THE EPIONTIC PRINCIPLE, TIME AND THE LAWS OF PHYSICS

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ABSTRACT. In this short essay we postulate the "Epiontic Principle" (EP), a concept which underlies more or less explicitly many physical theories, and we study its implications, in particular for the nature of time. After a brief discussion about the distinction between temporal dimension and time evolution, we adopt the EP as a guideline in Gedankenexperiments in order to understand the *indefinite* and *shifting* essence of what it is commonly called "the past". Real experimental results – analyzed here in accordance with the epiontic paradigm – confirm our qualitative predictions. In a subsequent speculative section, the EP is applied to the understanding of temporal evolution and thus to the laws of physics. The essay terminates with some thoughts of a cosmological nature and on desirable future quantitative developments allowing to study the EP with the aid of toy-models: the *epiontic foils*.

1. INTRODUCTION

One of the most gratifying activities for a theoretical physicist is to derive a physical theory from first principles alone, guided merely by intuition and pure thoughts about nature. However, actual examples are very rare, and it is not a matter of chance that two among the most cited theories are those of relativity. What normally happens, otherwise, is at best the construction of an extremely efficient and well-defined theory – as it is the case with quantum mechanics – which is sustained by a coherent set of postulates but whose intrinsic meaning is unclear. The interpretations of quantum mechanics are countless, and so are the attempts to re-derive it, but there is always some element of disappointment left – even today quantum physics is studied beginning with Von Neumann and Dirac's axiomatization (with a few simple variants), and the famous "*shut up and calculate!*" still echoes in the university halls.

In the absence of a first principle of a physical nature theorists are guided by their mathematical intuition alone. Sometimes this results in exceptional predictions (see for example Gell-Mann's quark model), but more often, when experimental data are lacking, in very elegant mathematical theories which unfortunately then prove false.

This is why we decided to analyze a specific "first principle" – which is already rooted in many theories, albeit not always explicitly – and use it as an investigative tool and interpretative filter for many aspects of reality, focusing especially on the nature of time. Even if the assumed principle did not mirror an

essential feature of the real world, the thoughts which could stem from it could reward us with a new point of view to observe our universe from. And that would already be a considerable step forward on the road of finding an answer to the *fundamental questions*.

2. THE EPIONTIC PRINCIPLE

The Epiontic Principle (EP), in brief, states that *reality is epiontic*. The concept of "epiontic" [1] is the fusion of the two terms "epistemic" and "ontic", and it suggests something whose existence is intrinsically intertwined to the knowledge one has of it. The epiontic principle therefore states that (our) reality coincides with what we know about it.

This statement may seem cryptic or ambiguous, so we will now attempt to present a better formulation of the principle by means of a couple of intermediate definitions.

Definition 1. *An* element of reality *is any exchangeable and finite packet of physical information.*

For example, the result of a measurement is an element of reality.[1] Please note that elements of reality need to be transmittable and processable – thus *finite*. In a universe that admits *hypercomputation* (i.e. the existence of physical structures with the ability to perform non-Turing-computable operations) it could be that the requirement of finiteness is not mandatory, but for now there is no evidence that it is so, neither ideas on how an observer could receive or handle an infinite amount of information, despite some famous opinions on the matter [2].

The discussion above may be considered as a *definition of physical existence*: everything that is completely inexpressible or non-finite simply does not exist (or it is like it did not exist, which is exactly the same thing as far as we are concerned).

Only the elements of reality and their relations can be the subjects of any physical theory. Then who or what exchanges elements of reality?

Definition 2. *An* observer *is a physical system capable of memorizing or handling elements of reality.*

So an observer, in order to exist, must be made of elements of reality, and when we speak about the "memory" of an observer, we mean the complete collection of the observer's elements of reality. We will say that an observer "knows" its elements of reality.

Examples of observers could be a galaxy, a cat, a photographic plate, a chunk of wood. Each of these observers is able to memorize and process information, each one in different ways: a packet of photons coming from a dog is handled differently by a chunk of wood, a photographic plate and a cat. It is possible

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[1] This definition is very different from that of the EPR paper [4]. According to Einstein *et alia*, an element of reality is something certain which is *in correspondence with* a measured physical quantity. Here, that passage is skipped and information is identified with an element of reality (in this sense, this is already an epiontic formulation).

to derive an upper-bound limit to the computational power and memory of an observer [3].

On the basis of these definitions, we may state the

Epiontic Principle (EP). *The proper reality of an observer is made up only of the elements of reality the observer knows. Anything that is not a known element of reality is undefined.*

Applying the EP to the whole universe (which is an observer) it follows that the known elements of reality are everything that exists. With regards to everything that is not a known element of reality, anything could be possible – as long as it is coherent with what is known.

The philosophical motivation beyond the EP is a generalization of the scientific method: the elements of reality are the only entities upon which science can be based (with its peculiarities of being objective, provable, repeatable) and so we assume – epiontically – that they are the *only* constitutive elements of reality.

The EP is the antithesis of the "realist" philosophical current – the idea that there is an independent external reality (for a "mathematical" presentation, see [5]). In the epiontic paradigm, *there is no existence without knowledge.*

2.1. **Corollaries of the Epiontic Principle.** Even though the EP is not a formal theorem, for the purpose of this essay let us call its implications "corollaries", and divide them in two categories. On one side there are the general and methodological implications which concern the *construction* of physical theories, but which are not directly provable ("the metaphysical corollaries"); on the other side there are the immediate repercussions of a physical and experimental nature ("the physical corollaries").

A first metaphysical corollary of the EP is an incarnation of Leibniz's *principle of the identity of indiscernibles.* If reality is made *only* by elements of reality, two seemingly distinct physical situations which always present the same results should be equated.

Given a physical theory, we can construct an equivalence relation according to which any two states of the theory are equivalent if they produce the same elements of reality. The EP then suggests that the "true" theory is the one obtained by quotienting the states of the original theory with respect to the equivalence relation. We are saying nothing new here: this is exactly what is done in general relativity by equating the free fall in a gravitational field with an accelerated motion. Likewise, this is recognizable in the procedure of promotion of symmetries from global to local in the gauge theories, a necessary passage to then eliminate the non-observable degrees of freedom by selecting a representative element from the "quotient set" through the operation of *gauge fixing.*

A second metaphysical thought – we cannot quite define it a corollary – concerns "the unreasonable effectiveness of mathematics in the natural sciences". The elements of reality are packets of information, and information, if redundant, can be compressed (in case, through *lossy* algorithms). A mathematical model of reality is therefore an algorithmic and compact description of reality.

What we could find unreasonable, actually, is the fact that our reality is so much redundant and regular – but we will come back to this later.

Let us now focus on the physical corollaries. One of the consequences of the EP concerns the status of the elements of reality unknown to the observer-universe.[2]

Let us consider the simplest element of reality: a *bit*, that is something that may only take two values, which we call '0' and '1'. The EP tells us that if the element of reality is unknown to the universe, its value is therefore indefinite for any observer. In other words, the bit takes any possible value which is coherent with the known elements of reality, so '0' *and* '1' rather than '0' *or* '1'. The bit is therefore in an indefinite state '0/1'. One could already tell where our discussion seems to be heading: the quantum superposition. And yet what we have stated up to this point descends from the EP alone, we have not adopted the cumbersome framework of quantum mechanics.

Furthermore, a second physical corollary could be a *"finiteness-induced" uncertainty principle* (not to be confused with Heisenberg's uncertainty principle). The finiteness of the elements of reality imposes a restricted precision in the knowledge of continuous quantities, which then turns out to be indefinite beyond a scale that depends on the amount of accessible information.

2.2. **Quantum *caveat*.** Some of the previous results recall quantum mechanics, and this is not by chance. As Zurek says, the nature of the wave function is epiontic, and one could argue that the whole quantum physics is deeply imbued with epiontic effects. Unfortunately, this fact has caused a broad misconception on what is strictly "quantum mechanical", intended as consequence of a specific theory, and what is "epiontic".

One of the aims of this essay is to analyze the EP as an antecedent of the laws of physics, a principle underlying them. If we adopted the whole quantum framework straight away, we would incur in the risk of confusing the two logically distinct aspects.

For this reason, in the following exposition the approach will be "semi-classical". Of course, use will be made of the results of the experiments originally carried out in the background of quantum mechanics – very much because the most part of epiontic effects have been studied in this context –, but the tools of analysis used will only be those deriving from the EP.

3. Time

Talking about time, it is possible to mean at least two interwoven and yet distinct concepts: time evolution and temporal dimension(s) (i.e. "time coordinates"). The two notions are independent, meaning that neither derives from the other.

The *block universe*, for example, is a model of reality in which the temporal dimension exists, whereas evolution is only an illusion. The presentist model on the other hand states that there is only one single and ever-changing moment:

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[2] Talking about "unknown" elements of reality is not actually correct. More correctly, for a specific observer (universe included) any not-known element of reality is a non-element of reality. An "unknown element of reality" is in fact a *subjective projection* based on regularities of known elements of reality.

"here and now". There is yet another view which tries to conciliate both aspects, the *growing block universe*. For the philosophical debate between these factions, and its ever growing literature, see [6].

Let us now adopt the instruments of inquiry offered by the EP with the aim to make some speculations about the nature of time.

In order to assert that a *time dimension* exists, we must be able to show some elements of reality that prove its existence. It is well known, however, that time is not directly measurable in the same way we could measure a position. What you do is take periodic phenomena as *definitions* of time intervals, and then compute the passage of time by actually measuring spatial lengths or by counting periods. Since there exist relations between non-temporal elements of reality only – e.g. the position of a sphere on a inclined plane and the angle of a pendulum –, we are led to believe that the time dimension is not an intrinsic aspect of reality. According to this view, it is possible to develop a timeless and purely relational physics [7].

With regards to *time evolution*, if we accept the EP its existence follows directly from the definitions given.

In fact, the definition of "element of reality" requires an "exchange of information", and so it implies a dynamical context. The elements of reality must be interpreted as *processes* rather than static *things*: they are data about change, imbued of Berkeley's *esse est percipi*. The logic beyond this assumption is not unreasonable in the epiontic framework: without becoming there could not be any exchange of information, no perceived reality and therefore no reality at all. For all of these reasons, in the epiontic paradigm the evolutionary aspect of time is intrinsic – by definition – to reality, whereas time as a dimension is not.

3.1. **Time ordering.** All observers experience that their set of elements of reality *evolves*, and their reality changes accordingly. Thanks to their memory, observers are able to keep track of the changes. We name "events" the elements of reality embedded in a temporal context.

More complex observers will tend to store events in memory according to a partial order relation: $A \leq B$ if the event A has happened simultaneously to or before than event B, and we can have $A \leq B$, $B \leq A$, or A and B are not comparable – we call this structure "subjective temporal poset". Here time represents a set of coordinates, a pointer inside an algebraic construct.

With an adequate *coarse graining*, the subjective temporal poset may take the form of a totally ordered set, the one-dimensional timeline we are used to, which still is *subjective*. In fact, special relativity tells us that the time ordering depends on the chosen inertial frame, and that different observers may disagree on the time ordering of two events A and B.

However, there exists a partial order sub-relation on which all observers agree by definition.

Definition 3. *The* causal structure *of the universe is the partially ordered set maximally compatible with the subjective temporal posets of all observers.*

So it is by *definition* that causality must be respected by all physical theories, whereas it is a postulate that the maximum speed of propagation of causal relations is equal to the speed of massless particles. Actually, we may conjecture

that a limit of some sort has to exist as a logical necessity, otherwise "everything would happen at once". One of the non-mainstream approaches to quantum gravity is the *causal sets* programme; for a review, see [8].

3.2. **The past.** So far we have presented definitions and mostly metaphysical remarks. Now we intend to show a physically relevant realization of the Epiontic Principle, examining an aspect of time ordering: *the past.*

Generally, we believe that the past is something *static* and *well-defined* – after all, it is made of events that have already happened. We are comforted in this simplistic view by a mix of residual positivism and interpretations of the theory of relativity (the Minkowskian spacetime).

However, we also know that all the information that an observer has labeled as "past" are a reprocessing of data the observer has access to in his/her *here and now*. Thanks to this present information, the observer may retrodict his past. Even when we receive a message from the past (e.g. a photon from a far away galaxy) we actually receive a photon *here and now*. It is through a complex process of retrodiction that we infer that the photon comes from the Large Magellanic Cloud.

If the past were perfectly retrodictable, present data would let us univocally reconstruct the past, and therefore to argue whether it has existed or not would be a purely dialectic exercise.

However, the past is never perfectly retrodictable, not even in principle – even if the physical laws were reversible – because:

- The precision of estimate of the initial conditions of a system is limited by uncertainty principles;
- Many systems show chaotic behavior (i.e., arbitrary small differences in the initial conditions may lead up to great deviations in the trajectories);
- Part of the information about the past has spread into the universe; the more one goes back, the more information must be recovered.

For all of these reasons, we are not able to retrieve all the elements of reality which we would say "belong to the past". According to the EP, we must acknowledge that all the unknown elements of the past are indefinite. In other words, there is no such a thing as *one* past, but there is a set of equivalent pasts, which have the only requirement of being compatible with the current elements of reality.[3]

In the following section we will prove what we have just affirmed.

4. Gedanken and real experiments

The EP is not directly verifiable *per se*, because it is a principle and not a full-fledged theory; we can however prove its physical corollaries or the predictions made by models which follow the EP.

Consider the following meta-experiment: let us suppose to have an element of reality – to make it simple, a single bit – of which we ignore the actual value. There are two possibilities: either (a) the bit of reality is known to some observer

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[3] In a more complex model we could define a "measure" on the space of the possible pasts on the basis of their compatibility with the known elements of reality.

other than us, and therefore the universe knows its value ('0' or '1'), or (b) the bit of reality is not known to anyone, and therefore the universe ignores its value, which turns out to be indefinite ('0' *and* '1').

If the EP is valid then it has to be possible an experiment capable of distinguishing between the two cases (a) and (b). Otherwise, they would be equivalent, and there would be no difference between elements of reality and non-elements of reality, but this would contradict the EP itself.

Let us now consider Young's double-slit experiment – well-known in the context of quantum mechanics and quantum interpretations – as a realization of this meta-experiment. However, we are going to approach it from a new point of view – that of the EP alone – without all the complications brought in by the quantum framework.

4.1. **Experimental layout.** Let us take Young's experiment ideal setting: we interpose between a particle emitter and a screen a thin plate with two parallel slits labeled '0' and '1'. The particles are beamed one by one by the emitter, with an initial uncertainty on the motion compatible with the passage through either slit. The screen allows us to mark the arrival point of each particle.

The bit of reality we are interested in is represented by which slit a particle goes through in its path from the emitter to the screen. The observable result is the pattern which appears on the screen (after many reiterations of the experiment).

First of all, let us suppose that the bit of reality is unknown by default. If the slits were large compared to the particle's size, the particle's arrival position on the screen would generally allow us to reconstruct a linear trajectory and therefore to extrapolate the bit of reality. However, by reducing the width of the slits progressively, we increase the phenomenon of random scattering between the particles and the edges of the slits, thus making it actually impossible to univocally determine the value of the bit. Let us now imagine to put a detector beside either slit, which one it does not matter. We may switch the detector on or off at any time. When the detector is on, the bit value (either '0' or '1') is known. If the detector is off, the bit value is indefinite ('0/1'). That is, the particle passes simultaneously through both slits – whatever that means.

4.2. **Results and discussion.** The single particle double-slit experiment has been carried out with all kind of "particles", from photons and electrons to fullerene molecules [9, 10, 11]. The results are the same: whenever the bit is known – it does not matter *how* – a diffusion pattern (d) appears on the screen. When the bit is unknown, an interference pattern (i) manifests itself.

The specific form of the pattern does not matter in our current analysis, since the EP alone does not provide quantitative results. What does matter is that the outcomes (d) and (i) are distinct and depend *uniquely* on the knowledge or ignorance about the element of reality.

The moment when the information is acquired is not relevant, as the realization of the "Wheeler's delayed choice experiment" variant shows [12]. In another variant, the "quantum eraser", the information on which slit has been crossed can be removed after it has been obtained [13], and the pattern observed is the same as if the bit's value had not ever been known.

These results, besides corroborating the EP, already support the argument that the past is *indefinite* and *shifting*. In fact, the past of the particle – its trajectory – exists only depending on the knowledge we *currently* have about it, an information that can be lost, as the quantum eraser experiment shows.

In order to remove all doubts about the fact that the past is not fixed, we recall a seminal experiment, a realization of the delayed-choice quantum eraser [14] in which the choice of erasing the bit of information may be taken *after* the photon has actually hit the screen.

We mention that for simplicity we have considered only the extremal cases of "completely known bit" or "completely unknown bit", but the setup could be generalized to a situation of partial knowledge. In this case, we would qualitatively expect an intermediate outcome, i.e. an hybrid pattern between (d) and (i), and the definiteness of either would depend on how much the bit is known or unknown.[4] And this also has been experimentally proved [15].

The aforementioned experiments and results are neatly described by the quantum mechanical formalism, but their interpretation has always been problematic. The two conditions of "known bit" and "unknown bit" have been linked respectively to the status of "particle" and "wave", from which arises the famous mystery of complementarity or "wave-particle duality", which has produced during the years a vast and varied literature. In particular, it is recent the observation that the complementarity phenomenon may be due to the finiteness of information [16].

In leaving this dispute, we will point out that the epiontic principle not only provides us with a simple explanation of the phenomenon, but in fact it predicts the possibility of a dual behavior even without adopting an exact quantum framework.

5. Evolution and the laws of physics

Following from what we have exposed in the previous sections we can argue that in the epiontic paradigm there is no basic difference between a retrodiction of the past or a prediction of the future. In fact, the only things that matter are the elements of reality, and so the actual meaningful distinction is between what is known and what is unknown. The temporal evolution must therefore be intended more properly as the *change of a state of knowledge*.

The rules that control this *becoming* would be the fundamental laws of physics, something near to the long sought-after Theory of Everything. We have listed some of the features that a physical theory should have in order to comply with the EP, however it is unclear why our universe should favor one specific set of physical theories over any other.

A physical law is nothing else than a relation between elements of reality, and therefore an element of reality itself. Consequently the answer suggested by the EP is that our universe does not choose any physical law at all. The laws of physics are *all* the laws which are consistent with the present elements of reality – weighted according to some measure in the space of physical theories.

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[4] Described in quantum mechanics by the Englert-Greenberger duality relation.

The epiontic state of the universe and its evolution would therefore be intrinsically intertwined.

It could be that the "fittest" physical laws (those more regular and efficient in propagating the information) actually gain greater and greater diffusion "with time", just like the most stable quantum states emerge from Hilbert spaces according to the growing theory of *Quantum Darwinism* [17].

We are aware that these concepts need well-founded frameworks in order to stop all of this from being mere handwaving. Fortunately, an investigation in the "space of theories" has already begun in the current known as *quantum foils*, see for example [18, 19]. The theories expressed in these studies do not aim to be faithful models of reality, but they are often revealing in highlighting various features of the laws of physics. And maybe they will allow us to better understand the epiontic paradigm.

6. CONCLUSIONS

From the Epiontic Principle derive many counterintuitive implications.

The past, contrarily to what we commonly think, is *indefinite* and *shifting*, since it depends uniquely on what we know. If our elements of reality changed, the past would adjust itself accordingly, as the experiments of the *delayed-choice quantum eraser* show. The apparent stability we experience every day derives only from the redundancy of the elements of reality in the macroscopic world, called *decoherence*.

It might seem impossible that we could "lose" elements of reality, except in *ad hoc* experiments, but a context in which this may happen is the cosmological evolution. What will happen to the universe when the density of information will be so low that it could account for more and more different pasts – and therefore presents?

Furthermore, one could argue that even the laws of physics depend uniquely on the epiontic state of the universe, being themselves elements of reality, and so they end up evolving and self-determining. Is it then possible to formalize the idea of a single "self-explaining universe" [20] in which the laws of physics compete to assert themselves?

Last, in the epiontic paradigm the *becoming* – the change of the state of knowledge of an observer – is accepted by definition. But is it possible to derive it in a more general framework, by proving that the becoming is what inevitably appears to a finite observer after quotienting all the equivalent alternatives?

The Epiontic Principle introduces many interesting considerations about the nature of reality, the laws of physics and time. Even a purely qualitative analysis raises new fundamental questions.

Certainly, we could persist to consider the epiontic effects just like bizarre and unexpected sub-products of the known theories of physics, limiting ourselves to examining them in familiar and accepted frameworks. Alternatively, we could recognize the Epiontic Principle as a fundamental building block of nature and try to give it a rigorous foundation. Whatever the choice, we can confidently affirm that the study of quantitative models which implement epiontic features – the "*epiontic foils*" – will deepen our understanding of reality.

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