Pierre Auger

TWO TIMES, THREE MOVEMENTS

The arrow and the wheel have both been used to represent time, which has been measured by the flowing of water or sand, unilateral and definitive, or by the movement of a needle on a dial, an ever recurring cycle. These two aspects of time—the unlimited advance without stop or return and the cycle which passes again and again through exactly the same states—have for various reasons preoccupied both philosophers and astronomers. A universe of infinite duration which never returns to any of its preceding states, the sort suggested by application of the second principle of thermodynamics, has little appeal for certain thinkers and leads them to a sort of cosmic pessimism. A cyclical evolution, on the other hand, with an eternal return to states, if not identical, at least very similar, to the one in which we live, gains more sympathy by providing the mind with a sort of repose, a vague consolation for death. This preference can be observed in action whenever the progress of astrophysics presents a new hypothesis on cosmic evolution. The expansion of the universe, an irremediable evolution, met with a hostility which, under cover of scientific arguments, concealed an affective malaise induced by metaphysical anguish in the presence of this final fading-away, far as it might be from our day. The theories which say that nebulae evolve but regenerate, and which lead to a sort of permanent

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regime in the universe, enjoyed, on the other hand, a very wide success, the deeper reason for which is not always admitted or even consciously recognized. It may be simply a vague feeling of similarity between the human microcosm and the macrocosm which makes us perceive in the thermal end of the world a great general death, as hateful as our own death, while a cyclical or permanent universe presents a pulsing and persistent life similar to the one we feel in ourselves and in our race. But is there, in fact, any basis of reality accessible to science? Or does this profound disparity between a flow which is lost without hope of return and a duration which conserves something—or finds it again—correspond to nothing more than purely subjective classification?

Before beginning an analysis of the notion of time, and in order to establish it on a solid base, let us touch briefly on the structural level of matter—the atomic level—and note how things present themselves in this microscopic world composed of distinct individuals, atoms or molecules, governed only by their reciprocal relationships. The equations of physics are written there, as in our familiar universe, as a function of time. But various authors have noted that the time which figures in the inner laws of the atomic and molecular structures does not have exactly the same meaning as the time introduced in formulas representing their exterior (whether classical or statistical) mechanics. Interior time, that of wave mechanics, has no unique direction, and its sign can be changed without affecting the validity of the results—as is the case in ordinary mechanics where stationary waves are concerned. It is a "time," beyond all doubt, but one which does not advance in some way or other, which does not lead to an evolution, more or less slow, but inevitable. Long before their internal laws were seriously analyzed, it had already been said that atoms and molecules do not age. An atom of oxygen which beheld the formation of the earth is still identical to itself at this moment. It may, during the ages, have undergone temporary transformations, been ionized and then neutralized, entered into combination with other atoms and been freed. It shows not the slightest trace of these incarnations and, after several billions of years, is perfectly "clean" and brand-new. This is also true of molecules when they are replaced in the same chemical state; they are always exactly the same, and no distinction is possible between those which have just been formed and those which have been constituted for thousands of years. It is an essentially immaculate universe, exempt from any contamination by the past, without anguish for the future. It is also a universe where nothing is irreversible and where one can always return to a former state—

by means of some expending of free energy—and leave it again under no handicap. It is a universe always alert, where nothing is lost, nothing tires, where affinities a thousand times satisfied and undone are always equally alive and ready to see the same steps retraced.

The picture changes completely if statistics are introduced, that is, when the object of our study includes numerous atomic or molecular elements. These individuals are independent of one another, or, rather, they present among themselves but brief and weak links deriving from gravitation, from electric and magnetic polarizations, forces whose characteristic is the power of varying in a continuous fashion. A description of the state of such an ensemble should be based on the movement and the relative position of the various elements of which it is made. But the parameters, which can vary in continuous fashion, are so great in number that we must generally be content with indications of a statistical order, either on the vivacity of the movement—leading to the notion of temperature—or on the relative proportions of the different atomic or molecular species—leading to the evaluation of the concentrations. Temperatures, concentrations, all general parameters permitting a definition of our ensemble, evolve with time, and here we are concerned with an oriented time, an arrow, which goes forward and cannot be made to turn back, since the laws themselves cannot be turned back in time, as in the case of individual atoms. And with this inexorable time appear all the characteristics which separate our familiar universe from that of the atoms: the decrease of energy which little by little (but irretrievably) breaks down all the ordered structures which we utilize or construct; memory, that is, the traces of the past which are inscribed on solids, in the movement and the composition of fluids; the alteration and impurity from which the universe of the atoms is exempt and which are a part of that memory. This evolution in the course of time, slow or catastrophic, is such that one cannot return *exactly* to an initial state, even by an expenditure of free energy, for no power on earth can replace individually atoms or molecules in the situation (and in the conditions) where they were earlier in a scheme of continuous parameters. This is why on our scale everything ages, changes, and never turns back; it is why our familiar world possesses a future and a past—and it is also why the present which separates future from past cannot be grasped. The atoms have but one present, eternal, except in case of catastrophe.[1] They are, as the physicists modestly put it, in a "stationary" state.

1. Catastrophes which, by the way, are reparable.

All this obviously poses a series of problems, for it is not easy to admit that time, the fourth dimension of the universe, appears under two such different aspects.[2] And, first, if time is but an eternal present in the atom, what is to become of all those internal movements to which the physics of the past half-century has accustomed us? Now we are told that the position of the electrons in their orbits cannot be precisely determined, except that they are everywhere present to a certain degree. But what, then, is the meaning of the kinetic energy they possess or the mechanical moments resulting from their rotation? To explain the latter, it would seem necessary that these particles move in a certain direction—that, consequently, they have a future and a past, however short and however quickly effaced these may be by cyclical returns.

A close analysis of the instantaneous and successive events in the complex structure of atoms and molecules is however unrealizable, forever ruled out by what are called the "laws of indetermination." Two attitudes are then possible: one consists in refusing every concept which cannot by its own nature lead to observable facts—and consequently in accepting as a whole the dynamic present offered to us by atoms; the other leads us to suppose the existence of movements of the ordinary type within the atoms, with positions and speeds, but forever separated from us and all the rest of the universe by an impenetrable shell. This second attitude sees in the different atoms of oxygen present around us individuals different from one another, since their inner state cannot be identical.[3] But it gives no procedure for designating, sorting, and classifying them in relation to these supposed internal circumstances. It would be prudent then to admit the inaccessibility of the interior of atoms and to permit full rein to time without direction, and movement without stages—since there are no events which might be used to mark them.

Returning to our familiar world, we find spatial dispositions and displacements by which we mark off advance of time: needles on a dial or return of our globe in its position in relation to the sun. But we know that these mechanical movements, even if they appear perfectly cyclical, never close at exactly the same point; the clock wears out, the earth's revolution slows down, and the sun itself consumes its supply of hydrogen. A great movement sweeps the whole universe, a great evolution which at every

2. A duality in the nature of time has, however, already been considered for different reasons, particularly by Milne and Haldane.

3. While the first point of view, although it distinguished one atom from another, found them equal.

moment lowers the potential of order by widening the domain of chaos. Hot bodies radiate, cold bodies absorb; rapid particles are slowed by shocks and become "ordinary citizens" of cosmic gasses or solids. This evolutionary movement, to which the notion of entropy is attached, takes place inexorably in one direction only, the entropy increasing in every isolated part of the world. It is linked to the continuous character of parameters which allow a description of every portion of the universe without presenting any of the levels of stability which we have encountered among atoms and molecules, even when they were undergoing change. It flows, it flees, it is indeed a movement linked to that arrow-time which our efforts can neither stop nor slow down—that time which leaves behind it the fine traces of memory, then the marks of age, and, finally, a few fossils.

In the presence of these two times and of the two movements inscribed in them, we must call attention to several rather paradoxical situations. Intra-atomic time is an immovable present, but it leads to sudden changes which have no history. Statistical time passes ceaselessly, but in its framework can be found precise marks of past events. It is in the inner movement of the atom—in the strict, pure world where everything, like Achilles, is "fixed in large steps"—that the vague area called "indetermination" resides, an area in which the only solid supports on which the future may be built are evaluations of probability. It is in the statistical motion of the universe, in the middle of this great shoreless river whose flow cannot be stopped or reversed, that scholars calculate with certainty to the tenth decimal place. But are not these paradoxical aspects due only to the contact of two worlds, atomic microcosm and universal macrocosm? And does not this dualism also give birth to the third movement which represents life and which leads its creatures toward a richness of constantly increasing complexity?

Before penetrating the terrain of life itself, let us look more closely to see what may be the nature of the contacts between the two worlds we have just described. Is the transition from one to the other absolutely sudden, and does it represent a metaphysical barrier, or, on the contrary, might one find certain characteristics which enable us to understand the other even in the absence of a freely open passage between the two? This was tried, with success, in the early days of the quantum theory, in the form of Bohr's principle of "correspondence." If one applies the continuous laws of classical physics to the planetary systems which, at that time, were supposed to exist in the atom, various rules can be deduced which are in effect verified by observations, at the same time that the principal characteristics of these observations require the introduction of the discontinuous laws of quantum physics. This correspondence is all the more exact for the fact that the calculation is applied to states of the atom where quantic numbers are greater, and which thus approach the macrophysical systems where continuous physics reigns. There exists a clear boundary between these two physics, but in the vicinity of this limit one notes a sort of preparation for the crossing of the boundary.

Inversely, if statistical systems (of the kind represented by a gaseous volume, for example—and which are under the jurisdiction of the laws of classical thermodynamics) are supposed to be maintained for a long time in absolute isolation, i.e., without any external intervention (even for observation), one can apply the quantum theory to them. They should then be considered as being in discontinuous states, escaping entropic evolution, and consequently plunged into time of the first sort, into an indefinite present.[4]

In this last example we may in a way catch in action one of the characteristic elements of the passage from microcosm to macrocosm. In fact, if we heed common sense, we will reason as follows: we are dealing, after all, with a gas, composed of molecules in great but well-determined numbers; at any instant we might therefore decide to verify by observation the situation and the motion of these molecules and thus to penetrate into time of the first species, which is reputed to be impenetrable. We could do this in principle, but at the price of breaking the isolation which was a part of the condition of the supposed experiment. To observe molecules, we must illuminate them, bombard them with photons and electrons, and profoundly trouble their movements. We would, in short, be acting like an investigator who, wishing to follow the development in the thought of a group of friends engaged in conversation, made each of the participants submit from time to time to judicial questioning. Time of the first sort and the type of movement linked to it do not admit the presence of an observer; or, rather, every observation ends its career, its present, and casts it into a new period having no continuous relation with the former. Moreover, it requires for its establishment a considerable duration of these isolated states—all the greater in that the number of particles involved is great and that they are less dependent on one another.

4. Of course it is not surprising that they should escape entropic evolution, since they are isolated and can therefore neither receive nor lose energy, and since they are in thermic equilibrium because of the very long duration of the experiment.

A precise analysis of the circumstances in which external events can influence the permanent interior state (stationary state) also leads to a sort of "tangential junction" between the two qualities of time. Let us take the simple case of an electrified particle in rapid motion which passes near an atom or molecule. Thanks to its electric charge, it can exercise an action on those elements of the atomic system which are themselves characterized by an electric charge. Under certain well-defined conditions this action may end the stationary state by substituting another, thus bringing about one of those interior crises which separate two successive elements from the discontinuous existence of the atom. Now among the conditions required for an effective action is a condition of time, and what is still more remarkable is that this condition is the reverse of that generally produced in the macroscopic world within which an action of long duration is more assured of bringing about a decisive result than is too brief an action. For atoms, on the contrary, it is an action of short duration—or at least of duration less than a certain critical value—which has the greatest chance of producing an effect. Such a "premium for violence" is encountered in classical mechanics only in the case of systems of periodic motion. When a pendulum receives a brief shock, it begins to move. A progressive attraction by a nearby body, which lasts much longer than the pendulum's period of free oscillation and which also stops progressively, finally produces no effect: the external force is thus exercised in vain on the attached point of the pendulum. A link can thus be observed between the critical duration of action on an atom and an interior period, so that every more rapid action has a chance of exercising an effect on one of the parts of the atomic system and of acting on it as though it were free, while a slower action finally exercises an effect on the ensemble, thanks to the intervention resulting from the interaction of the different parts on each other. It would be only too easy to find analogies in human affairs: an attempt to persuade one member of a social group has chances of success if it is rapid and energetic. If it is too slow, social bonds will intervene, the reaction ceases to be individual, and the external action encounters the total mass of the group.[5] There, too, a critical duration could be defined, dependent upon the rapidity of the exchanges and their intensity: this is a duration characteristic of interior time, apparent to observation only if caused to be "put in gear" with exterior time by an intervention located in the latter. Finally, one can choose among microphysical systems those which present to the

5. The occasional success of an action of long duration is due to the fact that it led to a "conversion" of the individual under consideration, who no longer obeys the same laws.

highest degree the properties of isolation in relation to external conditions, that independence of internal conditions vis-à-vis the surrounding macrocosm, by which I mean atomic nuclei, and more especially the nuclei of radioactive atoms whose permanent state is suddenly brought to an end by a spontaneous crisis which causes them to throw off a part of their mass, leaving them in a new state vastly different from the first. We know that these perishable atoms do not grow old any more than stable atoms but that they have, throughout their existence and during each unit of passing time (as measured by external observation), an equal chance to undergo the crisis which disintegrates them. If we reason within the internal time of the atom, that probability of explosion is simply one of the permanent and unchanging properties of the present reigning therein. It does not permit any evaluation or measurement of the time which would pass in the way of external time, since, if the crisis takes place, internal time simply ceases to exist—and since, so long as it does not take place, no event occurs which might announce the crisis. For the outside observer as well it can serve no purpose, and for the same reason, in the case where the atom observed is the only one of its kind. But, if we are concerned with a sizable number of identical atoms, everything changes, for the observation of their successive crises allows us to follow and to measure the flow of time—of entropic time, of time without return. Here, again, by means of the bias of statistics, the time which passes is connected with time which endures, and this connection shows, by the equality of their measurements, their quantitative identity.

We have cited several applications which show some harmony among the laws and principles governing atomic microcosms and the microcosm of the universe. But the similarities thus discovered cannot be developed beyond the very strict conditions which we have indicated, and their interest is thus limited to certain narrow fields of physics. It is not in this direction, but rather in the field of biology, that the most impressive extension of the quantic world has been produced within our familiar classical universe. In life, as a matter of fact, one encounters bodies which, despite their large dimensions, present a structure relating them very closely to atoms and molecules. Crystals, in which certain characteristics of very large molecules can be recognized, but which have neither individuality nor definite limits and which do not constitute closed microcosms, have often been cited as an example. On the other hand, the very large organic molecules conserve their nature while attaining dimensions whose form the new instruments of electronic physics are making accessible to our eyes. This is the case with viruses and bacteriophagi, whose molecular quality is hardly in doubt; it is also the case with genes and perhaps even with entire chromosomes—or at least with their central chain. Through their relation of development, living beings of great size whose anatomy and physiology are governed by the genes of their cells, and finally man himself, are directly linked to the molecular world.

But let us examine more closely the meaning of this extension and what may be deduced from it as far as the time and the movement in living organisms is concerned. Let us return to the characteristics we attributed to atoms and molecules: transposed to the level of life, they show us the elementary organisms—viruses, phages, genes—as constituting definite chemical species, all of whose representatives are identical and inalterable, hence without memory, and which change only to disintegrate or to pass by a single leap to another species. Delimited units in space and time, though potentially eternal, they are not subject to entropic evolution. Some of these characteristics are indeed those of living beings: their species are maintained and transformed only by discontinuous passages from one to another; the individuals themselves are maintained for some time in their complexity, thus resisting the progressive disorganization imposed by thermodynamic movement. But does life not consist of continual change? Do not monocellular organisms themselves show the presence of memory? Far from being fixed in a perpetual present,[6] they are drawn by the arrow of time, without return, from birth to death.

These opposing points of view can be reconciled only if one recognizes the double nature of living organisms, that is, if one places them at the same time in the permanent molecular present and in the passing flow of statistical movement. The material supports of these two natures are physically distinct from each other, but they are also indissolubly linked one to the other. Some, guardians of permanence and carriers of heredity, are true large-size molecules, possessing among their catalytic chemical functions[7] that of identical catalysis or self-reproduction. The others constitute a transforming physicochemical machine of energy and entropy, but a machine which functions blindly and is inevitably halted, no matter how well regulated it may be, and sooner or later falls into chaos.[8]

6. Perpetual in the sense as secretaries of the Académie Française, that is, as long as it continues.

7. It must be a question of catalysis, the only chemical function which leaves its operator unchanged.

8. Which justifies the biological adage: There is no living matter; there are only living organisms.

The molecule is in principle eternal, and it is possible that certain of the genes present in the beings surrounding us are the very ones which were included in beings of the same species living a million years ago. More precisely, there is no sense in asking whether they are the same or others, since they are indistinguishable. The machine may also be perpetuated, but, like Jeannot's knife, only by the continual replacement of worn-out parts. This may of course preserve for it an appearance of identity, though quite a different identity from that of the molecule of which it is but the reflection. By its functioning, the machine maintains around the molecule the very condition of its perpetuity, that is to say, it delays as long as possible the final catastrophe which will win out over its present and will disintegrate it. The virtue of the molecule is stability (with the motto: "I stand fast"), while the function of the machine is metabolism (with the motto: "I serve").

In order that this association of the blind machine and the paralytic molecule may endure and draw all the advantages from the two times and from the two movements in which it participates, two conditions are necessary. On the one hand, the machine must receive food for its functioning in order to realize the metabolisms it commands—and this may be sunlight or complex chemical substances prepared by the activity of other organisms, which will assure its continuance from day to day. On the other hand, the molecule may disappear accidentally, causing the definitive ending of the species if it had been unique. Only the property of identical multiplication (or autocatalysis) can give it a character of plurality wide enough for the population thus created to have a chance for some of its members to escape a catastrophe which always threatens an offensive return to chaos.

Without any pretense of reaching an explanation of life, we have sought its place in the universe. We have located it, at the boundary between the molecular world and the thermodynamic world, participating in the two movements and extending into the two times. Perhaps we may be permitted to draw several further consequences from that situation, before venturing forth on the terrain of evolution. The idea of the double nature of life may in fact be generalized to its superior manifestations, which leads us to perceive among beings of large size some cells or tissues devoted to the one function and others to the second. Thus the "present" may be found in the states of consciousness of our brain. Even if of short duration, this present could not be reduced to an infinitely short contact between a past and a future—neither of which exists in fact within a time which passes in continuous fashion. On the other hand, the flow of time "as an arrow" inscribes its marks in our memory, in our growth, in our aging. Finally, the extreme point of consciousness, this indivisible and unalterable "I" so long as it endures, this simple unity which persists through events and for which memories constitute only a context surrounding it, this little flame seen by D'Annunzio to shine, calm and constant, at the bottom of a well of darkness for an instant of respite in the whirlpool of revolutions, do we not feel that it realizes in us that provisional eternity of the atom whose only property is existence?

Let us go still farther. Do not the societies of men also show this attraction toward two modes of life, examples of which may be found in the historic duration of happy peoples or monastic communities—with laws forming a permanent and unchanging whole—or on the contrary in the changing and adventurous lives of conquerors, prophets, and revolutionaries? The philosophies of Parmenides and Heraclitus, the Yin and the Yang of the Chinese, are reflections of these two tendencies. Religions themselves have not failed to create symbols corresponding to them, some seeing the world as regulated by a total and immovable law, forming a wheel which turns without moving forward or an infernal cycle which must be broken in order to achieve freedom; others seeing in the world the meeting of two principles and a long struggle with various ups and downs, a fatal march toward an end now foreseeable and for which active preparations must be made. Buddhism and Manichaeism, religions of contemplation and religions of salvation—the rule and the century, grace and works. But these are extremes; for life, as we have seen, necessarily wears a double face.

Two times, commanding two movements, with man taking part in both. But is there not a third movement which escapes these categories? Living species do not remain the same indefinitely, protected by their genetic molecules. We see them not only resisting the force which drags them toward chaos but even reversing the movement by becoming more and more complicated. The same evolution from the simple to the complex appears in the ideas of men, in their artistic or industrial achievements.

No doubt such changes can be identified with "movements" of the same type as the material movements inscribed in the framework of the second principle of thermodynamics, but we have already called "movement" the temporal infrastructure of the interior laws of atoms, while we are assured that there, too, it is not a question of the displacement of material objects in the usual sense of the term. Here, in this third movement, one might say that it is "forms" which are mobile, since one sees in successive epochs the same organic matter occupying structures more and more delicately organized. The use of the term "movement" is justified by the fact that we are concerned with variations in time. Besides, these variations respect a principle of contiguity, since one form gives birth to another, and so on, by small, successive modifications.

To render our symbolism more exact and Cartesian, we can imagine a space of forms[9] in which one point would correspond to a certain complex structure, for example, to a chromosome or a virus. The evolution of a phylogenetic animal line would then be represented by a series of points tracing a trajectory through that space. The points symbolizing the successive fauna of the globe would be displaced by small stages from one region to another of the space of forms.

If we apply such considerations to a material mass, isolated and not living, containing, that is, no animal or vegetable organism, we shall see the representative points of the structures present moving toward the regions of the space of forms which include systems more and more disordered and statistically simple. That is in effect the evolution required by the principle of disorganization, the principle of increasing entropy. If we now imagined that our mass of matter received from an external source a flow of free energy (or of negative entropy), the second principle will no longer be opposed to order's maintaining itself, and even growing, in that material mass on condition that it retain at least temporarily a part of this flow. Structures of increasing complexity can then appear and be conserved; for example, molecular structures of important dimensions. Calculation indicates, however, that the forms thus realized will not be very complex. A priori probabilities of the appearance of each of these forms are in fact approximately equal, of equal complexity, and the number of possibilities increases in an excessively rapid way with the complexity. This, by the way, agrees with the observations which have been made by submitting contexts properly constituted to ultraviolet rays or to electrical emanations. Quite varied organic combinations appear in these contexts but their complexity seldom passes certain limits. If the context contains the necessary nitrogen, carbon, hydrogen, and oxygen, the compounds produced under the influence of the electric current may include amino acids, groups characteristic of the constitution of proteins.

The conditions thus realized are, however, extremely favorable to the

9. A hyperspace having obviously a large number of dimensions.

production of complex groupings, requiring a considerable consumption of free energy. These groupings, called "endothermic," are those which appear at high temperature and under high pressure; but their existence is then very precarious, since the violent molecular shocks which brought about their formation demolish them just as rapidly. To the contrary, in the experiment described here the temperature is low (the normal temperature on our globe), so that, if the free energy which is brought by solar radiation or the electrical emanation produces syntheses of complex molecules, the latter are then conserved (as in a refrigerator) and not demolished immediately by thermic shocks. As, on the other hand, the density of matter is great, the concentration of complex endothermic molecules may become as important as it would be at very high temperature and pressure, but with an individual duration of existence infinitely longer. There is thus constituted a context entirely abnormal at an ordinary temperature, containing in great number these endothermic groups created by radiation and conserved by cold. These molecules turn in upon themselves and take, wherever they may be transported (particularly in the shelter of the rays which caused their birth and which might also destroy them), a reserve of negative entropy ready to work anew in the course of various chemical reactions. The Bordeaux wine of which Mauriac speaks then really carries within its substance the brilliance of past summers. But, let us repeat, without life this chemical evolution of direct products of sunlight is short lived and rapidly leads back to simple compounds, stable at ordinary temperatures. The picture changes profoundly if a living form is introduced into the context under consideration; the variety of substances is not increased, but the quantity in which certain of them are present does increase tremendously. Can it be said that such an evolution is contrary to the principle of increasing entropy? Certainly not if one evaluates, quantitatively as it were, the importance of the structuring of the context being studied. There is actually no reason to think that the total negative entropy of the system is not entirely explained at each instant by the portion of the flow, from the outside, which is there retained. It is in the structural composition of the context that the true difference is found. In the first case, without any living being, the tableau of substances present included a large number of molecules of little complexity which were continually transformed so as to occupy in the course of time all possible places. In the second case, in the presence of the germ, there appears in the picture a group of substances whose complexity becomes very great but which are well defined in number and no longer vary with time.[10] The picture thus constituted undergoes no more important variations thereafter, at least not unless the duration of the observations extends to very considerable periods of time. In this last case, as a matter of fact, we would witness the appearance of new groups of complex substances and on the whole an evolution attaining, step by step, higher and higher levels of organization. However, it must not be thought that the "secular" modifications of the picture would represent a systematic advance only toward higher complexities, for a great number of new groups of less-organized substances would also appear at the same time as the very complex bodies. Indeed, it is rather a sort of "oil-spot" invasion of the whole of the picture that this evolution should bring to mind.

We are thus in the presence of two spreading movements representing the progressive occupation of a tableau of possibilities by reality. In order to perceive the differences more clearly, let us begin with a simple structure, practically homogeneous, and introduce into it a flow of free energy, that is, of negative entropy. In the non-living case the structure is going to tend toward more complex states, made possible by the inflow of free energy, but this extension is made in a total movement, touching one by one *all* the possible complex states, deriving one from the other, and is soon lost in the sands of the immensity of realizable combinations without reaching forms of high complexity.[11]

In the living case the extension is made under the action of the same motor force, toward the same possibilities, but channeled along particular lines, so that the notion of "choice" is imposed upon us. By the very fact of that channelization, the movement of extension, limited in its diffusion, attains regions farther removed from the point of departure, more highly ordered, more complex. Never, however, at any moment, is the principle of entropy violated by the system under consideration, for the flow entering has always been very largely sufficient to compensate for the increase of order.[12]

Here, then, lies the crux of the problem—there is choice; certain combinations are favored at the expense of others, also possible, but unrealized.

10. At the same time the number of molecules of small complexity diminishes; they are in effect consumed in the course of the synthesis of more complex groupings, to which they bring the necessary negative entropy.

11. This is most probably, however, the way in which, for the first time on earth, an *autoreproductive* molecule, initial germ of all life, was produced. But a billion or two years of waiting were perhaps required for that chance to occur once. And perhaps also certain favorable circumstances aided, of which we shall speak further.

12. In fact, this passing flow may represent, millions of times, the order retained by the context under the form of organic complexity.

This choice on the molecular scale inevitably brings to mind that which Maxwell's Demon was supposed to make between rapid and slow molecules. However, an essential difference separates these two kinds of choice: in the case of Maxwell's Demon, the question was to escape to the second principle in the achievement of negative entropy, of order. And the paradox is resolved when it is perceived that the Demon—who keeps in custody the mechanism which opens or closes the door to the molecules—must receive from each molecule that approaches information relative to its speed, which is costly from the entropic point of view and which offsets, thus, the gain resulting from the choice of the rapid molecules. Here we are supposed to work within an excess of free energy—a wave of negative entropy which will be finally lost but which may be retained for a time by chemical mechanisms. The non-living context itself, thanks to molecular stability, already conserved a little of this *richesse* seized in passage, but without according any privilege to certain forms rather than to others. Let us enumerate several of the mechanisms by which negative entropy (or, again, complexity, order, improbability) stored in endothermic compounds resulting from solar action can emigrate into molecules still much more complex. One such mechanism is that of catalysis. Certain bodies, called "catalytic," facilitate the obtaining of the products of certain chemical reactions by favoring them over others. But this is merely a matter of increased speed for the privileged reactions, and the end product does not differ from that which would be obtained in the absence of the catalyst after a delay of sufficient length—a time which may, by the way, be extremely long. The catalysts often present a structure very similar to that of the bodies whose production they facilitate. In the extreme case, the most interesting for us, the catalyst determines the appearance of molecules identical to its own. It is then a self-catalyzer, or a self-reproducing molecule.

But the simple catalyst plays no "entropic"—or energetic—role, since it facilitates specific reactions to which it is adapted *in both directions* and is found, after the operation, in its initial state. Certain of the bodies produced may, however, be much higher in the scale of complex forms than any one of the bodies at the beginning of the process, on condition that among the latter there are enough which *regress* on that scale during the reaction, thus furnishing to others a supplement of negative entropy which permits them a compensatory *rise*. The catalyst then plays exactly the role of a "machine" like those which make possible the transfer of usable energy from a chemical mixture (air and gasoline) to a mechanical system (automobile) with as small a loss as possible. Here the chemical machine realizes the coupling between "exothermic" reactions which regress in the entropic scale and liberate usable energy and "endothermic" reactions which consume it. Self-reproduction of large living molecules is no doubt based on such a mechanism. Radiation from the sun (and consequently its high temperature compared to that of the earth) is always the source of the negative entropy which we recognize in all these transformations. And the end products may finally be of an order of complexity which could in no way be realized in the sun itself, because they would not benefit from that *thermic tranquillity* which they enjoyed on the earth.

To summarize, we can see how favored lines of development are, in some way, "cut out" in the table of the forms made possible by the supply of negative entropy coming from the sun. This cutting-out, which may present multiple ramifications, is determined by the catalyses and the transfers, following certain structural laws of organic chemistry, as well as by the play of natural selection among living beings which correspond to the complex molecules of the table. We shall make no attempt here to enter into the mechanism of this determination, being satisfied to consider it as conceivable. The extension of real forms in this "structured" table then no longer escapes our principles, and we find ourselves facing our third movement, that of the evolution of beings (and of ideas) with the *start of an interpretation*.[13]

We must be content, then, to ask the great questions again—with, perhaps, some more definite elements on hand—in an effort to approach the solution. Time is no longer that continuous entity, safe from attack, where one could not place even our little human present, since it found itself immediately crushed between the immense voids of the past and the future. There are true presents which introduce structures into this time; and, however great the apparent difference to us between atomic systems and our minds, this at least opens a way toward the analysis of time such as we live it. Existence, in these "beads" of present time, of times which differ by their quality from that which flows by carrying them off, but which are quantitatively in harmony with it, thus doubtless leads to a parallel distinction between the systems subject to these two sorts of time. The movements produced there, differing in their profound natures, are also in har-

13. This interpretation may be found quite insufficient to satisfy our minds. Or, rather, it might be satisfactory from the qualitative point of view—for everything we see around us figures in the table of possibilities—but not from the quantitative point of view. In fact, certain of the combinations of this table, very particular, therefore highly improbable, are present in great numbers—while billions of others, often more probable a priori, are absent.

mony at their frontiers through that essential correspondence so closely recalling the pre-established harmony of Leibniz. The stability of these monads, perfect as long as it lasts, no doubt justifies the recognition of their quality as *existing things*, secure in a universe with continuous laws—which itself can *be* only in instantaneous fashion.

But, in all this, life is still lacking. It is then that the third movement comes into play.[14] This "ascending" movement is produced within continuous time, but it is based on discontinuous existing things. There can be evolution—creative evolution—only thanks to this dualism which gives solid footing to each of the tiny steps staking out the extension of *realized* forms throughout the domain of *possible* forms. The motive force of this movement? We know it; there can be no other than the sun. Its direction? We have analyzed several of its mechanisms—catalysis, transfers, selection—surely there are others which science will discover step by step. No doubt a more subtle principle than that of entropy will one day give us views profound enough to satisfy our thirst for a "sufficient reason." This principle may perhaps be based on the notion of form, more refined than that of order, on which all our hopes have rested so far.

14. The three movements might be symbolized by the play of water under the effects of gravity and wind. In a lake, under a calm surface, inner currents can stir the surface eternally without any change in its future. An opening in the surface suddenly precipitates it into disorder without return, in the bed of a torrent. But along comes the wind, and the waves it creates strike rocks, breaking into droplets, rising always higher and higher.

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