*5.2.13 Corollary*

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1 \\ {}^{NP}\overline{\mu}_2^1 + {}^{NP}\overline{\mu}_3^1 + \ldots + {}^{NP}\overline{\mu}_{2K+1}^1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{LW}\varphi_1^1 \\ {}^{LW}\overline{\varphi}_1^1 \end{bmatrix}$$

*Proof*:

Corollary 5.2.13 follows from assumption 5.2.10 and the elementary principle of local equilibrium 4.2.12. □

*5.2.14 Corollary*

$$\begin{bmatrix} {}^{LW}\varphi_1^1 \\ {}^{LW}\overline{\varphi}_1^1 \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.14 follows from corollaries 5.2.12, and 5.2.13, and the general deduction rule 4.2.22. □

At this point in the early universe, spatial phase quanta, that together with nonlocal wavelike phase quanta are to function as "carrier" for nonlocal wavelike phase quanta, do not yet exist. This first local wavelike phase quantum in the universe, ${}^{LW}\varphi_1^1$, therefore has its spatial extension immediately. Furthermore, because there is not yet such a thing as spatial momentum, the local wavelike phase quantum ${}^{LW}\varphi_1^1$ contains no photons.

*5.2.15 Corollary*

$$\begin{bmatrix} {}^{LW}\varphi_1^1 \\ {}^{LW}\overline{\varphi}_1^1 \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + \ldots + {}^{NP}\mu_{2K+1}^1 \\ {}^{NP}\overline{\mu}_2^1 + {}^{NP}\overline{\mu}_3^1 + \ldots + {}^{NP}\overline{\mu}_{2K+1}^1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu_2^1 + {}^{EP}\mu_3^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\overline{\mu}_2^1 + {}^{EP}\overline{\mu}_3^1 + \ldots + {}^{EP}\overline{\mu}_{2K+1}^1 \end{bmatrix}$$

*Proof*:

Corollary 5.2.15 follows from assumption 5.2.10 and the elementary principle of local mediation 4.2.14. □

*5.2.16 Corollary*

$$\begin{bmatrix} {}^{EP}\mu_2^1 + {}^{EP}\mu_3^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\mu_2^{-1} + {}^{EP}\mu_3^{-1} + \ldots + {}^{EP}\mu_{2K+1}^{-1} \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.16 follows from corollaries 5.2.12, 5.2.14, and 5.2.15, and the general deduction rule 4.2.22. □

*5.2.17 Assumption*

$$\begin{bmatrix} {}^{EP}\mu_2^1 + {}^{EP}\mu_3^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\mu_2^{-1} + {}^{EP}\mu_3^{-1} + \ldots + {}^{EP}\mu_{2K+1}^{-1} \end{bmatrix} = \begin{bmatrix} {}^{EP}\varphi_1^1 \\ {}^{EP}\varphi_1^{-1} \end{bmatrix}$$

Although all $2K$ extended particlelike matter quanta ${}^{EP}\mu_j^1$, formed in the one process from the $0^{\text{th}}$ to the $1^{\text{st}}$ degree of evolution, have a different position, there exists no real distance between the different matter quanta because the early vacuum has no metric. The $2K$ extended particlelike matter quanta ${}^{EP}\mu_j^1$ thus constitute a single extended particlelike phase quantum ${}^{EP}\varphi_1^1$, which is the starting point of the one process from the $1^{\text{st}}$ to the $2^{\text{nd}}$ degree of evolution. Thus speaking, it has to be taken that $\omega(1) = 1$, so that $S_{\omega(1)} = \{1\}$, cf. definition 4.1.3.(iii).

Furthermore, in the one process from the $0^{\text{th}}$ to the $1^{\text{st}}$ degree of evolution, the composite particlelike phase quantum ${}^{EP}\varphi_1^1$ has been formed out of the simple particlelike phase quantum ${}^{EP}\varphi_1^0$, but that initial phase quantum ${}^{EP}\varphi_1^0$ existed in an empty space with no surroundings: it is therefore best to label the chain of events in the world as a decay reaction (nuclear disintegration) due to intrinsic instability, rather than as a weak interaction.

*5.2.18 Corollary*

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_2^1 + {}^{EP}\mu_3^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\mu_2^{-1} + {}^{EP}\mu_3^{-1} + \ldots + {}^{EP}\mu_{2K+1}^{-1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NW}\varphi_1^1 \\ {}^{NW}\varphi_1^{-1} \end{bmatrix}$$

*Proof*:

Corollary 5.2.18 follows from corollary 5.2.16, assumption 5.2.17, and the elementary principle of nonlocal equilibrium 4.2.10. □

*5.2.19 Corollary*

$$\begin{bmatrix} {}^{NW}\varphi_1^1 \\ {}^{NW}\varphi_1^{-1} \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.19 follows from corollaries 5.2.16, corollary 5.2.18, and the general deduction rule 4.2.22. □

At this point the binad $\beta_1^1 = {}^{EP}\varphi_1^1 + {}^{NW}\varphi_1^1 = {}^{EP}\mu_2^1 + \ldots + {}^{EP}\mu_{2K+1}^1 + {}^{NW}\varphi_1^1$ is a state of being composed of $K$ pre-electrons and $K$ pre-protons. Since the matter quanta ${}^{EP}\mu_j^1$ form a single phase quantum ${}^{EP}\varphi_1^1$, these pre-electrons and pre-protons cannot be considered to be free electrons and free protons; the monads 2 to 2$K$+1 are therefore pre-electronic and pre-protonic monads, and not electronic and protonic monads. Together with the wavelike phase quanta ${}^{LW}\varphi_1^1$ and ${}^{NW}\varphi_1^1$, these matter quanta ${}^{EP}\mu_j^1$ form what can be called a “primordial soup”.

*5.2.20 Corollary*

$$\begin{bmatrix} {}^{S}\varphi_1^2 \\ {}^{S}\varphi_1^{-2} \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.20 follows from corollary 5.2.14 and the elementary principle of formation of space 4.2.18. □

Due to the fact that in the one process from the $0^{\text{th}}$ to the $1^{\text{st}}$ degree of evolution energy has been emitted in the form of the local wavelike phase quantum ${}^{LW}\varphi_1^1$, at the $2^{\text{nd}}$ degree of evolution space is formed. Thus, while time already existed, now also three dimensional space exists.

*5.2.21 Corollary*

$$\begin{bmatrix} {}^{NW}\varphi_1^1 \\ {}^{NW}\bar{\varphi}_1^1 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_2^1 + {}^{EP}\mu_3^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\bar{\mu}_2^1 + {}^{EP}\bar{\mu}_3^1 + \ldots + {}^{EP}\bar{\mu}_{2K+1}^1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\varphi_1^2 \\ {}^{NP}\bar{\varphi}_1^2 \end{bmatrix}$$

*Proof*:

Corollary 5.2.21 follows from the elementary principle of nonlocal mediation 4.2.10 and assumption 5.2.17. □

*5.2.22 Assumption*

$$\begin{bmatrix} {}^{NP}\varphi_1^2 \\ {}^{NP}\bar{\varphi}_1^2 \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_{2K+2}^2 + {}^{NP}\mu_{2K+3}^2 + \ldots + {}^{NP}\mu_{2K+L+1}^2 \\ {}^{NP}\bar{\mu}_{2K+2}^2 + {}^{NP}\bar{\mu}_{2K+3}^2 + \ldots + {}^{NP}\bar{\mu}_{2K+L+1}^2 \end{bmatrix}$$

Substituting assumption 5.2.22 in corollary 5.2.21 yields the formula

$$\begin{bmatrix} {}^{NW}\varphi_1^1 \\ {}^{NW}\bar{\varphi}_1^1 \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_2^1 + {}^{EP}\mu_3^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\bar{\mu}_2^1 + {}^{EP}\bar{\mu}_3^1 + \ldots + {}^{EP}\bar{\mu}_{2K+1}^1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{2K+2}^2 + \ldots + {}^{NP}\mu_{2K+L+1}^2 \\ {}^{NP}\bar{\mu}_{2K+2}^2 + \ldots + {}^{NP}\bar{\mu}_{2K+L+1}^2 \end{bmatrix} \tag{5.22}$$

The interpretation of formula (5.22) is that the component $\begin{bmatrix} {}^{NW}\varphi_1^1 \\ {}^{NW}\bar{\varphi}_1^1 \end{bmatrix}$ mediates an equilibrium between the component $\begin{bmatrix} {}^{EP}\mu_2^1 + \ldots + {}^{EP}\mu_{2K+1}^1 \\ {}^{EP}\bar{\mu}_2^1 + \ldots + {}^{EP}\bar{\mu}_{2K+1}^1 \end{bmatrix}$ and the component $\begin{bmatrix} {}^{NP}\mu_{2K+2}^2 + \ldots + {}^{NP}\mu_{2K+L+1}^2 \\ {}^{NP}\bar{\mu}_{2K+2}^2 + \ldots + {}^{NP}\bar{\mu}_{2K+L+1}^2 \end{bmatrix}$. Following interpretation rule 4.2.15, this entails that the nonlocal wavelike phase quantum ${}^{NW}\varphi_1^1$, which emerged from the superposition ${}^{EP}\mu_2^1 + \ldots + {}^{EP}\mu_{2K+1}^1$ of $2K$ extended particlelike matter quanta, has collapsed into the superposition ${}^{NP}\mu_{2K+2}^2 + \ldots + {}^{NP}\mu_{2K+L+1}^2$ of $L$ nonextended particlelike matter quanta. While the $2K$ monads 2, 3, …, $2K$+1 concerned $K$ pre-protonic and $K$ pre-electronic monads, the newly arisen matter quanta precede the $L$ monads numbered $2K$+2, …, $2K$+$L$+1 that concern $p$ protonic monads, $p$ electronic monads, and $q$ neutronic monads for which $2p + 2q = 2K$. At the positions of these $L$ nonextended particlelike matter quanta ${}^{NP}\mu_j^2$, there will thus appear extended particlelike phase quanta: these are states of rest, each of which is part of a state of being of a proton, electron or neutron (depending on whether the monad concerned is protonic, electronic, or neutronic).

*5.2.23 Corollary*

$$\begin{bmatrix} {}^{NP}\mu^2_{2K+2}+\ldots+{}^{NP}\mu^2_{2K+L+1} \\ {}^{NP}\bar{\mu}^2_{2K+2}+\ldots+{}^{NP}\bar{\mu}^2_{2K+L+1} \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.23 follows from corollaries 5.2.16, 5.2.21, assumption 5.2.22, and the general deduction rule 4.2.22. □

*5.2.24 Corollary*

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu^2_{2K+2}+\ldots+{}^{NP}\mu^2_{2K+L+1} \\ {}^{NP}\bar{\mu}^2_{2K+2}+\ldots+{}^{NP}\bar{\mu}^2_{2K+L+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{LW}\varphi^2_1 \\ {}^{LW}\bar{\varphi}^2_1 \end{bmatrix}$$

*Proof*:

Corollary 5.2.24 follows from assumption 5.2.22 and the elementary principle of local equilibrium 4.2.12. □

*5.2.25 Corollary*

$$\begin{bmatrix} {}^{LW}\varphi^2_1 \\ {}^{LW}\bar{\varphi}^2_1 \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

Corollary 5.2.25 follows from corollaries 5.2.23 and 5.2.24, and the general deduction rule 4.2.22. □

*5.2.26 Corollary*

$$\begin{bmatrix} {}^{LW}\varphi^2_1 \\ {}^{LW}\bar{\varphi}^2_1 \end{bmatrix} : \begin{bmatrix} {}^{NP}\mu^2_{2K+2}+\ldots+{}^{NP}\mu^2_{2K+L+1} \\ {}^{NP}\bar{\mu}^2_{2K+2}+\ldots+{}^{NP}\bar{\mu}^2_{2K+L+1} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{EP}\mu^2_{2K+2}+\ldots+{}^{EP}\mu^2_{2K+L+1} \\ {}^{EP}\bar{\mu}^2_{2K+2}+\ldots+{}^{EP}\bar{\mu}^2_{2K+L+1} \end{bmatrix}$$

*Proof*:

Corollary 5.2.26 follows from assumption 5.2.22 and the elementary principle of local mediation 4.2.14. □

*5.2.27 Corollary*

$$\left[\frac{{}^{EP}\mu_{2K+2}^{2}+\ldots+{}^{EP}\mu_{2K+L+1}^{2}}{{}^{EP-2}\mu_{2K+2}+\ldots+{}^{EP-2}\mu_{2K+L+1}}\right]=\left[\frac{{}^{EP}\varphi_{1}^{2}+\ldots+{}^{EP}\varphi_{\omega(2)}^{2}}{{}^{EP-2}\varphi_{1}+\ldots+{}^{EP-2}\varphi_{\omega(2)}}\right]$$

*Proof*:

Corollary 5.2.27 follows from postulate 4.2.17. □

Due to the existence of spatial phase quanta at the 2nd degree of evolution, cf. corollary 5.2.20, the superposition ${}^{EP}\mu_{2K+2}^{2}+\ldots+{}^{EP}\mu_{2K+L+1}^{2}$ of $L$ extended particlelike matter quanta, formed by the local mediation 5.2.26, no longer form a single phase quantum: instead, these $L$ matter quanta form $\omega(2)$ extended particlelike phase quanta ${}^{EP}\varphi_{j}^{2}$ that are now spatially separated. If $\omega(2) = L$, then all $L$ extended particlelike matter quanta ${}^{EP}\mu_{j}^{2}$ are spatially separated from each other, and each such matter quantum ${}^{EP}\mu_{j}^{2}$ then on its own forms a (simple) phase quantum ${}^{EP}\varphi_{i}^{2}$. If $\omega(2) < L$, then there is at least one phase quantum ${}^{EP}\varphi_{i}^{2}$ composed of more than one matter quantum ${}^{EP}\mu_{k}^{2}$, but still all phase quanta ${}^{EP}\varphi_{j}^{2}$ are then spatially separated. The case $\omega(2) > L$ is physically impossible.

*5.2.28 Remark* (*horizon problem*)

In this one individual process from the 1st to the 2nd degree of evolution, in the world the phase quantum ${}^{EP}\varphi_{1}^{1}$, which was composed of $2K$ subconstituents, has been transformed into $\omega(2)$ spatially separated phase quanta ${}^{EP}\varphi_{j}^{2}$. The nonlocal wavelike phase quantum ${}^{NW}\varphi_{1}^{1}$, which essentially effected the separation according to 5.2.21 and 5.2.22, could “see” the emitted local wavelike phase quantum ${}^{LW}\varphi_1^1$; the chain of events in the world is therefore best labeled an electroweak interaction. In addition, this yields a new point of view towards the so-called “horizon problem” (Misner 1969), different from Guth’s inflation (Guth 1981). In a nutshell, this horizon problem is the following: taking into account the estimated age of the universe, then the currently most distant galaxies could never have originated from one point, even if they would have traveled close to the speed of light: they were already lightyears apart at $t = 0$, see figure 5.1 for an illustration. The point of view that the EPT offers is that there is no such thing as the speed of light at the $0^{th}$ and $1^{st}$ degree of evolution, and thus no principle such as “no object can travel faster than the speed light” is valid in this early universe: for the nonlocal mediation in the one process from the $1^{st}$ to the $2^{nd}$ degree of evolution, cf. corollary 5.2.21 and assumption 5.2.22, there is thus no restriction on the spatial positions at which the $L$ nonextended particlelike matter quanta ${}^{NP}\mu_j^2$ arise in the superposition ${}^{NP}\mu_{2K+2}^2 + ... + {}^{NP}\mu_{2K+L+1}^2$. The $\omega(2)$ spatially separated phase quanta ${}^{EP}\varphi_j^2$ that are formed from there can thus be located at the $2^{nd}$ degree of evolution at positions that cannot be reconciled with Einstein’s relativity. See figure 5.2 for an illustration of this approach to the horizon problem.

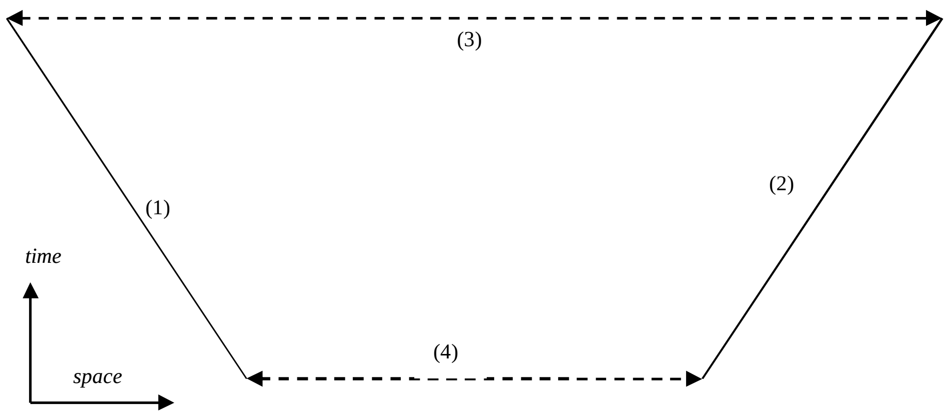


*Figure 5.1: illustration of the horizon problem. In a space vs. time diagram, the lines (1) and (2) depict the path traveled by the objects, that are now furthest apart in the universe, assuming a speed close to the speed of light; the arrows (3) and (4) indicate the distance between the objects now and at t = 0, respectively.*

*5.2.29 Corollary*

$$\begin{bmatrix} {}^{EP}\varphi_1^2 + \ldots + {}^{EP}\varphi_{\omega(2)}^2 \\ {}^{EP}\varphi_1^{-2} + \ldots + {}^{EP}\varphi_{\omega(2)}^{-2} \end{bmatrix} + \begin{bmatrix} {}^{S}\varphi_1^2 \\ {}^{S}\varphi_1^{-2} \end{bmatrix} + \begin{bmatrix} {}^{LW}\varphi_1^2 \\ {}^{LW}\varphi_1^{-2} \end{bmatrix} + \begin{bmatrix} {}^{LW}\varphi_1^2 + \ldots + {}^{LW}\varphi_{\omega(2)}^2 \\ {}^{LW}\varphi_1^{-2} + \ldots + {}^{LW}\varphi_{\omega(2)}^{-2} \end{bmatrix} \in M_{\mathrm{E}}$$

*Proof*:

The proof is omitted. □

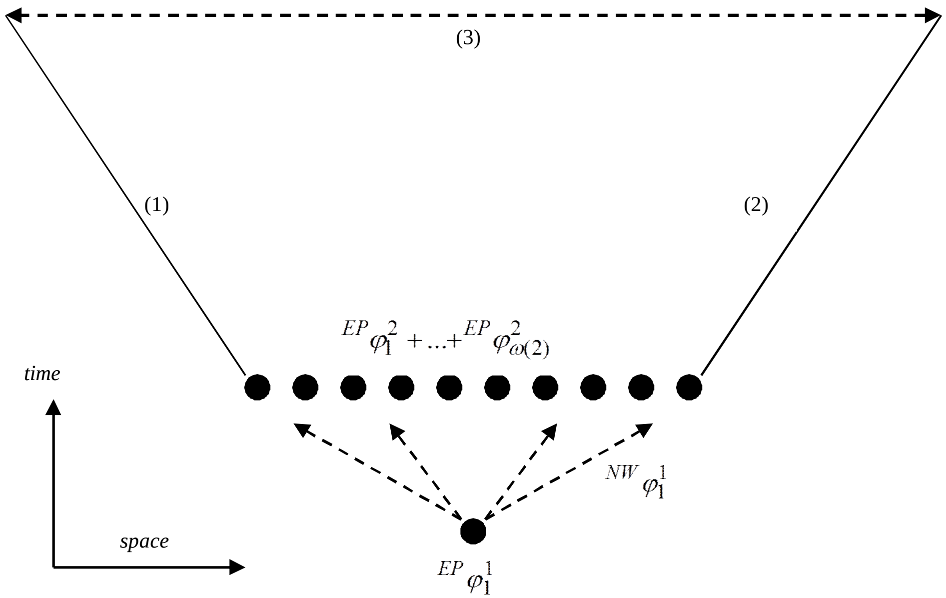


*Figure 5.2: illustration in a space vs. time diagram of the approach to the horizon problem based on the EPT. The interpretations of the lines (1) and (2) and the arrow (3) are identical to those for figure 5.1. The array of dots schematically indicates the positions of the matter quanta in the superposition* ${}^{EP}\varphi_1^2 + \ldots + {}^{EP}\varphi_{\omega(2)}^2$*; the lowest dot indicates the position of the phase quantum* ${}^{EP}\varphi_1^1$*, and the dotted arrows illustrate the action of the nonlocal wavelike phase quantum* ${}^{NW}\varphi_1^1$*.*

*5.2.30 Remark* (*condensed matter field in a vacuum*)

The superposition ${}^{EP}\varphi_1^2 + \ldots + {}^{EP}\varphi_{\omega(2)}^2 + {}^{S}\varphi_1^2 + {}^{LW}\varphi_1^2 + {}^{NW}\varphi_1^2 + \ldots + {}^{NW}\varphi_{\omega(2)}^2$ concerns a condensed matter field in a heterogeneous vacuum. The condensed matter field is the superposition ${}^{EP}\varphi_1^2 + \ldots + {}^{EP}\varphi_{\omega(2)}^2$ which is composed of spatially separated phase quanta ${}^{NW}\varphi_1^1$. The superposition ${}^{S}\varphi_1^2 + {}^{LW}\varphi_1^2 + {}^{NW}\varphi_1^2 + \ldots + {}^{NW}\varphi_{\omega(2)}^2$ is the heterogeneous vacuum, in which the superposition ${}^{S}\varphi_1^2 + {}^{NW}\varphi_1^2 + \ldots + {}^{NW}\varphi_{\omega(2)}^2$ is a homogenous phase, and the one local wavelike phase quantum ${}^{LW}\varphi_1^2$ is a homogenous phase. The phase ${}^{S}\varphi_1^2 + {}^{NW}\varphi_1^2 + \ldots + {}^{NW}\varphi_{\omega(2)}^2$ is observable as a space with non-Euclidean geometry: the constituent ${}^{S}\varphi_1^2$ in itself has a homogenous energy density, but is transcended by the constituent ${}^{NW}\varphi_1^2 + \ldots + {}^{NW}\varphi_{\omega(2)}^2$ which is the source of curvature, that is, of differences in energy density. Any metric $g$ of this space would depend on these phase quanta: $g = g({}^{S}\varphi_1^2, {}^{NW}\varphi_1^2, \ldots, {}^{NW}\varphi_{\omega(2)}^2)$. This homogenous phase acts as a carrier for the second homogenous phase, at the $2^{nd}$ degree of evolution formed by the one local wavelike phase quantum ${}^{LW}\varphi_1^2$, which spreads out with the speed of light.

## 5.3 A principle solution to the mind-body problem

In this section, the first three subsections, 5.3.1, 5.3.2 and 5.3.3, provide the background of the mind-body problem in philosophy. Subsection 5.3.4 provides the motivation for applying the EPT to this problem. The next three subsections, 5.3.5, 5.3.6, and 5.3.7 introduce a solution on the basis of the EPT. The final three subsections, 5.3.8, 5.3.9, and 5.3.10, discuss this solution.

### *5.3.1 The physicalist point of view*

Although the idea of a dualism was first proposed by Plato (427 – 347 B.C.), the mind-body problem has arisen from the now historical substance dualism of Descartes, according to which the mind is distinct from the body and is a nonmaterial substance: Descartes, namely, never succeeded in successfully answering the question how body and mind interact, and from this failure the mind-body problem arose – it is *the* central issue in the philosophy of mind.

A possible approach to the mind-body problem is to investigate it from a physicalist point of view: this comes down to describing at object level, *using the vocab-*

*ulary and assumptions of physics*, what the mind is and how, if at all, mental causation can occur. Sine there is no consensus on what *the* language and assumptions of physics are, a dilemma analogous to Hempel's dilemma (1969) arises: does one have to use the vocabulary and assumptions of a *well-established* physics paradigms, or can a physicalist approach also be based on some *ideal future* physics paradigm? To resolve this dilemma, here the following position is taken:

> a physicalist point of view is the point of view of a well-defined disciplinary matrix for the study of physical reality

Note that a well-defined disciplinary matrix for the study of physical reality is not necessarily a well-established physics paradigm. According to this definition, there is thus no such thing as *the* physicalist point of view: there is *a* physicalist point of view for every such well-defined disciplinary matrix.

Thus far, two disciplinary matrices for the study of physical reality have been used as a basis for a physicalist approach to the mind-body problem: the framework of classical mechanics and the framework of quantum mechanics. Below, the variety of resulting approaches is illustrated by selected examples, but without the intention to give a complete overview or an in-depth review.

### *5.3.2 The mind-body problem in the framework of classical mechanics*

Despite the falsification of classical mechanics as a true physical theory, the corresponding physicalist point of view is still widely held today due to the "tremendous inertia from the philosophers of the past, philosophers of the classical world" – as Stapp put it, cf. (Kuhn 2010). While there is a variety of approaches to the mind-body problem that more or less remain within this paradigm, the common denominator is that the mind is not a substance of any sort in itself (McLaughlin 1999: 688) – a stance that is naturally rooted in the fact that there is no such thing as "mental substance" in the classical-mechanical universe.

The most straightforward philosophy to fit the mind in the ontology of classical mechanics is the so-called “identity theory” that the mind simply *is* the brain, where the brain is a system of particles; this ontological monism was developed by Feigl (1958) and Smart (1959).

Various other philosophies, simply put, reject the idea that the mind can be *reduced* to the brain (as in identity theory) as an oversimplification, but maintain that the mind can be *explained* by the brain as a complex system of classical particles; for an elaborate review see the literature, e.g. (Kim 2005).

Concerning mental causation, Van Inwagen has shown that the idea of free will is incompatible with a deterministic world view (1975). The various physicalist approaches to the mind-body problem solutions that are based on classical mechanics therefore all meet the general criticism that they discard free will as an illusion: “the important lesson we have learned from three decades of debate” is that these approaches “run aground on the rocks of mental causation” (Kim 2005: 158). Such approaches “have been generally accepted, [only] because they do not violate the closedness of World 1”, that is, because they do not violate the classical-mechanical view that the world of matter-energy is completely unaffected by any non-material agency such as the mind (Eccles 1986).

Another criticism is hereby that classical mechanics has already been falsified: how can an approach to the mind-body problem based on classical mechanics lead to a fundamental understanding of mental causation, when the laws, that are assumed as representations of the workings of the physical world, are *known* to be false? Apparently, mental causation uses laws of nature at a more fundamental level than classical mechanics, that is, laws of nature from which classical mechanics emerges at the macroscopic scale – it may be the case that it is hitherto unknown which laws of nature that are, but one thing is for sure: mental causation does not use the laws of classical mechanics. *All* physicalist approaches to the mind-body problem based on classical mechanics are therefore futile beforehand – that is, it may be true that identity theory and variations thereof such as eliminative materialism are sufficient to explain experimental data obtained from measuring brain activity, but these deterministic doctrines have nevertheless to be rejected as a definite solution of the mind-body problem. One might thus take the point of view that the denial of mental causation *is* the definite answer to the question of mental causation, but that point of view is then based on the false assumption that the laws of classical mechanics are universally true: the denial has, thus, been developed from a falsehood and has, thus, to be discarded.

### *5.3.3 The mind-body problem in the framework of quantum mechanics*

The falsification of classical mechanics as fundamental laws of nature has in recent decades caused interest in a physicalist approach to the mind-body problem based on quantum mechanics (QM).

Important for the question what the mind is from the quantum-mechanical point of view, is the framework of complementarity, which was developed by Bohr in the 1920's as a general framework for the interpretation of QM (Bohr 1928). The aspect of complementarity relevant for the mind-body problem is the so-called wave-particle dualism, an ostensible paradox which arises when one tries to apply the classical concepts of waves and particles to atomic phenomena and "[fails] to realize that such different descriptions refer not to the same object but to complementary phenomena which only together provide an unambiguous description of the nature of the objects which give rise to these phenomena" (Folse 1987: 183). While Bohr already in 1929 hinted at an application of this framework of complementarity to the subject-object problem in philosophy (Bohr 1929), it was not until decades later that Pauli suggested an application of complementarity to the mind-body problem: "It would be most satisfactory if *physis* and *psyche* could be conceived as complementary aspects of the same reality" (1952: 164).

Since then, several dual-aspect approaches to the mind-body problem have been developed within the paradigm of QM. An example is the dual-aspect monism proposed by Polkinghorne, which concerns duality of matter: "there is only one stuff in the world (not two – the material and the mental), but it can occur in two contrasting states (material and mental phases, a physicist would say) which explain our perception of the difference between mind and matter” (1994: 21). Another example is the dual-aspect theory introduced by Stapp, which involves a duality of events: “in this [dualistic] model the thinking and the doing do not occur in tandem. The thought and the physical act that implements it are two faces of a single mind/brain event” (2009: 22). Such a physical act that implements a thought is a *probing action*: this is a measurement process. Concluding, the dual-aspect approach dóes provide several versions of an answer to the question what the mind is from a physicalist point of view.

Concerning mental causation, several solutions have been proposed within the paradigm of QM. Of these, the mechanism published by Stapp is the most elaborate one staying strictly within the quantum paradigm. In a nutshell, Stapp assumes that the brain evolves according to the laws of QM. This means that it evolves continuously in accordance with the quantum analogue of the deterministic laws of classical mechanics – the Schroedinger equation – until a specific probing action is taken by an agent, say a human being. Nature’s reply is then that the quantum state of the brain immediately reduces to a state compatible with both the state attained at the previous probing action ánd the increment of knowledge imparted by nature's reply. This reduction can actualize a large-scale pattern of brain activity that can cause an intended bodily action to occur (Stapp 2009: 119-149). Another proposed solution is the dualist hypothesis of mind-brain interaction by Eccles; this is the hypothesis “that the mental influence modifies the probability of vesicular emission from an activated bouton in a manner analogous to the probability fields of quantum mechanics” (1986). However, Eccles’ theory contains an additional statement that is not implied by QM: he postulates, namely, that besides the physical world of matter-energy there exists a separate, autonomous world of nonmaterial mental events (*ibid.*). Eccles refers to Margenau, who stated the following: “The mind may be regarded as a field in the accepted physical sense of the term. But it is a nonmaterial field, its closest analogue is perhaps a probability field” (1984: 97). Obviously, Eccles’ Cartesian-like dualism differs from Stapp’s dual-aspect theory qua ontology: in Eccles’ theory, the mind is a field while in Stapp’s theory only events are ontologically real. However, there is also a difference concerning mental causation:

while in Eccles' theory a mental event *precedes* the neural activity that leads to an intended action, in Stapp's theory this is not the case (Stapp 2009: 140). Another dual-aspect quantum approach that "explores Pauli's idea that mind and matter are complementary aspects of the same reality" uses two concepts of time: reality has a nonmaterial, tensed domain, which is related to a mental world, and a tenseless domain, which is related to physical objects; both domains are connected to each other in a non-classical way by *entanglement* (Primas 2003). So this approach suggests yet another mechanism for mental causation.

Nagel criticized all dual-aspect approaches formulated within the paradigm of QM with the remark that "talk about a dual-aspect theory … is only to say roughly where the truth might be located, not what it is" (Nagel 1986: 30). This criticism, however, seems to be too general to rule out *all* such approaches; it is, for example, not clear how this refutes Stapp's approach. On the other hand, it does seems to apply to Eccles' and Margenau's dualistic thesis that the mind is analogous to a probability field in QM: this thesis, namely, meets the antithesis that wave states in QM (and thus, probability fields) have no ontological connotation: as mentioned earlier, wave states are nothing but *purely mathematical* instruments that can be used to do statistical predictions about the outcome of experiments. Eccles' dualism thus requires a more precise formulation before it can be said that it fits the ontology and structure of the universe of QM.

What the various quantum approaches do have in common is that they all still lack experimental support, not in the last place because measurements of brain activity necessarily involve the whole of the brain as a macroscopic object.

### *5.3.4 Motivation for the application of the EPT*

It is currently not the case that any consensus exists about a physicalist solution of the mind-body problem. That is, there is currently absolutely no agreement whatsoever about what the mind is in physical terms, nor about what the physical principles at object level are by which an intentional thought can cause a bodily action.

To summarize the current state of affairs, it suffices to quote Searle: “we are nowhere remotely near having a solution” (2007: 11). Even stronger, Norman wrote that one must face the conclusion that “entire epistemic system of [contemporary] science is based on a faulty set of premises” if mental causation is possible (Norman 2004). Or, as Robert Lawrence Kuhn put it: “explaining consciousness will require something radically new – either finding physical stuff beyond current boundaries or revealing the reality of *non*physical stuff” (2010).

The preceding sections and chapters have introduced a *third* disciplinary matrix for the study of physical reality that can serve as the basis for a physicalist approach to the mind-body problem. The motivation to indeed use this approach is that the world view of the EPT is fundamentally different both from the deterministic world view of classical mechanics and from the probabilistic world view of QM: it thus might be the case that the mind and mental causation fit more naturally in the present ontology than in the ontologies of classical and quantum mechanics.

### *5.3.5 Man as a trinity of body, spirit and soul*

Applying the particle/wave dualism of the EPT, theorem 4.2.21, to the macroscopic scale, it can thus be said that a human being has, at any degree of evolution, a “body” and a “spirit”: the body of a human being is a composite entity made up of condensed matter, that is, an object made up (solely) of particlelike constituents; the spirit of a human being is a composite entity, made up of precisely those wavelike constituents that arise in individual processes from the particlelike constituents making up the body. To apply the formalism of the EPT, consider that the body $B_x$ of a human being at the $x^{\text{th}}$ degree of evolution is made up of $N$ extended particlelike phase quanta; then

$$B_x = {}^{EP}\varphi^x_{k(1)} + {}^{EP}\varphi^x_{k(2)} + \ldots + {}^{EP}\varphi^x_{k(N)} \tag{5.23}$$

for $N$ integer indices $k(1)$, $k(2)$, …, $k(N)$. The spirit $S_x$ of the human being at that degree of evolution is then made up of $N$ nonlocal wavelike phase quanta:

$$S_x = {}^{NW}\varphi^x_{k(1)} + {}^{NW}\varphi^x_{k(2)} + \ldots + {}^{NW}\varphi^x_{k(N)} \tag{5.24}$$

This separation of body and spirit is a material substance dualism: the spirit is distinct from the body, but it is not nonmaterial – in the universe of the EPT wavelike forms of energy exist (nonlocal wavelike phase quanta) that do not occur in the universes of classical or quantum theory, and precisely thát feature of the present ontology enables to formulate this substance dualism. However, since the particle/wave dualism is universal in the framework of the EPT, it also applies to other entities such as, for example, stones: it can thus also be said that a stone has a body and a spirit. Thus, if a human being is *at all* able to cause physical events that would not have occurred if human beings would be without a free will like stones, then on account of the causal closure principle it is not sufficient to say that a human being is a duality of body and spirit.

To solve this, the starting point is that the spirit of a human being has, as a wavelike entity, at any degree of evolution a short, finite duration: at every point in time $t$ of this time interval of existence, there is an internal state $\Psi_t$ . This is not necessarily a constant: the internal state may vary over time during the time interval of existence of the wavelike entity. Now consider that the time interval of the existence of such wavelike entity contains the open interval $\langle t_1, t_2\rangle$; then the following relation is always valid for any two internal states $\Psi_t$ and $\Psi_{t+\Delta t}$ attained within this time interval:

$$\Psi_{t+\Delta t} = \Psi_t + \Delta\Psi \tag{5.25}$$

The change, $\Delta\Psi$ , which is thus a *fluctuation* in the wavelike entity (5.24), consists then of changes due to fundamental interactions (gravitation, electromagnetism) *plus* changes due to thinking: a human being thus *has to have*, besides a body and a spirit, an active principle, which accounts for awareness (consciousness) and intentional thoughts, and which is ontologically realized in fluctuations of the spirit. This active principle can be given many names; here it is called a “soul”. In the framework of the EPT, soul and spirit can thus be seen as an integrated whole, but they are not the same thing. And given the concept of stepwise motion of the EPT, this trinity gives rise to a counterintuitive concept of motion of a human being: it is not at all the body of a human that moves from $A$ to $B$, it is the spirit and soul of a human that move from a body at a position $A$ to a body at a position $B$.

*5.3.6 The mind in the framework of the EPT*

Up till now, the talk has been limited to physical entities and fluctuations thereof: body, spirit and soul exist *ontologically* in the universe of the EPT. Now what happens in the physical world are physical processes, but what a human being experiences are mental processes: in this picture, the concept of "mind" requires a dual-aspect approach in addition to the material substance dualism that describes the trinity of body, spirit and soul.

To relate mental processes to the individual physical processes described by the EPT, it is interesting to cite Kim's variant of McLaughlin's widely accepted correlation thesis: "for every type of sensation state, *S*, there is a type of physical state *P* such that it is nomologically necessary that for any organism, *x*, *x* is in *S* if and only if *x* is in *P*" (Kim 2005: 127; McLaughlin 2001: 319). Given that the EPT corresponds with a process-philosophic approach to reality, this correlation thesis has to be reformulated in process-philosophic terms to be applicable in the present framework; a suitable formulation is the following:

> For every observer *O* and for every mental process *M* in *O* there is a physical process *P*, such that *M* occurs in *O* if and only if *P* occurs in the physical world.

This process-philosophic correlation thesis works both ways, that is, holds for both perception (from the physical to the mental domain) and intention (from the mental to the physical domain).

Given this process-philosophic correlation thesis, a mental process and its correlated physical process are complementary aspects of one and the same psychophysical process: the mental processes are *nothing but* the parallel ongoing images of the correlated physical processes – there is nothing more to it[11]. To put that in other words: the stream of mental states is nothing but the subjective form of the stream of internal states $\Psi_t$ that occur in the wavelike entity formed by spirit and soul: the stream of mental states *is* the self-aware subject. The idea of a "mind" is then created by the combined total of mental processes, and has thus absolutely no

[11] That is, it is not the case that the psychophysical process is some illusive thing in itself, which gives rise to the mental process and the corelated physical process.

ontological connotation in the framework of the EPT: it is not a substance of any kind – spirit and soul are together are a real entity (a stream of wavelike states), the mind merely arises as an idea from the subjective form of that real entity. The mind is thus not a thing in itself in the noumenal universe.

### *5.3.7 Mental causation*

Let at the $x^{\text{th}}$ degree of evolution the body of a human being be denoted by $B_x$ and the spirit by $S_x$. Physically, the spirit is a form of energy that transports the energy of the body $B_x$ to the body $B_{x+1}$ at the next degree of evolution; this can be expressed by the following general formula[12]:

$$S_x : B_x \to B_{x+1} \tag{5.26}$$

This has to be read as: the spirit at the $x^{\text{th}}$ degree of evolution, $S_x$, effects a transition from the body at the $x^{\text{th}}$ degree of evolution, $B_x$, to the body at the $(x+1)^{\text{th}}$ degree of evolution, $B_{x+1}$. Now let the body $B_x$ be made up of $N$ individual constituents as in (5.23); the state of $B_x$ then depends on the $N$ spatiotemporal positions $X_1, \ldots, X_N$ where these $N$ individual particlelike constituents are located:

$$B_x = B_x(X_1, \ldots, X_N) \tag{5.27}$$

At this $x^{\text{th}}$ degree of evolution, it is determined *that* there will be a body of the human being at the next degree of evolution, $x+1$, but it is not yet determined in *which* state the body will be: the universe of the EPT is *nondeterministic*. Thus speaking, because there is a set $\Theta^{x+1}_{k(j)}$ of parallel possible nonextended particle phase quanta for every of the $N$ constituents ${}^{EP}\varphi^{x}_{k(j)}$ of $B_x$, there is at the $x^{\text{th}}$ degree of evolution also a set $P_{x+1}$ of possible next states of the human being's body, which can be indexed by some set $F$, and the next body, $B_{x+1}$, will be one of those:

$$P_{x+1} = \{\, B^{i}_{x+1} \mid i \in F \} \tag{5.28}$$

$$B_{x+1} \in P_{x+1} \tag{5.29}$$

The spirit, $S_x$, depends as a physical wavelike entity on its energy distribution: *due to thinking* this energy distribution can change, cf. (5.25). The general expression

[12] (5.26) is a special notation for a relation $\langle S_x, B_x, B_{x+1}\rangle \in T$ for some ternary relation $T$ on the set of all entries in the upper row of the elements of the monoid $M$, cf. 4.1.3.(v).

for this wavelike entity $S_x$ is then the following:

$$S_x = S_x^0 + \Delta S_x \tag{5.30}$$

Here $S_x^0$ denotes the wavelike entity that would occur without thinking (for example, if the human being would be dead) and $\Delta S_x$ denotes a change due to thinking: stones and other entities without a soul can thus *not* generate such a change $\Delta S_x$. Different intentional thoughts then correspond with different changes. Thus, suppose that an intentional thought #1 corresponds with a change $\Delta S_n^1$, then

$$S_x = S_x^1 = S_x^0 + \Delta S_x^1 \tag{5.31}$$

Thus, $S_x^1$ denotes the spirit $S_x$ in the particular case the intentional thought #1 takes place. And suppose that another intentional thought #2 would correspond with a change $\Delta S_x^2 \neq \Delta S_x^1$, then in that case

$$S_x = S_x^2 = S_x^0 + \Delta S_x^2 \tag{5.32}$$

Using the general expression (5.26), this yields

$$S_x^0 : B_x \to B_{x+1}^0 \tag{5.33}$$

$$S_x^1 : B_x \to B_{x+1}^1 \tag{5.34}$$

$$S_x^2 : B_x \to B_{x+1}^2 \tag{5.35}$$

where $B_{x+1}^0$, $B_{x+1}^1$ and $B_{x+1}^2$ are all elements of the set $P_{x+1}$ in (5.28). Naturally, as is the case with the state $B_x$ in (5.27), each such state $B_{x+1}^i$ depends on the $N$ spatiotemporal positions of the $N$ individual particlelike constituents that make up the state $B_{x+1}^i$ in question. Applied to expressions (5.33)-(5.35), this yields

$$B_{x+1}^i = B_{x+1}^i(Y_1^i, \ldots, Y_N^i) \tag{5.36}$$

for $i$ = 0, 1, and 2. The crux is then that for any different $i, j \in \{0, 1, 2\}$

$$\{Y_1^i, \ldots, Y_N^i\} \neq \{Y_1^j, \ldots, Y_N^j\} \tag{5.37}$$

so that also

$$B_{x+1}^i \neq B_{x+1}^j \tag{5.38}$$

Now suppose that the body of the human being at the $(x+1)^{\text{th}}$ degree of evolution, $B_{x+1}$, has become $B_{x+1}^1$. The point is then that the change of state from $B_x$ to

$B^1_{x+1}$ *could not have been effected* without the intentional thought #1: without intentional thought or with another intentional thought, another state $B^i_{x+1} \in P_{x+1}$ with $B^i_{x+1} \neq B^1_{x+1}$ would have been attained (causal exclusion principle). In effect, the element $B^1_{x+1}$ has thus been chosen from the set of possibilities $P_{x+1}$; in general, this can be expressed by the formula

$$B_{x+1} = f_{\Delta S_x}(P_{x+1}) \tag{5.39}$$

where $f_{\Delta S_x}$ is a choice function determined by the fluctuation $\Delta S_x$. Substituting (5.30) and (5.39) in (5.26) then yields

$$S^0_x + \Delta S_x : B_x \to f_{\Delta S_x}(P_{x+1}) \tag{5.40}$$

Expression (5.40) supports the view that the spirit ( $S^0_x + \Delta S_x$ ), as a form of energy, transports the energy from the body at the $x^{\text{th}}$ degree of evolution ( $B_x$ ) to the body at the next degree of evolution ( $f_{\Delta S_x}(P_{x+1})$ ), but that the actual state of the latter is chosen by the soul, which is carried by the spirit as a fluctuation $\Delta S_x$ thereof. The general expression (5.40) is thus an *irreducible* agent causation. That is, $S_x$, $B_x$, and $B_{x+1}$ can be written as a superposition of billions of indivisible constituents as in (5.23) and (5.24), but the choices made in the individual processes are *imposed* by the choice made by mental processes at the macroscopic level. By this mechanism, mental causation takes place in the universe of the EPT; see figure 5.3 for an illustration. The sense of choice of a human being is thus not *imagined* but *real* – a human being has the *real* ability to make choices, and thus a free will!

### *5.3.8 Relation with classical views*

Ever since the mind-body problem arose from Descartes' dualism in the 17th century, virtually every philosopher who investigated it from a physicalist point of view has searched either in the direction of explaining a *duality* of body and mind, or in the direction of reducing body and mind in a *monism*: a search in the literature has produced no physicalist accounts of a *trinity* of body, spirit and soul in the period after Descartes. The Bible, however, suggests that man is a trinity of “spirit, soul and body” (1 Thessalonians 5:23), whereby soul and spirit are definitely not the same thing (Hebrews 4:12). Further philosophical-theological research is then necessary to establish whether or not the trinity that is introduced in the preceding sections is in agreement with the teachings of the Bible. Below some relations between aspects of classical philosophies (since Descartes) and the present view will be established.

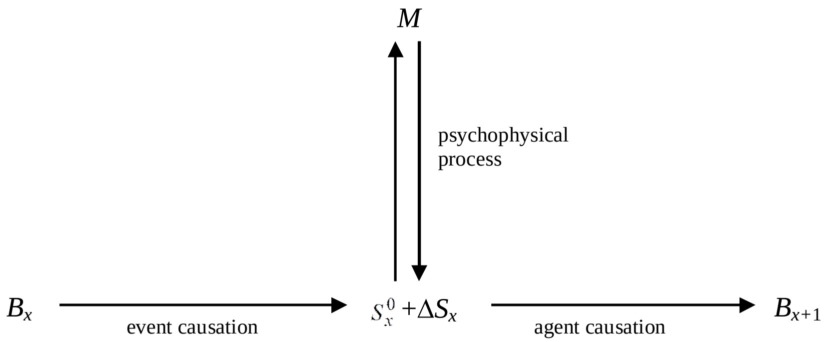


*Figure 5.3: schematic illustration of mental causation in the framework of the EPT. The left arrow indicates that discrete state transitions (events) cause the transition of the body at the $x^{th}$ degree of evolution, $B_x$, to the spirit plus soul at the $x^{th}$ degree of evolution, $S_x^0 + \Delta S_x$; this is a stream of wave states: the vertical double arrow indicates that this is correlated to mental processes (M in the figure) in one psychophysical process; the right arrow indicates that the body at the $(x+1)^{th}$ degree of evolution, $B_{x+1}$, emerges from the spirit plus soul at the $x^{th}$ degree of evolution by an irreducible agent causation.*

In the Cartesian dualism, the mind is distinct from the body and is a nonmaterial substance. This dualistic aspect is found back: in the present view, mind and body are also distinct. However, if the “Cartesian mind” is compared with the “mind” in the present view, then an agreement between the two views is that the mind in both cases is nonmaterial, but a difference is that in the present case it is not viewed as a substance, i.e. something that exists in itself: in the present philosophy, it is merely the case that the idea of a mind arises from a stream of mental states – and these are just the subjective form of the correlated stream of wavelike states in the noumenal universe. If, on the other hand, the "Cartesian mind" is compared with the "spirit" or the "soul" (or a combination thereof) in the present view, then the agreement is that in both cases it is a substance; the difference is then that in the Cartesian dualism the mind is nonmaterial, while spirit and soul are physical entities in the present philosophy. But interpreted one way or the other, the present philosophy dóes provide an answer to the question how body and mind interact – a question to which Descartes never gave a satisfactory answer.

In the dual aspect monism of Spinoza, mind and body are two concomitant aspects of a single entity: the human being. While it remains true in the present philosophy that mind and body are two aspects of a human being, there are two major differences with the view of Spinoza. The first is that from the present point of view a dual-aspect approach is insufficient to describe human beings: body and mind are not the whole story. The second major difference is about the relation between mind and body: in the present philosophy one may speak of a psychophysical parallelism as far as it concerns mental processes and the correlated physical processes, but the 'physical' part of the adjective 'psychophysical' then refers to spirit and soul, and not to the body. And there is also the issue of free will: in Spinoza's pantheistic worldview, free will is an illusion; in the present philosophy, human beings definitely have a free will – formula (5.40) expresses the free will of human beings in the universe of the EPT.

*5.3.9 The present view versus impossibility arguments*

In 1949, Ryle criticized the idea that the mind is distinct from the body. His argument against dualism, to which he referred with the term "the dogma of the ghost in the machine", is that it is entirely false – he called it a "category mistake" – to assume that mental processes can be seen as something isolated from physical processes; (Ryle 1949: 13-20); according to Stapp, "Ryle's 1949 arguments are still influential today" (2009: 21). However, while Ryle's writing may be a valid counterargument against *Cartesian* dualism, it does not apply against the *material* substance dualism of the present view. Ryle's "destructive purpose" is, namely, to demonstrate the falseness of "the representation of a person as a ghost mysteriously ensconced in a machine" (1949: 19): the subject of Ryle's attack is the *immaterial* ghost (i.e. Descartes' mind), but in the present view spirit and soul are *material* entities. Thus, Ryle's "ghost" is absolutely not the same as "spirit" or "soul" in the present view. And neither does Ryle's argument apply against the dual-aspect approach of the mind in the present view: it is, namely, not at all the case that a mental process can be seen as something occurring in itself, without any associated physical process. The present view does, thus, not make Ryle's category mistake. Concluding, Ryle's impossibility argument does not apply to the present philosophy of man as a trinity.

In 1991, Dennet gave the following physical counterargument against dualism: "a fundamental principle of physics is that any change in the trajectory of a particle is an acceleration requiring the expenditure of energy … this principle of conservation of energy … is apparently violated by dualism"; he regarded this as the "inescapable flaw of dualism" (Dennet 1991: 35). From the wording of Dennet's argument, however, it is clear that it is based entirely on the paradigm of classical mechanics, where particles move on continuous trajectories under the influence of forces: on account of Newton's laws, any change in such a continuous trajectory requires an acceleration, and thus a net force and thus energy. The present view, however, is formulated in the framework of the EPT: motion here is stepwise, so there is no such thing as a continuous trajectory, and Newton's laws are not universally valid. In other words, Dennet's "fundamental principle" is not at all fundamental in this framework. In the universe of the EPT, *other* laws of conservation of energy have been formulated for the individual processes that take place at supersmall scale, cf. Section 6.2. Now Dennet's argument against dualism would still have merit for the present case, if the mechanism for mental causation introduced in §5.3.7 would violate these laws of conservation of energy that have been formulated for the EPT. The point is, however, that this is *not* the case. The physical realization of an intentional thought, as laid down in equation (5.30), does not even have to imply a change in the energy content of the wave entity: the change $\Delta S_x$ can be a mere change in energy distribution. Concluding, Dennet's impossibility argument does not apply to the material substance dualism of the present view.

*5.3.10 Relation with modern views*

In the quantum-mechanical view on the mind-body problem of Stapp, it is assumed that mental events and physical events (probing actions) are complementary aspects of a single mind/brain-event, but the point is that "the causal origin of the … probing actions is not specified, even statistically, by the presently known laws of physics" (Stapp 2009: 271). In other words, in Stapp's mechanism for mental causation it is assumed *that* probing actions take place, but the paradigm of QM offers no answer to the question *why* these probing actions take place. Furthermore, in order to actualize the large-scale pattern of brain activity necessary for an intended action, not just *a* probing action is required: no, a very *specific* probing action is required. With respect to that, Stapp writes the following:

> "*according to the Copenhagen philosophy, there are no presently known laws that govern the choices made by the agent about how the observed system is to be probed. This choice is, in this very specific sense, a free choice. It is not ruled out that some deeper theory will eventually provide a causal explanation of this choice*" (2009: 217).

In other words, the explanation of free will is that a human being chooses a specific probing action by "choosing" an intentional thought – these are namely connected in a mind/brain event – but the paradigm of QM offers no answer to the question *why* a thought corresponds with a certain probing action: it is merely assumed *that* this is the case. While the present view on the mind-body problem is *ontologically* of course very different from Stapp's view, the comparison of the mechanisms for mental causation yield a remarkable agreement: both yield a mechanism, strictly formulated within a well-defined disciplinary matrix, for how intentional thoughts can cause the material brain to develop a large-scale pattern of neural activity, necessary to cause a certain bodily action. A difference between the two mechanisms is that Stapp's view is much coarser: the present mechanism identifies *all* the precise steps at the most fundamental level according to which an intentional thought leads to a certain brain activity – there are no open question such as the above ones concerning Stapp's approach. It needs to be said, however, that it is true that Stapp's mechanism is coarser, but it is as refined as it gets in the paradigm of QM: the aforementioned open questions are *inherent to the quantum paradigm*. In addition, the difference may not be directly measurable: it is doubtful that experimental observations of brain activity will ever be able to distinguish between the two mechanism, largely because such measurements take place on macroscopic scale. A better route towards distinguishing between the two mechanisms seems to be the falsification of the underlying physics: the EPT is incompatible with QM (see the next chapter for a proof), so the scientific method can decide which of these two theories has to be discarded. That, then, also decides between the mechanisms for mental causation. Another difference with Stapp's theory is that intentional thought *precedes* neural activity in the present view.

At the same time, this is an agreement of the present view with an aspect of Eccles' theory. However, regarding another aspect the present point of view is fundamentally different from Eccles' Cartesian dualism, because the mind has no ontological connotation in the universe of the EPT, while on the other hand body and soul are not nonmaterial. Furthermore, the central aspect of Primas' theory, that there are two concepts of time, is found back in the EPT, in the sense that in the present framework the notion of discrete degrees of evolution exists besides the notion of time as a linear continuum: the observable processes of evolution can be indexed by degrees of evolution, while internal states of nonlocal wavelike phase quanta can be indexed by moments in time; since body and soul are made up of such wavelike matter, this may account for the perception of time that every human being has.

It would be wrong, however, to call nonlocal wavelike phase quanta the "mental phase of matter" that occurs in Polkinghorne's view: the universe of the EPT is made up of five different kinds of indivisible constituents, but these are not just "aspects" or "states" of one underlying "stuff". That is, in the framework of the EPT, Polkinghorne's statement that "there is only one stuff in the world" remains true in the sense that every individual constituent of the universe of the EPT is a form of energy, but the fundamental difference is that each such constituent is a thing in itself in the physical world – the *forms of energy* are the building blocks of the physical universe, not the *energy in itself*.

# 6

## DISCUSSION

Section 6.1 presents the laws of conservation of energy that hold at the supersmall level in the universe of the EPT; Section 6.2 critically confronts the EPT with current fundamental theories; Section 6.3 relates the EPT to the original research question; Section 6.4 brings the language of the EPT in closer contact with the existing language of physics by addressing the question what an electron is in the framework of the EPT; Section 6.5 addresses some process-philosophical aspects of the EPT; Section 6.6 discusses the open issues concerning the EPT; Section 6.7 identifies conditions under which the results of the present research have implications for the foundations of physics as a branch of science.

### 6.1 Laws of conservation of energy

The first law of thermodynamics, the law of conservation of energy, is an empirically established law of the *macroscopic* world: over time it has been subject to quite a number of modifications, but at it has thus far never been violated. Below, laws of conservation of energy are given that are to hold at *microscopic* level in the universe governed by the EPT.

*6.1.1 Definition*

Let $E(.)$ be a real-valued function, such that for any element $\begin{bmatrix} x \\ \bar{x} \end{bmatrix}$ of the monoid $M$, the real number $E(x)$ designates the amount of energy distributed in the object $x$. □

The first law is then an inequality rather than a law of conservation: for every nonlocal equilibrium, the amount of energy distributed in the newly created phase quantum ${}^{NW}\varphi_k^x$ is always larger than or equal to the amount of energy distributed in the extended particlelike phase quantum ${}^{EP}\varphi_k^x$ from which it originated:

$$E({}^{NW}\varphi_k^x) \geq E({}^{EP}\varphi_k^x) \tag{6.1}$$

In case $E({}^{NW}\varphi_k^x) > E({}^{EP}\varphi_k^x)$, the excess energy is absorbed from the surroundings, that is, from the vacuum. At the subsequent nonlocal mediation, the new constituent ${}^{NP}\varphi_k^{x+1}$ is created by the collapse of the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$; energy is conserved in this collapse:

$$E({}^{NW}\varphi_k^x) = E({}^{NP}\varphi_k^{x+1}) \tag{6.2}$$

The energy of the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ is then conserved in the emitted local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ and the remaining superposition of extended particlelike matter quanta ${}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1}$:

$$E({}^{NP}\varphi_k^{x+1}) = E({}^{LW}\varphi_k^{x+1}) + E({}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1}) \tag{6.3}$$

In any individual process, energy is thus first absorbed from the surroundings in the discrete transition ${}^{EP}\varphi_k^x \rightarrow {}^{NW}\varphi_k^x$, then energy is conserved upon the collapse ${}^{NW}\varphi_k^x \rightarrow {}^{NP}\varphi_k^{x+1}$, and finally energy is emitted into the surroundings in the form of a local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ upon the transition from ${}^{NP}\varphi_k^{x+1}$ into the superposition ${}^{EP}\mu_{\tau(1)}^{x+1} + ... + {}^{EP}\mu_{\tau(q)}^{x+1}$.

This is thus the mechanism of any interaction. During an individual process, only once is thus energy absorbed from the surroundings and only once energy is emitted: the framework of the EPT is thus consistent with the idea that there really is only one kind of interaction – there is no such thing as an electromagnetic interaction or a gravitational interaction, there are only electromagnetic and gravitational aspects of a single cosmic interaction. A corollary of (6.2) and (6.3) is then the following law:

$$E({}^{EP}\mu^{x+1}_{\tau(1)} + ... + {}^{EP}\mu^{x+1}_{\tau(q)}) - E({}^{EP}\varphi^{x}_{k}) = E({}^{NW}\varphi^{x}_{k}) - E({}^{EP}\varphi^{x}_{k}) - E({}^{LW}\varphi^{x+1}_{k}) \quad (6.4)$$

Given (6.1), and keeping in mind that the local wavelike phase quantum ${}^{LW}\varphi^{x+1}_{k}$ is emitted, the difference $E({}^{NW}\varphi^{x}_{k}) - E({}^{EP}\varphi^{x}_{k}) - E({}^{LW}\varphi^{x+1}_{k})$ on the right hand side of (6.4) thus designates the net amount of energy exchanged with the vacuum. The left hand side of (6.4) is merely the difference in energy between 'output' and 'input' of the process: this is, thus, exactly equal to the net amount of energy exchanged with the vacuum.

Furthermore, (6.1) is always valid for the energy $E({}^{EP}\varphi^{x}_{k})$ distributed in an extended particlelike phase quantum ${}^{EP}\varphi^{x}_{k}$, while (6.2) is always valid for the energy $E({}^{NP}\varphi^{x+1}_{k})$ distributed in a nonextended particlelike phase quantum ${}^{NP}\varphi^{x+1}_{k}$: these are therefore different kinds of particlelike phase quanta.

*6.1.2 Remark (conservation of energy in the early universe)*

Concerning the laws of conservation of energy, the following equations now hold in the early universe, discussed in Section 5.2:

$$E({}^{NP}\mu^{0}_{1}) = E({}^{EP}\mu^{0}_{1}) \quad (6.5)$$

$$E({}^{EP}\mu^{0}_{1}) = E({}^{NW}\varphi^{0}_{1}) \quad (6.6)$$

$$E({}^{NW}\varphi^{0}_{1}) = E({}^{NP}\mu^{1}_{2} + {}^{NP}\mu^{1}_{3} + ... + {}^{NP}\mu^{1}_{2K+1}) \quad (6.7)$$

$$E({}^{NP}\mu^{1}_{2} + ... + {}^{NP}\mu^{1}_{2K+1}) = E({}^{EP}\mu^{1}_{2} + ... + {}^{EP}\mu^{1}_{2K+1}) + E({}^{LW}\varphi^{1}_{1}) \quad (6.8)$$

Equation (6.5) shows that the law of conservation of energy (6.3) holds at the $0^{\text{th}}$ degree of evolution; it is used that ${}^{NP}\mu^{0}_{1} = {}^{NP}\varphi^{0}_{1}$ and ${}^{EP}\mu^{0}_{1} = {}^{EP}\varphi^{0}_{1}$, and it has to be seen that $E({}^{LW}\varphi^{0}_{1}) = 0$. The amount of energy $E({}^{EP}\mu^{0}_{1})$ is also the rest mass of the first monad at the $0^{\text{th}}$ degree of evolution. Equation (6.6) shows that in the initial stage of the one individual process from the $0^{\text{th}}$ to the $1^{\text{st}}$ degree of evolution no energy is absorbed of the vacuum; the inequality (6.1) holds. The energy needed for the transition ${}^{EP}\mu_1^0 \rightarrow {}^{NP}\mu_2^1 + {}^{NP}\mu_3^1 + ... + {}^{NP}\mu_{2K+1}^1$, cf. (5.21), was thus already present in the initial nonextended particlelike matter quantum ${}^{NP}\mu_1^0$. Equation (6.7) shows that the law of conservation of energy (6.2) holds at the 0th degree of evolution. Equation (6.8) is an instance of the law (6.3). From (6.6), (6.7) and (6.8) it follows that

$$E({}^{EP}\mu_1^0) - E({}^{EP}\mu_2^1 + ... + {}^{EP}\mu_{2K+1}^1) = E({}^{LW}\varphi_1^1) \tag{6.9}$$

The term on the left is the rest mass of the initial matter quantum ${}^{EP}\mu_1^0$ minus the sum of the rest masses of the pre-protons and pre-electrons that emerged. The difference is then positive, that is, $E({}^{LW}\varphi_1^1) > 0$. This leads to the formation of space, in accordance with the principle 4.2.18.

## 6.2 Relation with existing theories

*6.2.1 Proposition (incompatibility of QM with the EPT)*

The theory, obtained by extending the EPT with the following translation of the orthodox quantum-mechanical view on nonzero rest mass entities in the language of the EPT, is inconsistent:

$$\exists x \in Z_{\mathrm{N}} \exists k \in S_{\omega(x)} \left( \begin{bmatrix} \beta_k^x \\ \bar{\beta}_k^x \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \notin M_{\mathrm{E}} \right) \tag{6.10}$$

*Proof*:

Formula (6.10) yields a contraposition of theorem 4.2.21. □

The orthodox position of QM implies that observable nonzero rest mass entities, such as electrons, have no definite position in absence of observation. Translated in the language of the EPT, this would imply that (6.10) would be true. Obviously, this view yields a contradiction with the EPT. To spell it out, QM is irreconcilable with the EPT. One of the fundamental differences, expressed by the fact that theorem 4.2.21 and formula (6.10) contradict each other, is that according to QM the wave function of a microsystem does not collapse in absence of observation, while according to the EPT nonlocal wavelike phase quanta spontaneously collapse.

*6.2.2 Proposition (incompatibility of GR with the EPT)*

The theory, obtained by extending the EPT with the following translation of the classical view on nonzero rest mass entities in the language of the EPT, is inconsistent:

$$\exists x \in Z_N \exists k \in S_{\omega(x)} \left( \begin{bmatrix} \beta_k^x \\ \bar{\beta}_k^x \end{bmatrix} \in M_E \wedge \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} \notin M_E \right) \tag{6.11}$$

*Proof*:

Formula (6.11) yields a contraposition of theorem 4.2.21. □

The classical view, which is also incorporated in GR (General Relativity), implies that an observable nonzero rest mass entity is in a particlelike state at every point of its worldline. Translated in the language of the EPT, this would imply that (6.11) would be true. Obviously, this view yields a contradiction with the EPT. To spell it out, GR is irreconcilable with the EPT. One of the fundamental differences, expressed by the fact that theorem 4.2.21 and formula (6.11) contradict each other, is that according to GR a nonzero rest mass particle does not spontaneously transform into a wavelike state, while according to the EPT extended particlelike phase quanta do spontaneously transform into nonlocal wavelike phase quanta.

Now recall the Gedankenexperiment of Section 1.2, whereby one and the same electron is observed first at position $\underline{x}_a$ and next at position $\underline{x}_b$. The difference of the worldview, based on the EPT, with the worldviews, based on QM or GR, comes then to expression in a difference answer to the question: how has the electron got from $\underline{x}_a$ to $\underline{x}_b$? In the universe governed by the EPT, discrete processes underlie perceived motion. So, putting the two consecutive measurements in the language of the EPT, that one electron must have existed in the form of an extended particlelike phase quantum at positions $\underline{x}_a$ and $\underline{x}_b$. In the worldview of the EPT, the extended particlelike phase quantum at $\underline{x}_a$ is absolutely motionless, and the transition to the extended particlelike phase quantum at $\underline{x}_b$ (that is also motionless) has then occurred in a finite number of discrete steps; the total chain of processes is then perceived as the motion of an electron from $\underline{x}_a$ to $\underline{x}_b$. Starting with the electron existing motionless at the position $\underline{x}_a$ in the form of an extended particlelike phase quantum, by a discrete phase transition, that is certain to occur, a nonlocal wavelike phase quantum comes into existence. The electron then exists for a finite amount of time in the form of this nonlocal wavelike phase quantum: the wavelike phase quantum is certain to collapse, which leads to the existence of a high-energetic nonextended particlelike phase quantum at a new position $\underline{x}_1$. A local wavelike phase quantum is then emitted immediately, and because of this the high-energetic nonextended particlelike phase quantum transforms into a low-energetic extended particlelike phase quantum at the same position $\underline{x}_1$: the electron thereby arises in a particlelike form at the position $\underline{x}_1$. The next individual process then leads to the electron existing in the form of an extended particlelike phase quantum at a next position $\underline{x}_2$, and so forth until the position $\underline{x}_b$ is reached. This worldview based on the EPT is schematically illustrated below in figure 6.1.

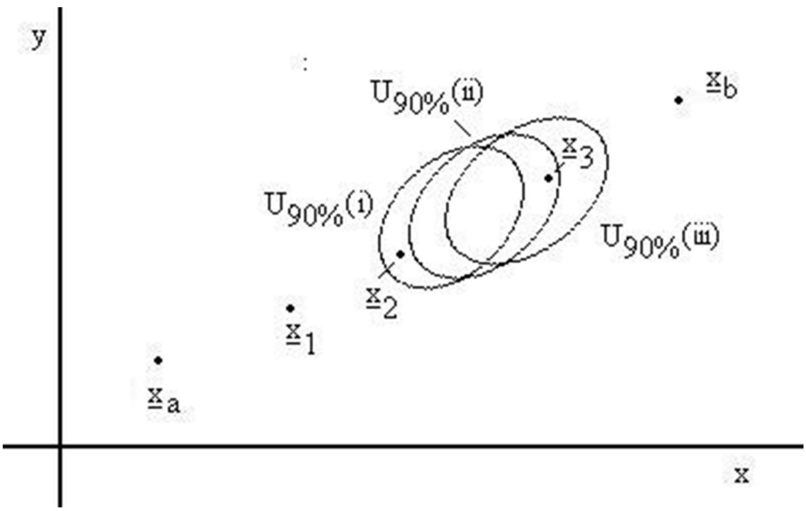


*Figure 6.1: schematic illustration of the concept of stepwise motion of the EPT. In the xy-plane the positions $\underline{x}_a$, $\underline{x}_1$, $\underline{x}_2$, $\underline{x}_3$, and $\underline{x}_b$, where a particlelike phase quantum of the electron exists, are shown, and three regions $U_{90\%}$(i), $U_{90\%}$(ii) and $U_{90\%}$(iii). These three regions represent the area's at three intermediate points of time, with $t_2 < t_i < t_{ii} < t_{iii} < t_3$ , where 90% of the energy is concentrated in internal wave states of the wavelike phase quantum, that effects the motion from the particlelike phase quantum at $\underline{x}_2$ to that at $\underline{x}_3$ . Note that the electron has finitely many times (three in this case) a definite position between $\underline{x}_a$ and $\underline{x}_b$.*

*6.2.3 Remark (relation between the EPT and SR)*

Arriving at the relation between the EPT and SR (Special Relativity), it should be noted that SR entails a rejection of the idea of an aether, while in the context of the EPT spatial phase quanta occur as energetic constituents of the vacuum system. Although it is widely believed that the idea of an aether has been disproved by the Michelson-Morley experiment, the implications of the outcome of this experiment should be reviewed: what has been disproved, namely, is the idea of an aether such as mathematically represented by classical theory. In particular, it has been disproved that the Galilean law of velocity transformation is universally applicable.

Proceeding, the first major point is that the Galilean law of relativity, that it is not possible to determine the absolute velocity of a nonzero rest mass entity, has no meaning in the context of the EPT: at the supersmall level, where the concept of stepwise motion applies, there is no such thing as the “velocity” of a monad (electron, proton, etc.). To put that in other words: in the context of the EPT, velocity is a *secondary* property – it is present in the observation of the object but not in the object itself. Thus, one can perform measurements on microsystems and use the obtained results to calculate a value that can be called “velocity”, but the idea, that the calculated velocity then corresponds to a really existing property of the material object that was subjected to measurement (e.g. an electron), is purely classical, and is connected to the concept of continuous motion of classical mechanics. In the context of the EPT, particlelike phase quanta do not move at all, and thus simply have no velocity. In other words, the Galilean principle of special relativity has no meaning in the context of the EPT.

The second of the two postulates of SR, Einstein’s principle of universality of the speed of light is to be retained in the framework of the EPT. It should be noted that nonextended particlelike phase quanta, from which local wavelike phase quanta (and thus light – photons occur in such phase quanta, cf. remark 5.1.5) are emitted, do not move at all: therefore, there is no such thing as “the motion of the light’s source” in the framework of the EPT, nor does the Galilean law of velocity transformation, falsified by the Michelson-Morley experiment, apply to light in the framework of the EPT. The speed of change of the changing spatial extension of the local wavelike phase quanta is identical to the speed of light, and this speed of light is then a property of the vacuum system, having at every point of position space $\underline{x}$ the same value $c(\underline{x})$ for all observers. Einstein's principle of universality of the speed of light thus remains valid in the framework of the EPT; it should be noted that the principle is then analytic in the context of the EPT. A quantitative formulation of the principle in the context of the EPT is to be incorporated in a mathematical model of the EPT. □

*6.2.4 Remark (relation with the quark hypothesis)*

From the point of view of the EPT, there is no reason to assume the quark hypothesis. However, the existing experimental support for the quark hypothesis is not accepted as a refutation of the EPT: since it is laid down in the foundations of the Standard Model that physics is not about *reality in itself* but instead about *our observations of reality*, one cannot bend over backwards and claim that the existence of quarks in the universe-in-itself has been proved!

The point is that the frameworks of QM and the EPT correspond with two very different philosophies of physics. The EPT, on the one hand, is assumed to correspond with reality in itself. For QM, on the other hand, this is not the case:

> "*as every physicist knows, or is supposed to have been taught, [quantum] physics does not deal with physical reality. [Quantum] physics deals with mathematically describable patterns in our observations. It is only these patterns in our observation that can be tested empirically*" (Stapp 1991).

In other words: if it is the case that the quark hypothesis has merit for recognizing patterns in observations, then that does *absolutely not* imply that quarks in themselves exist in physical reality.

Once again, a central aspect in the discussion is the difference between primary and secondary properties: primary properties are properties that are present in our observation that also occur in the observed object in itself, while secondary properties are properties that are present in our observation but that do not occur in the object in itself. □

## 6.3 The original research question

In this section it will be shown that the EPT indeed supports a repulsion of antimatter by the gravitational field of the earth. However, given that the EPT contradicts the accepted theory of gravitation (GR), cf. proposition 6.2.2, it has to be redefined what 'gravitation' is in order to explain the original hypothesis on gravitational repulsion. For the sake of simplicity, the case is narrowed down to the simplest individual processes (definition 5.1.2).

*6.3.1 Definition*

Let the language of the EPT be extended with the following individual constants:

(i) the subset {–1, 0, 1} of the set $Z$ of all integers, elements of which are to be denoted with a symbol $c_n$, so $c_n \in \{-1, 0, 1\} \subset Z$;

(ii) the set $R^{Z_N}$ of all functions from $Z_N$ to the reals $R$, elements of which are to be denoted with a symbol $s$, so $s = \{[0 \quad m_0], [1 \quad m_1], \ldots, [N{-}1 \quad m_{N-1}]\}$; here the 2×1 matrices $[a \;\; b]$ represent two-tuples $\langle a, b\rangle$ as in (3.10). □

*6.3.2 Interpretation rule*

A constant $c_n \in \{-1, 0, 1\}$ represents a characteristic number of normality; this is an essential property of a monad according to the following rule:

(i) $c_n = 1$ for all normal monads;

(ii) $c_n = -1$ for all abnormal monads;

(iii) $c_n = 0$ for all annihilating monads, cf. example 5.1.8. □

*6.3.3 Interpretation rule*

A function $s \in R^{Z_N}$ represents a rest mass spectrum; this is an essential property of a monad. If the $j^{\text{th}}$ monad has the rest mass spectrum $s$, and if $[x \quad m_x] \in s$, then the amount of energy, distributed in the extended particlelike matter quantum ${}^{EP}\mu_j^x$, is identical to $m_x$, that is, if the extended particlelike matter quantum ${}^{EP}\mu_j^x$ indeed exists. In other words, for every extended particlelike matter quantum, the rest mass is predetermined at every degree of evolution. □

An *electronic monad* is then a normal monad with the rest mass spectrum $s_e$ for electrons; a *positronic monad* is an abnormal monad with the rest mass spectrum $s_{\bar{e}}$ for positrons, for which $s_{\bar{e}} = s_e$. Likewise, a *protonic monad* is a normal monad with the rest mass spectrum $s_p$ for free protons, and an *antiprotonic monad* is an abnormal monad with the rest mass spectrum $s_{\bar{p}} = s_p$ for antiprotons; a *neutronic monad* is a normal monad with the rest mass spectrum $s_n$ for free neutrons, and an *antineutronic monad* is an abnormal monad with the rest mass spectrum $s_{\bar{n}} = s_n$ for antineutrons. Thus, using remarks 4.1.7 and 4.1.10, if the $j^{\text{th}}$ monad is, for example, a protonic monad with rest mass spectrum $s_p$, then in accordance with definition 6.1.1 one would get:

$$\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_j^x \\ {}^{EP}\bar{\mu}_j^x \end{bmatrix} \Rightarrow E({}^{EP}\mu_j^x) = s_p(x) \tag{6.12}$$

The matter quantum ${}^{EP}\mu_j^x$ is thus the state of rest that is part of the state of being of a free proton, which in the language of the EPT is a binad. If the $j^{\text{th}}$ monad would have been an antiprotonic monad, then the rest mass, that is, the amount of energy distributed in ${}^{EP}\mu_j^x$, would have been the same because $s_{\bar{p}} = s_p$. With respect to the original hypothesis, interpretation rule 6.3.3 then covers the observation that the antimatter counterparts of ordinary matter constituents such as electrons, protons, and neutrons have the positive same rest mass; interpretation rule 6.3.2 can then be used to explain how matter and antimatter can behave differently under the influence of a long-distance interaction with predominantly gravitational aspects.

Let the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x+1)^{\text{th}}$ degree of evolution be a simplest individual process for which

$$\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^x \\ {}^{EP}\bar{\mu}_{\tau(1)}^x \end{bmatrix} \quad \text{for some } \tau \in P \tag{6.13}$$

Then one of the two following cases hold:

(i) if $c_n = 1$ for the $\tau(1)^{\text{th}}$ monad, then during the nonlocal mediation in this simplest process the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ has the tendency to effect a transition ${}^{EP}\mu_{\tau(1)}^{x} \to {}^{NP}\mu_{\tau(1)}^{x+1}$ in the world towards a stronger gravitational field (higher energy density);

(ii) if $c_n = -1$ for the $\tau(1)^{th}$ monad, then during the nonlocal mediation in this simplest process the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^x$ has the tendency to effect a transition ${}^{EP}\mu_{\tau(1)}^{x} \to {}^{NP}\mu_{\tau(1)}^{x+1}$ in the world towards a weaker gravitational field (lower energy density).

The $n$ consecutive positions $X_x$, $X_{x+1}$, …, $X_{x+n-1}$ attained by $n$ consecutive extended particlelike matter quanta ${}^{EP}\mu_{\tau(1)}^{x}$, ${}^{EP}\mu_{\tau(1)}^{x+1}$, …, ${}^{EP}\mu_{\tau(1)}^{x+n-1}$ arising in a sequence of simplest processes in which gravitation is the dominant factor thus depend on the characteristic number of normality $c_n \in \{-1, 0, 1\}$, so that $X_j = X(c_n)_j$. See figure 6.2 for an illustration.

To see the symmetry, let the $k^{th}$ individual process from the $x^{th}$ to the $(x+1)^{th}$ degree of evolution be a simplest individual process involving the $\tau(1)^{th}$ monad, for which $c_n = 1$ (e.g. a protonic monad). Let the $l^{th}$ individual process from the $y^{th}$ to the $(y+1)^{th}$ degree of evolution be a simplest individual process involving the $\tau(2)^{th}$ monad, for which $c_n = -1$ (e.g. an antiprotonic monad). Then the following nonlocal mediations happen in these two individual processes:

$$\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\tau(1)}^x \\ {}^{EP}\bar{\mu}_{\tau(1)}^x \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{\tau(1)}^{x+1} \\ {}^{NP}\bar{\mu}_{\tau(1)}^{x+1} \end{bmatrix} \tag{6.14}$$

$$\begin{bmatrix} {}^{NW}\varphi_l^y \\ {}^{NW}\bar{\varphi}_l^y \end{bmatrix} : \begin{bmatrix} {}^{EP}\mu_{\tau(2)}^y \\ {}^{EP}\bar{\mu}_{\tau(2)}^y \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NP}\mu_{\tau(2)}^{y+1} \\ {}^{NP}\bar{\mu}_{\tau(2)}^{y+1} \end{bmatrix} \tag{6.15}$$

Focussing on the gravitational aspects, then the nonlocal wavelike phase quantum ${}^{NW}\bar{\varphi}_k^x$ in (6.14) has the tendency to effect a transition ${}^{NP}\bar{\mu}_{\tau(1)}^{x+1} \to {}^{EP}\bar{\mu}_{\tau(1)}^{x}$ towards a weaker gravitational field, ánd the nonlocal wavelike phase quantum ${}^{NW}\varphi_l^y$ in (6.15) has the tendency to effect a transition ${}^{EP}\mu_{\tau(2)}^{y} \to {}^{NP}\mu_{\tau(2)}^{y+1}$ towards a weaker gravitational field. That is, the behaviour of abnormal matter ($c_\mathrm{n}$ = –1) in the world resembles the behaviour of normal matter ($c_\mathrm{n}$ = 1) in the antiworld in opposite time-direction.

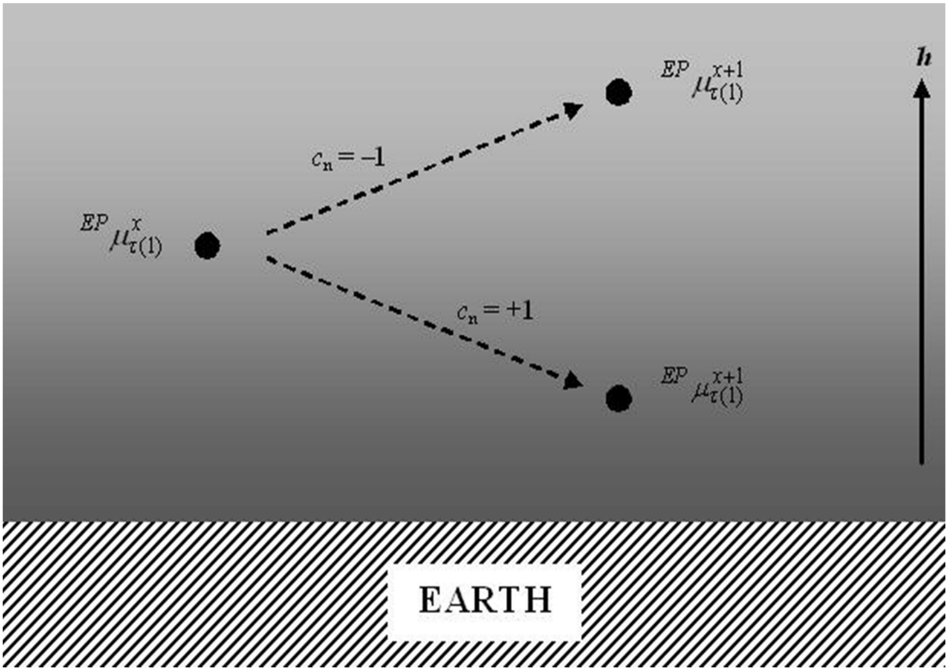


*Figure 6.2: illustration of how matter and antimatter can behave differently in the gravitational field of the earth according to the EPT. The upper grey area depicts the gravitational field of the earth: the arrow on the right indicates the direction of increasing height (h) above the earth's surface, and an increasing darker tint indicates a stronger gravitational field. The lower hatched area indicates the earth's surface. The left dot indicates the position of the extended particlelike matter quantum* $^{EP}\mu^{x}_{\tau(1)}$ *before the gravitational interaction. The two dots on the right indicate the position where its successor, the extended particlelike matter quantum* $^{EP}\mu^{x+1}_{\tau(1)}$, *arises áfter the gravitational interaction: the upper right dot applies to the case that it concerns antimatter (the* $\tau(1)^{th}$ *monad is then abnormal), and the lower right dot applies when it concerns ordinary matter (the* $\tau(1)^{th}$ *monad is then normal). The upper arrow indicates the action of the intermediate nonlocal wavelike phase quantum for a constituent of antimatter (e.g. when the* $\tau(1)^{th}$ *monad is an antineutronic monad) with* $c_n = -1$; *the lower arrow indicates the action of the intermediate nonlocal wavelike phase quantum for a constituent of matter (e.g. when the* $\tau(1)^{th}$ *monad is a neutronic monad) with* $c_n = +1$

Furthermore, while rest mass $m_0$ is connected with Newton's theory of gravitation and all energy is connected with Einstein's theory of gravitation, for the idea of gravitation in the context of the EPT the following relation is suggested between the gravitational mass $m_g$, the amount of energy $E({}^{NW}\varphi_k^x)$ distributed in the state of motion that is part of the binad $\beta_k^x = {}^{EP}\mu_{\tau(1)}^x + {}^{NW}\varphi_k^x$, and the characteristic number of normality $c_\mathrm{n}$ of the $\tau(1)^\mathrm{th}$ monad:

$$m_g = c_\mathrm{n} \cdot E({}^{NW}\varphi_k^x) \tag{6.16}$$

This formula results in negative gravitational mass for antimatter components such as positrons, antineutrons, antiprotons, etc. The negative sign is not meant to indicate that the energy quantum, distributed in the corresponding nonlocal wavelike phase quantum is negative (which is not the case!): it merely indicates that the action of the corresponding nonlocal wavelike phase quantum is opposite. In the universe of the EPT, gravitational mass is thus a *secondary* property. From the inequality (6.1) it follows then that $|m_g| \geq m_0$; rest mass $m_0$ is determined by the rest mass spectrum, cf. interpretation rule 6.3.3 and formula (6.12). Thus, inequality (2.6) has been retrieved. Concluding, gravitational repulsion of matter and antimatter can be described by the EPT; laws of conservation of energy that are consistent with gravitational repulsion have been given in Section 6.1.

### *6.3.4 Remark*

Using the notion of a rest mass spectrum, consider the case that electrons have an *increasing* rest mass spectrum, that is, a rest mass spectrum $s_e$ that satisfies the following inequality for all $x \in Z_\mathrm{N} \backslash \{N-1\}$:

$$s_e(x+1) > s_e(x) \tag{6.17}$$

Furthermore, consider that protons have a *decreasing* rest mass spectrum $s_p$ satisfying the following equation for all $x \in Z_\mathrm{N}$:

$$s_p(x) = s_e(N-1-x) \tag{6.18}$$

This allows an answer to the question "what makes the universe expand?" by De Sitter (1930): the gradually disintegrating protons (i.e. the gradual decrease of rest mass of protons). Namely, in every individual process involving a proton, the positive amount of energy corresponding with the decrease in rest mass is emitted in a local equilibrium, and is contained in a local wavelike phase quantum in the form of a subconstituent $\xi_k^{x+1}$ as in (5.9) and (5.13); the latter then form space in accordance with the elementary principle of formation of space. By this mechanism, the decrease in rest mass of protons leads to an increase in distance between extended particlelike phase quanta in the world: the universe thus expands, as long as this effect exceeds the opposite effect caused by the increase in rest mass of electrons, that is, as long as

$$s_p(x+1) + s_e(x+1) < s_p(x) + s_e(x) \tag{6.19}$$

The currently established rest mass ratio between protons and electrons, the estimated age of the universe and the expansion of the universe should yield the rest mass spectra for electrons and protons. Given that neutrons decay in electrons and protons, for the rest mass spectrum $s_n$ for neutrons one gets $s_n(x) \approx s_p(x) + s_e(x)$. A simple idea for the rest mass spectrum $s_n$ for neutrons is then

$$s_n(x) = s_p(x) + s_e(x) \quad + C \tag{6.20}$$

where $C$ is a (small) real constant. As mentioned earlier, the rest mass spectra $s_{\bar{e}}$, $s_{\bar{p}}$, and $s_{\bar{n}}$ for positrons, antiprotons, and antineutrons, respectively, satisfy $s_{\bar{p}} = s_p$, $s_{\bar{e}} = s_e$, $s_{\bar{n}} = s_n$. □

## 6.4 Language: what is an electron in the framework of the EPT?

The EPT is a theory of the noumenal universe that uses its own ontological repertoire: it poses a challenge to let the EPT make contact with existing language, which has its basis in observations. The simple question can be raised: just what is an electron, using *strictly* the language of the framework of the EPT?

To see how the concepts ‘phase quantum’ (remark 4.1.7), ‘monad’ (remark 4.1.9) and ‘binad’ (axiom 4.2.19) relate to the existing concept ‘electron’, it is best to give an example that (i) uses the formalism of the EPT and (ii) makes contact with observations. Thus, let's assume that in the $k^{\text{th}}$ individual process from the $x^{\text{th}}$ to the $(x + 1)^{\text{th}}$ degree of evolution, a nonextended particlelike phase quantum ${}^{NP}\varphi_k^{x+1}$ is created at the $(x + 1)^{\text{th}}$ degree of evolution that consists of a single nonextended particlelike matter quantum:

$$ {}^{NP}\varphi_k^{x+1} = {}^{NP}\mu_j^{x+1} \tag{6.21} $$

Following interpretation rule 4.1.14, this matter quantum ${}^{NP}\mu_j^{x+1}$ is a motionless point-particle that *precedes* the $j^{\text{th}}$ monad. That is, *upon* the existence of the matter quantum, the properties of the $j^{\text{th}}$ monad exist. And that means, that the property 'rest mass spectrum' already exists at this point; let's assume that the $j^{\text{th}}$ monad has the rest mass spectrum $s_e$ of an electron. According to the Elementary Principle of Local Equilibrium, a local wavelike phase quantum ${}^{LW}\varphi_k^{x+1}$ is emitted from the nonextended particlelike matter quantum ${}^{NP}\mu_j^{x+1}$; according to the Elementary Principle of Local Mediation, this immediately brings about the discrete transition ${}^{NP}\mu_j^{x+1} \rightarrow {}^{EP}\mu_j^{x+1}$. That is, the nonextended particlelike matter quantum ${}^{NP}\mu_j^{x+1}$ ceases to exist and the extended particlelike matter quantum ${}^{EP}\mu_j^{x+1}$ is created at the same spatiotemporal position. Following the interpretation rules of the EPT, this matter quantum ${}^{EP}\mu_j^{x+1}$ is a form of energy that *involves* the $j^{\text{th}}$ monad. What that concretely means is that the amount of energy, distributed in the matter quantum, is predetermined by the rest mass spectrum $s_e$:

$$ E({}^{EP}\mu_j^{x+1}) = s_e(x+1) \tag{6.22} $$

This value $s_e(x+1)$ is then the rest mass that *all* electrons have at the $(x + 1)^{\text{th}}$ degree of evolution. Rest mass is defined as the inertial mass of a particle in rest, where inertial mass $m_i$ is defined in the framework of Newtonian mechanics as a particle's resistance to a change in motion, as laid down in Newton's second law: $F = m_i \cdot a$. Thus, if one could measure the inertial mass in an experiment under nonrelativistic conditions at the $(x+1)^{\text{th}}$ degree of evolution, one would find $m_i = s_{\text{e}}(x+1)$: the conclusion would thus be that the observed particle has the rest mass of an electron.

Proceeding, let's assume that the extended particlelike matter quantum ${}^{EP}\mu_j^{x+1}$ forms a simple extended particlelike phase quantum ${}^{EP}\varphi_k^{x+1}$, the starting point of the $k^{\text{th}}$ individual process from the $(x + 1)^{\text{th}}$ to the $(x + 2)^{\text{th}}$ degree of evolution:

$$ {}^{EP}\mu_j^{x+1} = {}^{EP}\varphi_k^{x+1} \tag{6.23}$$

According to the Elementary principle of Nonlocal Equilibrium, a discrete transition ${}^{EP}\varphi_k^{x+1} \rightarrow {}^{NW}\varphi_k^{x+1}$ then occurs, which is to say that the extended particlelike matter quantum ${}^{EP}\varphi_k^{x+1}$ ceases to exist and the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^{x+1}$ is created. This latter phase quantum ${}^{NW}\varphi_k^{x+1}$ is a noumenon of finite duration, and is responsible for what is observed as motion. This observable motion depends on another property of the $j^{\text{th}}$ monad, namely the characteristic number of normality $c_{\text{n}}$: what that entails is that the observable gravitational mass $m_g$ depends on both the characteristic number of normality and the amount of energy distributed in the phase quantum ${}^{NW}\varphi_k^{x+1}$:

$$ m_g = c_{\text{n}} \cdot E({}^{NW}\varphi_k^{x+1}) \tag{6.24}$$

Let's assume that $c_{\text{n}} = +1$ in the present case, so that $m_g = E({}^{NW}\varphi_k^{x+1}) \geq s_{\text{e}}(x+1)$; the inequality follows from (6.1), (6.22), and (6.23). Now gravitational mass is defined in the framework of Newtonian mechanics as the 'charge' of a particle for the gravitational force $F_g$ as in

$$ F_g = G \cdot \frac{m_{g(1)} \cdot m_{g(2)}}{r^2} \tag{6.25}$$

Thus, if one could measure the gravitational mass in an experiment under nonrelativistic conditions at the $(x + 1)^{\text{th}}$ degree of evolution, one would find $m_g = s_{\text{e}}(x + 1)$: the conclusion would thus be that the observed particle has the gravitational mass of an electron. Note that if the characteristic number of normality $c_{\text{n}}$ would have been negative as in $c_{\text{n}} = -1$, then an observer on earth would detect an acceleration *away* from the earth's surface and thus a negative force in (6.25), and thus a negative gravitational mass $m_g = -s_e(x + 1)$ consistent with (6.24): in that case, the observer would conclude that the observed particle has the gravitational mass of an positron.

Proceeding, the extended particlelike matter quantum and the nonlocal wave-like phase quantum together form a binad $\beta_k^{x+1}$ as in

$$ {}^{EP}\mu_j^{x+1} + {}^{NW}\varphi_k^{x+1} = \beta_k^{x+1} \tag{6.26} $$

Given that the $j^{\text{th}}$ monad has the rest mass spectrum of an electron and the characteristic number of normality $c_n = +1$, this binad is thus a bipartite noumenon, of which an observer would say in existing language that it is the state of being of an electron. According to the Elementary Principle of Nonlocal Mediation the nonlocal wavelike phase quantum collapses: by this collapse it ceases to exist, and a phase quantum ${}^{NP}\varphi_k^{x+2} = {}^{NP}\mu_j^{x+2}$ is created: this has a different spatiotemporal position than the matter quantum ${}^{EP}\mu_j^{x+1}$. The above then repeats itself again and again, and maintaining the label $k$ for the consecutive individual processes this gives rise to consecutive *electronic binads*[13]:

- $\beta_k^{x+2} = {}^{EP}\mu_j^{x+2} + {}^{NW}\varphi_k^{x+2}$
- $\beta_k^{x+3} = {}^{EP}\mu_j^{x+3} + {}^{NW}\varphi_k^{x+3}$

and so forth. In existing language, one would say that these are consecutive states of being of *one and the same* electron. The concept 'electronic binad' thus translates into existing language as 'state of being of an electron', but one cannot identify the existing concept 'electron' with the concept 'electronic binad' in the framework of the EPT: then, namely, *different* binads cannot concern the *same* electron[14]. It is thus on the basis of the concept 'monad' that one can say that a series of ob-

[13] An electronic binad is thus a binad $\beta_l^y = {}^{EP}\mu_i^y + {}^{NW}\varphi_l^y$ for which the $i^{\text{th}}$ monad is an electronic monad.

[14] It is important to realize that in the framework of classical mechanics, an electron is identified with a particle: there one can speak of the *same* individual (particle) at a *later* time. In the framework of the EPT, however, the electronic binad at the next degree of evolution is a *different* individual (binad) – it is *not* the same individual at a later time.

served states concerns *one and the same* electron: it is because of the invariant properties of the monad, which manifest themselves in observable properties such as rest mass and gravitational mass, that one is justified to say that the observations concern an ‘electron’, and it is because of the fact that the binads concern the *same* monad (as indicated in the formalism by the use of right subscripts of the mathematical symbols referring to matter quanta), which manifests itself in observable properties of the state of motion, that one is justified to say that the observations concern the *same* electron. See figure 6.3 for an illustration.

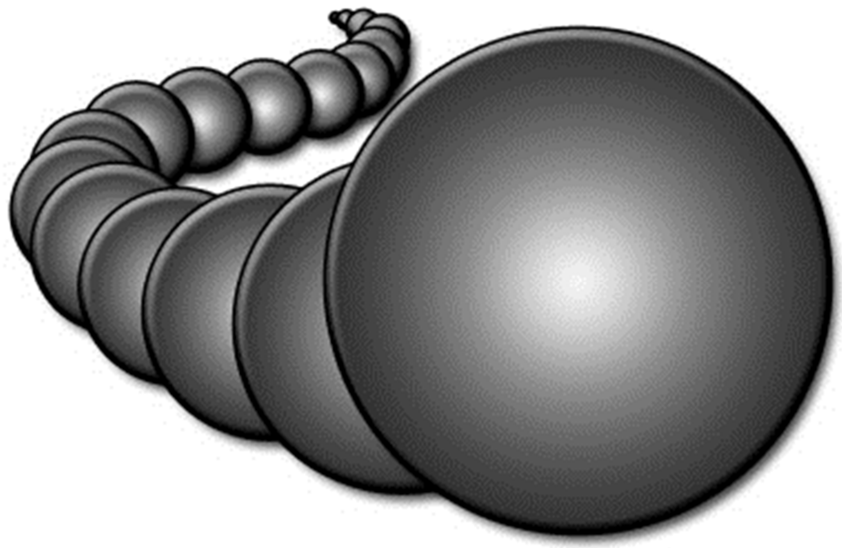

*Figure 6.3: illustration of the concepts ‘phase quantum’ and ‘monad’. The chain of balls abstractly depicts binads* $\beta_k^{x+a} = {}^{EP}\mu_j^{x+a} + {}^{NW}\varphi_k^{x+a}$ *for a = 1 to 17, that is, binads at 17 consecutive degrees of evolution: the balls depict the motionless matter quanta* ${}^{EP}\mu_j^{x+a}$*, while the phase quanta* ${}^{NW}\varphi_k^{x+a}$ *are not shown (these exist “in between” the matter quanta; motion is stepwise in the framework of the EPT). Upon the transition from one degree of evolution to the next, the state of being of the electron at the ”old” degree of evolution ceases to exist, and a new one arises at the new degree of evolution. These binads are thus different objects, but the monad involved has remained the same: the states of being therefore concern the same electron.*

The above demonstrates that the apparently simple question “what is an electron?” is not that simple to answer in the framework of the EPT – one can say that the concepts ‘electronic binad’ and ‘state of being of an electron’ are comparable, but it has been shown above that the concept ‘electron’ cannot be identified with the concept ‘electronic binad’, because then the next binad (a different object) would be a different electron. Thus, as it turns out, the existing concept ‘electron’ has strictly speaking no exact equivalent in the language of the EPT: given the definition of an “electronic monad” from §6.3, then at best the statement “these are consecutive binads that concern one and the same electronic monad” in the language of the EPT and the statement “these are consecutive states of being of one and the same electron” in existing language are equivalent – the same holds analogously for positrons, (anti)protons, (anti)neutrons, etc.

The crux is that the EPT, as any axiomatic theory, makes use of primitive concepts. There is, however, no substitute for these concepts: one might be inclined to think that all that is needed to make the EPT more accessible is to translate its language into existing language, but that is an error. As J.W. Cobb put it: “One cannot translate the new vision into the vocabulary of the old. (2008; 7)”

## 6.5 Some process-philosophical aspects

In this section, some process-philosophic aspects of the EPT are discussed. Subsection 6.5.1 deals with the categorization of the EPT as a process theory. Subsection 6.5.2 contrasts the EPT with Cahill’s Process Physics. Subsection 6.5.3 addresses the major agreements and differences between the EPT and Whitehead’s Process Philosophy. Subsection 6.5.4, last but not least, presents a process that is strictly forbidden by the EPT.

### *6.5.1 Categorization of the EPT as a process theory*

The EPT primarily consists of a scheme of formal expressions plus a physical interpretation: the categorization as a process theory – that is, as a theory that implies the view that the world is best understood as a process – is thus secondary, and is nothing but a consequence of the physical interpretation. The point is thus that the axioms of the EPT are fundamental and *not* its categorization as a process theory.

As a result, it is thus not the case that metatheorems that have thus far been valid in the field of process philosophies are acceptable as an argument against the EPT – that is, its formal expressions and their physical interpretation – or aspects thereof: the counterargument is then simply that the area of validity of the metatheorem in question is limited. For example, the observation that other process philosophies do not distinguish between a changing being and an underlying, invariant being is not acceptable as an argument against the introduction of the concept 'monad' in the framework of the EPT: the counterargument is thus that this may very well be the case for *other* process theories, but that that does not necessarily imply that it *thus* has to be the case for the EPT also. As another example, it is not the case that the inclusion of monads as sets of invariant properties in the framework of the EPT disqualifies the EPT as a process theory because change has to be essential in a process theory: the EPT is clearly about the individual processes and thus about change, but that does not necessarily imply that *all* aspects of the universe have to change – in other words, it does not imply that a series of different objects, brought about by change, cannot share some invariant properties. For comparison, in Heraclitus' view one cannot step twice in the same stream; in both cases, however, the water in the stream is wet. Thus, the fact that monads are invariant does not render the EPT the negation of a process theory.

### *6.5.2 Contrast of the EPT with Cahill's Process Physics*

In Australia, a research program is being carried out on so-called Process Physics (PP), founded by Reginald Cahill. A review of PP is published in (Cahill 2003). Below a handful of differences between the EPT and PP will be discussed; the discussion is at a very elementary level, but it turns out that this is enough to indicate the scope of the contrast between the two theories.

In the first place, the EPT is an axiomatic theory written in a mathematical formalism, while in the framework of PP the entire concept of an axiomatization in mathematical language is rejected on account of Gödel's incompleteness theorem: PP uses a formalism analogous to neural network theory. The formalizations of the EPT and PP are thus radically different. As a side note, Cahill's argument against a mathematical formalism does not apply to the EPT, because the EPT is finite, that is, because there are only a finite number of components in the entire universe of the EPT.

A second major difference is that the EPT implies the view that there are ultimate building blocks of the universe, while PP entails the negation of this view: the universe of PP has a fractal structure. This difference is one of Kant´s four antinomies: the two views are contradictory, but both can be defended with rational arguments. So neither view can be refuted rationally: this has to be taken as a radical difference in ontological presuppositions between the EPT and PP.

A third point is that the ultimate building blocks of the universe of the EPT are material objects, while PP is devoid of material objects: in PP, information is fundamental. This raises the question whether PP is actually a form of Berkeleyan idealism: according to the latter view, namely, there is no material world that underlies the mental impressions. But not only is PP devoid of objects: also space is emergent. This raises a next question: if space is emergent, i.e. outside the ontological presumptions of PP, then what separates the nodes in the network?

A fourth radical difference is that PP entails the view that there is a fundamental randomness in nature, while the universe of the EPT is neither probabilistic nor deterministic. That is, both theories share the view that the future of the universe is not determined, but according to PP the future unfolds by genuinely random events, while according to the EPT it unfolds by making choices. With respect to this probabilistic aspect, PP corresponds with contemporary quantum physics, which is supported by experimental evidence; it still needs to be proven that the same experimental results can also be explained on the basis of the EPT.

On the basis of these four differences the conclusion is justified that the EPT and PP are two radically different theories: the only agreement seems to be the word 'process' in the name of the theory. The above is absolutely not meant as an exhaustive account on the differences between the two theories: it would require further research to map out all the differences and agreements between these two theories.

*6.5.3 Interplay between the EPT and Whitehead's Process Philosophy*

In 1929 the philosopher Alfred North Whitehead published his process philosophy in his book *Process and Reality*, cf. (Whitehead 1929). While this is primarily a philosophy of the process of human experience, his philosophical system contains the additional assumption that there is a similarity – although not necessarily in all aspects – between the processes of human experience and microprocesses. On that basis, the EPT can be compared with Whitehead's view on microprocesses. A word of caution here is that Whitehead's system is rather complex and uses its own vocabulary: as the comparison with the EPT below is based on a reading of secondary literature, cf. (Cobb 2008), it is necessarily based on this author's interpretation of Cobb's interpretation of Whitehead. That is to say: it may very well be the case that some terms of Whitehead's vocabulary are interpreted differently than he may have intended. Still, the comparison gives a first indication of the agreements and the differences between the EPT and Whitehead's process philosophy (WPP).

An interesting starting point for the comparison is the following remark of Cobb (2008; 54-55):

> "*Many philosophers have come to assume that, on an empirical basis, we cannot affirm the reality of a world beyond our sensory experience. This has led many philosophers to move farther and farther away from common sense. ... For Whitehead the common sense view is correct. We know there is a world*

*beyond ourselves because we experience it as such. Of course, common sense can lead to naïve views about that world that Whitehead does not share. … But the external world possesses the actuality that common sense assumes, and Whitehead speculates that what is felt as there and what is actually there have some real connection.*"

From this quote it is obvious that both the EPT and WPP are realist theories.

While both the EPT and WPP share the view that there are ultimate constituents, the two theories differ radically with respect to the nature of these ultimate constituents. In the framework of the EPT, phase quanta are material objects; WPP, however, holds an entirely different view:

> "*Whitehead's judgment was that the actual entities that make up the world are all 'actual occasions.' That means that they are happenings, occurrences, or events rather than substantial entities that endure unchanged through time. … Actual occasions are the actual entities of which the world, meaning thereby this cosmos and any other cosmos that may have been, may now be, or may come to be, is composed. This is a sharp challenge to most of the Western tradition and to the 'common sense' inculcated in us by our language. When we say, 'the dog barks,' or 'the rug is blue,' most of us think of the dog and the rug as actual entities. Whitehead disagrees*. (ibid; 16-17)"

Thus, the EPT and WPP differ fundamentally qua ontology: in the EPT substantial entities are fundamental, and in WPP events are fundamental. The events in WPP, however, are nothing like the events in classical mechanics, which are defined as bits of matter in motion:

> "*For most modern Westerners an event is … completely explained as nothing but bits of matter in motion. Whitehead reverses the relation of stable entities and events. The stable entities are ultimately made up of quantum events complexly structured. The events are most concretely analyzed into the smaller events of which they are composed. The events that cannot be analyzed into smaller events, that is, the "atomic" events are the actual occasions or occasions*. (*ibid*; 23)"

In the EPT, the material substantives (phase quanta) and the discrete transitions (which are events) are different: it is not the case that matter is made up of discrete transitions. In WWP, however, the universe is thus made up of quantum events.

Furthermore, while in WPP *macroscopic* processes are distinguished from *microscopic* processes, these microscopic processes differ fundamentally from the individual processes described by the EPT. A Whiteheadian microscopic process can be analyzed into three different phases: the initial or "conformal" phase, the "supplementary" phase, and the "satisfaction" (*ibid*; 61-62). While it may be the case that some aspects of these phases can, in a sense, be found back in the individual processes of the EPT, it is certainly not the case that these three phases cover the chain of discrete state transitions that take place in the individual processes in the universe of the EPT. That is to say: WPP and the EPT differ fundamentally with respect to the view on what happens in individual processes.

A further fundamental difference revolves around the principle of locality. WPP contains the following definition of the concept 'contemporary world':

> "*The 'contemporary' world is made up of all the occasions that are neither causally effective in the occasion in question nor causally affected by it. That is, contemporaries are occasions that do not affect one another.* (*ibid*; 78)"

This is in contrast with the nonlocal wavelike phase quanta that occur at the same degree of evolution in the EPT: these do affect one another. That is, WPP is a local theory and the EPT is a nonlocal theory.

But the relation between the EPT and WPP does not consist solely of differences. In particular, the idea of a single long-distance interaction, of which gravitation and electromagnetism are aspects, can be explained in Whiteheadian terminology. It is emphasized that this explanation cannot replace a mathematical model of such an interaction: it is merely meant to get an intuitive grasp on the matter.

The point is that in WPP all actual entities (occasions) are both objects and subjects: as subjects they prehend (feel) other objects, as objects they are prehended by other subjects – this is the basic idea of interaction. To get to a more detailed picture of the idea of long-distance interaction in the framework of the EPT, consider Whitehead's notion of a nexus:

> "*The idea of a nexus is very important for translating back and forth between Whitehead and most other philosophical systems. What many others call 'actual entities,' Whitehead calls 'nexūs.' This is most obvious in relation to philosophies that stay close to ordinary language and treat the objects of everyday experience as actual entities. But it is true also of most process philosophies, which take events as primary. Most of the events that are so treated are, for Whitehead, nexūs, that is, they are composed of multiple actual occasions.* (*ibid*; 27)"

Ignoring the fact that the universe of the EPT consists of material substances and the universe of WPP of quantum events, the vacuum in the framework of the EPT is then a nexus: it is composed of spatial phase quanta, local wavelike phase quanta, and nonlocal wavelike phase quanta. In WPP, the "initial data" of a nexus has to be distinguished from its "objective datum":

> "*The initial data constitute the prehended nexus formally, that is, with all the features of all the entities intact. The objective datum of the occasion as a whole is the way the new occasion prehends the nexus.* (ibid; 28)"

For the vacuum as a nexus, the EPT thus describes the initial data: this is the nexus as it is in itself, the nexus in its "formal completeness". The objective datum of the nexus is then a curved spacetime: this is how the vacuum is experienced. Thus, a nonlocal wavelike phase quantum that comes into existence "feels", "prehends" the vacuum: not the individual phase quanta that make up the vacuum, but the nexus as a whole – its objective datum. After a short existence, the nonlocal wavelike phase quantum collapses: the collapse is nothing but a discrete transition into a nonextended particlelike phase quantum. By that collapse, a choice is made from a set of parallel possible nonextended particlelike phase quanta: the one nonextended particlelike phase quantum, into which the nonlocal wavelike phase quantum collapses, is chosen from that set. According to Whitehead, *“All occasions have some indeterminacy in their origins. … However, the occasion completes itself as something entirely determinate. This involves cutting off all possibilities except one. This is its ‘decision.’ This decision is its own.* (*ibid*; 57)”

This aspect of WPP thus applies to nonlocal wavelike phase quanta: the above quote is fairly correct if the term ‘occasion’ is replaced by the term ‘nonlocal wavelike phase quantum’. The decision that is made – note that this results in an observable displacement in the framework of the EPT – then reflects the interaction with the vacuum: this is the long-distance interaction.

The above demonstrates that there are not only differences, but also agreements between the EPT and WPP. But what has been said in the previous section also applies here: the above is absolutely not meant as an exhaustive account on the interplay between the two theories: it would require further research to map out all the differences and agreements between the EPT and WPP.

*6.5.4 A process forbidden by the EPT*

Consider, in the periodic table of elements, the element boron. There are just two naturally occurring isotopes: ${}^{10}_{5}B$ and ${}^{11}_{5}B$. What is interesting about boron is that both isotopes are stable: there is thus no radioactive decay. Now consider a system under standard laboratory conditions that consists solely of boron: according to the EPT, this system thus evolves *exclusively* by means of simple processes. That is, the boron nuclei participate in simple processes, and the electrons in the electron shells participate in simplest processes.

What the EPT then strictly forbids, is that the boron under consideration ceases to exist. This is not at all trivial: from the empty set of assumptions, namely, it cannot be predicted that any amount of boron, existing at given moment, will still exist a moment later.

This aspect of the EPT can also be tested in an experiment. Under standard laboratory conditions an amount of, say, 1.6578432 g of analytically pure boron can be placed on a Mettler Toledo XP2U Ultra-microbalance. The prediction of the EPT, supplemented with some auxiliary hypotheses, is then that the measurement apparatus will continue to give the same reading for, say, 10 minutes. Note that this prediction is then confirmed with an accuracy of eight digits. Of course, the same prediction could have been made on the basis of another theory, so this experiment is not very suitable for distinguishing the EPT from other theories. However, the aim here is not to decide between the EPT and some other theory: the aim is merely to give an example of a process that is strictly forbidden by the EPT – that the same process is also forbidden by other theories is irrelevant.

Suppose, on the other hand, that the reading of the Mettler balance suddenly would have changed to 0.0000000 within the given period of ten minutes. That would have falsified the set of assumptions, which consists of the EPT *plus the auxiliary hypotheses*. One of these is that the rest mass spectra of the nucleons (the protons and neutrons in the boron nuclei) are constant functions for the given amount of time. A possible explanation for change in reading would then be that the rest mass spectra suddenly have gone to zero: such would manifest itself in the observation that boron would have disappeared everywhere (literally). If boron would elsewhere still be there, then at least one of the other assumptions is not correct. One other auxiliary hypothesis is that the spatiotemporal displacements, which are effected in the nonlocal mediations, are such that the boron nuclei remain located on the weighing scale: this reflects the assumption that influences from outside are negligible during this experiment. If this hypothesis is false, then the boron that was initially there could still exist, only somewhere else: that would explain the change in reading. The question is then how this is possible. That is to say: such a negative result would not necessarily falsify the EPT *directly*, but would pose a problem for the research program on the EPT that might turn out to be insolvable: the scientific method here is *refined* falsification, not *naïve* falsification!

## 6.6 Outstanding open issues

The crux is that there is currently insufficient proof that the seven elementary principles of the EPT indeed correspond with physical reality. But that does not imply that further research cannot yield such proof: although the supersmall level is not directly experimentally accessible in a laboratory, the scientific method still applies. A concrete mathematical model of physical reality, based on the EPT, can namely be used to predict how a physical system, governed by the principles of action of the EPT, will behave on the long run. In a research program, aimed at showing the correspondence between the EPT and physical reality in this way, three key problems – all still open – have to be solved; these will be discussed below.

The first major open issue is that the EPT has currently no concrete mathematical model: the terms of the EPT are defined without reference to any concrete mathematical structure. The first objective of further research is therefore to develop a concrete mathematical model $M$ of the EPT, that is, an interpretation of the terms of the EPT in a concretely defined set-theoretical structure (such as the space of all functions from a well-defined position space $X$ to some field $F$), such that the following first-order conditions are satisfied:

(i) $M \models A_i$ for any of the seven axioms $A_1, \ldots, A_7$ being the translation of the seven axioms of the EPT in terms of the model $M$;

(ii) $M \models P_j$ for any of $n$ formulas $P_1, \ldots, P_n$ being a formulation of $n$ empirical premises in terms of the model $M$;

(iii) $M \models H$ for a formula $H$, being a formulation of the hypothesis of Section 1.3 in terms of the model $M$.

This is a non-standard mathematical-physical problem; the notion of a model $M$ of a theory $T$ is well-known, cf. (Shoenfield 2001: 21). Note that such a model is necessarily inconsistent with GR because of (iii). From logical consistency of the EPT, consistency of the EPT with experiment, and the completeness theorem of first order logic it follows that such a mathematical model $M$ of the EPT must exist, but that does not necessarily imply that such a model is easy to find. More precisely, it is questionable whether there are enough experimental data (to be translated in empirical premises $P_j$) to develop a model covering the weak and strong interactions. The intention is therefore to first develop a mathematical model of a single long-distance interaction having gravitational and electromagnetic aspects.

The second major open issue is that there is currently no mathematical proof that QM and GR are approximations of the EPT in their respective areas of application. A direct such proof is mathematically impossible, because the EPT is defined in an abstract mathematical setting, while QM and GR on the other hand are each formulated in a concrete set-theoretical domain. The proof in question has to be done in two steps. The first step is to develop a concrete mathematical model *M* of the EPT, as outlined above: this yields an interpretation of the abstract expressions of the EPT in a concrete set-theoretical domain. The second step is then to prove that the mathematical model *M* of the EPT adheres to the principle of correspondence, that is, that the mathematical expressions of QM and GR are approximately true in the mathematical model *M* of the EPT in their area of applicability. This too is a non-standard mathematical-physical problem.

The third open issue is that experimental facts have to be produced which cannot or not easily be incorporated in the research programs based on GR or QM: the idea is that the research program on the EPT has to be *both* theoretically *and* empirically progressive compared to the research programs on GR and QM before the EPT can be called a "scientific" theory.

## 6.7 The EPT, GR or QM?

From Section 6.3 it is clear that a theory, the EPT, has been developed that supports gravitational repulsion of matter and antimatter. From Section 6.6, however, it is clear that there is currently insufficient evidence that the universe governed by the EPT corresponds with physical reality. From Section 6.2 it is clear that the EPT is incompatible with the contemporary foundations of physics: *if* there is sufficient evidence that the EPT corresponds with reality, then the cornerstones of modern physics, QM and GR, consequently have to be discarded as the correct foundational theories of physics. The question is then: *when* is there sufficient evidence for the EPT? In this section, this question will be dealt with.

The incompatibility between the EPT and GR, cf. proposition 6.2.2, implies that these two theories cannot both be universally true: for at least one of the two theories, the assumed correspondence with reality thus creates a contradiction with at least some physical systems. In the case of GR and the EPT, the scientific method can decide which of these two theories has to be rejected, that is, which of the research programs having either of these theories in its hard core has to be eliminated. All other things equal, this decision can be based on the outcome of a crucial measurement that establishes the coupling between antimatter and gravitation:

- if the coupling is found to be negative, that is, if antimatter is repulsed by the gravitational field of the earth, then the principle of equivalence of GR is directly falsified: in that case, the research program(s) based on GR can be terminated;
- if the coupling is found to be positive, then the EPT has been developed from a falsehood; in that case, the research program based on the EPT can be terminated.

In the first of these two events, it remains the case that three open issues of Section 6.6 have to be solved before the EPT can be called a scientific theory. That is, the fact alone that the choice between the EPT and GR falls on the EPT does not render the EPT a scientific theory: it remains a protoscientific theory until all conditions for the predicate “scientific” are met.

Analogously to the above case, the incompatibility between the EPT and QM, cf. proposition 6.2.1, implies that at least one of these two theories has to be rejected as an adequate foundational theory for physics. In this case also the scientific method can decide which of these two theories has to be rejected, but unlike the previous case this may result in a battle between research programs.

Although there is currently no quantum theory of gravitation available, the experiment to establish the coupling of antimatter with gravitation is also crucial for the choice between QM and the EPT. As is the case in the comparison of the EPT with GR, it remains the case that the EPT has to be rejected if it is established that gravitation is attraction only. If, however, gravitational repulsion of matter and antimatter were to be detected experimentally, then it is true that the Standard Model has been falsified because of its build-in TCP-invariance, but since the Standard Model is an application of QM this does not imply that then also QM itself has been falsified. In other words, an experimental detection of gravitational repulsion does not falsify QM, so the research programs based on QM remain coexisting with the research program on the EPT in that case. Several scenarios are then possible that yield a decision between the EPT and QM:

- the research programs based on QM remain degenerate, and the research program based on the EPT yields an output that solves the three issues of Section 6.6: in that case there is sooner or later no point anymore in sticking to the research programs on QM, and the decision between QM and the EPT is then in favor of the EPT;
- the Standard Model can be fixed, a quantum theory of gravitation can be developed, and the research program based on the EPT does *not* yield an output that solves the three issues of Section 6.6: in that case at some point the research program based on the EPT has to be terminated, and the decision between QM and the EPT is in favor of QM;
- the Standard Model can be fixed, a quantum theory of gravitation can be developed, and on the long run the same phenomena can be explained by the research program based on QM and by the research program based on the EPT: in that case, the decision between QM and the EPT is still in favor of the EPT on the basis of Ockham's razor, because the finite universe of the EPT is much more simple than the infinite summations of the Standard Model.

So, obviously, the pair of theories made up of the EPT and QM yields a more complicated choice procedure than the pair of theories made up of the EPT and GR. The reason is that GR strictly forbids gravitational repulsion of matter and antimatter, which QM doesn't: GR is thus refuted by an observation of such a gravitational repulsion, but QM, on the other hand, isn´t. An observation of gravitational repulsion may thus lead to what Lakatos called a “clash between two research programs”: the one based on QM and the one based on the EPT.

# 7

## CONCLUSIONS AND RECOMMENDATIONS

Section 7.1 shows the significance of the results of this PhD research, Section 7.2 the implications of these results, and Section 7.3 their limitations. Section 7.4 gives recommendations for further research.

### 7.1 Significance of the results

The main conclusion is that an answer has been found to the research question: which laws of physics might underlie the hypothesis that rest-mass-having antimatter will be repulsed by the gravitational field of the earth? Since the 1950's this research question has been investigated several times at various institutes, but the output of this PhD project constitutes the first non-classical answer. And this is not just a "set of hunches and calculations suggesting that a theory might exist", as Holt described string theory: the main result, the Elementary Process Theory (EPT), consists of seven universal elementary laws, *positively formulated* in mathematical language, that are incorporated in a formal axiomatic system, and that are demonstrated to support a gravitational repulsion of matter and antimatter. In addition, these laws satisfy the general principle of relativity, that is, the EPT is the same for all observers.

A second conclusion is that the results of this PhD research form an entirely new disciplinary matrix for the study of physical reality. The EPT has been critically confronted with the contemporary foundational theories of physics, General Relativity (GR) and Quantum Mechanics (QM), and it has been demonstrated that both GR and QM contradict the EPT. That is, there exists a formal statement Ψ in the language of the EPT reflecting an essential aspect of QM, and a formal statement Φ in the language of the EPT reflecting an essential aspect of GR, such that

$$\vdash_{EPT} \neg\Psi \tag{7.1}$$

$$\vdash_{EPT} \neg\Phi \tag{7.2}$$

The EPT thus has to be seen as a *fundamental* theory that is assumed to govern the universe at supersmall scale – an area to which neither QM nor GR are proven to apply. The scope of the difference with the contemporary foundations of physics is that the EPT is formalized in an entirely different mathematical setting, and that in addition the corresponding worldview is described in an entirely different terminology. Both the formalism and the terminology might seem cumbersome at first sight, but one has to keep in mind that the subject matter here is the universe at supersmall level: as the Roman philosopher Cicero put it, new terminology can then not be found on the marketplace.

The third conclusion is that a correspondence of the EPT with physical reality is only within the realms of possibility. It is true that the EPT satisfies traditional criteria of quality – such as conceptual coherence, logical consistency, mathematical rigor, physical completeness, experimental testability – but that does not make the EPT more true as a physical theory. It is also true that a number of applications of the EPT have been developed to demonstrate applicability to real world problems, but that does not suffice as scientific evidence for a correspondence of the EPT with reality. To elaborate, a variety of observed processes has been formalized in the framework of the EPT: it is true that these processes cannot *all* be formalized in the framework of any other theory, but each of the processes separately can also be described adequately by another theory – the description on the basis of the EPT then doesn't add anything. Furthermore, the EPT has been applied to a theory of the Planck era of the universe: it is true that no such theory exists on the basis of QM or

GR, but on the other hand there are also problems, such as the perihelion precession of Mercury, for which solutions exists on the basis of QM or GR but not on the basis of the EPT. Finally, the EPT has been applied to formulate a principle solution to the mind-body problem in philosophy: that also is not a decisive argument *for* the EPT or *against* the existing approaches to the mind-body problem based on classical and quantum mechanics. The EPT has thus the status of a *protoscientific* theory, and further research is needed to establish whether it has to be discarded or to be accepted as a scientific theory.

## 7.2 Implications of the results

The main implication of the results of this PhD research is that they give rise to a fundamentally new, potentially progressive research program in physics. The newly arisen research program on the EPT does not *supersede* the currently mainstream research programs in physics: it *coexists*. However, given the radical difference between the EPT and the contemporary foundations of physics, the emergence of this research program on the EPT effects a transition from *modern physics*, i.e. the relative unanimous “field” of research programs based on QM or GR, to *postmodernism in physics*. The newly arisen bigger picture in physics as a branch of science is, namely, that there now is a variety of ongoing research programs that differ radically from each other qua fundamental assumptions about the physical world (hard core), qua methodology and heuristics, and qua aims – a pluralism not unlike the pluralism in the postmodernism in philosophy. However, there is also a major difference between this postmodernism in physics and the postmodernism in philosophy: the latter idea, namely, is that the pluralism has to be accepted as *final* or *irreducible*, while the postmodernism in physics, on the other hand, is only about the *temporary* acceptance of a pluralism – the point is, namely, that the scientific method will in the end decide which research programs have to be terminated.

A secondary implication of the research results concerns the scope of the pluralism: this is, namely, not limited to the object level – also at the metalevel, the research program on the EPT differs from the currently mainstream research programs. At object level, the EPT postulates, for example, the existence of forms of energy (nonlocal wavelike phase quanta) that do not occur in GR or in the Standard Model. But at the metalevel, physics is about *reality in itself* in the research program on the EPT, while on the other hand the most widely held view today is that physics is not at all about the physical world in itself, but instead about doing statistical predictions about the outcomes of *observations of reality*. Another point is that in modern physics virtually unanimous the view is taken that the world is best studied by *interaction theories,* while in the research program based on the EPT the view is taken that the world that is best studied *as a process*. These examples indicate that the present results give rise to a host of issues, both at object level and at metalevel.

A further implication is that the currently accepted foundational theory for mathematics, Zermelo-Fraenkel set theory (ZF), has to be rejected in the research program of the EPT, because it is inappropriate for the formalization of the EPT. Thus, notwithstanding the fact that ZF is adequate as a foundational theory for (virtually) all of *mathematics*, it is not the case that ZF is adequate as a mathematical foundation for all of *physics*. Instead, set matrix theory (SMT), a generalization of ZF, has to be taken as the foundation for mathematics; the adage "*mathematica ancilla physicae*" is thus the point of view from which the replacement of ZF by SMT is justified – this point of view is thus implicitly taken in the research program on the EPT. The scope of this implication is limited to the research program on the EPT: only in the eventuality that the research program on the EPT supersedes the other research programs in physics, the inappropriateness of ZF for the formalization of the EPT may have implications beyond its current limit.

In the last-mentioned eventuality that the research program on the EPT would supersede the current research programs in modern physics – hypothetically speaking, thus – the implications may be far-reaching. For physics this would obviously entail a drastic departure from its contemporary foundations: if the EPT is accepted as fundamental then GR and QM are certainly *not* fundamental. If that situation would occur, then the current physicalist approaches to the mind-body problem based on classical and quantum mechanics would be based on false assumptions about the workings of the physical world: a future establishment of the EPT as a scientific theory would thus also have implications for the study of the workings of the mind. And not only that: a gravitational repulsion of matter and antimatter would have implications for technology, too – a repulsive aspect of gravitation would namely be applicable to the generation of a vertical displacement without fossil fuel. Apart from wild speculations about what that may mean for society, that would offer perspectives for future technologies for the conservation of energy; of course, in this early stage no statement can be made about its efficiency.

## 7.3 Limitations of the results

Besides being only potentially applicable to physics under the condition that gravitational repulsion exists, a limitation of the main result of this PhD research, the EPT, is its inability to do quantitative predictions, which is due to its degree of abstractness. It is not the case that the EPT makes no predictions *at all*: the axiomatic system, in which the EPT is incorporated, contains a predicate calculus. But suppose that the EPT predicts that the constituent $\varphi$ will exist in the world: because the symbol $\varphi$ is an abstract-mathematical *designator* – as opposed to a *representation* of the state of the constituent in question – the EPT does not predict *when* that constituent will exist or *where*. Simply put, the EPT describes *how* an apple falls from a tree, but not *how fast*. The EPT is thus an example of a theory that can be tested by *refined* falsificationism, but not by *naive* falsificationism – its high degree of abstractness is thus both a blessing and a curse.

Furthermore, the results of this PhD research are limited to the *process-theoretic* aspects of a universe in which matter attracts matter, antimatter attracts antimatter, and matter and antimatter repulse each other: it is true that these are completely covered, but this is still only an aspect of reality. Even in the case that a negative coupling of antimatter with the gravitational field of the earth would be observed, interaction theories consistent with the EPT must still be developed. This is far from just a matter of filling in the blanks: it may even turn out that unsolvable problems emerge in further research towards an interaction theory. The EPT is *consistent with* the idea of a single cosmic interaction, but that is *not* the same as an accomplished unification of gravitation and electromagnetism: with that regard, the EPT only provides first principles of a *new approach* to a description of gravitation and electromagnetism as two aspects of a single long-distance interaction. If the EPT remains consistent with experimental results in the future, then it is *theoretically* a certainty that a mathematical model of the EPT exists that covers the fundamental interactions of nature, but there is no guarantee whatsoever that the research program aimed at that model will produce a positive output *in practice* within, for example, a hundred years.

## 7.4 Recommendations for further research

Further research within the disciplinary matrix of the EPT can be undertaken in three areas:

(i) a mathematical model of the EPT;

(ii) the mathematical foundation of the EPT;

(iii) the applications of the EPT.

Below, recommendations for these three areas will be given.

Concerning the first area, a general methodology can be given for research towards a mathematical model of the EPT. The development of an adequate mathematical model can, namely, theoretically be accomplished in three phases: the first phase is aimed at a mathematical model that satisfies the first-order conditions set forth in Section 6.6; the second phase is then aimed at a proof that it adheres to the principle of correspondence; the third phase is aimed at theoretical and empirical progression compared to rival research programs – this involves an overlap with the above third area of research: applications of the EPT. Given the incompatibility of QM and GR with the EPT, negative heuristic rules for research towards a model of the EPT are then that it is not interesting to try to unify, or "merge", the EPT with GR or with QM. In addition, given that the EPT has to be considered fundamental, another negative heuristic rule is that it is not interesting to search for "deeper" physical principles, such as a single equation from which the EPT can be derived. Furthermore, given the degree of abstractness of the EPT, there will always be several mathematical models possible that satisfy the preset first-order conditions: a positive heuristic rule is then that a pragmatic attitude can be adopted. That is, if the model satisfies the conditions, then that's good enough. For the nearby future, the recommendation is to aim further research in this direction at a model incorporating gravitation and electromagnetism, but not the other two fundamental interactions. However, in Lakatos' terminology, a mathematical model of the EPT is an auxiliary hypothesis that allows testing of the EPT – the model can thus be replaced by another, more refined model without having to change the EPT. A more refined model can then be developed by adding more empirical premises to the first-order conditions; the crux is then that the above three phases and heuristic rules also apply when the $n^{\text{th}}$ mathematical model of the EPT has to be replaced by the $(n+1)^{\text{th}}$, more refined, mathematical model.

As to the second area for further research, the current mathematical foundation of the EPT, SMT, is an *uncountably* infinite theory because it is a generalization of ZF. However, Muller recently reported that a finite axiomatization of Cantor-Von

Neumann set theory (CVN) is possible (2011): if SMT can be defined as a generalization of CVN, then this would yield a *countable* axiomatization of SMT. This is interesting if in addition a proof of consistency can be given: even if a countably axiomatized SMT will be *weaker* than ZF, it can still be *preferable* when it is proven to be consistent – that, namely, is a step further in Hilbert's program! Last but not least, for the third area further research is recommended on the mind-body problem: the present mechanism of mental causation is a *principle* solution, as opposed to a *full* solution, to the question how the mind can effect bodily motion. This has to be classified as *speculative philosophy*: further results are needed, both theoretical and empirical, for this matter to evolve to the level of *natural science* – e.g. as a starting point for psychology. A specific recommendation is to investigate whether Penrose's view can be translated in the language of the EPT to extend the current mechanism, such that testable predictions can be derived. As a different direction in the same area further philosophical-theological research is recommended to establish in how far the present solution to the mind-body problem – or, more general, the present disciplinary matrix – corresponds to the teachings of the Bible.

The bottom line is that a completely formalized framework for physics, containing fundamental laws of nature governing the supersmall scale, has been put forward and that this gives rise to a potentially progressive research program. Further research in this direction may yield a proof that QM and GR are not applicable to the supersmall scale and are thus not fundamental – such further research is then recommended: the intention is, after all, to find the truth, and nothing but the truth.

# APPENDIX A

## PROOF OF THE PARTICLE/WAVE DUALITY OF THE EPT

*4.2.21 Theorem* (*principle of particle/wave duality of the EPT*):

$$\forall x \in Z_{\mathrm{N}} \forall k \in S_{\omega(x)} \left( \begin{bmatrix} \beta_k^x \\ \overline{\beta}_k^x \end{bmatrix} \in M_{\mathrm{E}} \Rightarrow \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \right)$$

*Proof*: (formula number – formula – justification)

| | | |
|---|---|---|
| (A.1) | $\begin{bmatrix} \beta_k^x \\ \overline{\beta}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | assumption, $x$, $k$ arbitrary |
| (A.2) | $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} + \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | (A.1), 4.2.19 |
| (A.3) | $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \vee \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | (A.2), 4.2.3, 4.2.4, 4.2.7 |
| (A.4) | $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | assumption |
| (A.5) | $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | (A.4), 4.2.8, 4.2.22 |
| (A.6) | $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \Rightarrow \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | (A.4), (A.5) |
| (A.7) | $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\overline{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ | assumption |

(A.8) $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ (A.7), 4.2.8, 4.2.22

(A.9) $\begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \Rightarrow \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ (A.7), (A.8)

(A.10) $\begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ (A.3), (A.6), (A.9)

(A.11) $\begin{bmatrix} \beta_k^x \\ \bar{\beta}_k^x \end{bmatrix} \in M_{\mathrm{E}} \Rightarrow \begin{bmatrix} {}^{EP}\varphi_k^x \\ {}^{EP}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}} \wedge \begin{bmatrix} {}^{NW}\varphi_k^x \\ {}^{NW}\bar{\varphi}_k^x \end{bmatrix} \in M_{\mathrm{E}}$ (A.1), (A.10)

(A.12) theorem 4.2.21 (A.11), Gen.

□

# APPENDIX B

## ABOUT THE LOGICAL CONSISTENCY OF THE EPT

Currently, logical consistency of the EPT is assumed. A proof of logical consistency can be based on the following well-known meta-logical theorem:

*B.1 Theorem*

If a closed formula $\neg\Psi$ is not provable from a consistent first-order theory $T$, then the first-order theory $T^*$, obtained from $T$ by adding $\Psi$ as an axiom, is consistent

*Proof*:

See (Mendelson 1987: 67-68).

There are then two options. The first is to consider the EPT in its current formalization in the mathematical-logical framework of set matrix theory. For the proof of logical consistency of the EPT in its current formalization, it has to be assumed that the mathematical-logical framework of set matrix theory is consistent; a proof of logical consistency of the EPT would thus yield *relative* consistency. Another option is to reformalize the EPT as a truly first-order theory; this would require a language for the EPT without the $\in$-symbol, so that the EPT would become a many-sorted first-order theory; the terms of the theory are then not sets or set matrices but merely symbols. Logical consistency is then *absolute*, because the predicate calculus is consistent, cf. theorem B.2:

*B.2 Theorem*

Any first-order predicate calculus is consistent

*Proof*:

See (Mendelson 1987: p58).

Regardless whether the EPT is viewed as in its current formalization or as 'just' a first-order theory, a proof of the logical consistency of the EPT might be given as set forth below.

*B.3 Theorem*

The theory $T_1$, consisting solely of the elementary principle of nonlocal equilibrium, axiom 4.2.8, is consistent.

*Proof*:

The negation of axiom 4.2.8 cannot be proven from the predicate calculus, using the language of the EPT, nor from the axioms of set matrix theory. Therefore, axiom 4.2.8 forms a consistent theory. □

*B.4 Theorem*

The theory $T_2$, obtained by extending the theory $T_1$ with the elementary principle of identity of binads, axiom 4.2.10, is consistent.

*Proof*:

$T_2$ is consistent because the negation of axiom 4.2.10 cannot be proven from $T_1$. □

*B.5 Remark*

Axiom by axiom, postulate by postulate, the above method can be continued until the logical consistency of the EPT has been proven. It should be noted that the number of individual constants in the EPT is finite: using "brute force and ignorance" (as John Fraleigh called it), the entire proof of logical consistency can thus be based on counting arguments. □

# APPENDIX C

**IN MEMORIAM: SERGEY S. SANNIKOV**

The initial supervisor of this PhD research, the physicist Sergey Sannikov, who as a specialist in the field of elementary particles worked at the Kharkov Institute of Physics and Technology (Ukraine), has passed away after long illness on the 25th of March 2007 at the age of 72.

Sergey Sannikov
8.1.1934 – 3.25.2007

Sergey Simeonovich Sannikov was born on the 1st of August, 1934, in the city of Chelyabinsk (Soviet Union) in a family of intelligentsia. His father was an engineer, his mother a teacher. Already at the age of five he began to play violin, and began to show interest in mathematics. After World War II the Sannikov family moved to Saratov, where he finished his secondary education and also had lessons in playing the violin. Because of his progress therein, in 1950 he was admitted to the Music School of Saratov at a younger than usual age. In 1952 he began to study at the State University, on the faculty of physical-mathematical sciences. Apart from his study, he also visited the music school, played in orchestras, and performed as a soloist.

When Sergey was a third year student, the Sannikov family moved to Kharkov. In 1958, Sergey there graduated as a physicist at the State University of Kharkov. From 1958 on Sergey Sannikov was set to work as a junior scientific coworker at the Kharkov Institute of Physics and Technology, on the department of Theoretical Physics. At that time this department was headed by the renowned Soviet-scientist Aleksandr Il'ich Akhiezer (11.31.1911 – 5.4.2000). Sergey Sannikov became a personal student of Akhiezer, who on his turn had been a personal student of Lev Davidovich Landau (1.22.1908 – 4.1.1968), who himself had been a personal student of the Dane Niels Bohr (10.7.1885 – 11.18.1962), one of the founders of quantum mechanics. The articles that Sannikov published under the guidance of Akhiezer during this starting period of his professional career dealt with the scattering of electrons and photons at high energy. In that period he also met his later wife, Vera Aleksandrovna, who then worked as a librarian at the Kharkov Institute of Physics and Technology. On the 27th of November 1962 he married with her; they were to have a daughter, Tatyana (born the 7th of April 1965). In 1963 Sergey Sannikov succesfully defended his thesis "Towards a theory on the scattering of electrons and photons at high energy"; he thereby received the academic degree of "candidate in the physical-mathematical sciences", which is comparable to a PhD degree in the US, with theoretical and mathematical physics as speciality. As a part of his PhD research, by the way, Sannikov had to master the demanding so-called "theoretical minimum", such as it had been introduced in the 1930's when the renowned Kharkov school of theoretical physics was founded[15].

But it was not all gold that glittered. As a professional theoretical physicist Sannikov was interested in elementary particles, cosmology, quantum electrodynamics, dynamical systems, and the theory of Lie-groups, Lie-algebras and their representations. He sought the development of his own theory of elementary particles, to be based on quantum mechanics, and doing so he had no belief at all in Regge poles, in the quark-gluon model of strong interactions, in intermediate mesons, in the twistor-program, in supersymmetrical partners, in string theory, in superstring theory, in grand unification, in deformed Lie algebras, or in non-commutative geometry: he termed any and all of these 'misphysics'. This rejection of mainstream research programs in theoretical physics, however, was not taken

[15] The Kharkov school of theoretical physics was established by Lev Landau, using the Copenhagen school of Niels Bohr in Denmark as a model. It has to be added that the trend of specialisation (read: narrowing) of physics education, that began in the West after WWII (cf. E. Prugovecki, 1992, *Quantum Geometry*, Kluwer, 439), did not set foot in the Soviet Union: in Kharkov, no concessions were ever made to the broad philosophical and mathematical basis of the education.

well in the Soviet-era: in the 1980's he got fired, and he had to carry bricks on construction sites for five years to earn a living. During this period he could not devote any time to physics research; however, after his work he usually went to the local library and read the works of Plato, Kant, Hegel, Heidegger, and others. Sergey Sannikov was a well-read man. Luckily, after some time a befriended physicist, Nikolai Zhuck, succeeded to create a position for Sannikov, this time at the Institute for Radio-Electronics of the State University of Kharkov. Here he could continue his research; in the 1990's he ultimately returned to the Kharkov Institute of Physics and Technology.

In 1992 Sergey Sannikov defended his second dissertation, titled "Non-standard representations of groups of spatial symmetries and Heisenberg-algebras in the theory of semi-spinors". He was awarded the academic degree of doctor in the physical-mathematical sciences; this higher doctorate does not have an equivalent everywhere, but it is comparable to, for example, a so-called habilitation in Germany. In this capacity he continued to work as a chief scientific co-worker at the Kharkov Institute of Physics and Technology until his decease. His later work dealt, among other things, with bi-Hamitonian dynamics, and lead to the development of non-unitary quantum mechanics. During his entire career he held on to what can only be called the "hard line": he considered a rigorous formalisation in mathematical language a necessary condition for a physical theory. If something was not formalised, then in his view it thus did not belong to theoretical physics. From 1997 to 2002 Sannikov was actively involved in the development of the Elementary Process Theory, presented in this dissertation; his influence comes to expression among other things in the mathematical rigor of the presentation. In the years thereafter, until his decease in 2007, Sannikov made efforts to enable a peer-reviewed publication. Of the work of Sergey Simeonovich Sannikov, more than ninety publications have appeared in peer-reviewed journals; for an overview, see the list of publications further below.

For the person Sergey Sannikov science was not only work: it was also his hobby, and his first love. He was strongly convinced that someone had "to be" a scientist in order to be able to work at the cutting-edge of science. His always scientific attitude can best be illustrated with some examples. One of these occurred during the Soviet-era, when the possession of Geiger-counters was prohibited. Together with a befriended astronomer, Sannikov then smuggled a Geiger-counter past the military guards out of the heavily secured laboratory, to find out by measurements whether they could find a reason for this prohibition of Geiger-tellers – that no radio-activity was measured does not detract from the enterprise on itself. On another occasion, Sannikov walked with the undersigned in Kharkov, having a casual conversation. All of a sudden he stopped talking, made a quarter turn, and pulled an earthworm of about 70 centimeters out of the grass beside the road: suddenly science, in this case: biology, again became central in the conversation. These events are by far not sufficient to describe the person Sergey Sannikov, but they illustrate his way of life as a scientist: he had a very broad interest, not a superficial curiosity but a desire to sort out the world around him and go to the bottom of it. Apart from that, Sannikov loved music, such as Beethoven, Schumann, and, most of all, Rachmaninov. And not only passively as a listener, but also actively as a pianist and violinist. With his wife Vera, who at the end would work over forty years as a librarian at the Kharkov Institute of Physics and Technology, he frequently went to an opera, or a philharmonic orchestra. Sergey Sannikov divorced from his wife in 1968, but they would remain friends all their lives. During the tragic illness of Vera Aleksandrovna he never went from her side; on her death-bed she acknowledged that he was the most decent man she ever met in her life. Vera Aleksandrovna passed away on the 7th of Februari 2005, aged 68. Their daughter, Tatyana Sergeyevna Tyberg, lives in Norway, and is a writer of lyric prose. And there are also two grandchildren: Tatyana (born the 30th of May 1990), currently living in Norway, and Aleksandr (born the 10th of June 1987), who remained in Kharkov. When Sannikov's teacher, Alexander Il'ich Akhiezer, passed away, it was written that theoretical physics had lost one of its last remaining universalists[16]. With the decease of Sannikov, theoretical physics may have lost its very last.

Marcoen Cabbolet – with thanks to Tatyana Tyberg

[16] Physics Today, 2000, **53**(10), 103

**Publication list of Sergey Sannikov**:

1. S.S. Sannikov, 1961, *High energy electron scattering*, Soviet Physics JETP, **13**(1), 163-168
2. S.S. Sannikov, 1962, *Theory of scattering of high-energy photons by photons*, Soviet Physics JETP, **14**(2), 336-342
3. S.S. Sannikov, 1962, *Inelastic photon scattering in the Coulomb field of a nucleus*, Soviet Physics JETP, **15**(1), 196-198
4. S.S. Sannikov, 1963, *Theory of photon scattering in the Coulomb field of a nucleus at high frequencies*, Soviet Physics JETP, **17**(2), 492-496
5. E.A. Kuraev, S.S. Sannikov, 1963, *Coalescence of photons in the Coulomb field of nuclei*, Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki, **44**(3), 1015-1022 (in Russian)
6. S.S. Sannikov, 1963, *Depolarization of relativistic electrons in a magnetic field*" Soviet Physics JETP, 1964, **18**(2), 546-547
7. S.S. Sannikov, 1964, *Polarization of electrons in an inhomogeneous magnetic field*, Soviet Physics JETP, 1964, **19**(5), 1186-1187
8. S.S. Sannikov, 1964, *An irreducible representation of the rotation group in three-dimensional Euclidean space, which is realised in the class of functions witrh an infinite number of linearly independent elements*, Ukrainskii Fizicheskii Zhurnal, **9**(10), 1139-1141 (in Ukrainian)
9. S.S. Sannikov, 1964, *Elastic scattering and photon coupling in the Coulomb field of nucleus in high frequency*, Nukleonika, 9, **4-5**, 393-395 (in Russian)
10. S.S. Sannikov, E.I. Dubovoi, 1965, *On an allowed model in quantum electrodynamics*, Soviet Physics JETP, **20**(4), 908 ff.
11. S.S. Sannikov, *Matrix elements of infinite-dimensional representations of a rotation group*, Ukrainskii Fizicheskii Zhurnal, **10**(4), 453-455 (in Ukrainian)
12. S.S. Sannikov, 1965, *Extracting the square root of a spinor*, Ukrainskii Fizicheskii Zhurnal, **10**(6), 684-685 (in Ukrainian)

13. S.S. Sannikov, 1965, *Two realizations of representations of a rotation group with complex spin*, Ukrainskii Fizicheskii Zhurnal, **10**(6), 689-691 (in Ukrainian)
14. S.S. Sannikov, 1965, *Polyvalent representations of a rotation group*, Ukrainskii Fizicheskii Zhurnal, **10**(8), 920-921 (in Ukrainian)
15. S.S. Sannikov, 1965, *The creation of muons by electrons in the Coulomb field of a nucleus*, Yadernaya Fizika, **2**(4), 728-729 (in Russian)
16. S.S. Sannikov, 1965, *Unstable bound states of the schrödinger equation*, Physics Letters, **19**(3), 216-217
17. S.S. Sannikov, 1966, *Non-compact Symmetry Group of a Quantum Oscillator*, Soviet Physics JETP, **22**(6), 1306 ff.
18. S.S. Sannikov, 1966, *Representation of a Lorentz group with complex spin*, Ukrainskii Fizicheskii Zhurnal, **11**(1), 106-107 (in Ukrainian)
19. S.S. Sannikov, 1966, *Representation of a rotation group by generalized functions*, Ukrainskii Fizicheskii Zhurnal, **11**(1), 110-111 (in Ukrainian)
20. S.S. Sannikov, 1966, *Scattering of 'spiral' electrons in a Coulomb nucear field*, Ukrainskii Fizicheskii Zhurnal, **11**(2), 159-162 (in Ukrainian)
21. S.S. Sannikov, 1966, *Spinor representation of a rotation group on a sphere*, Ukrainskii Fizicheskii Zhurnal, **11**(4), 448-449 (in Ukrainian)
22. S.S. Sannikov, 1966, *Representation of a cone group with complex spin*, Ukrainskii Fizicheskii Zhurnal, **11**(4), 450-451 (in Ukrainian)
23. L.G. Zazunov, S.S. Sannikov, 1966, *A resonance in the ep system*, Yadernaya Fizika, **3**(5), 892-894 (in Russian)
24. S.S. Sannikov, 1966, *Representations of the Rotation Group with Complex Spin*, Soviet Journal of Nuclear Physics, **2** , 407 ff.
25. S.S. Sannikov, 1967, *Complex angular momentum states in quanntum mechanics*, Yadernaya Fizika, **4**(4), 896-903 (in Russian)
26. S.S. Sannikov, 1967, *Spinor representations of a sphere*, Nuclear Physics, **87**(7), 834-835
27. S.S. Sannikov, 1967, *Dynamic group and SU(n) symmetry of oscillator*, Ukrainskii Fizicheskii Zhurnal, **12**(2), 339-341 (in Russian)

28. S.S. Sannikov, 1967, *Representation of cone group and quantization of oscillator*, Ukrainskii Fizicheskii Zhurnal, **12**(2), 341-342 (in Russian)
29. S.S. Sannikov, 1967, *Structure of mappings of rotation group with complex weight*, Ukrainskii Fizicheskii Zhurnal, **12**(2), 342-344 (in Russian)
30. S.S. Sannikov, 1967, *Coalescence of photons in a uniform magnetic field*, Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki, **52**(5), 1303-1305 (in Russian)
31. S.S. Sannikov, 1967, *Completeness of irregular representations of a rotation group*, Ukrainskii Fizicheskii Zhurnal, **12**(7), 1216-1218 (in Russian)
32. S.S. Sannikov, 1967, *Square root extraction for anticommuting spinors*, Soviet Mathematics. Doklady, **8**, 32-35
33. S.S. Sannikov, 1967, *Complex angular momentum and unstable levels of H-like atoms and positonium*, Nuclear Physics B, **1**(9), 577-580
34. S.S. Sannikov, 1967, *Four-valued representations of the three-dimensional rotation group in Euclidean space*, Nuclear Physics B, **1**(9), 594-596
35. S.S. Sannikov, 1967, *Group properties of one-dimensional operators of complex co-ordinate and momentum in quantum mechanics*, Nuclear Physics B, **1**(10), 686-687
36. S.S. Sannikov, 1967, *Unstable states with complex angular momentum in quantum electrodynamics*, Physics Letters A, **24**(10), p. 551-553
37. S.S. Sannikov, 1967, *Expansion of the Direct Product of Representations of the Discrete Unitary Series* $D^{+}{}_{\lambda}$ *of the Lorentz Group* $L_3$, Soviet Physics Doklady, **11**, 1045-1047
38. S.S. Sannikov, 1967, *Complex spin and decay* $K_2^0 \rightarrow 2\pi$, Nuclear Physics B, **2**(3), 326-328
39. S.S. Sannikov, 1967, *Scattering of Photons in a Homogeneous Electromagnetic Field*, Soviet Physics JETP, **25**, 306 ff.
40. S.S. Sannikov, 1967, *Fusion of Photons in a Uniform Electromagnetic Field*" Soviet Physics JETP, **25**, 867 ff.

41. S.S. Sannikov, 1968, *A Realization of Infinite-Dimensional Representations of the Rotation Group with Complex Spin by Entire Functions*, Soviet Physics Doklady, **12**, 932 ff.

42. S.S. Sannikov, 1968, *Infinite-domensional Representations of the Rotation Group*, Soviet Journal of Nuclear Physics, **6**, 788 ff.

43. S.S. Sannikov, 1968, *New Representations of the Lie Algebra of the Rotation Group*, Soviet Journal of Nuclear Physics, **6**, 939 ff.

44. S.S. Sannikov, 1968, *Spaces of Test Functions and Generalized Functions of Index Type*, Soviet Physics Doklady, **13**, 95 ff.

45. V.D. Gershun, S.S. Sannikov, 1969, *The two-component Thomas-Fermi model*, Buletinul Institutului Polytehnic din Iasi, 14, **1-2**, 165-169 (in Russian)

46. S.S. Sannikov, 1973, *Theory of representations of the group SL(2, C)*, Soviet Physics Doklady, **18**, 173 ff.

47. S.S. Sannikov, 1978, *Equations for fields with complex spin*, Theoretical and Mathematical Physics, **34**(1), 21-29

48. S.S. Sannikov, I.I. Uvarov, 1990, *Non-Hamiltonian dynamical systems*, Russian Physics Journal, **33**(10), 815-820

49. S.S. Sannikov, A.A. Stanislavskii, 1994, *Renormalization problem in the quantum electrodynamics of non-point particles*, Russian Physics Journal, **37**(6), 578-589

50. S.S. Sannikov, A.A. Stanislavskii, 1994, *Renormalization problem in the quantum electrodynamics with hidden parameters*, Ukrainskii Fizicheskii Zhurnal, **39**(5), 525-532 (in Russian)

51. S.S. Sannikov-Proskuryakov, 1995, *Cosmological aspects of the theory of relativistic bi-Hamiltonian systems. 1. Formation of the space-time continuum of the general theory of relativity*, Russian Physics Journal, **38**(2), 197-204

52. S.S. Sannikov, A.A. Stanislavskii, 1995, *Lamb shift in the quantum electrodynamics of bilocal fields*, Russian Physics Journal, **38**(4), 430-436

53. S.S. Sannikov, 1995, *Electromagnetic wave scattering by an external field*, Russian Physics Journal, **38**(8), 796-803

54. S.S. Sannikov, 1996, *Renormalization of the fine structure constant at high energies*, Russian Physics Journal, **39**(1), 1-8
55. S.S. Sannikov, 1996, *New interpretation of experiments on the intermediate meson*, Russian Physics Journal, **39**(2), 125-138
56. S.S. Sannikov-Proskuryakov[17], 1997, *Lepton Theory*, Russian Physics Journal, **40**(7), 616-623
57. S.S. Sannikov-Proskuryakov, 1997, *Theory of the sommerfeld fine-structure constant*, Russian Physics Journal, **40**(10), 982-984
58. S.S. Sannikov-Proskuryakov, 1999, *Quantization of the Dirac fiber and its application to the theory of elementary particles*, Russian Physics Journal, **42**(11), 968-976
59. S.S. Sannikov-Proskuryakov, 2000, *Dynamical Structure of Space and Time*, Ukrainian Journal of Physics, **45**(1), 9-15
60. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2000, *Renormalized Newtonian Constant and Equivalence Principle*, Spacetime & Substance, **5**(5), 203-207
61. S.S. Sannikov-Proskuryakov, 2000, *Toward the Granule Theory*, Ukrainian Journal of Physics, **45**(6), 639-642
62. S.S. Sannikov-Proskuryakov, 2000, *Dynamical Structure of Granules*, Ukrainian Journal of Physics, **45**(7), 778-780
63. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2000, *Fermion-Antifermion Asymmetry in the Universe*, Ukrainian Journal of Physics, **45**(8), 895-900
64. S.S. Sannikov-Proskuryakov, 2001, *A New Field Theory of Fundamental Particles*, Ukrainian Journal of Physics, **46**(1), 5-13
65. S.S. Sannikov-Proskuryakov, 2001, *Non-Unitary Quantum Theory (Mathematical Foundations). 1*, Ukrainian Journal of Physics, **46**(2), 138-141
66. S.S. Sannikov-Proskuryakov, 2001, *Non-Unitary Quantum Theory (Mathematical Foundations). 2*, Ukrainian Journal of Physics, **46**(3), 263-271

[17] From 1997 on Sannikov used the double name Sannikov-Proskuryakov consistently; here Proskuryakov is the male form of Proskuryakova, the maiden name of his mother.

67. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2001, *On Some Processes of Quantum Gravitation (Radiative Corrections)*, Russian Physics Journal, **44**(4), 427-434

68. S.S. Sannikov-Proskuryakov, 2001, *Topological Structure of Momentum Space in High-energy Region*, Ukrainian Journal of Physics, **46**(7), 647-651

69. S.S. Sannikov-Proskuryakov, 2001, *Extended Quantum Theory*, Ukrainian Journal of Physics, **46**(7), 661-667

70. S.S. Sannikov-Proskuryakov, 2001, *Elementary Particles in a New Quantum Scheme. 1*, Ukrainian Journal of Physics, **46**(8), 775-783

71. S.S. Sannikov-Proskuryakov, 2001, *Quantum Mechanics of Systems with a Nonenumerable Number of Degrees of Freedom*, Russian Physics Journal, **44**(8), 863-868

72. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2001, *Towards the Ether Theory (Apology of the Ether)*, Spacetime & Substance, **9**(4), 171-175

73. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2001, *Elementary Particles in a New Quantum Scheme. 2*, Ukrainian Journal of Physics, **46**(10), 1019-1027

74. S.S. Sannikov-Proskuryakov, 2001, *Problem of Interactions: Electromagnetic Interactions of Particles*, Russian Physics Journal, **44**(12), 1304-1309

75. S.S. Sannikov-Proskuryakov, 2001, *Problem of Interactions: Gravitational Interactions*, Russian Physics Journal, **44**(12), 1310-1315

76. S.S. Sannikov-Proskuryakov, 2001, *Dynamical structure of space-time discontinuum and spin 1/4*, Nuclear Physics B (Proc. Suppl.), **102&103**, 328-333

77. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2001, *Galilean Experiment at the Elementary Particle Level*, Problems of Atomic Science and Technology, Nr. 6, 88-90

78. S.S. Sannikov-Proskuryakov, 2001, *About the New Quantum Mechanics*, Problems of Atomic Science and Technology, Nr. 6, 91-94

79. S.S. Sannikov-Proskuryakov, 2001, *A New Theory of Gravity*, Problems of Atomic Science and Technology, Nr. 6, 95-97

80. S.S. Sannikov-Proskuryakov, 2002, *About Strong Interaction of Fundamental Particles*, Ukrainian Journal of Physics, **47**(7), 615-628
81. S.S. Sannikov-Proskuryakov, 2002, *Subquantum Level of Matter*, Ukrainian Journal of Physics, **47**(9), 819-826
82. S.S. Sannikov-Proskuryakov, 2002, *The Problem of Interactions in a Dynamical Theory of Particles (General Questions). 1*, Ukrainian Journal of Physics, **47**(11), 1016-1023
83. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2002, *The Problem of Interactions in a Dynamical Theory of Particles (General Questions).*, Ukrainian Journal of Physics, **47**(12), 1109-1117
84. S.S. Sannikov-Proskuryakov, 2003, *The Green's Causal Functions of Bilocal Fields*, Russian Physics Journal, **46**(4), 379-385
85. S.S. Sannikov-Proskuryakov, 2003, *Quantum Mechanics of an Oscillator with Infinitesimal Frequency*, Russian Physics Journal, **46**(4), 432-434
86. S.S. Sannikov-Proskuryakov, 2003, *On Noninertial Frames of Reference*, Russian Physics Journal, **46**(6), 669-676
87. S.S. Sannikov-Proskuryakov, M.J.T.F. Cabbolet, 2003, *Non-Einsteinian Theory of Gravity*, Spacetime & Substance, **16**(1), 22-29
88. S.S. Sannikov-Proskuryakov, 2003, *About Non-inertial Frames*, Spacetime & Substance, **16**(1), 35-40
89. S.S. Sannikov-Proskuryakov, 2004, *On the Physical Principles of Gravitation*, Russian Physics Journal, **47**(1), 42-52
90. S.S. Sannikov-Proskuryakov, 2004, *The New Cosmological Model*, Spacetime & Substance, **21**(1), 1-6
91. S.S. Sannikov-Proskuryakov, 2004, *Wave Meachanics on the Bohr's Compact*, Spacetime & Substance, **21**(1), 23-29
92. S.S. Sannikov-Proskuryakov, 2004, *Cosmology and a Living Cell*, Russian Physics Journal, **47**(5), 500-511
93. S.S. Sannikov-Proskuryakov, 2004, *A New Wave Meachanics*, Spacetime & Substance, **23**(3), 121-125

94. S.S. Sannikov-Proskuryakov, A.A. Usenko, 2005, *Poly-Hamiltonian Dynamic Systems and Turbulence*, Russian Physics Journal, **48**(3), 244-254
95. S.S. Sannikov-Proskuryakov, 2005, *Non-Neumannian Representations of Rotation Group (to the Ether theory). 1*, Spacetime & Substance, **26**(1), 1-8
96. S.S. Sannikov-Proskuryakov, 2005, *Non-Neumannian Representations of Rotation Group (to the Ether theory). 2*, Spacetime & Substance, **26**(1), 21-28
97. S.S. Sannikov-Proskuryakov, 2007, *About Pressure in Model of the Expanding Universe*”, Problems of Atomic Science and Technology, Nr. 3, 200-205
98. S.S. Sannikov-Proskuryakov, 2007, *Some Problems in the Theory of Early Universe Evolution*, Problems of Atomic Science and Technology, Nr.3, 206-209
99. S.S. Sannikov-Proskuryakov, 2009 (postmortem), *Particle Interactions and Quantum Mechanics: Mathematical Foundations*, Physics of Particles and Nuclei **40**(7), 1100-1144

# REFERENCES


Anderson P. W., 1972, More is Different, *Science* **177**, 393-396

Bell J., 1964, On the Einstein Podolsky Rosen Paradox, *Physics I*, 195-200

Bohm D., 1952[a], A suggested interpretation of quantum mechanics in terms of 'hidden' variables I, *Physical Review* **85**, 166-179

Bohm D., 1952[b], A suggested interpretation of quantum mechanics in terms of 'hidden' variables II, *Physical Review* **85**, 180-193

Bohr N., 1928, The Quantum postulate and the recent development of atomic theory, *Nature* **121**, 580 - 590

Bohr N., 1929, Wirkunsquantum und naturbeschreibung, Naturwissenschaften **17**, 483-486. Trans. into English as 'The quantum of action and the description of nature' in: *Atomic Theory and the Description of Nature* (Cambridge University Press, Cambridge, 1934), pp. 92-101.

Cabbolet M.J.T.F., 2010, Elementary Process Theory: a Formal Axiomatic System with a Potential Application as a Foundational Framework for Physics Supporting Gravitational Repulsion of Matter and Antimatter. *Annalen der Physik* **522**(10), 699-738

Cahill R.T., 2003, *Process Physics*, Process Studies Supplement, issue 5, 1-131

Casanova A., Spallucci E., 2006, TeV mini black hole decay at future colliders, *Classical and Quantum Gravity* **23**(3), R45

Chardin G., Rax J-M., 1992, CP violation. A matter of (anti)gravity?, *Physics Letters B* **282**, 256-262

Cobb J.R., 2008, *Whitehead Word Book* (P&F Press, Claremont CA, USA)

Dalen D. van, Doets, H.C., de Swart, H.C.M., 1975, *Verzamelingen: Naïef, Axiomatisch, Toegepast* (Oosthoek, Scheltema & Holkema, Utrecht)

Dantzig D. van, 1937, Some possibilities of the future developments of the notions of space and time, *Erkenntnis* **7**(1), 142-146

Dennet D.C., 1991, *Consciousness Explained* (Little, Brown and Company, Boston)

De Witt B.S., 1967, Quantum Theory of Gravity. I. The Canonical Theory, *Physical Review* **160**, 1113-1148

Dirac P.A.M., 1968, *Methods in Theoretical Physics*, lecture at the International Center for Theoretical Physics in Triest, Italy; reprinted in A. Salam (ed.), 1990, *Unification of Fundamental Forces* (Cambridge University Press, Cambrigde), 125-143

Doplicher S., 2006, Quantum field theory on quantum spacetime, *Journal of Physics: Conference Series* **53**, 793-798

Duff M.J., 1998, The Theory Formerly Known as Strings, *Scientific American* 1998(2), 54-59

Dyson F.W., Eddington A.S., & Davidson, C.R. 1920, A Determination of the Deflection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919 *Philosophical Transactions of the Royal Society of London A* **220**, 291-333

Eccles J.C., 1986, Do mental events cause neural events analogously to the probability fields of quantum mechanics? *Proceedings of the Royal Society of London, Series B* **227**: 411-428

Einstein A., 1916, Die Grundlage der allgemeinenen Relativitätstheorie, *Annalen der Physik* (*Leipzig*), **49**, 769-822

Einstein A., 1918, *Prinzipien der Forschung*, speech at the Physical Society, Berlin, for Max Planck's sixtieth birthday; transcript in A. Einstein, *Ideas and Opinions* (Dell Publishing Company, New York, 1976)

Feigl H., 1958, The ‘Mental’ and the ‘Physical’, in: H. Feigl, M. Scriven, G. Maxwell (eds.), *Minnesota Studies in the Philosophy of Science*, vol II, *Concepts, Theories, and the Mind-Body Problem* (University of Minnesota Press, Minneapolis), pp. 370-497

Feynman, P.R., 1949, The Theory of Positrons, *Physical Review* **76**, 749-459

Folse H.J., 1987, *The Philosophy of Niels Bohr. The Framework of Complementarity*, (North Holland Physics Publishing, Amsterdam)

Fuchs C.A., Peres A., 2000, Quantum Theory Needs No ‘Interpretation’, *Physics Today* **53**(3), 70

Ghirardi G.C., Rimini A., Weber T., 1986, Unified dynamics for microscopic and macroscopic systems, *Physical Review D* **34**(2), 470-491

Good M.L., 1961, $K_2^0$ and the Equivalence Principle, *Physical Review* **121**, 311-313

Green B., 2000, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (Vintage Books, New York), p. 231

Green B., 2004, in: Einstein A., *The Meaning of Relativity*, 5th ed. (Princeton University Press, Princeton), p. xxi

Guth A., 1981, The Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems, *Physical Review D* **23**, 347

Hawking S., 1974, Black hole explosions?, *Nature* **248**, 30-31

Hemholtz H. von, 1896, *Handbuch der physiologischen Optik*, Hamburg – Leibzig; excerpt translated in Dutch language in W.M. *Weber, De Meningen van de Filosofen*, Deel I (Uitgeverij Konstapel, Groningen, 1981) pp. 244-245

Hempel C.G., 1969, *Reduction: Ontological and Linguistic Facets*, in: S. Morgenbesser, P. Suppes,. M. White (eds.), *Philosophy, Science and Method. Essays in Honor of Ernest Nagel* (St. Martin's Press, New York) pp. 179–199

Holt J., 2006, Unstrung, *The New Yorker* **82**(31), 86-91

Hubble E., 1929, A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae, *Proceedings of the National Academy of Sciences* **15**(3), 168-173

Kim J., 2005. *Physicalism, or Something Near Enough* (Princeton University Press, Princeton)

Kuhn R.L., 2010, Solutions to the Mind-Body Problem, *Science and Religion Today*, june 3, 2010

Latecki L.J., 1992, *Digitale und allgemeine Topologie in der bildhaften Wissensrepräsentation* (Infix Verlag, Sankt Augustin, Germany)

Laughlin R.B., Pines D., 2000, The Theory of Everything, *Proceedings of the National Academy of Sciences* **97**(1), 28-31

Margenau H., 1984, *The Miracle of Existence* (Ox Bow Press, Woodbridge)

McLaughlin B.P., 1999, entry ‘philosophy of mind’ in: The Cambridge Dictionary of Philosophy, 2nd ed. (Cambridge University Press, Cambridge), pp. 684-692

McLaughlin B.P., 2001, *In Defense of a New Wave Materialism: a Response to Horgan and Tienson*, in: C. Gillet, B. Loewer (eds.), *Physicalism and Its Discontent* (Cambridge University Press, Cambridge), pp. 319-331

Mendelson E., 1987, *Introduction to Mathematical Logic*, Chapman & Hall, New York

Misner C., 1969, Mixmaster Universe, *Physical Review Letters* **22**, 1071-1074

Morrison P., 1958, Approximate Nature of Physical Symmetries, *American Journal of Physics* **26**, 358-368

Muller F.A., 2011, Cantor-Von Neumann Set Theory, *Logique et Analyse* **213**, 41-48

Nagel T., 1986, *The View from Nowhere* (Oxford University Press, Oxford )

Neumann J. von, 1955, *Mathematical Foundations of Quantum Mechanics* (Princeton University Press, Princeton)

Nieto M.M., Goldman T., 1991, The Arguments against "Antigravity" and the Gravitational Acceleration of Antimatter, *Physics Reports* **205**, 222-281

Nieto M.M., Goldman T., 1992, *Physics Reports*, **216,** 343 (Erratum)

Norman D.A., 2004, Beyond Reductionism and Dualism: Towards a Christian Solution to the Mind Body Problem, *Science and Christian Belief* **16** (1), 3-12

Pauli W.E, 1930, Adress to Group on Radioactivity, Tübingen, Germany, the 4th of December 1930 (unpublished letter)

Pauli W.E., 1952, Der Einfluss archetypischer Vorstellungen auf die Bildung naturwissenschaftlicher Theorien bei Kepler. In: C.G. Jung, W. Pauli (eds.), *Naturerklärung und Psyche* (Rascher Verlag, Zürich), pp. 109–194.

Polkinghorne J., 1994, *Science & Christian Belief: Theological Reflections of a Bottom-up Thinker* (SPCK Publishing, London)

Primas H., 2003, Time-Entanglement Between Mind and Matter, *Mind and Matter* **1**(1), 81-119

Rovelli C., 2003, A dialog on quantum gravity, *International Journal of Modern Physics D* **12**, 1509-28

Rovelli C., 2008, Loop Quantum Gravity, *Living Reviews in Relativity* **11**, 5. URL: http://relativity.livingreviews.org/Articles/lrr-2008-5/ (cited on 2011-18-2)

Ryle G., 1949, *The Concept of Mind* (University of Chicago Press, Chicago)

Sachs M., 1988, *Einstein versus Bohr: the Continuing Controversies in Physics* (Open Court, New York)

Sannikov S.S., 1978, Equations for Fields with Complex Spin, *Theoretical and Mathematical Physics* **34**, 21-29

Sannikov S.S., 1996, Cosmological Aspects of the Theory of Relativistic Bi-Hamiltonian Systems II, *Russian Physics Journal* **39**(8), 767-775

Santilli R.M., 1999, A Classical Isodual Theory of Antimatter and its Prediction of Antigravity, *International Journal of Modern Physics A* **14**(14), 2205-2238

Schiff L.I., 1958, Sign of the gravitaitonal mass of a positron, *Physical Review Letters* **1**, 254-255

Schiff L.I., 1959, Gravitational Properties of Antimatter, *Proceedings of the National Academy of Sciences* **45**, 69-80

Schopenhauer A., 1844, *Die Welt als Wille und Vorstellung*, 2nd ed., volume 2, (Brockhaus, Leipzig)

Searle J., 2007, *Freedom & Neurobiology: Reflections on Free Will, Language, and Political Power* (Columbia University Press, New York)

Shoenfield J.R., 2001, *Mathematical Logic* (AK Peters Ltd., Natick USA)

Sitter W. de, 1930, Algemeen Handelsblad, July the 9th; discussed in: P.J.E. Peebles, *Principles of Physical Cosmology* (Princeton University Press, Princeton, 1993), p.81

Smart J.J.C., 1959, Sensations and Brain Processes. *Philosophical Review* **68**, 141-156

Stapp H.P., 1991, EPR and Bell's Theorem; A Critical Review, *Foundations of Physics* **21**, 1-23

Stapp H.P., 2009, *Mind, Matter and Quantum Mechanics*, 3rd Edition (Springer. Heidelberg)

Toms D.J., 2010, Quantum gravitational contributions to quantum electrodynamics, *Nature* **468**, 56-59

Van Inwagen P., 1975, The incompatibility of free will and determinism, *Philosophical Studies* **27**, 185-199

Veltman M.J.G., 2003, *Facts and Mysteries in Elementary Particle Physics* (World Scientific Publishing Co. Pte. Ltd., Singapore)

Whitehead A.N., 1929, *Process and Reality: an Essay in Cosmology* (Macmillan, New York)

Will C.M., 1993, *Theory and Experiment in Gravitational Physics* (Cambridge University Press, Cambridge)

Will C.M., 2001, The Confrontation between General Relativity and Experiment, *Astrophysics and Space Science* **283**(4), 543-552

Witten E., 1985, in R. Jackiw, N.N. Khuri, S. Weinberg and E. Witten (eds.), *Proceedings of the 1983 Shelter Island Conference on Quantum Field Theory and the Fundamental Problems of Physics* (MIT Press, Boston, 1985)

Witten E., 1988, in Davies P., Brown J., eds., *Superstrings: A Theory Of Everything* (Cambridge University Press, Cambridge), p. 98