ON THE CONCEPT OF TIME IN EVERYDAY LIFE AND BETWEEN PHYSICS AND MATHEMATICS

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ABSTRACT
In this paper I consider the concept of time in a general way as daily human time and then within physics with relation to mathematics. I consider the arrow of time and then focus the attention on quantum mechanics, with its particular peculiarities, examining important concepts like temporal asymmetry, complexity, decoherence, irreversibility, information theory, chaos theory. In conclusion I consider the notion of time connected to a new theory in progress, called "Superfluid Dynamic Space" theory, based on a time-invariant universe that overcomes the Big Bang model and is connected on the so called "bijective physics".
Keywords: Time, Modern Physics, Irreversibility, Decoherence, Symmetry/Asymmetry, Entanglement, Complexity, Superfluid Dynamic Space (SDS), Education.

Introduction
The problem of time is one of the fundamental problems of human existence; even before being the subject of philosophical investigation, it constitutes the man's ever-present problem, since even in an unconscious way it is intrinsically linked to our life. From the viewpoint of existential philosophy, it also involves the problem of the destiny of man, considered only indirectly by mathematical and naturalist philosophy. It is in fact over time that the destiny of human existence is realized.

A double meaning is linked to the time: on a hand we have the fear, the worry, which temporalize the being, on the other hand the hope, the change produced by creative activity. This dualism is intrinsic in the structure of the person, in the sense of union between the changeable and the immutable. Time is therefore a change in two distinct meanings: as development of life and as death.

The man's destiny is fulfilled in time, in the past and in the future; but this past and this future exist only in the present. Furthermore, the past can be considered under a double aspect: the past that has existed and is now over, and the past that still lasts in the present and which exists in the present memory as a transfigured past.

The relation between the three dimensions of time involves another very important existential aspect: how to act so that a painful past no longer exists and so that a beloved present continues to exist and does not die in the past.

Time is for some aspects an evil and its passing can be sad. This evil consists in the impossibility of savoring the present in all its fullness, due to the impossibility of completely freeing yourself by the sadness of the past and the fear of the future.

The joy of living the present moment as total fullness is always denied by the elapse of time. Without the loss of many things of the past, the man should not be able to live; a total memory would destroy him. This need to forget the past denotes an evil of time.

The temporal dualism becomes evident in the present moment. The instant can be seen as a small fraction of time, an infinitesimal fraction between the past and the future; but we can also see it as not belonging to time, as instant that cannot be divided into past and future. This problem has evident links to our age, dominated by technology and by speed.

The value of the instant is lost in it, which becomes only a means for the following instant. Time becomes thus an accelerated time, where the man is leaning towards the future and his ego decomposes in this temporal speed, losing the unity that is instead deeply connected to the unity of the indivisible moment.

The time-man relation is for some aspects paradoxical: on a hand the person is change, realization over time, on the other hand she/he is immutability, unity through the change, and therefore is damaged by time.

Another fundamental problem closely connected with time is the problem of death. Death occurs in time, resides in life and is its end. In the relation between time and infinity, we can consider two meanings: a quantitative and a qualitative one. Time seen as quantitative infinite brings death with it; on the other hand, victory over death and healing from the evil of time is linked to the meaning of qualitative infinity of time or eternity (Di Sia, 2015).

The intensity of our inner life can change the character of time; time that can accelerate or slow down in relation to the richness of life has no mathematical character (Di Sia, 2018[a]). Two of man's greatest problems, i.e. the problem of the foundation and that of the future, are both inseparably linked to time and reveal time as the intimate destiny of man. The human existence is immersed in time; its origin and conclusion seem to go beyond it.

The notion of time is present in all areas of thought that reflect and study the reality and the human being, from mathematics to physics, from philosophy to neurosciences. The problem of time escapes our senses and mathematics and physics often lead to results that are logically far from ordinary human thinking.

Mathematically, time is indicated as a variable t present in the equations; time flows and the term t defines some dynamics. Time can be defined on an oriented line, each instant is in one-to-one correspondence with a point of this line. When we graphically represent a movement in space, time is considered as if it were another spatial dimension. This is a static way of interpreting time, there is also the dynamic way, related to the flow of time (Di Sia, 2017).

In particle physics, space-time is flat, rigid and static; in general relativity it is curved, flexible and dynamic; they are two different conceptions of time. The canonical scientific theories developed to date use different notions of time (differentiable time, time in different dimensions, non-continuous time) and there are also time-independent theories (Fiscaletti, & Šorli, 2015; Di Sia, 2015[b]).

The subjective time, as memory of every moment of the present of our consciousness, has an asymmetrical structure and is elastic. The past seems written, frozen; we can remember it, but we can no longer hear that it runs. The future appears uncertain, not firmly attached to reality. In everyday life, past and future are not equivalent; there is a relative condition due to our consciousness (Šorli, 2019[a]).

Time flows constantly, even if our perception of its flow varies according to our emotional state; when we say that time runs quickly, we imagine something flowing at an increasing speed. This something is not actually time, it is the different way in which we emotionally experience the running reality (Fraisse, 1963).

To date, it has been not fully possible to demonstrate, on a scientific level, that time exists and flows from a past to a future. The human being appeals to basic personal feelings, to the fact that we are witnessing our aging, to the fact that disorder, in a closed system, spontaneously grows (Schroeder, 1999).

In relation to irreversibility, the concept of arrows of time has been studied. It seems difficult to be able to untie the concepts of change and invariance, two contradictory but inseparable components in the human effort to understand reality; it seems not possible to fully explain the change without referring to the invariance, and vice versa.

Within physics and science in general, there are different times, reflections on cosmological, thermodynamic, gravitational, biological arrows of time; each of them is based on different principles, and it is difficult to determine whether one is more fundamental than the others (McGucken, 2017; Mersini-Houghton, & Vaas, 2012; Savitt, 1997).

Mathematics has been studied and used since ancient times; however, it is starting by Descartes, Galileo and Newton that the mathematical language has been elevated to the rank of true language of Nature, allowing to talk about phenomena and make predictions.

In some cases it is possible to create, starting by differential equations with respect to time, solutions in which the parameter t is completely eliminated; as example, from the time-dependent solutions of Newton's equations for an orbital motion, $r(t)$ and $\alpha(t)$, one can build time-independent solutions $r(\alpha)$. The motions in the universe could be replaced by timeless trajectories in a larger space of configurations. This is an interesting theme, because it demonstrates how the interpretation of the t parameter can present many more aspects than we think, and also, in some sense, leads to the elimination of a generic absolute time.

The mathematized time of physics does not exhaust the sense of lived time, not more than lived time gives the intuition of all aspects of physical time. The simplest scheme adopted by science consists of a homogeneous one-dimensional (1D) time, composed of instants that follow one by another in an identical way. According to the thinking of some authors, it would not grasp the essential nature of the duration of the true time of life, which is continuous invention, continuous emergence of novelty (Canales, 2016). A current line of research considers a time-invariant flat universe, which goes beyond the Big Bang model and refers to the two concepts of "fundamental time" and "emergent time" (Di Sia, & Šorli, 2020[a]).

Time and irreversibility

The theme of the time irreversibility of physical theories has been the protagonist of heated debates over years in classical and quantum physics. Problems arose with the birth of thermodynamics, in particular in relation to the principle of growth of the entropy in a closed system, having found a temporally asymmetric fundamental law.

The temporal asymmetry of the reality surrounding us seems to be quite evident. We are witnesses of irreversible phenomena and we feel that there is a substantial difference between past and future. This evident asymmetry of Nature is in contrast with the laws of classical dynamics, symmetrical by time inversion, namely invariant with respect to the change of the time variable "*t*" into "- *t*".

The attempt to reconcile classical mechanics with thermodynamics began with Boltzmann's work. He noted that the microstates, that became states with higher entropy after a time evolution, were much more probable than those that became states with lower entropy. In essence, the time reversibility of the Newtonian law of evolution leads to the conclusion that entropy should increase towards the future and, symmetrically, also towards the past (Darrigol, 2018).

Over years, various solutions have been sought for this problem, from the treatment of entropy as a function of probability distributions to the question of special initial conditions, resorting to the use of asymmetric temporal boundary conditions. This led to the question of why the macroscopic world, which should spring from the microscopic one, regulated by quantum laws, shows evident signs of temporal asymmetry, i.e. of irreversibility.
In physics, irreversible phenomena often occur, to the point of having created cases of hypothetical arrows of time in various physical disciplines. We can think, as example:

- to the phenomenon of electromagnetic radiation, in which there are delayed and advanced solutions, although only the first ones seem to occur in Nature;
- to the self-organization of matter, in physical and biological processes, which has been of enormous importance in Prigogine's reflections. It is known that global entropy, when the surrounding environment is considered, always grows in harmony with the second law of thermodynamics, but in relation to the single system (for example a cell) we can witness an entropic decrease (Kondepudi, Petrosky, & Pojman, 2017);
- to the law of exponential decay, concerning unstable physical systems;
- to gravity, although its time direction may be linked to a question of initial conditions; gravity describes an attraction in both time directions, since Newton's equations are of second order with respect to time.

Superposition and entanglement

The superposition of quantum states represents an anomaly compared to what happens in classical physics; this derives by the fact that quantum mechanics is governed by a linear differential equation, so if two wave-functions ψ_1 and ψ_2 are solutions of the Schrödinger equation, even their superposition (a linear combination) is a solution (Griffiths, & Schroeter, 2018). This fact is incredible in the sense of the common logic, i.e. to think for example to an electron in a state of spin up and down simultaneously. It is difficult to put into words what mathematics indicates as possible. The collapse of the wave-function leads to the cancellation of the initial superposition (Di Sia, 2018[b]).

One might think that superposition is a simple mathematical tool, useful exclusively to calculate the probabilities related to each single eigenstate, but macroscopic superpositions have been observed in very sophisticated experiments; they are not impossible to see and, therefore, must not be considered non-existent (Mari, De Palma, & Giovannetti, 2016). If superpositions really exist, why does it seem so difficult to see them? An answer to this question has been provided by the decoherence theory and the continuous elimination of the superposition of states could provide a time direction (Zeh, 2002).

Entanglement is an extremely interesting and peculiar aspect of quantum mechanics; it provides that the states of two or more objects can be described in relation to each other, even if they are separated by enormous spatial distances, leading to an immediate action that contradicts the fact that the speed with which the signals are transmitted can not exceed the speed of light, i.e. $3 \cdot 10^8$ m/s in vacuum.

Quantum entanglement leads to holistic visions of Nature, in the sense that, assuming that everything began with a space-time singularity called Big Bang, but even without a hypothetical initial Big Bang, every single element of the universe would be in correlation with any other, in a global interconnection network; a measurement on an object would have repercussions on all the others, independently by distances (Di Sia, & Bhadra, 2020[a]; Di Sia, & Bhadra, 2020[b]).

An experiment on a system "here and now" would have repercussions on all systems throughout the universe; as a consequence, at the level of analysis of the temporal flow, the collapse of the wave-function, due to a measurement that can provide irreversibility resulting by a time direction, would automatically be accompanied by innumerable other collapses, due to total entanglement, leading to a universal time direction and to the natural disappearance of the superposition of states (Kiefer, & Joos, 1998; Zurek, 2003; Di Sia, 2020[a]).

Quantum mechanics between innovation and complexity

The theme of irreversibility plays a central role in the debate on the challenge of complexity that led to talk of complex sciences in recent decades. One of the focal points characterizing the reflection on complexity concerns the importance of the temporality of physical, biological and social processes. This temporality has often been ignored in favor of static visions, in which the flow of time is conceived as a simple manifestation of a timeless necessity (Ali, *et al.*, 2020).

It was a sort of separation between "observer" and "observed system"; the idea that the run of time is a disturbance led to the creation of experimental situations that remove any observer influences as much as possible, considering processes that could be described through symmetrical equations by time inversion.

Thinking the macroscopic irreversibility as governed by more fundamental microscopic laws, implies an assumption that there would be a hierarchy of levels of reality, the first of which is the smallest; all this has been challenged by reflections on complexity (Rueger, & McGivern, 2010).

As far as physical laws are concerned, we are seeing that a clear division between "observer" and "system" cannot be made, with the need for a physics that integrates within itself the strength of a historical description; the historicity of the laws of physics follows from the request not to neglect the observer through temporal processes, and therefore he cannot ignore them. The observer, with his actions, modifies the reality surrounding him.

Concerning the hierarchy of levels of reality, the complex thinking has questioned the reductionist thought between disciplines and within them, rejecting the idea that different aspects of reality could be described by a single point of view, more fundamental than others (Gallagher, *et al.*, 1999).

Prigogine's approach does not replace classical and quantum mechanics with a temporal reformulation of physics, but joins traditional physics, trying to reach previously inaccessible problems and to explain new phenomena. On a hand, Prigogine sought an irreversibility independent by the observer, on the other one he wanted to formulate a more human physics, in the sense that time, i.e. history, could be inscribed in the physical descriptions provided by theories. However, these are two goals in some sense in contrast one with the other, since it is difficult to distance the observer from the theory for making it more human. Prigogine emphasized also the delicacy of the concept of environment, in relation to who establishes the distinction between an object and its environment, questions that often goes back to the analysis of the problem of decoherence (Prigogine, & Stengers, 1984; Prigogine, 1997).

The irreversibility of quantum mechanics is manifested in the probabilistic nature of its predictions. The constraint as a possibility, fundamental idea of complex thought, is strongly present in quantum theory, helped by chaos theory as a representative theory of complex sciences.

Compared to chaos theory, quantum mechanics has less orthodox characteristics (in the sense of classical physics). Chaos theory describes a basic determinism, which however does not lead to some predictions after a more or less long time, due to the strong sensitivity to the initial conditions. Quantum mechanics instead moves away from determinism in a deeper and more fundamental way; it is intrinsically probabilistic, even in the interpretations in which it has tried to restore determinism, not simply tied to the basic equations of the theory (Butterfield, & Pagonis, 2010).

In the context of standard quantum mechanics, the "measurement" opens the system to the potential possibilities it carries, to the personal decision to measure some variables and the actual implementation of this measurement; it is an incredibly innovative theory from this point of view (Becker, 2019).

The indeterminism it describes is not an exclusively mathematical fact; the possibility of knowing the probabilities of the measurement outcomes through the knowledge of the square modules of coefficients in the development of the wave-function in the eigenstates of the observable, it is not a question linked only to formalism. These probabilities become current after a measurement process.

In classical physics it does not happen; the system assumes all values described by the equations of motion in well-defined times, and speaking of measurement is therefore superfluous. The measurement is necessary to physically know the value already predicted by the equations.

With quantum theory we cannot speak on a measurement result if we do not associate the measurement itself; there can be no knowledge of the system if there is no act that physically makes man interacting with it. Also for this reason it is a complex vision of Nature, which detaches itself from the paradigms of classical physics and which has inscribed in its essence the need for the presence of the observer to define the values that an observable of the system can assume.

For classical physics, that is essentially mechanistic, time does not have a decisive importance, because it reflects a mechanical nature, independent by time; for quantum mechanics it is more difficult to evade the importance of the time direction. But the quantum flow of time is linked to the choices and physical acts that the observer performs, so it is possible to consider time as a psychological element, an illusion, as Einstein argued (Šorli, & Di Sia, 2020). Time, read through the eyes of quantum theory, becomes inevitably linked to the human action and, conversely, our action develops over time, in a continuous choice between different possibilities.

Even in the past (we can think for example to the work of St. Augustine), man had admirably emphasized that time is experienced, it is not "a priori" defined; for this reason, time and man cannot be divided. Precisely because he lives, man produces a temporal unfolding that leads him to a goal (Saint Augustine, 1961). Quantum mechanics, in its various interpretations, has managed to represent this idea better than classical mechanics, also thanks to its indeterminism closely linked to the act of measurement.

The difference between thermodynamics and quantum mechanics lies in particular, in addition to the domain of application and the different mathematical formalism, in the role that is given to the observer; from an "active role", such as that of the quantum observer, we move to a "more classical role", i.e. non-fundamental, of the thermodynamic observer. These are qualitatively different times.

Our interaction with reality cannot be neglected, and quantum mechanics states it clearly, not only with regard to the inevitable perturbation of systems by the observer, but also more deeply about our personal act of deciding which observable to measure, and therefore how to expand the wave-function (Di Sia, 2020[b]). Therefore, just as the observer must be taken into due consideration for the results of experiments, he must also be taken into consideration with regard to the flow of time.

Information, complexity and arrow of time

The universe tends to degrade into a uniform state of disorder known as "thermal equilibrium". The astronomer and philosopher Sir Arthur Eddington in 1927 cited the progressive dispersion of energy as proof of an irreversible arrow of time. But this arrow of time does not seem to follow the basic laws of physics, that work in the same way both forward and backward in time (Price, 2013). With quantum physics, a more fundamental source for the arrow of time seems to have emerged, due to the way in which elementary particles intertwine when they interact, namely the effect of "quantum entanglement".

A line of research argued that objects reach equilibrium, or a state of uniform distribution of energy, in a finite time and in time scales proportional to their size, becoming quantum mechanically entangled with the surrounding environment (Jost, *et al*., 2009). The history of the arrow of time begins with the idea of quantum mechanics that Nature is intrinsically uncertain. An elementary particle lacks definite physical properties and is only defined by the probability of being in various states. Quantum uncertainty generates entanglement, which could be the source of the arrow of time. When two particles interact, they can no longer be described by themselves; they become entangled components of a more complicated probability distribution describing both particles together.

It is as if particles gradually lose their individual autonomy for becoming elements of a collective state; these correlations ultimately contain all the information, and the individual particles none. The arrow of time would therefore be an arrow of increasing correlations. Advances in quantum computing have over time transformed quantum information theory into one of the most active branches of physics (Nielsen, & Chuang, 2000).

Objects interact with the surrounding environment; as, for example, particles of a liquid in a glass collide with the air, the information of an object is dispersed out of it and we find it spread over the whole environment, a kind of local loss of information that we find globally in the surrounding environment. Except for rare random fluctuations, its state stops changing over time; consequently, the liquid in the glass, once cooled, does not heat up spontaneously. This statistical improbability would give to the arrow of time the appearance of irreversibility.

The local decrease of information through quantum entanglement brings the liquid into equilibrium with the surrounding room, which balances itself with the external environment, and this latter slowly balances itself with the rest of the universe. The first creators of 19th century thermodynamics interpreted this process as a gradual dispersion of energy that increases the overall entropy, or disorder, of the universe (Belavkin, & Ohya, 2002).

According to the point of view involving the entanglement, information becomes more and more widespread, but does not disappear completely; even if it increases locally, overall in the universe remains constant. The universe as a whole would therefore be in a pure state, but with its individual pieces, which are entangled one with each other, would be in mixtures, therefore not in pure states. This kind of approach could help in understanding the fundamental limitations of quantum computers and also about the ultimate fate of the universe.

When we read a message on a piece of paper, the brain is correlated with it through photons that reach the eyes; only from then on we will be able to remember what the message says. The present can therefore also be defined as the process of becoming related to the environment.

Physics emphasizes that, despite great advances in understanding how changes over time occur, no substantial progress has been made in discovering the deep nature of time and why it looks different, both perceptually and in the equations, with respect to the three dimensions of space.

"Past hypothesis", gravity and arrow of time

An explanation, called "past hypothesis", assumes that the universe began with a particular state of low entropy, and then progressively moved towards a state of greater disorder (*plato.stanford.edu*). According to this hypothesis, the arrow of time can be attributed to a trend in the universe towards greater confusion. But cosmological observations suggest the opposite, namely an evolution from a very disordered state of the past to the well-ordered structures we see today, with galaxies, solar systems, humans, and so on.

A way to reconcile the second law of thermodynamics with observations is to assume that, while matter in the universe appears to have more order, the gravitational field would increase in entropy, compensating the order of matter so that global entropy is increasing. However, attempts to define a notion of entropy for the gravitational field has so far not yielded good results (Chaichian, Oksanen, & Tureanu, 2011).

Furthermore, this hypothesis makes too many unreasonable assumptions about the early universe, stating that we are the result of a statistical fluke or an implausibly special initial conditions of the universe, unsatisfactory explanations from a scientific point of view.

A more satisfying explanation is related to the concept of complexity. The universe is a structure whose complexity is growing; our perception of time could be the result of a law that determines an irreversible increase in complexity. By connecting the arrow of time to the topological properties of the universe, the growth of complexity would be accompanied by a growth of local information and the problem of time is so connected with the theory of information.

If the fundamental laws of Nature are invariant by time reversal, i.e. time is symmetric, then the origin of the thermodynamic asymmetry in time could lie in temporally asymmetric boundary conditions. This conclusion would follow even if the fundamental laws are not invariant by time reversal.

None of the possible studied candidates for a unified theory of Nature seem to involve the thermodynamic arrow: string theory, canonical quantum gravity, quantum field theory, general relativity, all allow solutions without a thermodynamic arrow. So the universe could have a thermodynamic arrow due, in whole or in part, to its temporally asymmetrical boundary conditions.

Recent advances on the concept of time

The Wheeler-deWitt equation and other proposals, as the timeless path integral approach for relativistic quantum mechanics, a fundamental level of physical reality based on an invariant set postulate, and models of a non-dynamical timeless space, suggest a timeless background space of physics, and the fact that the duration of physical events has not a primary existence. The view of time as emergent quantity that measures the numerical order of material changes brings to a interesting unifying re-reading (Šorli, & Di Sia, 2020).

Several authors suggest that the space background of physical processes is timeless, namely time cannot be considered a primary physical reality flowing on its own in the universe. These research suggests that time can be an emergent quantity, that measures the numerical order of physical events (Fiscaletti, & Sorli, 2015). Also Einstein and Gödel considered the idea of a timeless universe at the half of the 20th century.

The time of general relativity and that of quantum theory are mutually incompatible, and this gave problems in the attempts to unify these two theories into a unifying framework. The problem of time has become one of the most investigated topics in quantum gravity.
We can say that the two fundamental questions concerning the features of time are as follows:
- if time is a fundamental quantity of Nature;
- how the clock time emerges in the experimental description of dynamics.

To date, the fundamental idea is that the physical time cannot be considered as a primary physical reality; the idea is that, at a fundamental level, the background space of physics is timeless, i.e. that the duration of physical events measured with clocks is an emergent quantity.

According to a recent line of approach, physical processes do not take place in an idealized time and have no duration on their own. In physical space, time is an "emergent mathematical quantity"; with clocks we measure the speed and the numerical order of material changes. Changes of the state of universe and of the state of any physical system can be considered the primary phenomena generating the evolution of the universe. This evolution can be described with the introduction of a mathematical parameter, providing only the order of events.

Recent NASA measurements have confirmed that the universe is flat and infinite, with an infinite amount of energy. Bijective analysis confirms that the Big Bang model is a prediction without any experimental evidence. The universe would be a non-created system in a permanent dynamic equilibrium, falsifiable and based on a direct reading/interpretation of data (Šorli, 2019[b]; *wmap.gsfc.nasa.gov*; Di Sia, & Šorli, 2020[b]; Di Sia, & Šorli, 2020[c]).

Conclusion

Man has always placed his attention and tried to understand the meaning of time, from its presence in everyone's daily life and in a more rigorous and deep way through philosophy and science, mathematics and physics in particular.

Physics has dealt and deal with the problem of time and its technical language is mathematics. From classical physics, time has placed its stamp in modern physics, involving important key concepts such as decoherence, superposition, entanglement, information theory and chaos theory. It is an elusive concept and not yet fully defined and framed, even by a strictly scientific point of view.

Recent interdisciplinary insights show that in physics the concept of time is used in two different ways: as an outer attribute of motion or as an implicit variable that measures the inner evolution of a system. In the first case, time is a label attached to the system, in the second one it is a quantity informing about its intrinsic evolution.

In both cases, time measured with clocks cannot be considered as a primary physical reality, but it is an emergent quantity indicating the numerical order of material changes. Moreover, the duration of a given material change requires the measurement of an observer.

Therefore, in physics we can consider two kinds of times:
a) a "fundamental time", that is the numerical order of change that exists independently by an observer;
b) an "emergent time", that is a duration of material change and is originated by the measurement of an observer.

References

Ali, T., Bhattacharyya, A., Shajidul Haque, S., Kim, E.H., Moynihan, N., and Murugan, J. (2020). Chaos and complexity in quantum mechanics, *Physical Review D*, 101, 026021.
Available online (2020-08-26) at: https://plato.stanford.edu/entries/time-thermo/.
Available online (2020-08-26) at: https://wmap.gsfc.nasa.gov/universe/bb_cosmo_infl.html.
Becker, A. (2019). *What Is Real?: The Unfinished Quest for the Meaning of Quantum Physics* (Reprint edition), New York: Basic Books.
Belavkin, V.P., and Ohya, M. (2002). *Entanglement, quantum entropy and mutual information*, Proceedings of the Royal Society A, 458, 209-231, https://doi.org/10.1098/rspa.2001.0867.
Butterfield, J., Pagonis, C. (2010). *From Physics to Philosophy* (Reprint Edition), Cambridge: Cambridge

University Press.
Canales, J. (2016). *The Physicist and the Philosopher: Einstein, Bergson, and the Debate That Changed Our Understanding of Time*, Princeton: Princeton University Press (Reissue edition).
Chaichian, M., Oksanen, M., Tureanu, A. (2011). On gravity as an entropic force, *Physics Letters B*, 702(5), 419-421.
Darrigol, O. (2018). *Atoms, Mechanics, and Probability: Ludwig Boltzmann's Statistico-Mechanical Writings - An Exegesis*, Oxford: OUP Oxford.
Di Sia, P. (2015)[a]. Looking at the Dimension of Time among Science, Psychology and Everyday Reality, *International Letters of Social and Humanistic Sciences* (ILSHS), 1(2), 146-153.
Di Sia, P. (2015)[b]. Approaching youngs to unified theories: the charm of string theories, *Procedia - Social and Behavioral Sciences Journal*, 174C, 10-16.
Di Sia, P. (2017). A Hystorical-Didactic Introduction To The Key Concepts Of Mathematical Analysis, *TOJET* (The Online Journal of Educational Technology), 60-68.
Di Sia, P. (2018)[a]. Mindfulness, Consciousness and Quantum Physics, *World Scientific News*, 96, 25-34.
Di Sia, P. (2018)[b]. *On Quantum Physics, Metaphysics and Theism*. In: Bertini, D., Migliorini, D. (Eds), Relations. Ontology and Philosophy of Religion, Milan-London: Mimesis International. https://www.amazon.com/Relations-Ontology-Philosophy-Daniele-Bertini/dp/8869771261.
Di Sia, P. (2020)[a]. On philosophy of mind, quantum physics and metaphysics of the uni-multiverse, *Philosophical News* - Official publication of the European Society for Moral Philosophy, 18, 161-174. https://www.philosophicalnews.com/issues/issue-n-18/.
Di Sia, P. (2020)[b]. *On advances of contemporary physics about mindfulness and consciousness*, Proceedings book of the International Conference "MINDfulness 2020", August 29-30, 2020, Olimia Spa, Podčetrtek (Slovenia), http://www.eduvision.si/com.
Di Sia, P., Bhadra, N.K. (2020)[a]. Origin of consciousness and contemporary physics, *World Scientific News*, 140, 127-138.
Di Sia, P., Bhadra, N.K. (2020)[b]. Everything in a part: about the creation of universe and consciousness, *Ergonomics International Journal* (EOIJ), 4(1), 000228 (6 pp).
Di Sia, P., Šorli, A.S. (2020)[a]. The difficulties of Big Bang theory and a new explanatory scenario, *Ergonomics International Journal* (EOIJ), 4(2), 000231 (5 pp). https://medwinpublishers.com/EOIJ/index.php.
Di Sia, P., Šorli, A.S. (2020)[b]. The Superfluid Dynamic Space (SDS) Unified Field Model, *The European Physical Journal Plus* (under review).
Di Sia, P., Šorli, A.S. (2020)[c]. Gravity and entanglement are carried by the same medium, *Journal of Experimental and Theoretical Physics* (JETP) (under review).
Fiscaletti, D., & Sorli, A.S. (2015). Perspectives of the Numerical Order of Material Changes in Timeless Approaches in Physics, *Foundations of Physics*, 45, 105-133, https://doi.org/10.1007/s10701-014-9840-y.
Fraisse, P. (1963). *The psychology of time*, New York: Harper & Row.
Gallagher, R., Appenzeller, T., Normile, D., Service, R.F. et al. (1999). Beyond reductionism, *Science*, 284(5411), 79-109.
Griffiths, D.J., Schroeter, D.F. (2018). *Introduction to Quantum Mechanics* (3rd Edition), Cambridge: Cambridge University Press.
Jost, J.D., Home, J.P., Amini, J.M., Hanneke, D., Ozeri, R., Langer, C., Bollinger, J.J., Leibfried, D., Wineland, D.J. (2009). Entangled Mechanical Oscillators, arXiv:0901.4779v1 [quant-ph].
Kiefer, C., Joos, E. (1998). Decoherence: Concepts and Examples, arXiv:quant-ph/9803052v1.
Kondepudi, D., Petrosky, T., and Pojman, J.A. (2017). Dissipative structures and irreversibility in nature: Celebrating 100th birth anniversary of Ilya Prigogine (1917-2003), *Chaos*, 27, 104501, https://doi.org/10.1063/1.5008858.
Mari, A., De Palma, G. & Giovannetti, V. (2016). Experiments testing macroscopic quantum superpositions must be slow, *Scientific Reports*, 6, 22777. https://doi.org/10.1038/srep22777.
McGucken, E. (2017). *The Physics of Time: Time & Its Arrows in Quantum Mechanics, Relativity, The Second Law of Thermodynamics, Entropy, The Twin Paradox, & Cosmology Explained via LTD Theory's Expanding Fourth Dimension*, New York: 45EPIC Golden Hero's Odyssey Mythology.
Mersini-Houghton, L., Vaas, R. (Eds) (2012). *The Arrows of Time: A Debate in Cosmology*, Berlin: Springer.
Nielsen, M.A., Chuang, I.L. (2000). *Quantum computation and quantum information*, Cambridge: Cambridge University Press.
Price, H. (2013). Time's Arrow and Eddington's Challenge. In: Duplantier B. (eds), Time. *Progress in Mathematical Physics*, 63, Basel: Birkhäuser. https://doi.org/10.1007/978-3-0348-0359-5_6.
Prigogine, I. (1997). *The End of Certainty*, New York: Free Press.
Prigogine, I., Stengers, I. (1984). *Order Out of Chaos* (1st Edition), New York: Bantam.
Rueger, A., McGivern, P. (2010). Hierarchies and levels of reality, *Synthese*, 176, 379-397, https://doi.org/10.1007/s11229-009-9572-2.

Saint Augustine. (1961). *Confessions* (New Impression Edition), London: Penguin Classics.
Savitt, S.F. (Ed.) (1997). *Time's Arrows Today: Recent Physical and Philosophical Work on the Direction of Time*, Cambridge: Cambridge University Press.
Schroeder, D.V. (1999). *An Introduction to Thermal Physics* (1st Edition), London: Pearson.
Šorli, A.S. (2019)a. How many Models of Time do we need in Physics?, *NeuroQuantology*, 17(01), 33-36, doi: 10.14704/nq.2019.17.01.1914.
Šorli, A.S. (2019)b. Mass-Energy Equivalence Extension onto a Superfluid Quantum Vacuum, *Scientific Reports*, 9-17, 11737, https://doi.org/10.1038/s41598-019-48018-2.
Šorli, A.S., Di Sia, P. (2020). Time is the duration of changes in time-invariant space, *The British Journal for the Philosophy of Science* (under review).
Zeh, H.D. (2002). Decoherence: Basic Concepts and their Interpretation, arXiv:quant-ph/9506020v3.
Zurek, W.H. (2003). Decoherence, einselection, and the quantum origins of the classical, arXiv:quant-ph/0105127v3.

