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Elements and Processes of Reality

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Abstract.-This article recalls the concept of element of reality and introduces a new more general concept: the process of reality, which includes the first one, the concept of change and the irreversibility of time. The problem of quantum non-locality is also discussed and a new discrete scenario with a single universal locality is suggested.

Keywords: Quantum locality, realism, element of reality, process of reality, arrow of time, cellular automata.

1. Introduction: infinity and history

In the literature related to the strangeness of quantum mechanics that I have had the opportunity to examine, I have always been struck by the constant absence of two issues of capital importance in the possible unraveling of this strangeness (one has the impression that strangeness adds value to contemporary physical theories). The first of these issues is the hypothesis of the actual infinity, subsumed in the Axiom of Infinity, which underlies the mathematics with which physicists construct their theories, including quantum mechanics. The second is the very history of the universe and its objects, a history that has always occurred in the same entropic direction, always without human observers and always leaving indisputable traces of the processes that have occurred, for example traces in the rocks of planets such as the Earth (quantum physics should be interested, even if only minimally, in stratigraphy).

Although the hypothesis of the actual infinity was hotly debated for more than twenty-six centuries, it suddenly ceased to be discussed. It was in the early years of the last century when the infinitist works of R. Dedekind, G. Frege, and especially G. Cantor, finally laid the foundations for modern set theories, all of which axiomatically admit (Axiom of Infinity) the existence of the infinite sets, whose infinity is the actual infinity, not the potential infinity [15]. The elements of an actual infinite set exist as a complete totality: any element that can belong to the set is in the set. For example, the ordered list of natural numbers in their natural order of precedence contains ALL the natural numbers, ALL OF THEM; even if there is no last natural number to complete the list. Or the real interval $(0, 1)$ contains all the real numbers greater than zero and less than 1, ALL OF THEM, even if there is neither a first real number greater than 0, nor a last real number less than 1. This is the infinity that physicists assume without complaint in all their theories.

The other infinity, the potential infinity, is not even considered in contemporary mathematics. For this potential infinity, the ordered list of natural numbers does not exist as a complete list, but as an unbounded list in which it is always possible to add natural numbers that are larger than any natural number in the list. Here, the incomplete cannot be considered as complete, as Aristotle would say [1, p. 291]. It is ironic, on the other hand, that it has been modern set theories that have ended up providing the formal instruments to prove the inconsistency of the actual infinity that underlies them. For example, the ω-order of the natural numbers; the dense order of the real numbers and rational numbers; transfinite arithmetic; supertask theory, etc. More than 40 such proofs can be examined in [15], and the shortest and simplest I could develop in the final appendix to this article: less than 300 words that take less than three minutes to read.

Concerning the importance of the history of the universe in the quantum debate on reality and locality, it seems to me convenient to begin by remembering that things happen; and then immediately add: things happen and leave traces that we can recognize, interpret and confirm in experimental terms. This is what seems to have been happening in the observable universe for at least the last 13.8 billion years. And since it is only what it seems, we will need a guiding principle to construct our discussion of that observable reality, we will call it the Principle of Directional Evolution:

> *The observable universe always evolves independently of its observers and in the same direction of increasing its global entropy.*

where the term entropy could be replaced with the term isotropy [13]. This principle is a generalization of the Second Law of thermodynamics. It is an inductive principle for which there is maximum empirical evidence. From it some results are deduced almost immediately that are also worth considering as part of the formal setting of the main discussion of this article (details and proves can be found, for example, in [16]):

Theorem 1 (of the Consistent Universe) *The uni- verse always evolves under the control of the same and unique set of invariant and consistent physical laws.*

Theorem 2 (of Formal Dependence) *No concept de- fines itself; no statement proves itself; no physical object is the cause of itself; and no cause is the cause of itself.*

Theorem 3 (of the First Cause) *The universe had an origin whose cause is external to the universe itself and scientifically unknowable in terms of knowledge extracted from within the universe.*

2. EPR and its elements of reality

In the first page of the famous article known as EPR, its authors already establish the necessary requirement for a physical theory to be considered complete [8, p. 777]:

> Every element of the physical reality must have a counterpart in the physical theory

And in the following paragraph they define their famous elements of reality [8, p. 777]:

> If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.

With them they build their argument on the incompleteness of quantum mechanics based on the incompatibility between realism and locality that follows from the Copenhagen interpretation [8, p. 780]:

> Previously we proved that either (1) the quantum-mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality. Starting then with the assumption that the wave function does give a complete description of the physical reality, we arrived at the conclusion that two physical quantities, with non-commuting operators, can have simultaneous reality. Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.

And as is well known the story continued in theoretical terms with Bell's theorem [5] and the GHZ states [10]; and in experimental terms with the respective experiments carried out since 1982 [4, 3, 20, 11, 7], all of which ended up proving the Copenhagen interpretation was not wrong.

3. Processes of reality

It is not possible to define everything: we would fall into a potentially infinite regress of definitions. For that reason we are obliged to use in all sciences primitive concepts, concepts that are not defined in terms of other more basic concepts; if we did, those more basic concepts would be the new primitive concepts. Which justifies B. Russell's ironic words that in mathematics we never know what we are really talking about [19], although some do seem to know what they are talking about.

The concepts of change, event, modification, transformation and process are intimately related and surely all of them are primitive concepts, of which it is not possible to give non-circular definitions. We have to construct our arguments with this inevitable restriction, which, although it should not be forgotten, should not stop us in our eagerness to understand the physical world. We will then say that *if an element of reality, observed or not, is modified in such a way that another element of reality always results and the modification always leaves the same observable traces, then that modification is a process of reality.*

Naturally, the processes of reality include the elements of reality and their modifications or changes. They also include the passage of time. Therefore, it is a richer concept than EPR's element of reality. The inclusion of the concept of change is really important. Indeed, the problem of change has been posed and not solved for 25 centuries. What is worse, physics, the science of change, has completely forgotten the old problem of change, as if it were possible to explain the physical world without having previously solved the problem of change. On the other hand, it can be proved that the problem of change has no solution in the spacetime continuum, but it does have a solution in a discrete model of space and time. [15, p. 293-302] [14, p. 502-512].

The EPR argument made its authors conclude that quantum mechanics was incompatible with local realism, and since both assumptions (locality and realism) were inalienable for them, they ended up declaring quantum mechanics incomplete. But the argumentative variations on EPR and their corresponding experimental verifications gave reason to the opposite conclusion: reality is not local, for instance, elementary particles can be influenced instantaneously and at arbitrary distances. Moreover, and according to some interpretations of quantum mechanics, it is not possible to detach observers from the observed physical facts. The question we pose here is what role do the elements and processes of reality play in the explanation of the physical world?

According to the formal scenario introduced above, the observable universe could not have originated by itself and had to have a first cause unknowable in terms of other known causes. It is a universe that, moreover, evolves always in the same direction and under the control of the same set of formally consistent laws. This is what it has been doing for 13.8 billion years, with no observers to influence the results. Consequently, it can be affirmed that all interactions, micro and macroscopic, causing the directional evolution of the universe have always occurred in the same direction in which they would have to occur, otherwise such directional evolution would be impossible. An evolution carried out through trillions of reality processes, affecting trillions of reality elements and leaving trillions of empirically verifiable proofs (trillions is a way of speaking).

We can, therefore, conclude this part of the discussion by suggesting an autonomous, observer-independent evolution of the observable universe. An evolution that has finely produced conscious observers who wonder about the reality of the processes from which they themselves have emerged. Processes of reality that have left a multitude of observable evidence confirming the autonomy of the directional evolution of the universe. It may be that certain experiments, mental or real, require more exotic and observer-dependent explanations, but that does not seem to be the case for the unobserved physical object that the universe has been for most of its history. Interpretations of quantum mechanics that link active observations to observed facts should consider the directional and autonomous evolution of the universe.

4. The universe as a unique locality

The elements and processes of reality serve to decouple the directional evolution of the universe from observation. But they do not solve the problem of quantum non-locality. In this final section we suggest a new way of discussion in which the spacetime continuum is replaced by a discrete space and time, with indivisible minimum units: qseats and qbeats respectively. And the substitution is not arbitrary, among other reasons because:

1. The infinite sets, such as the continuum, are inconsistent (see one of the proofs in the final appendix).
2. The vibrations of space are empirically detectable (gravitational waves) and therefore space must be a real physical object: that which does not exist neither vibrates nor can modify the length of the arms of the interferometers that detect gravitational waves.
3. Space and time are involved in numerous mathematical functions whose outputs must be discrete values of energy, which is impossible if continuous variables are involved in these functions. Therefore, if energy is discrete, space and time must also be discrete.
4. The problem of change can only be solved in a discrete space and time [14, 12]. And without solving the problem of change it is impossible to explain the physical world.
5. Discrete space is much simpler than the space continuum: if a qseat had a Planck volume, the observable universe (9.9 billion light years in diameter) would contain 7.6×10^{184} qseats, while any arbitrary volume of the space continuum contains the same non-numerable infinite number of points: $2^{\aleph_o}$.
6. Different regions of discrete space contain different numbers of qseats, whereas a Planck volume and the entire universe, whatever its actual size, have the same number of points: $2^{\aleph_o}$ points.
7. In a discrete space-time it is possible to define models in which all qseats evolve in unison, the whole system being the same deterministic locality.

There is a model compatible with all the above requirements in which, and according to the last one, the quantum locality problem could be solved: cellular automata (of which quantum versions are also available [9, 18, 2, 6]). This may seem an extravagant model, although I find the alternative of multiple universes much more extravagant. Actually, I am not proposing that the universe is a cellular automaton, but suggesting a change of perspective in the interpretation of quantum mechanics, a new perspective based on the finite and discrete nature of space and time in a universe in which all its discrete elements are actualized in unison, as in cellular automata.

Appendix: The inconsistency of the actual infinity

The next theorem is a very abbreviated version of the argument [15, p. 59-63]. A more detailed and complete version than the following can be found [17, here].

Theorem 4 *The Axiom of Infinity is inconsistent.*

Proof.-The open interval of rational numbers $(0,1)$ is denumerable and densely ordered. So, it can be put in one-to-one correspondence f with the set $\mathbb{N}$ of natural numbers in their natural order of precedence; and the interval $(0,1)$ can be rewritten as the set $\mathbb{Q}_{01} = \{f(1), f(2), f(3), \dots\}$. Let now x be a rational variable initially defined as $f(1)$; and let (the current value of) x be compared with the successive elements $f(1)$, $f(2)$, $f(3)\dots$ so that x is redefined as $f(i)$ if, and only if, $f(i)$ is LESS THAN the current value of x. Since, according to the Axiom of Infinity, all elements $f(1), f(2), f(3), \dots$ of $\mathbb{Q}_{01}$ are rational numbers which exist as a COMPLETE TOTALITY, x can be successively compared with ALL of them:

$$\begin{aligned} &\forall n \in N: \ x \text{ is compared with } f(n) \text{, and} \\ &\text{redefined as } f(n) \text{ iff } f(n) < x \end{aligned} \tag{1}$$

Once compared with all[1] elements of $\mathbb{Q}_{01}$, the current value of x is the smallest rational in that set. Indeed, if once compared with all elements of $\mathbb{Q}_{01}$, the current value of x were not the least rational in $\mathbb{Q}_{01}$, there would exist at least one element $f(n)$ in $\mathbb{Q}_{01}$ such that $f(n) < x$. But this is impossible according to (1). Therefore, it was compared with $f(n)$ and redefined as $f(n)$. So, it is impossible that $f(n) < x$. But it is also immediate to prove that: Once compared with all elements of $\mathbb{Q}_{01}$, the current value of x is not the smallest rational in that set. In effect, once compared with all elements of $\mathbb{Q}_{01}$, and whatsoever be the current value of x, each element of the infinite set $\{x/2, x/3, x/4 \dots\}$ is an element of $\mathbb{Q}_{01}$ less than x. This contradiction proves the Axiom of Infinity legitimizing the existence of $\mathbb{Q}_{01}$ as an actual (not potential) infinite totality is inconsistent. □

(1) This is formally proved by induction in [15], and can also be proved by Modus Tollens and by supertask theory.

Bibliographical References

[1] Aristóteles. *Metafísica.* Espasa Calpe, Madrid, 1995.

[2] P. Arrighi and J. Grattage. A Quantum Game of Life. *ArXiv e-prints*, pages 1 – 12, October 2010.

[3] A. Aspect. *Trois tests experimentaux des inegalités de Bell par mesure de correlation de polarization de photons.* PhD thesis, Universidad de Paris-Orsay, Paris-Orsay, 1983.

[4] A. Aspect, J. Dalibard, and G. Roger. Experimental test of bell's inequalities using time-varying analyzers. *Physics Review Letters*, 49:1804–1807, Dec 1982.

[5] J. S. Bell. On the Einstein Podolsky Rosen paradox. *Physics*, 1(3):195–200, 1964.

[6] D. Bleh, T. Calarco, and S. Montangero. Quantum Game of Life. *ArXiv e-prints*, pages 1 – 5, October 2010.

[7] G. Carvacho, F. Graffitti, V. D'Ambrosio, B. C. Hiesmayr, and F. Sciarrino. Experimental investigation on the geometry of ghz states. *Scientific Reports*, 7(1):13265, 2017.

[8] A. Einstein, B. Podolsky, and N. Rosen. Can quantum mechanical description of physical reality be considered complete? *Physical Review*, 47:777– 780, May 1935.

[9] A.P. Flitney and D. Abbott. A semi-quantum version of the game of Life. *eprint arXiv:quant-ph/0208149*, pages 1 – 6, August 2002.

[10] D. Greenberger, M. Horne, A. Shimony, and A. Zeilinger. Bell's theorem without inequalities. *American Journal of Physics*, 58(12):1131–1143, 1990.

[11] Paul G. Kwiat, Salvador Barraza-Lopez, André Stefanov, and Nicolas Gisin. Experimental entanglement distillation and 'hidden' non-locality. *Nature*, 409(6823):1014–1017, 2001.

[12] A. León. Physics and the problem of change. *Preprint version*, 2020. Pdf.

[13] A. León. *The Physical Meaning of Entropy*. Amazon's Kindle Direct Publishing, 2021. Free pdf.

[14] A. León. *Apparent relativity*. Amazon's Kindle Direct Publishing, 2022. Free pdf.

[15] A. León. *Infinity put to the test*. Amazon's Kindle Direct Publishing, 2023 (2021). Free pdf.

[16] A. León. *Towards a discrete cosmology*. Amazon's Kindle Direct Publishing, 2023. Free pdf.

[17] A. León. The Axiom of Infinity Is Inconsistent. *The General Science Journal*, 2024. Pdf.

[18] N. Ollinger. Intrinsically Universal Cellular Automata. *ArXiv e-prints*, pages 199 – 204, June 2009.

[19] Bertrand Russell. *Misticismo y lógica y otros ensayos*. Aguilar, Madrid, 1973.

[20] W. Tittel, J. Brendel, B. Gisin, T. Herzog, H. Zbinden, and N. Gisin. Experimental demonstration of quantum correlations over more than 10 km. *Phys. Rev. A*, 57:3229–3232, May 1998.