NOTES AND DISCUSSION

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PROBLEMS OF PHYSICAL TIME

H. REICHENBACH, *The Direction of Time*, posthumously edited by Maria Reichenbach, Berkeley, Calif., 1956 (hereafter designated as D.T.).
G. J. WHITROW, *The Natural Philosophy of Time*, London, Nelson, 1961 (N.P.T.).
O. COSTA DE BEAUREGARD, *La notion de temps*, Paris, Hermann, 1963 (N.T.).
O. COSTA DE BEAUREGARD, *Le second principe de la science du temps*, Paris, Seuil, 1963 (S.P.).
A. GRÜNBAUM, *Philosophical Problems of Space and Time*, New York, A. Knopf, 1963 (P.S.T.).
F. GONSETH, *Le problème du temps*, Neuchâtel, Griffon, 1965 (P.T.).

It is possible to propose purely empirical and extrinsic criteria to distinguish a *philosophic* question from other kinds: it interests and stimulates research and discussion, and it is susceptible to a purely rational approach, although there may not be any solution which will receive a unanimous *consensus* *.

Translated by Martin Faigel.

* All English language quotations have been retranslated from the French.

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If these criteria are acceptable, there is no doubt that the problems of physical Time are philosophical in nature. The works which the present paper will discuss were written in the last ten years, either by scientists or by philosophers particularly concerned with the laws of positivist science. Their confrontation shows that on some points there can be unanimous accord, but it also shows that on other issues there persist either irreducible misunderstandings or impenetrable obscurities. For the rest, each author brings into the discussion the themes, the postulates, and the preferences which are peculiar to him. In each one the thematic structure is complicated, and the preferences are not organized among them in the same way. Thus, Costa de Beauregard does not hide his spiritualist mental reservations; the same thing can be found in Whitrow. On the other hand, Reichenbach is a positivist, and with Grünbaum the positivism bends clearly in the direction of materialism. But if we compare the opinions of each author as to the degree of reality which one should allow to the *future,* to the temporality of things, we see that they line up differently. Whitrow affirms with vigor the originality and irreducibility of the future, and Costa de Beauregard uses just as much energy to demonstrate its illusory character. Inversely, Grünbaum criticizes Reichenbach for conceding too much to the thesis of the real future, in relating quantitative indeterminism to it.

The work of Gonseth, as much by intention as by the nature of the question under investigation, differs noticeably from that of the others. He deals mainly with the *measurement* of Time as an ideal example for showing the principles of the methodology of measure in contemporary science. That is to say, the ontology of physical Times is not directly treated in his book, and Gonseth, a particularly scrupulous philosopher, abstains from any conclusions which go beyond the boundaries he has fixed for his research. Within these limits, however, his conclusions are clear and philosophically well-defined. He holds that the methodology of measure is self-derived; it is from its own procedures that it derives its norms and it is acquired certainties which permit it to undertake the experiences which will lead to their renunciation in favor of more precise certainties. Thus, the progress of the techniques of measure is strengthened from its own motion, relying not only on experience but on the experiencing of experience. Self-derived, the methodology of measure has to be *open*, that is to say, ready to welcome the new experience and to accept its effect in turn on the principles which have made it possible. Thus, chronometry frees itself from any *a priori* operational principle which would confer, by an arbitrary decision, the privilege of an intangible norm for the measurements taken by a given instrument. In brief, Gonseth is an empiricist of consequences, trying to establish by experience that experience can be its own principle and its own judge.

Since the author of the present paper is no more exempt from prejudices and preferences than the philosophers who are about to be discussed, without doubt it is well for him to make his position explicit here to the degree that he himself is aware of it. As for general philosophical positions, he willingly puts himself on the side of Reichenbach, whose positivism is open enough to avoid the habitual simplifications of materialist ontology. For the problem of Time, he is unreservedly with whitrow in the affirmation of the future as a first, unconditional principle of physical existence. And he sees nothing to object to in the methodological empiricism of Gonseth.

Each of these works in fact deals with many questions which cannot be lined up, one against the other, for easy comparison. They are all based on detailed lines of argument, and they contain discussions which are too dense and on points too difficult to allow for easy resumé. One can do no more than sort out their common areas of interest and of controversy. We shall deal with the following: the order of Time and the causal theory of Time; the direction of Time and the problem of physical irreversibility; Time and Space-Time; Time in microphysics; Time and information; the measuring of Time.

THE ORDER AND DIRECTION OF TIME: THE CAUSAL THEORY

Reichenbach engages in a subtle analysis to introduce a distinction worth our interest between the *order* and the *direction* of Time. If we draw a straight line on a piece of paper and mark three points *A*, *B*, *C*, the *B* is to the right of *A*. (Cf. figure 1). This relationship ("to be to the right of") is evidently *irreflex-*

ive (A is not to the right of A), and *assymmetrical* (if B is to the right of A, then A is not to the right of B). It is also *transitive* (if B is to the right of A and C is to the right of B, then C is to the right of A). This is what logicians call a relationship of order. But if the line we have drawn has an *order,* it nonetheless does not have a *direction*, in the sense that if we look at the line in reverse through the paper or in a mirror, we see A to the right of B instead of B to the right of A. Two points whatsoever, X and Y, being chosen, they have an order when one decides, for example, that Y is to the right of X, but this preliminary decision is in itself arbitrary.

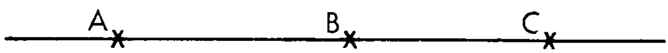

Figure 1

On the contrary let us take a series of whole numbers. The relationship "to be smaller than" defines an order in this series, but it also has a direction. No mirror in the world can make me say that 7 is less than 3, and writing the series from left to right or from right to left does not change the fact that 14 is smaller than 18. The thesis of Reichenbach is this: natural Time has an *order* as well as a *direction*, but the distinction between one and the other must be made explicitly, because the order of Time and its direction are considered in different ways in the development of the physical sciences and in a certain sense are on two separate levels. Out of this opens an idea which seems to a certain extent—on the condition that one does not try to situate it too precisely in an ontological context—to put all our authors into agreement: that the laws of structure, the causal laws which direct elementary phenomena and form the conceptual and symbolic armature of the physical sciences evidence the existence of an order of Time, but that the assigning of the direction of Time supposes the consideration of a state of fact independent of these laws.

The distinction between *order* and *direction* of Time is introduced by Reichenbach in connection with the *causal theory of Time* to which, all during his career, he dedicated an impor-

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tant part of his work. Historically, the causal theory of Time, whose origin goes back to Hume, is born from the attempt to establish a concept of causality which bases itself on experience, at the same time separating it from its traditional theological and metaphysical implications. Thus, with Hume and in a different way with Kant, it had the sense of a reduction of the causal order to the succession of phenomena, emptied of metaphysical content. On the other hand, it now signifies the reduction of the temporal order to the causal order, conceived this time as a functional relationship empirically verifiable and mathematically expressable. Its goal is to deny any support to the Newtonian idea of empty and absolute Time. It is thus postivist and relativist in the sense of the physical sciences.

In fact it is the success of a limited theory of relativity which is its direct origin. For the theory of relativity denies that any objective temporal order can be defined between two *points-events* (two events situated in two points in space) if no physical action, no signal connects them.

Nevertheless, despite this recommendation from relativity, the causal theory of Time—which essentially says that the cause comes before the effect, *by definition of the word "before"*—is difficult to formulate rigorously (Grünbaum does not completely accept the formulation given by Reichenbach), and its real importance can be contested, as Whitrow has done. What is in question to begin with is the very notion of causality. The causal theory of Time can be formulated in a satisfactory way only if one gives to the word causality or to the causal relationship a sense which differs somewhat from the semantic sense of the words "cause" and "effect." For example, one must admit, in the case of the spreading out of a wave, that the causal relationship is between two positions which are in immediate succession in advance of the wave, and that it is not between, on the one hand, the mechanical or electrical oscillation which is the "cause" in the ordinary sense of the word, and, on the other hand, the totality of the wave which is its "effect." Thus, one must also include as a special case in the causal relationship simple "genidentity," that is to say, the relationship between the successive states of the "same" physical object (the word being chosen to identify this relationship of simple logical identity, for to

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confuse genidentity and identity is to accept implicitly Leibnitzian postulates on te monad). In the sense of the causal theory of Time, to continue to exist is thus a *causal* process.

In brief, the causal theory of Time achieves its goal of logically reducing temporal order to causal order only by noticeably enlarging the notion of causality. Does it succeed, even at this price? Whitrow does not think so, feeling that in temporality there is something final, irreductible. Suppose, he says, a wave which propagates itself instantaneously (like the lamp in Cartesian physics). The causal relation would remain but not the temporal one. Therefore, one cannot reduce the latter to the former. This argument, which recalls the famous "one has to wait until the sugar melts" of Bergson, is perhaps less decisive that it seems at first view. But it is equally difficult to invoke a decisive argument in favor of the causal theory. Reichenbach has imagined a very ingenious experiment. Thanks to it, an observer who had no preliminary knowledge of the direction of Time could temporally order a series of events using the causal relationships observed between them. Unfortunately, this subtle "method of marks" is based on an appeal to hidden principles, as has been shown independently, as well as following the lead of others, by both Grünbaum (P.S.T., p. 181) and Whitrow (N.P.T., p. 274).

What emerges in any case from these discussions, as has already been indicated, is that, in the present state of knowledge and despite the difficult-to-interpret results of certain recent nuclear experiments, the laws of interaction and of evolution of elementary phenomena concern the *order* of Time but cannot define its *direction*. One must turn to a process which is in fact irreversible if the causal order is to be directed. Consequently, in the analysis of the temporal properties of the physical world, it is legitimate to separate the questions which have to do with the order of Time from those which deal with its direction.

THE ORDER OF TIME—OPEN TIME AND CLOSED TIME—WHAT IS THE INSTANT?

The order of Time is linear. If one abstracts the property of direction which it obviously possesses, in any case at our level, and if one tries to define this order by reference to the most elementary causal relationship, the simple continuation of the existence of the "genidentical" particle, we have a certain amount of liberty, as Grünbaum has shown in detail. Independently of the very direction of Time, experience seems to impose the topology of Newtonian Time, infinite in two directions. But genidentity allows for two other possibilities, geometrically analogous to the straight line and the circle. Grünbaum constructs ingenious models of a simplified universe in which Time would be closed in one or the other of its directions: given a genidentical particle *P* which travels a circular path in a vacuum, the particle passes from *A* to *B* to *C*, then returns to *A*, and so on. It is clear that the event "first move of *P* from *A*" is indiscernable from the event "second move of *P* from *A*"—even if we add the particles necessary to mark the space—for they correspond to "physical" configurations which are in fact identical. It is necessary then to identify them; Time is closed. (Cf. figure 2).

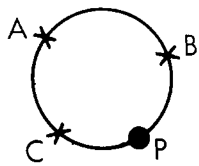

Figure 2

The other variant of closed Time is given by a model which is nearly as simple: in an empty universe where there is a uniform field of gravity, a simple pendulum oscillates indefinitely between two points *A* and *B*. The event "first passage of the pendulum from *A*" will also be indiscernable from the event "second passage from *A*." There also Time will be closed, but differing from the preceding example in that the nature of the movement makes an intrinsic distinction between two events poles apart, "passage of the pendulum from *A*" and "passage of the pendulum from *B*." (Cf. figure 3).

The characteristics of the topology of Time in these models is completely due to their nature and not only to their extreme simplicity, since Grünbaum constructs another model nearly as sim-

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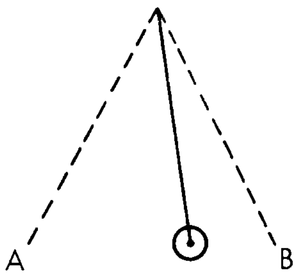

Figure 3

ple in which the "ordinary" topology of Time is causally based (in the large sense of the causal theory). In the same empty universe, with a uniform field of gravity, two pendulums oscillate periodically at the rate of 1 and $\sqrt{2}$, that is to say, incommensurably. Let us suppose that at some time they pass the vertical at the same instant. This coincidence has never happened before and will not happen again. It is an event discernable from all the others of the simplified universe. (Cf. figure 4). The instants of this universe, each one corresponding to a position relative to the two pendulums form a unit which can be translated into real numbers, on the condition that an origin and a direction have been arbitrarily chosen, for Time, open and closed, is not *directed,* with regard to the double pendulum.

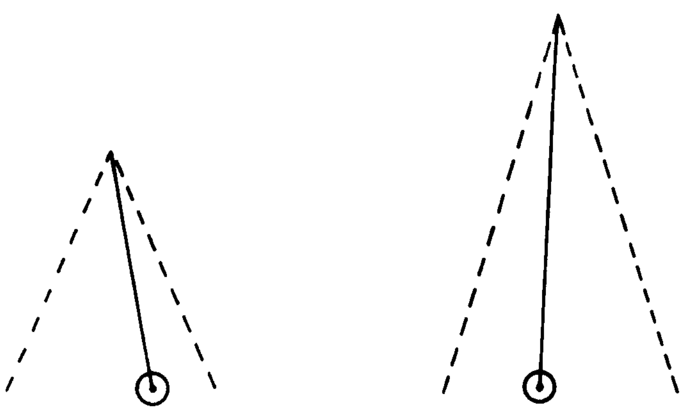

Figure 4

These analyses may seem gratuitous given the enormous distance which separates the models from the universe in which we live. Nonetheless, they have a double interest. To begin with, modern cosmology is much less removed from the idea of Time than the classic vision of the universe. The theory of general relativity allows for simple solutions of the cosmological problem which would take care of at least one of Grünbaum's variants of closed Time, that of the single pendulum. One of the founders of relativist cosmology, Friedman, had already noted this quite explicitly forty years ago. On the other hand, in Grünbaum's model of the double pendulum it is worth noting that it is *not the irreversibility* of the causal process which establishes the opening of Time, since the movement of the double pendulum is perfectly reversible. This is something which clearly should be taken into account in the discussion of problems specifically posed by the evident existence of local irreversibility in observed physical processes.

But before coming to that, we must first state that the simple problem of the order of Time, however abstract it may appear when isolated from other things, is in itself rich enough to permit very different approaches. Grünbaum is interested in the global topology of Time, but he does not question its continuity, associated for him with the relationship of the genidentity. On the other hand, Whitrow accepts the opening of Time without dispute, but he does not consider the continuity of instants evident because he does not take the instant as a first given, as an irreducible element of natural philosophy as it was for classical mechanics, which identified the ensemble of instants with that of real numbers.

Following Russell and Walker, Whitrow applies to the problem of the mathematical structure of Time a method derived from the "extensive abstraction" of Whitehead: the undefinables are not the instants but the "events" having a certain temporal density, and these events are connected by relationships of "precession" and "overlapping" whose axiomatic nature is made explicit. Whitrow shows how, starting from this position, one can construct the *continuum* of instants, with their traditional mathematical properties. He underlines that it is a question of a logical construction and he shows, in passing, that the initial axioms are not incompatible with the hypothesis of the *chronon*, of the indivisibility of Time, a hypothesis for which he shows a certain preference in various parts of is book (N.P.T., pp. 153-157). It is within this perspective that one finds the very interesting discussion which Whitrow gives of the paradoxes of Zeno of Elea, a discussion too lengthy and complicated to be summarized here. We shall only say that for Whitrow the paradoxes of Zeno leave a residue (at least the *Achilles*) if one thinks that they have been resolved by traditional mathematical means[1] brought to perfection by the theory of ensembles, for according to Whitrow what is at stake is exactly the identification of real instants with the elements of the cantorian continuum.

THE DIRECTION OF TIME AND THE PROBLEM OF PHYSICAL IRREVERSIBILITY

A most classic hypothesis links the direction of time to the evolution of the entropy of thermodynamic systems. In effect, according to the second law, in an isolated system the entropy can only be constant or increasing; there is no other fundamental physical quantity which shows such assymmetry with respect to Time. No less classic are the difficulties this hypothesis raises when confronted with the fact that the equations of dynamics are reversible with regard to Time, implying an *ordered* but not a *directed* Time. In effect, statistical mechanics gives a very satisfying mechanical explanation of thermodynamic phenomena, at least those which involve certain physical systems, notably gases. In that case one must infer a law of irreversibility (the second law) of elementary reversible laws (those of mechanics). Since Boltzmann we have known that these contrary factors can be made to match by means of the nearly always useful concept of *probability*. But this ingenious solution leaves a residue that, in one way or the other, here or there, reappears in the form of paradox.

Every isolated system in thermodynamic evolution defines a direction of Time locally, but when it reaches the state of equilibrium which establishes the maximum of its entropy, che "arrow

[1] Well before the invention of Calculus, Descartes had already refuted the *Achilles*, demonstrating that the series $10^{-1} + 10^{-2} + ... + 10^{-n} + ...$ is convergent and that sum is 1/9 (Letter to Clerselier, June or July 1646, *A.T.* IV, p. 442).

of Time" becomes obliterated; to rediscover it one must turn to the environment. Boltzmann has shown the ultimate consequences of this reasoning. If Time "flows" irreversibly, one must imagine the entropy of the universe, considered as an isolated system, as growing. But if one conceives of the universe according to the models of statistical mechanics, this state of growing entropy cannot be observed everywhere indefinitely; the entropy is a quantity limited from above (which amounts to saying that a probability cannot go beyond the value 1). Spread out over a long period, the entropic curve of an isolated system, irregular in detail, does not, however, present any dissymetry between the future and the past. But that does not agree with the hypothesis that *the* direction of Time, which one is logically inclined to consider as unique and universal (how else to connect, one to the other, two regions of the universe, two periods of its history in which *the directions* of Time are not congruent one to the other?), is associated with the growth of the entropy.

To resolve this enigma, Reichenbach—in without doubt the most original part of his book—proposes a hypothesis which agrees somewhat with what we have been able to learn of the distribution of energy in our cosmic environment. Instead of considering the universe from the point of view of thermodynamics as a unique system whose parts are continually in interaction, one must consider it as the juxtaposition of sub-systems ("branched systems") which at a certain moment of their past were in interaction with the total system but which are detached in order to continue to develop spontaneously (according to the second law) in a state of almost complete isolation. Unlike the curve of the entropy of the total system, that of the branched systems is not temporally symmetrical, the point of branching corresponding to an origin of low entropy. If one puts all the branched systems together, the direction of Time is defined there without equivocation by the variation of entropy (D.T., pp. 135-143). The hypothesis of Reichenbach is taken up by Grünbaum who refines it somewhat. Does he completely resolve the enigma?

For the ensemble of branched systems to play its part, it is necessary for the branching point to be situated on an ascending arc of the curve of universal entropy. And, if this is the case, taking into account the symmetry on a high level of this curve, the direction of time associated with the evolution of branched systems is still only a "local" circumstance of the cosmic ensemble. Furthermore, Reichenbach does not deny it, and Grünbaum concludes from this that it might be well to see if the direction of Time cannot be related to non-thermodynamic phenomena. This is the hypothesis that Popper had proposed on his part: a spherical wave spreading out in an infinite vacuum from an exact source is a non-entropic phenomenon but, nonetheless, it is unconditionally irreversible, since one cannot conceive that there might be reassembled on the sphere of the infinite radius the initial conditions of the converging wave which would come to concentrate themselves at the origin of the first one. One should note, however, that this reasoning is meaningful only with the hypothesis of a spatially infinite universe.

In effect, in a hyperspherical Riemannian universe, after it has diverged, the spherical wave will converge at the antipodes of its source, that is to say, eventually at its very source, in the topologically "elliptical" form of the hypersphere... always however with the condition that cosmic expansion is not rapid enough to prevent this reconcentration.[2]

Moreover, these brief remarks provide us with a new reason for accepting with some reservations the discussions of Reichenbach and Grünbaum, and, more generally, all analyses of the problem of the irreversibility of Time which do not take into account the present state of empirical and theoretical research into cosmology. All attempts to explain irreversibility thermodynamically—those of Boltzmann, of Reichenbach, of Grünbaum—are based on a "classic" model of the universe. In these discussions none of the most original aspects of the universe as it is viewed by contemporary cosmology is explicitly taken into consideration, either in what concerns its spatio-temporal form, or in what concerns its content. Now, if for example one states that the "dematerialization" of atoms of hydrogen, which are transformed in ra-

[2] In Riemannian space, the luminous rays which in ordinary geometric space are straight lines can be curves which intersect in more than one point. In the simple case of the hypersphere, all the "photons" leaving at a given instant from any point whatsoever will meet at the antipodes if the space is empty. Thus, on the surface of the earth, two travelers leaving the North Pole at the same time and moving along two different meridians at the same speed will meet at the South Pole, supposing that no psychological or material obstacle has intervened.

diating a part of their mass, is a fundamental cosmic phenomenon, it is easy to conclude that the irreversibility of physical time is located on some sort of level much more profound in the hierarchy of phenomena than the analogies with statistical mechanics suggest. For statistical mechanics, the models of the irreversible process are phenomena of diffusion which leave intact the genidentity of particles, a relationship which, as we have said, is temporally *ordered* but not *directed*. On the other hand, the fact that the geometric structure of the universe in present theories of cosmology connects space and time in such a way that the size of the space depends on the time certainly modifies the givens of the problem. The expansion of the universe defines a direction of cosmic evolution which, considered as a phenomenon of structure, is not necessarily irreversible, but whose agreement with irreversible physical phenomena, whether thermodynamic (dematerialization) or not (divergent spherical waves), poses all sorts of problems which cannot in all cases be treated by preterition.

It is impossible for us to go into detail about the always subtle analyses of our authors on a problem as slippery as an eel, and still more difficult to match the results with the present givens of cosmology. It seems, however, that there is one conclusion to which cosmology has nothing to object:

That the direction of Time, connected to the existence of irreversible physical processes, is a property of the things themselves and cannot be characterized as a simple illusion due to our way of perceiving phenomena, or as the result of the projection on the world of our intimate experience of the future. As Grünbaum has said, Spinoza was wrong when he wrote to Oldenburg that *tempus non est affectio rerum, sed merus modus cognoscendi.* This conclusion is all the clearer in that, from the principal difficulties which the translation of this temporal irreversibility into the scientific description of the world raises, it seems to be that the irreversibility is not expressible in laws, that it is not *nomological*, to use the expression of Mehlberg, that it is a characteristic *of fact* of the universe. Like the diversity of beings, the irreversibility of Time marks the limit at which the possibilities of the logical reduction of existence stop. So much so that in the attempt of the mind to imagine the world, two factors combine

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strongly to eliminate temporal irreversibility from the image which the reason creates: the emotional importance of Time which Reichenbach claims has blinded the greatest philosophers, and the spontaneous preference of logical thought for the intemporal and the reversible.

Must one search there, in a sort of turn-about of outraged logic, for the distinction which Grünbaum made between the *anisotropy*[3] of Time, which he clearly proves is real, and the *future*, whose name and idea he wished to banish completely (P.S.T., pp. 314-329)? For us, the future is nothing more than that which one calls the anisotropy of Time in the vocabulary of geometry. But for Grünbaum, while the anisotropy of Time is something objective, the *future* of beings, the "happening" of events does not mean anything other than the perception by someone of this event. Nonetheless, to take away from words like "becoming" or "happening" their objective significance, is to put oneself gratuitously in opposition to the intuitive semantics of these words. Grünbaum certainly uses "occurring" and "happening" properly. He knows that in "happening" there is a nuance of the unforeseen, of the pure event, which is not present in "occurring." On the other hand, "occurring" always suggests that someone knows about the thing in question, whether a series or a thing that one can expect. But the energetic denials of Grünbaum empty "happening" of its proper significance. Nevertheless, if the word has been formed and has established itself in English with this nuance, is this only the effect of an illusion? There certainly have been produced ("happened") innumerable explosions of supernovae in the universe which have never come ("occurred") to the notice of anyone. Contemporary science permits us to doubt that any one of them, with its exact circumstances, might have been foreseeable, even by the infinite mathematical intelligence which Laplace imagined. Shall we deny that these were *events*, in the

[3] "Isotropy" and "anisotropy" are words borrowed from optics by geometry. A transparent crystal is "anisotropic" when its index of refraction varies according to the direction of the beam of light which passes through it. By analogy, a space is called anisotropic if the directions are not freely interchangeable as they are in the space of ordinary geometry. In speaking of the anisotropy of Time, Grünbaum means that the direction past → future is not interchangeable with the direction future → past.

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strongest and simplest sense, the most ontological sense of the word? The author of these lines is for his part not disposed to concede this to Grünbaum.

TIME AND SPACE-TIME

One no longer needs to demonstrate the technical value of *Space-Time* as a process of figuration and as an expression of the terms and problems which the theory of relativity brings up.

On the other hand, the epistemological and ontological significance of this process poses delicate problems. One can consider, and this view seems to us the most reasonable, that the Minkowskian geometric structure[4] expresses not so much a property of things as that it adequately translates the epistemological consequences which result from the fact that no action is without delay, the fact also that the empirically known properties of light strongly suggest that they are involved in the speed of its propagation in space, playing the role of a speed limit for all its physical interactions.

Nevertheless, once the formulas have been written out, once Space-Time is developed by the imagination (with whose habits its characteristics are nevertheless in conflict), there is a great temptation to invest this geometrical form with a real significance, to interpret the movement from the traditional representation—which separates space and Time—to the new one which relates them—as progress in the knowledge of the basic essence of matter. This is the thesis which Costa de Beauregard defends vigorously. Certainly, with him it is a question in the first place of a sort of methodological faith in the creative value of the theory of relativity. In his eyes, this faith is based on history and also on the recent gains made by activist physics: all classical physics was waiting for and presaged relativity, somewhat as the Old Testament was a harbinger of the New, and the theory of relativity is truly itself only as it is expressed in Minkowskian for-

[4] Hermann Minkowski demonstrated in 1908 that the kinetic laws of a partial theory of relativity, so surprising when one envisages them within the framework of traditional, "Euclidian" and "Galileian" conceptions of Space and Time, are in fact the theorems of a geometry which relates Space and Time in a "Space-Time;" this "continuum" or this "diversity" in four dimensions possesses analogous metrical properties, but not identical to those of the space of ordinary geometry.

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malism. The grand test was theoretical microphysics, whose origin is contemporaneous with relativity, but which, in order to account for the more and more surprising experimental results that developed as the techniques for exploring phenomena of intra-atomic origin progressed, took to paths entirely new in some respects, yet more classic in others. It tended thus to move away from—in fact unfortunately, according to Costa de Beauregard—relativity, which it never should have abandoned: "a serious technical casualty of growth" (N.T., p. 144) which surprises one still, to read this "brief history of fifty years of physics" (N.T., pp. 101-137) that it could not be avoided. For the author intends to show us that attempts made at different times across the years to introduce or reintroduce relativist principles in microphysics have led to important progress. This was the case in 1916 when Sommerfeld applied relativist dynamics to Bohr's theory of the electron-planet, in 1924 when de Broglie laid the foundations of wave mechanics, in 1928 when Dirac constructed his famous equation of the wave for the electron. In 1965, the quantitative and relativist electrodynamics of Tomonaga, Schwinger, and Feynmann, which had been developing since 1949 and which showed itself capable of taking into account certain experimental fact which until then were outside the scope of previous theories, was crowned with the Nobel Prize.

Although it may seem surprising, to read Costa de Beauregard, to learn that such a sovereign remedy has not been more constantly and more unanimously put into practice, there is no reason to dispute the methodological value of his postulate which cannot but be shown by the progress of research. But in fact, for him, the methodological postulate has the double face of a metaphysical thesis, of a "realism" of "Space-Time put into action," as he willingly says, accompanied by a partial negation of the future, reduced as for Grünbaum to the role of simple appearance which the temporal dimension of Space-Time takes in human perception. This thesis provokes serious reservations. One can moreover question if the form of Minkowskian geometry did not exclude all "realist" interpretation of Space-Time, whatever Minkowski himself might have said in a famous paper. In effect, if one tries to make the geometric elements of Space-Time (point, lines, "tubes," of surfaces) correspond to the physical entities which they represent (particles, events, physical systems and trajectories), one sees that Space-Time represents the unreal just as well as it does the real and in a way which mixes them inseparably. For, if all the *points* of Space-Time are shown as "events in a place" and therefore are all real (taking into account the universal presence of fields in the universe), not all the *lines* which join these points can be real, by virtue of the axioms of the theory of relativity. In effect, the "lines of the genus space" cannot show any continuous physical existence, any movement, any real processes. All the points of a geometric unit would thus be physically real, even though the unit might not be. Could this *realism* accommodate such a strange factor, which is without consequence if one simply admits that Space-Time is only a convenient language for relating the spatial and temporal aspects of natural multiplicities in the same algebraic system? It remains to understand the reasons for this convenience which it would evidently not be very philosophical merely to take note of.

Reichenbach, at least in the book which we are discussing, only indirectly puts into a spatio-temporal form the data of the theory of relativity; but it is implicit that this is for him only a consequence of the relativity of simultaneity, which is itself a consequence and confirmation (to the extent that it accounts for observed facts) of the causal theory of Time. The idea of a real value of Space-Time seems to be extraneous to his philosophy.

Whitrow carries on the discussion of relativist Time from a point of view which is frankly methodological. Lorentz's transformation is *deduced* from the conditions which any attempt to obtain in a satisfying way the determination of Time at a distance must content and the correlation of temporal perspectives (N.P.T., pp. 183-208). Here Whitrow benefits from his experience in contributing to the development of Milne's theory of kinetic relativity. But in his latest work the demonstration that he gives of the possibility of *a priori* constructing the formula of Lorentz is all the more convincing in that it is completely independent of Milne's cosmology. On the other hand, it is too bad that Whitrow has not shown in a better way the connection between this demonstration and the more general one of Robertson and Walker that he cites without much explanation. In effect, they had independently shown that one can also construct *a priori* a measurement of Space-Time more general than that of Minkowski, using purely methodological principles, a measurement which still serves, at least as a point of departure and term of reference, for all cosmological theory. For this demonstration, at the same time that it shows the usefulness of spatio-temporal formalism, shows also the irreductible originality of the temporal dimension, and as a consequence the mistakenness of a *realism* of Space-Time against which Whitrow inveighs, without however using all the arguments available to him.

TIME IN MICROPHYSICS

The arguments of Costa de Beauregard in favor of realism in Space-Time are above all drawn from the recent success of relativist formalism in microphysics. However, it is enough to read his book to be convinced that the problem of Time is like all those set before natural philosophers: when one crosses the frontiers of the atom, when one penetrates into the domain of microphysics, everything which has already been known tends to have less force, and one encounters obscurities and enigmas everywhere.

It may seem in certain respects that the temporal reversibility of elementary laws which is apparent in classic and relativist mechanics is also the rule at the level of microphysics. This is what Reichenbach tries to show, and nothing has happened in physics since the publication of his book which would authorize a different conclusion, despite the ideas mentioned above. In fact, since the famous paper of Feynmann, now more than fifteen years old but which, as has been said, still has a future, the intemporality or the semi-temporality of microphysical phenomena seems to be still more accentuated, for Feynmann's mathematical formalism leads to the possibility of a journey in two directions of the temporal dimension in the small areas of Space-Time involved in phenomena such as the collision, the creation, and the annihilation of positive electrons (of which we observe the results everywhere on our detection systems after the fact). Reichenbach saw in that "the most serious blow that the concept of Time has ever received in physics" (D.T., p. 268). The order of Time in effect was questioned and not just its direction.

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Nevertheless, the domain of microphysics is also that of indeterminism. Assuredly this is a question of forty years which is still open, but as time passes, a quasi-certitude emerges: the theory of quantitative phenomena may indeed take forms still unknown, but it seems henceforth impossible that we shall return to the precise determinism whose suitability, at least in principle, for the effective order of natural events was postulated by classical science. Now, with indeterminism the only possibility for prevision is a statistical one. Consequently, unless we suppose an infinite intelligence which, unlike the one imagined by Laplace, would not use the same reasoning and calculating procedures that we do, indeterminism creates at each point and each instant—to the extent that these words retain a sense which is perhaps approximative—an irreductible difference between the past and the future, that is to say, between the determined and the undetermined. The prospective and retrospective figuration, which continuous Space-Time displays, remains therefore ontologically inadequate, even if it is useful mathematically. Or again, as Whitrow puts it: "There certainly exists a profound connection between the reality of Time and the existence of an incalculable element in the universe" (N.P.T., p. 295). This is also clearly the case in the analyses of Reichenbach, even if not as explicitly stated. On the other hand, it is vigorously contested by Grünbaum, for whom indeterminism and future are two totally different questions. But on this point, Costa de Beauregard (in a recent article) thinks Grünbaum goes too far.

Will quantitative electrodynamics, to take it in the sense of its latest developments, modify the givens of the problem? Costa de Beauregard makes one think so, while a close examination of his arguments shows that he feels even the most fundamental ideas remain still more enigmatic (N.T., p. 162, beginning of § 13).

"Despite all attempts," he writes, Minkowskian form has not been led to absolute determinism (p. 152). Perhaps here there might be a good reason for doubting the reality of "Space-Time developed in action". Costa de Beauregard certainly does not go that far; in fact he still brings up, despite all attempts, but to the surprise of his readers, the *complementarity* of Bohr. For although quantitative electrodynamics has reason to be relativist, that does not prevent, still following Costa de Beauregard, this consequence so surprising and so celebrated of quantitative mechanics of the 1925s, that is, the possibility of two readings of microphysical experience complementary one to the other, the one of waves, the other of particles. From these two *complementary* descriptions, allowed for by the new theories, one, that of waves, totally excluded the future which still had a place in the second, of particles. Costa de Beauregard does not hide his preference for the former and speaks about this in "Physics sub specie aeternitatis" (N.T., p. 155), which seems at the very least strange when one sees the state of mutation in which this science remains after fifty years. At any rate, in our opinion it is enough that two possible and *complementary* descriptions exist for all realism to be excluded, at least provisorily.

In 1949 when he justified the "spatio-temporal method of approach" of quantitative electrodynamics, Feynmann himself invoked only strictly methodological reasons for preferring the relativist method to the usual "Hamiltonian" processes. Only the nature of certain problems had suggested to him the separation of the temporal evolution of phenomena and to consider as a spatio-temporal unit certain extremely localized physical processes; and in his methodological considerations, Feynmann remained very far from any ontology of Space-Time (*Physical Review,* 76, 1949, p. 771).

TIME AND INFORMATION

It is difficult, as we have seen, to speak about Time or to think about what it might be without closely mixing the subjective and the objective, without introducing some implicit or explicit reference to the situation of the person thinking with respect to the world or to the possibilities of his perception and of his action. Besides, it is this very strong connection of all temporal representations to the life of the mind in its relationship with the world, which makes so fertile in *quiproquos,* in misunderstandings, and controversy of all sorts the question of knowing, in effect, which of the properties of Time we attribute to it and which are projected upon it by us.

In this respect, it is notable that Reichenbach, after a somewhat

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polemical introduction in which he accuses the great philosophers of having given in to the temptation of denying the objective reality of Time, from a failure to have dared to look the fact of death in the face, that the same Reichenbach who tries to construct a completely objectivist theory of Time, takes as a point of departure for his analysis certain data of common sense in which "we" figure, either implicitly, as in, "The present which divides the past from the future is *now,*" or explicitly, as, "We cannot change the past but we can change the future" (D.T., p. 20).

The paradoxical character which the world would take on if it followed the course of Time in the eyes of an individual who himself continued to travel in the same direction, has often been underlined. The innumerable and strange examples which can be found are often invoked to show the strong *anisotropy* of real Time. But a closer analysis shows above all that these examples reveal to what extent our thought and our action demand, in order simply to be possible, that the phenomena of the world go in the direction from *our* past to *our* future. Thus, in a world in reverse, a man in a pool of tepid water would be threatened at every moment by serious accidents: the tepid water could at any instant separate itself into boiling and cold water, without the possibility of ever determining the moment of the "demixing" nor the distribution of its results. More generally, in a world which spontaneously evolved from the homogeneous to the heterogeneous, anything could happen at any moment to result in any kind of distribution of dispersed elements—out of a rocky desert a Doric temple, a mosque, or a simple hill; out of a heap of cinders the Iliad or a sheaf of bills.

Because of this, qualitative reasoning, as necessary as it is vague, concludes that Time rolls on in the direction in which our forecasting is possible. Now, it is worth noting that this conclusion is indeed confirmed by the mathematical shape taken by problems of communication and information. There is a striking analogy between the formulas arrived at by theoreticians of information and those of statistical thermodynamics. The information of physical quantities appears in equations like an entropy with its sign changed, a "neguentropy", to use Brillouin's epression.

And in fact, this sort of congruence between what one could call the epistemological sense of Time (the sense in which the events have a connection in our logic) and its real course is apparent in a number of ways. Thus, Costa de Beauregard has for a long time noted a close relationship between the second law of thermodynamics—an "objective" law—and the rule formulated by Baynes, idependently of any thermodynamic considerations, relative to the practical application of the calculation of probabilities to the problems of "retrodiction" research into the probability of *causes*). Such problems cannot be treated in the same way as problems of "prediction"; supplementary hypotheses are required. "Blind retrodiction" is impossible for calculating probabilities (S.P., pp. 22-27).

Given this congruence, the reader of Kant may be tempted to look for an *a priori* proof on which to base the following "transcendental" schema: since our science and and our action are real, they are possible. If they are possible, it is because their necessary conditions are givens, and one of the givens is certainly that the course of things and the course of our reasoning about the world are congruent.

But, ontologically, the congruence which we have noted remains equivocal. Does it mean that, perceptions being in the world and their ideas being of natural events, the epistemological direction of Time does nothing more than reflect and double its natural direction? Or, on the contrary, does it means that, in a world whose elementary laws show that "in itself" it is without temporal direction, it is an *a priori* form of thought, or simply the *existence* of the conscient being, the new dimension that this existence brings forth in the world, which extrinsically orients in some way the natural multiplicity in arranging it? Realism of the future on the one hand, "idealism" — Kantian[5] or not[6] — on the other.

[5] "Thus the idea inherent to causality, that that which is anterior is the determining reason for what follows, and not vice versa impresses on our judgement of probability a direction separate from that of Time." H. Weyl, *Philosophy of Mathematics and Natural Science*, Princeton, N.J., 1949, p. 203.

[6] "Time is not a real process, an effective succession that I limit myself to recording. It is born from *my* relationship with things." M. Merleau-Ponty, *Phénoménologie de la perception*, Paris, 1945, p. 471.

In fact, the lack of symmetry between past and future in the epistemological process seems rather to result not from any internal law of thought but from the necessity in which it finds itself to interpolate its operations into a world in which events orient themselves. Thus, Grünbaum presents and discusses the thesis according to which *explanation* is essentially different from *prevision,* although in both the basic inference goes in the direction of Time, from cause to effect, from past to future. Syphilitic infection *explains*, and explains only certain forms of paralysis, but it is impossible to predict that someone infected with syphilis will be struck by paralysis. Nevertheless, in both cases, the inference goes from the cause (anterior) to the effect (posterior). In fact, Grünbaum remarks, the connection between the *explanans* and the *explanandum*, the causal connection, is the same in both cases. What is different is simply that in the first case, the *fact* of paralysis is known, while it is not in the second. According to Grünbaum this is not enough on which to base an opinion that there is an epistemological difference between explanation and prevision (P.S.T., pp. 303-308). Nonetheless, this difference is indeed real, and it does not depend upon the thinker and his logic. It results from its position in the world, from the fact that it occupies a certain place in an objectively oriented temporal series. Thus, ontological orientation is superimposed on epistemological orientation to modify or make more precise the significance and the validity of the process of perception.

Other, less obvious dissymmetries appear under closer observation and seem to us to swing the balance towards an objectivism of the future. Here we must make note of the prescience of Costa de Beauregard, who has noticed a fact which seems to have passed unseen heretofore: Boltzmann's constant, which occurs in the classical statistical definition of entropy, can also have value as a coefficient of equivalence between information and neguentropy. Now, this is a very small constant in the system of unities of physics, which has been conceived on a scale of human measure. This, says Costa de Beauregard, is significant of the relationship between action and thought. One needs only a small amount of neguentropy to receive a great deal of information, but one needs much information to have a small amount of neguentropy. This means that man informs himself easily about the world but that the least of his actions—which in general go in a direction counter to the natural course of things—requires him to receive much information. This results, as Costa de Beauregard has wisely said, in the classic image of determinism and of science: man can understand the universe—for to know something is not to change it—but his liberty cannot really interpose itself in the infrangible web of determinism—an erroneous idea if taken to its extreme, for any acquisition of knowledge changes, however little, the course of events, and, inversely, information permits man to follow, to however little an extent, the entropic course of the universe (S.P., pp. 88-89).

WHAT DO CLOCKS MEASURE?

Although, as we have said, Gonseth's proposals may above all epistemological and methodological, it seems to us that one can draw from his book some consequences which remain implicit on the level of ontology but which are rather clearly visible in the results of his inquiry. If progress in the measurement of Time had consisted of developing a purely operational definition of the unit of Time, of relating the unit interval to a certain physical process experimentally realizable and reproducible at will, one could conclude from this that it is man the calculator and the manipulator of instruments who introduced into the universe, either by the *a priori* structure of his thought or by his technical operations, the metrical properties which it would not have without him. However, Gonseth has shown with great care that this is in fact not the case, that at every stage of progress the creation of a more exact clock depends on an entire experimental and theoretical context in which references to an objective order have never been absent.

For example, it is not within the power of *homo metiens* to decide arbitrarily that the sidereal second is the *true* unit of Time and that consequently the Time of the ephemerides (that which measures the revolutions of the planets) "advances." In effect, if it is the planetary clock which is regular, the slowing down of the terrestrial clock is easily explained (by the dissipation of the angular moment which rules the tides and the atmospheric movements), while if the terrestrial clock is taken as the absolute standard, the acceleration of planetary movements which would result from such a choice would seem to be a completely mysterious phenomenon. Or yet again, if *maser* clocks are henceforth considered indispensable instruments for the measurement of Time, despite their still precarious stability, it is because all our experimental and theoretical knowledge of atomic phenomena leads us to consider that the frequencies which characterize them are tied to *real* standards related to the basic structure of matter.

As has been said, Gonseth draws interesting methodological conclusions from these givens. On the level of ontology they strongly seem to suggest to us that temporality in all its aspects is part of the world. Classical mechanics could not carry out its experiments without a "good clock," able to give a concrete existence to the variables of its equations. But Gonseth tells us from his researches into chronometry that the construction of a good clock is, inversely, always based on the knowledge of the laws of mechanics. Nonetheless, he says, this is not a vicious circle, for the theory and the instrument form a whole which is united in the experimental proof. Without doubt, but what would this proof lead to if there were not in the world itself a property which justified at the same time the postulate of a good clock and that of a good mechanics? It is true that classical mechanics is only approximately verified, and it has not at all been proven that, taking into account relativity, the attempt at a more precise synchronization of the times of different planetary revolutions would still retain any sense (P.T., pp. 295-296). But it would be too much to expect a perfect certitude here which is wanting elsewhere.

Gonseth explains that every artificial clock is made up of two elements: an oscillator whose movement must be maintained and whose frequency maintained constant and an integrator which counts the oscillations. The frequency of a spring is arbitrary and this is the element of chance which makes the sidereal day significant for men. But the positions of atomic and molecular rays in the spectrum of electromagnetic frequencies belong to the elementary structure of matter. In refining itself, chronometry seems thus to rely on a hypothesis which was once alien to it and which seems to be like that which Whitrow explicitly places in the center

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of his reflections on Time: "... that here there is basically a single rhythm of the universe" (N.P.T., p. 46).

It will be said that if the oscillator of clocks made by men is related to the basic structure of the universe, the integration, the counting of periods, is a human operation of which nature gives hardly an example. Nevertheless, one can read the age of trees on the rings of their trunks, and the fission of radioactive atoms in minerals which contain them provides an example of a sort of spontaneous measuring of the intervals of Time. The age of these minerals is almost as directly legible by the physicist as that of trees, though the law of integration is less simple. It is true that nuclear fission measures discrete, non-temporal events rather than periods, and that regular natural clocks are not just those which measure periods. The past history of the solar system would certainly be clearer for cosmogonists if the number of revolutions of the earth were marked out, at least in part, on the sun or on the earth itself. It seems that in natural processes the exigencies of integration contradict those of uniformity. The human clock thus reunites two aspects of Time which nature tends to separate. It remains true that the attempt at chronometry would be given over to arbitrariness and chance if the elements of its synthesis did not pre-exist to some extent.