Editorial

The phenomenotechnique of time – Introduction

1. Introduction

After Bachelard, what do we know about time? In the 1930s, Bachelard took on the epistemological and ontological break brought about by Einsteinian physics by proposing a philosophy of the instant. One hundred years after *L'intuition de l'instant* (1932) and *Dialectique de la durée* (1936), have scientific and technological advances preserved, displaced or canceled out the fruitfulness of Bachelard's philosophy of time? Bachelard's historical epistemology[1] requires us to continue our work in the history of science and philosophy, to criticize outdated categories and update the reality of what science thinks today. It differs from other contemporary sociological[2] or philosophical research that aims to constitute a metaphysics of time and determine the ontological status of the present, the past and the future, or that of duration[3] in the continuity of the work of J.M.E. McTaggart (1866-1925), to trace a descriptive metaphysics of temporal modalities[4], or to account for our temporal experience phenomenologically[5]. Bachelard himself was conscious of choosing a third path between metaphysics and phenomenology: that of historical epistemology, which seeks to understand the negotiated conciliation between knowledge and reality, between rationalism and materialism.

[1] According to the expression coined by Dominique Lecourt in his master's thesis to characterize his philosophy of science in 1969, *L'Épistémologie historique de Gaston Bachelard,* Paris, Vrin, 2002.

[2] Hartmut, R., *Accélération. Une critique sociale du temps*, trad. par D. Renault, Paris, La Découverte, 2010.

[3] Declos, A. ; Tiercelin, Cl., éds. *La métaphysique du temps. Perspectives contemporaines*, Paris, Collège de France, 2021, wich includes contributions from leading time researchers: Baptiste Le Bihan, Vincent Grandjean, Philippe Huneman, Robin Le Poidevin. Voir aussi Bouton, Ch., Huneman, Ph., *Temps de la nature, nature du temps*, Paris, CNRS éditions, 2018.

[4] Wolff, F., *Le temps du Monde*, Paris, Le Seuil, 2023.

[5] Bouton, Ch., *Le temps de l'urgence*, Lormont : Le bord de l'eau, 2013 ; Accélération de l'histoire et expériences du temps dans la modernité, *Administration et éducation*, 2023/3, 179 ; Les métamorphoses du temps libre dans la modernité, *Mouvements*, 2023.2, 114 ; Vitesse, accélération, urgence. Remarques à propos de la chronopolitique. *Sens dessous,* 2017/1, 19, p. 75-84. View also Laurent Perreu researches about phenomenology and sociology.

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Indeed, philosophers and scientists compare their philosophical, epistemological, scientific and historical analyses to analyze how Bachelard characterized a fundamental evolution in the relationship between science and time that began with Einstein, and to examine the relevance of Bachelardian concepts and theses in the light of contemporary physics and metrology. Questioning the contemporary reality of time extends the work of Bachelard's[6] readings in the light of our present scientific history. Firstly, science is a phenomenotechnique; secondly, science and its history constitute the fundamental framework for our access to reality; and thirdly, history forces science and philosophy to evolve, forcing the scientific mind to grow and to question the role of science in our societies and our lives.

2. Bachelard, relativity, and time

Gaston Bachelard has a special place in philosophy, and especially in the philosophy of science. Firstly, although his attraction to the humanities was evident throughout his life, his keen interest in the sciences never waned. It was more than just an interest, however keen, for he actually practiced science. At the beginning of the 20th century, with a philosophy baccalaureate in his pocket, he turned to the cutting-edge technology of his time, telegraphy, when he joined the Post and Telegraph Office. At the same time, he prepared for a scientific baccalaureate, followed by postgraduate studies that enabled him to teach physics and chemistry at a secondary school for several years. Bachelard then devoted the first period of his work to understanding contemporary science, what he called its «inductive value», in particular what science teaches us about time by denying Bergsonian duration. The second period began in 1940, when Bachelard began to analyze the historical movement of science, which he conceived as a negation and thematized under the figure of *non*. His dual expertise in science and philosophy made him a privileged witness to the revolutions that overturned physics at the beginning of the 20th century: relativity, on the one hand, and quantum mechanics, on the other. No one understood the radical paradigm shifts that ensued better than he did. His work *Le nouvel esprit scientifique*, published in 1934, testifies both to his astute understanding of modern mathematical and physical theories, and to the depth of his philosophical reflections induced by these theories. It was in this context that he took up his concept of *phenomenotechnique*, defined a few years earlier:[7]

> les instruments ne sont que des théories matérialisées. Il en sort des phénomènes qui portent de toutes parts la marque théorique. Entre le phénomène scientifique et le noumène scientifique, il ne s'agit donc plus d'une dialectique lointaine et oisive, mais

[6] Alunni, Ch., *Spectres de Bachelard*, Paris, Hermann, 2019, p. 6.

[7] Bachelard, G., *Noumène et microphysique*, « Koyré », Puech et Spaier, vol. 1, Paris, Boivin & Cie, 1931-1932, p. 55-65.

> d'un mouvement alternatif qui, après quelques rectifications des projets, tend toujours à une réalisation effective du noumène. La véritable phénoménologie scientifique est donc bien essentiellement une phénoménotechnique [instruments are merely materialized theories. Phenomena emerge from them, bearing the mark of theory on all sides. The relationship between the scientific phenomenon and the scientific noumenon is no longer a distant and idle dialectic, but an alternative movement which, after some rectification of projects, always tends towards an effective realization of the noumenon. Genuine scientific phenomenology is therefore essentially phenomenotechnics].[8]

In fact, modern physics, and quantum mechanics in particular, confound the Kantian order of transcendental idealism to the point of total confusion: like many other concepts in physics, such as particles and waves, for example, the notions of noumenon and phenomenon are completely intertwined! The philosopher then seeks to understand the negation effected by contemporary science, showing how, thanks to mathematics, it gains access to an abstract rationality totally alien to our ordinary perceptions and intuitions. Substance becomes an overstance or an ex-stance, and reason a power of divergence, which abandons our ordinary intuitions, emancipating itself from habits of thought to induce syntheses capable of reconciling wave and corpuscle in the photon, the eternalism of general relativity (in McTaggart's sense), the entropy of systems and the unreality of time in quantum mechanics in the instant (in Rovelli's sense).

Science knows better, differently and more than we can say and name with our usual words. Language and thought must be converted to express what mathematical physics knows. Mathematical physics offers more than just a precise language to describe things as the Vienna Circle[9] theorists thematized them: it structures both reality and our minds. Faced with the logicism he criticizes, Bachelard promotes an engineer's style, the one he wanted to be at the start of his professional career in telecommunications. More fundamentally, to know something is not so much to define it, as to know how to make it, first theoretically, then experimentally, even industrially. Thus, techniques are not simply the application of science to act on reality according to our interests and utilities but express the dialectic of knowledge and reality that is being played out historically. They reveal «the new philosophical character of this rationalism and associated realism, both of which are essentially actualized in techniques formulated by mathematical theories»[10]. Science induces, in the sense that it produces in a given field, rationality and reality. It knows and acts together: scientific instruments, technical objects, devices and infrastructures express this operative dialectic. As a result, it finds itself obliged first to deny ordinary objects and logics in order to transform them. Certainly, science deals with reality, but it does not describe it as if it pre-existed in a natural world: it determines the reality in which we exist, not only through the instruments, machines and technologies we use, but also through the semantics and grammar according to which we think and say the

[8] Bachelard, G., *Le nouvel esprit scientifique*, PUF, 2013, pp. 16-17.
[9] Bachelard, G., *Le Nouvel esprit scientifique*, Paris, Librairie Félix Alcan, 1934, p. 53.
[10] Bachelard, G., *L'Activité rationaliste de la physique contemporaine*, Paris, P.U.F., 1951, p. 2.

real and ourselves[11]. What science knows and does at a given moment is real. In other words, science realizes its objects, it is phenomenotechnical[12]. It no longer targets natural, anhistorical, universal or eternal entities, as Newton or Laplace assumed, but a moment in a long process of transformation of our minds and of reality. By the same token, technique is not a related, accessory or secondary activity of science, but expresses the fabricating function of reason. «Un concept est devenu scientifique dans la proportion où il est devenu technique, où il est accompagné d'une technique de réalisation [A concept has become scientific insofar as it has become technical, insofar as it is accompanied by a technique of realization]»[13]. Bachelard's scientific realism does not mean constructivism or relativism in the sociological sense of David Bloor's «strong program»: it means historical realism, which traces the noumenal function that realizes the noumenon as a phenomenon. This noumenal function acts like electromagnetic induction: by linking phenomena of distinct fields, it produces a mixed real effect. Scientific experience becomes a phenomenal synthesis, a new kind of schematism capable of history, evolution and novelty, precisely insofar as the categories of understanding evolve and transform. In this way, science gives rise to a continuous, indefinite creation that reconfigures our history and ourselves. The mathematical thinking of science, allied to contemporary technologies, constitutes a dialectic of creation or construction that organizes phenomenotechnical devices. Bachelard calls this second nature realized by human reason a *natura constructa*: it is not reduced to reproducing, copying or resembling nature, but produces phenomena by reorganizing and renewing reality[14]. This second nature breaks with common sense and practical concerns in that it realizes noumena made possible by mathematics, which now organizes the real and the rational. Our minds must then rise to the level of contemporary science, in a constantly renewed effort: «En somme la science instruit la raison. *La raison doit obéir à la science, à la science la plus évoluée, à la science* évoluante [In short, science instructs reason. Reason must obey science, the most advanced science, evolving science]»[15]. The scientific history of time thus tells the story of the making of time, in the sense that time progressively determines several figures of scientific objectivity, which constitute our temporal reality at different historical epochs: reversible and absolute in classical mechanics, then irreversible and entropic in thermodynamics,

[11] Feyerabend, P., *Realism and the historicity of knowledge*, "Journal of Philosophy", 86, 1989, 393-406.

[12] Bachelard, G., *Noumène et microphysique*, « Études » [1970] p. 19 ; Bachelard, G., *La formation de l'esprit scientifique* [1934], 5e édition 1967, p. 71. View also Pariente, J.C., *Le Vocabulaire de Bachelard*, Paris, Ellipses, 2001. Rheiberger, Hans Jörg, *Gaston Bachelard and the notion of « phénoménotechnique »*, « Perspectives on science », 13/3, 2005, p. 313-328. Fabry, L., *Phenomenotechnique : Bachelard's Critical Inheritance of Conventionalism*. « Studies in History and Philosophy of Science », Part A, Elsevier, 2019, p. 34-42.

[13] Bachelard, G., *La formation de l'esprit scientifique* [1934], 5e édition 1967, p. 71.

[14] Bachelard, G., *L'engagement rationaliste*, Paris, PUF, 1972, p. 50.

[15] Bachelard, G., *La Philosophie du non. Essai d'une philosophie du Nouvel esprit scientifique*, Paris, PUF, 1940, p. 144.

devoid of absolute simultaneity in special relativity, differentiated into space-time unfolding in an eternalistic block universe, or perhaps purely local in the spatiotemporal sense.

Capturing the dialectics at work in regional sciences calls for a «philosophie dispersée»[16] that can be applied to each region, while accepting to do away with the beautiful a priori unity of the absolute time of Newtonian science. For a physicist of time, nothing better illustrates this phenomenotechnique than the evolution of the definition of the unit of time, the second, over the course of the twentieth century. In the first half of the century, this definition was based on the Earth's rotation, i.e. the length of the day: the second is the 1/86400th part of the average solar day[17]. To paraphrase Augustine, time is that noumenon of which we have a theoretical intuition without yet fully grasping it, whereas the length of the day is the experimental phenomenon that we can observe and measure precisely. But everything changed with the invention of the Cesium atomic jet clock and, above all, with the adoption of the atomic second in 1967, whose definition becomes totally abstruse to the non-physicist: The second is the duration of 9, 192, 631, 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Cesium 133 atom at rest, at the temperature of absolute zero[18]. So, to measure time, we use the experimental phenomenon of the atomic clock, which involves cesium atoms which, like all atoms, have energy levels defined by their atomic structure, i.e. the principal quantum number, the orbital, the magnetic moment and spin of each of their electrons, and can therefore change energy level by absorbing or emitting a photon whose frequency confers an energy, according to Planck's relation, exactly equal to the difference between two energy levels of the atom! And it's precisely this frequency observable in the case of an atomic clock that may be considered as a new time reference…

To do this, you need to master and have confidence in quantum theory, that highly mathematized and, to say the least, astonishing intellectual construct, in order to highlight the experimental phenomenon on which you're going to rely. Where is the noumenon? What is the phenomenon? To go beyond Bachelard's quote above, you could even say that an atomic clock smacks of theory! It's a world away from the pendulum of a mechanical clock, whose oscillations are a purely experimental phenomenon…

The other scientific revolution of the twentieth century, relativity, is less puzzling from an epistemological point of view, in that it does not directly attack the very foundations of physics, and hence the realism cherished by physicists. It does, however, shake up our conception of space and time. In *La valeur inductive de la relativité*, published in 1929, Bachelard demonstrates his exhaustive understanding of both the tensor mathematical formalism required to

[16] Bachelard, G., *La Philosophie du non*, op. cit., p. 50.

[17] A day is divided into 24 hours of 60 minutes of 60 seconds: 24 x 60 x 60 = 86400 seconds per day.

[18] Report of the 13th CGPM (1967), 1969, p. 103.

develop general relativity and its implications for space and time. Indeed, relativity takes us into a world where time ceases to be absolute, since it depends on the frame of reference in which we are situated; the notion of simultaneity becomes an arbitrary convention; space and time merge to form space-time; this space-time is no longer the container and the universe the content, but they interact to such an extent that they become inseparable. What's more, Bachelard doesn't fall into the many traps that relativity sets for common sense, particularly the very notion of relativity itself. He rightly wrote: «La relativité est une doctrine de l'absolu [relativity is a doctrine of the absolute]»[19] turning his back on a number of thinkers who believed it to be a powerful argument for philosophical relativism!

3. The physics and metaphysics of time

Newton believed that space and time formed a single framework within which the universe evolved. As we have just seen, Einstein's vision of the world was radically different. Based on two postulates shared by all physicists today, namely (1) Galilean relativity and (2) the constancy of the speed of light in any frame of reference[20], he demonstrated through a simple thought experiment that time cannot be absolute[21]. To do this, he first gives a definition of synchronicity: let's imagine two distinct points *A* and *B*, motionless in our frame of reference. We place a clock in the immediate vicinity of each of these two points. We'll assume that these two clocks are perfectly identical. A light beam is sent from *A* to *B*, reflected at *B* and returned to *A*. We note t_A on clock A, the instant when the beam first passes through *A*, t_B on clock *B* the instant when the beam passes through *B* and t'_A on clock A the instant when the beam returns to *A*. For Einstein, the clocks at *A* and *B* are synchronous if $t_B - t_A = t'_A - t_B$.

Now let's imagine that points *A* and *B* are the ends of a rigid rod moving in uniform rectilinear translation at speed v relative to our frame of reference and in the direction of *AB*. An observer, moving with the rod, measures time using clocks at rest in our frame of reference, which are identical, perfectly synchronized and distributed along the entire trajectory of the bar. Observing the back and forth movement of the light beam between points *A* and *B*, the observer will note :

$$t_B - t_A = \overline{AB}/(c-v)$$

and

$$t'_A - t_B = \overline{AB}/(c+v)$$

[19] Bachelard, G., *La valeur inductive de la relativité*, op. cit.

[20] This postulate began to appear at the beginning of the 20th century following the Michelson-Morley experiment (Michelson, A.A.; Morley, E. W., *On the relative motion of the Earth and the luminiferous ether*, « American Journal of Science », vol. s3-34, no 203, November 1, 1887, p. 333-345.

[21] Einstein, A., *Zur Elektrodynamik bewegter Körper*, « Annalen der Physik », vol. 322, n° 10, september 26, 1905, pp. 891-92.

where *c* is the speed of light. As Einstein put it, «*we must not attribute an absolute meaning to the notion of simultaneity, and two events which are simultaneous seen from a certain reference frame, can no longer be considered as simultaneous events, seen from a system in motion with respect to this frame of reference*»[22]. So, if two observers are in motion relative to each other, they will not date the events they witness at the same time. There isn't just one time for the whole universe, but an infinite number, attached to an infinite number of different frames of reference. Consequently, two events that are simultaneous in one frame of reference will generally not be so in another.

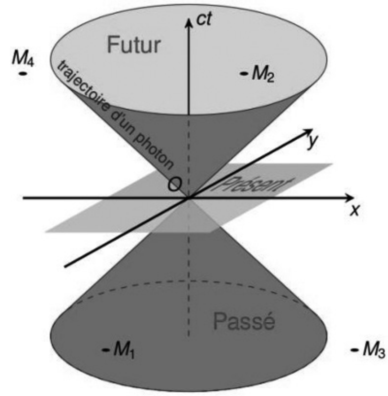

Figure 1: Example of a Minkowski diagram. Only 2 of the 3 dimensions of space (*Ox* and *Oy* directions) are represented to allow the time axis to be represented vertically. For reasons of dimensional homogeneity, the time *t* has been multiplied by the speed of light *c*..

This conception of time, although repeatedly verified by experiments using atomic clocks, has nothing to do with our experience of time. It seems legitimate to ask what's happening right now in another part of the world, or even in another part of the universe, in the Andromeda galaxy, for example. Yet, contrary to all expectations, such a question does not necessarily admit of a single, precise answer. It depends not only on the relative speeds of our two galaxies, but also on completely arbitrary conventions. To illustrate this point, let's look at a representation of relativistic space-time devised by mathematician and theoretical physicist Hermann Minkowski[23] following Einstein's publication on special relativity[24]. Figure 1 shows such a diagram, in which space has been restricted to *x* (transverse horizontal axis) and *y* (longitudinal horizontal axis) dimensions. The *z* dimension has been omitted to show the time axis, noted *ct* (vertical axis), where *c*, the celerity of light, gives this time dimension a magnitude equivalent to a distance, as for the *x* and *y* dimensions. This type of diagram, commonly referred to as a light cone, has the particularity of explicitly representing the past (bottom), the present (the grey hypersurface, which in this case is a surface since we've removed the *Oz* axis) and the future (top). It can also be used to represent the trajectories of all light beams passing through *O* at time *t=0*: this is the cone shown in blue in Fig. 1. Since a photon travels at the speed of light, it covers a distance *d=ct*, which corresponds to the equation for the surface of the cone. Since no massive body can reach the speed of light, the trajectory of

[22] *Ibidem*, p. 897.

[23] Minkowski, H., *Die Grundgleichungen für die elektromagnetischen Vorgänge in bewegten Körpern*, « Nachrichten der k. Gesellschaft der Wissenschaft zu Göttingen », mathematisch-physikalische Klasse, 1908.

[24] Einstein, A., *ibidem*.

any massive body passing through point *O* at *t=0* can only lie inside the cone of light. On the other hand, all points outside the cone of light correspond to the position of bodies that will not pass through *O*, if they are in the past (e.g. M_3), or that have not passed through *O*, if they are in the future (e.g. M_4). Since nothing moves faster than the speed of light, not even the interactions of the 4 forces of physics (gravitational, electromagnetic, weak interaction, strong interaction), points outside the light cone can't have had any causal influence on *O* if they're in the past, or can't have been causally influenced by *O* if they're in the future. On the other hand, points in *O*'s past light cone (e.g. M_1) may have causally influenced *O*, and points in *O*'s future light cone (e.g. M_2) may have been causally influenced by *O*. The advantage of using this type of diagram lies mainly in the study of causal relationships between events. To simplify the problem, we'll consider only one dimension of space, which we'll denote *x*, and the dimension of time *ct*. Let's imagine we're stationary at point *O* at time *t=0* (see Figure 2). Since we're not moving in the *x* direction, our trajectory in Minkowski spacetime will follow the *ct* direction. We'll be «carried away» by time along the vertical axis. The other axis, following the *x*-direction, corresponds to all points that are also at *t=0*, in other words, our present (in reality, a 3D hyperplane in 4-dimensional space-time). Now let's imagine a passer-by moving at constant speed from left to right, crossing us at time *t=0* (the red line labeled *ct*' in Figure 2). The trajectory of the passer-by who crosses us at *O* is called his universe line. The other line (the red straight line labeled x' in Figure 2, which in reality is also a 3D hypersurface in 4-dimensional space-time)[25] contains all the points simultaneous with the passer-by at a given instant. Now imagine a passer-by moving at constant speed from left to right, crossing us at time *t=0* (red line labeled *ct'* on figure 2). The trajectory of the passer-by who crosses us at *O* is called his universe line. The other line (the red straight line labeled *x'* in Figure 2, which in reality is also a 3D hypersurface in 4-dimensional space-time) contains all the points simultaneous with the passer-by at a given instant. So, in our 2-dimensional space-time, the hypersurfaces of the present are reduced to two straight lines, one horizontal for our own present, the other inclined for that of the passer-by. This representation of the world shows that one person's present is not another's present, and that the separation between past and

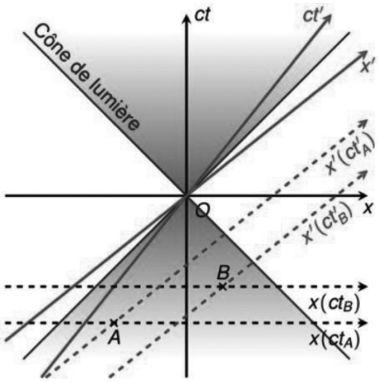

Figure 2: Minkowsky diagram reduced to one dimension of space and one dimension of time.

[25] This hyperplane of simultaneity, which appears naturally when using the formulae for changing reference frames known as the Lorentz equations, is the result of an implicit choice made by Einstein. Although this choice is by far the most convenient, other conventions exist in special relativity. Nevertheless, this does not change the reasoning below.

future is not as universal as we think! Indeed, the chronological order of events may not be the same in two different frames of reference (like events *A* and *B* in figure 2, where $t_B > t_A$ but $t'_B < t'_A$).

How, then, can we continue to adhere to the presentism that considers that only the present is, that the past is no more, and that the future is not yet? This is a crucial question, since it is precisely this conception of the world that underpins our behavior. If the past has created the present, and the present conditions the future, then we are comforted in our habit of choosing the actions we need to take in order to prepare the future that seems best to us. On the other hand, the illusory nature of the present and of the distinction between past and future forces us to seriously consider the opposite thesis to presentism, *eternalism*, a doctrine according to which 4D space-time would be frozen in a «block universe», where each frame of reference would only generate a contingent orientation of the axis of time and therefore of the hypersurface of the present. In this case, not only would the past-present-future sequence be an illusion, a kind of perspective effect[26], but so would our free will! As early as the beginning of the 20th century, the English philosopher McTaggart questioned the veracity of the passage of time[27], just three years after the publication of Einstein's seminal article on special relativity[28]. Yet this article does not appear to have had any direct influence on McTaggart's thinking. Nevertheless, the controversy over the metaphysics of time provoked by Einstein's article provided the context. Indeed, using completely different arguments, McTaggart also concluded that time was unreal. These two concurrent approaches not only collide head-on with our intimate conception of time, but also run counter to well-established principles in physics such as causality and the arrow of time induced by the concept of entropy in thermodynamics. If time has no real existence, how could it have any sense of flow!

Causality, as Bouton[29] has shown, is not, however, opposed to relativity, at least not in its restricted sense. Indeed, as we showed above, it is perfectly possible to observe chronological inversions between two particular events *A* and *B* by changing the frame of reference from which they are observed; this is, moreover, the main justification for the block universe. On the other hand, we can demonstrate that the situation is quite different when we consider causally linked events in the context of special relativity. To do this, we first need to introduce the relational operator «*is prior to*» symbolized by $\prec$. Thus $A \prec B$ means that event *A* is prior to event *B* in the causal sense, i.e. that *A* could (the conditional is important) be the cause of *B*. As a corollary, it follows that *B* must be within the cone of light of *A*, otherwise the influence of *A* on *B* would have to propagate at a speed greater than that of light, which is forbidden by the theory of relativity. The novelty lies

[26] Vigoureux, J.M., *L'univers en perspective*, Paris, Ellipses, 2006.
[27] McTaggart, J.M.E., *The Unreality of Time*, “Mind”, vol. 17, pp. 457-73, 1908.
[28] A. Einstein, *ibid*.
[29] C. Bouton, *Le futur est-il déjà présent ?* in Bouton, C., Huneman, P., *Temps de la nature, nature du temps. Études philosophiques sur le temps dans les sciences naturelles*, Paris, CNRS éditions, 2018, p. 115-148.

in the impossibility of finding a frame of reference for which $B \prec A$, or even $A \nprec B$, if there is a reference frame for which $A \prec B$. Causality is therefore conserved in special relativity. The problem becomes more complicated in general relativity but, although certain exotic topologies could theoretically lead to causality inversions, their realistic nature remains under debate. In any case, no violation of causality has yet been observed.

Causality therefore remains a valid principle as long as it has not been contradicted! Consequently, even if it is favored by a number of physicists, including Einstein, who wrote shortly before his death: «*Pour nous, physiciens dans l'âme, la distinction entre passé, présent et futur ne garde que la valeur d'une illusion, si tenace soit-elle* [*For us physicists at heart, the distinction between past, present and future is no more than an illusion, however tenacious it may be*]»[30], the block universe is still not inevitable and there is still room for free will.

4. Do scientists make time?

The present of a frame of reference could well be one hypersurface of space-time among others, thus casting doubt on the physical reality of one of the meanings of what we are used to thinking of as time, but the fact remains that the physical quantity that we measure with our clocks and that we also call, perhaps by misuse of language, time, is the quantity measured with the greatest precision[31] and by far the greatest. But what exactly are we measuring? As Bachelard showed with his concept of phenomenotechnique, theory and experience are closely intertwined. So, what does an atomic clock measure? According to Einstein, time is what a clock measures[32]. But if we define a clock as the instrument that measures time, we are faced with two circular definitions, and we are no further ahead either on the nature of time or on what a clock measures! However, physicists are realistic enough to regard the measurement given by clocks as the best approximation to the «true time of physics» which, locally, would be unique in the frame of reference under consideration, continuous and flowing in a perfectly regular manner. However, physicists are aware of the contradictions between these properties. Everything would be fine in an empty universe governed by special relativity, but our real world is material, so we have to use general relativity and add the term «locally» to all the properties set out above. This adverb considerably reduces the idea of true time! In the age of optical clocks, it is possible to detect differences in the passage of time between two clocks whose altitude differs by just ten centimetres or so. The global reference

[30] Einstein, A., *Lettre à la famille de Michele Besso* (1955), in Einstein, A., *Œuvres choisies*, t. 5, Seuil, 1991, p. 119.

[31] Time metrologists are wary of using the term 'precision', which they consider to be too… imprecise! They prefer better-defined concepts such as*accuracy* and *stability* (see BIPM et al, The international vocabulary of metrology – VIM,3rd edn, 2012, http://www.bipm.org/vim).

[32] Einstein, A., *Zur Elektrodynamik bewegter Körper*, « Annalen der Physik », vol. 322, n° 10, September, 26, 1905, p. 893.

time scale established by the Bureau International des Poids et Mesures (BIPM), which is still referred to as «universal» (UTC: Coordinated *Universal* Time), is therefore valid only on a surface surrounding the Earth whose gravitational potential is constant and whose altitude is arbitrarily chosen to be 0. This reference surface corresponds to what is commonly known as sea level. Any difference in altitude in relation to this reference must be known to at least 1 cm. The 450 atomic clocks involved in calculating UTC must therefore send their precise altitude in addition to the local time they indicate. The BIPM then corrects the local time of each of these clocks to bring it down to the level of altitude 0 and takes a weighted average to form UTC[33].

Each month, the BIPM publishes «Circular T», which gives the difference in 5-day steps between the time given by each of the clocks and UTC for the past month (see https://www.bipm.org/fr/time-ftp/circular-t). So, although it is totally compatible with general relativity, the official definition of time is based on several assertions whose arbitrary nature we tend to forget, such as: time is the quantity measured by atomic clocks or the flow of time is perfectly continuous.

However, we are not sure of any of these alleged properties. In fact, the time seen by certain micro-physicists, in particular the time of loop quantum gravitation, has nothing to do with this idealized time, just as space does not. It is neither unique, regular nor continuous. There is even talk of «spin foam»[34] which, with the addition of the causality ingredient, could lead to «space-time foam»[35]. There is undoubtedly as much of a gap between so-called continuous time and this foam of time as there is between the notion of particles imagined as little marbles at the end of the nineteenth century and the wave function model in their quantum conception. Finally, quantum cosmology also imposes a «Planck time»:

$$t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5 \cdot 10^{-44}\ \mathrm{s}$$

where $\hbar$ represents the reduced Planck constant, G the constant of universal gravitation and c the speed of light.

According to some authors, this t_P could constitute the quantum of time. We would then be in a stroboscopic world in which each discrete time step would run out t_P after t_P. The vision of the physicists interpolating the time of the clocks to make a perfectly continuous time could thus well appear naive even if we are not ready to approach time intervals of the order of 10^{-43} s; we are, in the best of the

[33] The calculation of UTC is a little more complicated: the mean time of these clocks is called the Échelle Atomique Libre (EAL); EAL is then corrected using frequency standards so that the flow of time conforms to the definition of the second: this is International Atomic Time (TAI); UTC corresponds to TAI increased periodically by leap seconds so that it does not deviate from the time given by the rotation of the earth (UT: Universal Time) by more than 0.9 seconds. A full explanation can be found on the BIPM website: https://www.bipm.org/documents/20126/59466374/6_establishment_TAR20.pdf/.

[34] Rovelli, C., *Et si le temps n'existait pas?*, Dunod, 2012, p. 128.

[35] Lachièze-Rey, M., *ibidem*, p. 377.

cases at the atosecond (10^{-18} s), that is to say a gap of a factor 10^{25} to fill: as much as between an atosecond and a century!

To come back to UTC, it is indeed an idealisation of time in the Platonic sense of the term. Yet it is this idealized time that society implicitly adopts, and which is considered by all to be the indisputable reference for time. It is the scientific time par excellence, whose veracity seems above suspicion. Have we, the metrologists of time, not become the manufacturers of time? With our atomic clocks, are we perhaps manufacturing a time that the whole of humanity adopts, even if it does not conform to reality? This is an important question when we consider the role that time measurement has taken on in society, whether explicit (telecommunications, transport, finance, energy, etc.) or implicit (positioning, space, etc.). Are we responsible for all the excesses that would have been impossible without such a mastery of time: high-frequency trading, 'surgical' missile strikes, etc.?

So, what about time: is it a quantity that exists by itself and that we can, at best, only measure, as the realist physicist thinks, who considers UTC to be the best approximation of real time? Or is UTC, which is a pure creation of metrologists, only valid among metrologists, in accordance with a certain relativistic approach (in the epistemological sense and not the Einsteinian sense). What if, rather than deciding between these two extreme positions, we turned instead to Bachelard's phenomenotechnique?

In a Bachelardian context, the question could then be rephrased as follows: can time be the subject of Bachelardian phenomenotechnique? If the answer is 'yes', then we have a false dilemma, because scientific phenomena are provoked by experience, by a technique of realization[36]: «*La phénoménotechnique étend la phénoménologie. Un concept est devenu scientifique dans la mesure où il est devenu technique, où il est accompagné d'une technique de réalisation* [*Phenomenotechnique extends phenomenology. A concept has become scientific insofar as it has become technical, insofar as it is accompanied by a technique of realization*]»[37]. At the same time, these same scientific phenomena have a noumenic dimension, a mathematical structure derived from the mind of the experimenter: «*Le microscope est un prolongement de l'esprit plutôt que de l'œil* [*The microscope is an extension of the mind rather than of the eye*]»[38]. So, it wouldn't be «to know *or* to make time», but «to know *and* to make time», so there's no dilemma. But is the answer really 'yes'? Is time really phenomenotechnical? We're not going to decide. In a way, that is the subject of the third part of this book, and it would be presumptuous to try to short-circuit it with a simple 'yes' or 'no'. At best, this question can serve as a useful thread for the reader as he or she examines the various contributions that follow, in the hope that by the end he or she will have a slightly deeper and more diversified insight into this problematic, if not necessarily a clearer one for all that.

[36] This contribution is inspired, in part, by: Juliette Grange. *L'invention technique et théorique : la philosophie des sciences de G. Bachelard. Imaginaire, Industrie et innovation*, Pierre Musso; Centre culturel de Cerisy, Sep 2015, Cerisy-la-Salle, France. pp.90. halshs-01336345.

[37] Bachelard, G., *La Formation de l'esprit scientifique*, 1ère éd. 1934a, Vrin, 1967, p. 61.

[38] *Ibidem*, p. 242.

To guide us, the Bachelardian dialectic between the noumenon, the mathematical theory, and the experimental phenomenon, can shed light on our understanding of time. The scientific phenomenon arises from the dialectic between the mind and the technique of realization:

> *Cette liaison si forte, si indispensable de la théorie à la technique nous paraît devoir s'énoncer comme un déterminisme humain très spécial, comme un déterminisme épistémologique qui n'était guère sensible il y a quelques siècles dans la séparation des cultures mathématiques et expérimentales.*
>
> [*It seems to us that this strong, indispensable link between theory and technique should be expressed as a very special human determinism, as an epistemological determinism that was hardly perceptible a few centuries ago in the separation of mathematical and experimental cultures*][39].

The experimenter does not simply observe the facts, he conditions them by his approach. Guided by theoretical and abstract concepts, they invent experiments and build instruments that contribute to the emergence of scientific phenomena. This is what enables us to structure the world: «Le véritable ordre de la Nature c'est l'ordre que nous mettons techniquement dans la Nature [The true order of Nature is the order that we technically put into Nature]»[40].Not just in the scientific laboratory, but far beyond that, in nature itself. And in doing so, it is the experimenter himself who renews himself: «*L'expérimentation nouménale dans le laboratoire se poursuit à grande échelle et à ciel ouvert. Ce dépassement de la Nature est aussi mutation de l'homme* [*Noumenal experimentation in the laboratory continues on a large scale and in the open air. This surpassing of Nature is also the mutation of man*]»[41]. Let's apply this thought to a particular example: Einstein tells us at the beginning of his 1905 paper «It seems possible that all the difficulties concerning the definition of 'time' could be overcome by replacing 'time' by 'the position of the little hand of my watch»[42]. He goes on to point out that while such a definition is sufficient as long as we are interested in events that take place only at the place where my watch is, it is no longer sufficient when we need to link together distant events, i.e. in most practical cases, such as the statement: «*a kilonova was observed by the VISTA telescope at Cerro Paranal (Chile) and a gravitational wave signal at the Virgo detector (Pisa) at the same time*». So, what does 'at the same time' mean in this case? For such cases, Einstein developed a mathematical and physical construction that operationally defined simultaneity and therefore synchronisation of distant clocks. He thus defines a 'time' beyond my watch[43]. Note that Einstein's definition is not unique to relativity; other definitions exist and are commonly used, for example for the time scales we use every

[39] Bachelard, G., *L'Activité rationaliste de la physique contemporaine*, PUF, 1951, p. 223.

[40] Bachelard, G., *La Formation de l'esprit scientifique*, 1ère éd. 1934a, Vrin, 1967, p. 111.

[41] Bachelard, G., *L'Engagement rationaliste*, PUF, 1972, p. 148.

[42] Einstein A., *Zur Elektrodynamik bewegter Körper*, « Annalen der Physik », 17, 1905, p. 893.

[43] We therefore have two definitions of time, a local one, given by my watch (today it is called proper time) and a non-local one that Einstein called «the time of stationary systems», today often equated with coordinated time.

day, such as Coordinated Universal Time (UTC). But let's attempt a phenomenotechnical analysis of Einstein's 'time'. First, we note the emergence of this time from a technological instrument constructed by the experimenter ('my watch', from the pendulum to the atomic clock). But to this we must add the theory, the mind of the experimenter (Einstein in this case[44]) who builds a whole mathematical and operational construction to end up with a satisfactory 'time'. These two aspects are perfectly in line with Bachelard's phenomenotechnical thinking. It therefore seems clear that time in special relativity is fully subject to Bachelardian phenomenotechnique. But is it? That clear? Does time only exist thanks to, and because of, our measuring instruments? Has time only «become scientific insofar as it has become technical, insofar as it is accompanied by a technique of realization»[45]? Einstein would probably be the first to take exception to such a conclusion. Let's not forget that it was special relativity that unified time and space into a whole that can be seen as an immutable and deterministic geometric whole, the «block universe», which is a long way from Bachelard's conception of scientific phenomena whose very existence is subject to experimentation: «La science est moins une science des faits que d'effets [Science is less a science of facts than of effects]»[46]. On the other hand, time (along with space) would be a matrix on which Bachelardian effects unfold, because the very notion of «effect» presupposes a time (and a place) in which it occurs! This little example shows that there is no obvious answer to the opening question «Can time be the subject of Bachelardian phenomenotechnique?» and the associated dilemma of whether or not it is true. But it is useful, in our opinion, to keep this question in mind as a grid for reading the rest of this book.

Conclusion

Rereading Bachelard can help us answer these questions. The third period of Bachelardian philosophy unfolds between 1949 and 1953. *Rationalisme appliqué* (1949), l'*Activité rationaliste de la physique contemporaine* (1951) and *Matérialisme rationnel* (1953) capture the dialectic of science as it operates in its epistemology and history in a dispersed way according to the regions of knowledge. Bachelard identifies a dual movement of applied rationalism and rational materialism, which constitute the two aspects of a single scientific dialectic – epistemological and historical – capable of bringing about a historical synthesis between what had previously seemed contradictory. In 1951, Bachelard gave a lecture on *L'actualité de l'histoire des sciences*[47] to emphasize the positive effect

[44] A little joke. Einstein only did thought experiments (Gedankenexperiment). Is that enough for a Bachelardian analysis? That's another interesting subject, but we won't go into it here.

[45] Bachelard, G., *La Formation de l'esprit scientifique*, 1ère éd. 1934a, Vrin, 1967, p. 61.

[46] Bachelard, G., *Noumène et microphysique*, « Études », p. 11-24 also in Recherches philosophiques,1931, p. 551-565.

[47] Bachelard, G., *L'actualité de l'histoire des sciences*, in *L'engagement rationaliste*, Paris, PUF, 1972, p. 136-150.

of science on our minds: in the truest sense of the word, science makes us think. The task of the philosophy of science is to make explicit this active thinking at the heart of scientific activity. To do this, it has to reread the historical path taken by knowledge in order to grasp the scientific gesture of negating the past and establishing new operational knowledge. This process continues unabated and invites us to return to Bachelard's own project by including Bachelardian philosophy as a moment in time. To judge the past properly, we need to go beyond it and get to know the present. To read Bachelard properly, we cannot be satisfied with an internalist reading of his work but must put it to the test of his future, which is also our present context. In other words, posing the question of Bachelard's actuality in the light of contemporary scientific developments does not mean criticising Bachelard anachronistically, but testing the matrix relevance of his analyses and concepts against the yardstick of contemporary science. To judge the past properly, including Bachelard, you need to know the present[48]. In 2001, Pariente reminded us that, «La seule façon d'être fidèle à Bachelard (1884-1962) serait de prolonger son geste en se mettant à la hauteur des derniers développements et des dernières interrogations de la connaissance [The only way to be faithful to Bachelard (1884-1962) would be to continue his work by keeping up with the latest developments and questions in knowledge]»[49]. Science does not go backwards: on the contrary, its apparent ruptures reinforce its profound continuity. «L'historien des sciences, tout en cheminant le long d'un passé obscur, doit aider les esprits à prendre conscience de la valeur profondément humaine de la science d'aujourd'hui [The historian of science, while following the path of an obscure past, must help people to become aware of the profoundly human value of today's science]»[50]. History sheds recurrent light[51] in the sense that it teaches us to spot the recurring series that organize the history of rationalism, understood as a function that brings our minds into relation with reality[52]. It judges when it knows: it normalizes[53], insofar as it necessarily embeds judgements, norms and values. This process transforms the truth of one moment into a particular case of a more general theory; history constantly rectifies its past to make it our present. This double gesture of expiry and sanction expresses our actuality, in the sense of an evolution of our scientific spirit, which is nothing other than the «epistemological act» of «currently active science»[54]. Each new stage makes it possible to encompass the recent past in a more global

[48] Ivi, p. 140.

[49] Pariente, J.C., *Le Vocabulaire de Bachelard*, Paris, Ellipses, 2001, p. 3.

[50] Bachelard, G., *L'actualité de l'histoire des sciences*, « Revue du palais de la Découverte », 18/173 (1951), p. 150.

[51] Bachelard, G., *L'actualité de l'histoire des sciences*, « Revue du palais de la Découverte », 18/173 (1951), p. 141.

[52] Canguilhem stressed the need to make good use of recurrence, G. Canguilhem, *Idéologie et Rationalité dans l'histoire des sciences de la vie*, « Etudes d'histoire et de philosophie des sciences », p.24.

[53] Bachelard, G., *Le Rationalisme appliqué*, Paris, Puf, 1949, p. 59.

[54] Bachelard, G., *L'Activité rationaliste de la physique contemporaine*, Paris, Puf, 1951, p. 25.

logic, and to situate the distant past more clearly according to its unforeseeable advent. This historical movement thus undermines any claim to a definitive history and imposes «a need to remake the history of science, an effort to understand by modernizing»[55].

This need is even more urgent in that the history of science is also our history. «Tout va de pair, les concepts et la conceptualisation (…), on peut assurer que la pensée se modifie dans sa forme si elle se modifie dans son objet [Everything goes hand in hand, concepts and conceptualisation (…), we can be sure that thought changes its form if it changes its object]»[56]. Our ontology is at stake in our epistemological and technical future. By tracing the path that leads to our present, the historian enables us to understand ourselves and our society. The history of science is not only the history of culture[57], but also the history of the scientific spirit, our history: «l'histoire des sciences est devenue l'histoire d'une cité scientifique. La cité scientifique, dans la période contemporaine, a une cohérence rationnelle et technique qui écarte tout retour en arrière [the history of science has become the history of a scientific city. In the contemporary period, the scientific city has a rational and technical coherence that precludes any turning back]»[58]. Science proves to be a «power of transformation»[59]; it organizes our concrete form of life and gives rise to a culture as a moment of what we are.

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[55] Ivi, p. 145.

[56] Bachelard, G., *Le nouvel esprit scientifique* [1934] 1968, Paris, PUF, p. 44.

[57] Bachelard, G., *Le rationalisme appliqué* [1949], Paris, PUF, 1966, p. 38

[58] Bachelard, G., *L'actualité de l'histoire des sciences*, in « L'engagement rationaliste », Paris, PUF, 1972, p. 150.

[59] Bachelard, G., *De la nature du rationalisme*, in *L'engagement rationaliste*, Paris, PUF, 1972, p. 45.

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