IS THE PASSAGE OF TIME ACCELERATING?

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Abstract

"There are many different opinions concerning the essence of time", said Blaise Pascal. Words that have resisted… time itself, for time continues to engender unfathomable paradoxes and remains one of the very hardest things to think about. It has been discussed with passion since the earliest records of philosophy, when science had not yet become a separate subject.

Our classical conception of time is rooted in the subjective experience of the "passing" present, which appears to "flow" through time and thereby to dynamically separate the past from the future. This has led to the formal representation of time by the real numbers and of the present by a point that "moves" in the direction characterized by their sign.

In the first part of this lecture, we will explain the physical and philosophical consequences of that mathematical representation of time: what do we really mean when we say that time goes by along a straight line? The discussion will bring us to see how the causality principle, that forbids any travel through time, expresses itself in the different physical theories: classical physics, relativity, quantum mechanics, quantum field theory.

In the second part of the lecture, we will leave physics and try to explore our usual way of speaking about time. For example, what is the real sense of a sentence like "time is accelerating", which is often heard nowadays?

1 INTRODUCTION

First I would like to thank Jean-Louis Laclare and Joël Le Duff very much for inviting me. It's a great honour but the mission they gave me is not an easy one. They asked me to discuss the link between time and acceleration. This link is not obvious and as you will see, I will have to follow strange circuits to find it.

2 THE BEGINNING OF PHYSICS

But let's begin by the beginning, the beginning of physics. Historians agree that modern physics truly began with Galileo in the 16th century. Galileo was interested in the way things fall. He realised that if it is time rather than distance travelled that is selected as the basic parameter, then falling objects obey a simple law : their speed is proportional to the duration of their fall. This discovery contradicted Aristotle's theory of movement, which prevailed still at that time. It opened the way for the first mathematical expression of time, on which Newton based his theory of mechanics.

So we can say that the law of falling bodies marked the true beginning of "modern" physics. It concerns your speciality, which is acceleration. But until recently, its anniversary could not be celebrated as the exact date on which Galileo made this discovery was not known. All that was certain was that the law of falling bodies was not included in a work he published in 1590, but was clearly stated in his famous book (*Dialogue concerning the two chief world systems*) published in 1632. Between these two works, Galileo produced a large number of undated notes. Luckily, and partly thanks to you, the accelerator physicists, we now know the exact date on which Galileo first stated that the rate of acceleration of every free-falling body is the same. During the last months, physicists from the Institute of Nuclear Physics of Florence have subjected Galileo's notes to a proton beam. On interacting with matter, protons emit X-rays whose energy spectra indicate the nature and concentration of the different chemical elements present in the material. So these physicists made it possible to determine the amount of iron, copper and lead in the ink used by Galileo. They could establish that the ink he used when he first stated his law was the same as that used by him for writing accounts bearing the date 1604. So in two years from now, we will have the opportunity to celebrate the fourth century of modern physics.

We often explain to people that collisions of particles at high energy recreate the physical conditions of the primordial universe and, hence that accelerators are machines for going back in time. But with this new "Galileo affair", it appears that physics can now make a contribution to the writing of his own history, and not only that of the universe. Thanks to accelerators, the physics is becoming his own historian. It began by studying acceleration and now accelerators pay their debt to physics by helping it in many different fields : particle physics and nuclear physics of course, but also material sciences, biology, and <u>now</u> history. This is a kind of "dialectical inversion", as one could say.

3 DOES TIME REALLY FLOW LIKE A RIVER?

But let us return to physical time and ask some naive questions.

The physical time is always represented as a continuous line. It is often compared to a kind of river. This comparison implicitly attributes to time certain properties that rivers have and thus contains some "hidden *a prioris*" that I would like to expose.

First of all, when we say "time passes", we assert that time exists: it passes therefore it is. This expression attributes to time the status of something that is independent of things and processes. Speaking that way, we forget that the reality of time and its autonomy have been the subject of unending debate by philosophers and also by physicists. We also omit the link between time and space, as stated in the special relativity, and also its link with matter and energy, as stated by general relativity.

Furthermore, the comparison of time with a river gives rise to images that are themselves a source of difficulties : what does time flow relative to ? If it is like a river, what serves as the river bed ? What are its banks? As we see, the idea of the flow of time implies the existence of some timeless reality in which time passes. Time is therefore locked to something outside itself. So it would have to be something "outside time". But usually, time is considered to contain everything. So there is a kind of paradox hidden inside the words we use everyday.

But this is not all. When we state that time flows like a river, we assume that it has a certain speed relative to its banks. But what could be the "speed of time" ? A speed is a derivative relative to time, so the speed of time is obtained by determining how the passage of time varies relative to itself. This has no meaning. The concept of the speed of time – or the acceleration of time – has no meaning. By the way, and that's the bad news, the title of my talk is also meaningless.

4 CAN TIME STOP?

Erwin Schrödinger, who was a specialist in quantum mechanics and also in women, has given a very simple recipe for stopping time "Love a girl with all your heart" he once wrote, "and kiss her : time then stops and space ceases to exist"[1]

In fact it is not so sure. If time is like a river, it is not a pond. One flows, the other does not. Taking time to be a river means that it can never stop. However, many science fiction writers have imagined the possibility of "time stopping". They always begin in the same way: they explain that the hands of the clock stop and they deduce from it that it is time itself that is no longer flowing. But this is absurd, as if the world continues to exist, it is that the reality persists, and if the reality persists, it is indeed because it is contained in a time that gives it a duration… Even if, in this reality, nothing more occurs, even if nothing still moves there, time, itself, must remain present *to continue to make the world exist*.

Time is not only responsible for change, but also for duration. Its true suspension would mean not only immobilisation of all things, but also the immediate disappearance of the present, that is the immediate disappearance of everything that exists.

5 IS THE TIME CYCLIC OR LINEAR?

With its single dimension, time is assigned a far simpler topology than space, which has three dimensions. One can represent it by a line. This line can be open ended or looped back on itself. In the first case, it corresponds to a straight line. In the second, it corresponds to a circle. Only two types of time are therefore possible, linear time and cyclic time. Please note that this is exactly the same as for particle colliders.

Over the centuries, the idea of cyclic time, making loops in a sort of "eternal comeback", has prevailed in the major myths of humanity, in certain religions and certain philosophies. This is very surprising because the idea that a single time cycle can continue infinitely is paradoxical. For the purpose of the discussion, let us accept that such a thing is possible. There are then two possibilities : either when the second cycle is begun, the first one is remembered, in which case it is not a true repetition of the first cycle but rather a "retake" as what is being relived is not a discovery ; or (second possibility) whenever a new cycle is begun the "counters are reset to zero", each cycle is lived as a new unique event, in which case it is not a true comeback as those who live it are unaware that they are reliving it…

We scientists, like everyone else, we carry out repetitive tasks, but there are always slight differences. It happens that these slight differences can create new things. I want to give you an example. In 1931, Albert Einstein published an important paper in which he explained that the discovery of the expansion of the universe by Hubble made the cosmological constant superfluous (Einstein had introduced this constant into his equations of general relativity to enable the universe to be stationary). The exact references of his paper are:

Einstein. A. (1931). Sitzungsber. Preuss. Akad. Wiss. 235-37.

But after that, many authors quoted the paper without reading it, with the result that copying errors caused the references to change. For instance, we find the following in the literature :

Einstein. A. (1931). Sitzsber. Preuss. Akad. Wiss. 235-37.
Einstein. A. (1931). Sitsber. Preuss. Akad. Wiss. 235-37.
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Einstein. A. S.-B. Preuss. Akad. Wiss.1931. 235-37.
Einstein. A. S.B. Preuss. Akad. Wiss.1931. 235-37.
Einstein, A., and Preuss, S.B., (1931), Akad. Wiss. 235-37.

In the same way that energy can become matter, a transcription error can thus invoke a new physicist from a kind of quantum vacuum. We can confidently predict that one day a journalist will investigate the interesting case of the young physicist S.B. Preuss, who wrote a single but highly important article before disappearing from the scene.

But let us return to cyclic and linear time. On the basis of the "causality principle", physicists have established that time is linear rather than cyclic. In its classic form, the causality principle stipulates that everything must have a cause, and that the cause of a phenomenon necessarily precedes it. It is impossible to apply this principle in cyclic time as moving into the future in cyclic

[1] Cité par J. Mehra et H. Rechenberg in *The historical development of Quantum Theory*, Springer Verlag, 1987, p.409 (Erwin Schrödinger, *carnets de 1919, A propos de philosophie kantienne*).

time is equivalent to returning to the past, with the result that what is considered to be the cause could equally well be the effect and *vice versa.*

The causality principle excludes the possibility of time being cyclic.

It also excludes time travel, as this would make it possible to return to the past and modify a sequence of events that had already taken place. Such a possibility would result in extremely curious situations : a human being could eliminate from the past one of the causes of his birth, for instance by preventing his father from meeting his mother. Such a paradox is not possible in linear time because the events are then ordered in an unchangeable chronological sequence.

So, as concerns the possibility of time travel, physics bears out that it is an illusion. But many hopes were raised by Einstein general relativity. This theory does indeed appear to be extremely promising for those seeking situations which would, in principle, change the present by topological tricks. In 1937, a Scottish physicist named *Van Stockum*, discovered a solution of the Einstein equations indicating that an infinitely long cylinder rotating rapidly could act as a time travel machine. This was rebuffed by affirming that there is nothing infinitely long in nature. In 1949, *Kurt Gödel* found another solution describing a universe in rotation but not expanding in which it would be possible to travel in time simply by moving far enough from the earth and then returning. The response was that our universe is not turning and that it is expanding. In 1976, *Franck Tipler* demonstrated that to create a time machine in a finite region of space, it is necessary to build it with “exotic” material having the singular capacity of defocusing light beams by gravity. But nobody knows what this exotic material could be made of. At the present time, some physicists mention the possibilities that “worm holes” could offer. These were discovered mathematically in 1916 by *Ludwig Flamm*. They are shortcuts in the space time topology, making it possible to connect two regions that are distant from each other. A worm hole has two entrances that can be distant from each other by several million light years, but a “tunnel” in space time makes it possible to connect them by a far shorter path. An american physicist, Kip Thorne, has studied how these worm holes could be used for time travel : all that would be required would be to pass through the tunnel, and thus travel the millions of light years that separate the two entrances in a few fractions of a second, without having exceeded the speed of light. But this purely theoretical possibility is probably precluded by the fact that the worm holes would be unstable (if they do exist) : as soon as it is formed, the tunnel would be destroyed by any particle entering it. So, until proof of the contrary, we must accept that time is not a region that can be opened up to tourism.

As I already said, the argument that physicists used to preclude the possibility of time travel are based on the causality principle. This principle differs with the physics. In classical physics, it is simply a matter of assuming the time is linear and there is no return to the past in advancing towards the future. In special relativity, the causality principle is expressed by the impossibility of transmitting energy at a speed faster than that of light in vacuum.

In particle physics, the situation is more delicate since its formalism must be capable of linking quantum physics and special relativity. But, if care is not taken, the equations obtained suggest situations in which the disappearance of a particle can precede its appearance ! Accepting such situations is tantamont to denying the very existence of causality. These situations are therefore excluded by constraining the formalism with additional mathematical rules which require that the creation of a particle precedes its annihilation[2]. This constraint necessitates the existence of new particles with negative energies, described as particles which “move backward in time”. But nobody knows what “moving backward in time” means. Therefore it is better to assume that time passes in a particular direction, and that this direction is the same for all particles. Particles with negative energies which appear to move backward in time can be reinterpreted as being antiparticles with positive energy which follow the normal flow of time. These antiparticles are now well known and you can even accelerate them.

To summarise the situation, we could say that the existence of antimatter is the material (or more precisely “antimaterial”) proof that time exists and has a unique direction.

6 TIME… FROM TIME TO TIME?

Physics has always considered that space and time are continuous. Will this concept be called into question? Could it be possible to establish that space and time are discontinuous ? We all know that the continuity of space gives rise to some difficulties, as it is possible to postulate lengths which are null. This is the case when, for instance, we study the electric field produced by an electric charge

[2] More precisely, and for those who understand the jargon of theoretical physics, the causality is expressed by means of field operator switching rules. The creation operator $\Phi^{*}(x)$ of a particle at space time point x and the annihilation operator of the same particle $\Phi(y)$ at space time point y must switch for a separation of x and y of the space type and not switch for a separation of the time type: these rules prevent a particle from propagating along a space type line (which would imply that the particle would be propagated at a speed faster than light) and, for the propagation of a time type line, that the creation of a particle precedes its annihilation. These rules can only be met if the breakdown into planar waves of the field operator includes negative frequency modes. As what is to be done about these modes which, in quantum physics, correspond to negative energies, i.e. particles which move against the flow of time? We simply reinterpret them as being *antiparticles* which follow the normal flow of time. Particles and antiparticles would therefore have the same mass and opposing electrical charges. The concept of the antiparticle and that of antimatter in general is therefore the price that has to be paid to make particle physics formalism (refer to as “field quantum theory”) compatible with relativity and causality.

at a certain distance from it. This field becomes infinite when the distance becomes equal to zero. Such singularities can be avoided by using different mathematical processes which exclude them and allow calculation. But it is possible to consider, more daringly, the other alternative, i.e. that space itself could be discrete, that space could be structured in a sort of network with a mesh whose size is finite. This mesh might correspond to a minimum distance below which it would not be possible to go. Any singularities would thus be avoided. However, this approach raises other problems. For example, such a mesh would introduce preferred directions and therefore would contradict the isotropy of space and consequently, the conservation of the kinetic moment would be lost.

So it seems that the possibility of the discontinuity of space is a non-starter, a dead-lock.

However, work carried out in the eighties by the mathematician Alain Connes could change all this. His work related to what is referred to as “non-commutative geometries”. These new geometries consider spatial structures with a discontinuous nature but without contradicting fundamental symmetries. They are obtained by replacing the usual spatial coordinates, which are ordinary numbers, by algebraic operators which have the property of not commutating between each other. These operators respect certain relationships which determine the properties of space at low scale. The beauty of these new constructions is that they restitute the normal properties of space at larger scales, as if the space that we know emerges from a structure that is very different from it.

The question is : could we apply these strange conceptions to time? Could it be discontinuous? This idea has already been brought up, but never with any useful theoretical backing. In fact, it leads to terrible questions : how could time consist of discrete instants separated from each others by timeless durations? And how long might the timeless periods last ? Could there only be time… from time to time? These questions show how the idea of discontinuous time brings us back to the difficulties in imagining that time could stop.

But may be that equations are more intelligent than we are. They may express situations that we are unable to imagine or understand. True time has perhaps nothing to do with our experience of it.

7 WHY NOT A NUMBER OF TIMES… AT THE SAME TIME?

One approach for unifying the four fundamental interactions is based on the superstring theory. This theory consists in a general framework capable of integrating quantum physics and general relativity. In this scheme, the particles are no longer represented by objects without size. They become long objects with no thickness that vibrate in spaces which have a number of dimensions greater than four. More precisely, the theory replaces all the point particles we know by a single extended object, the superstring, whose different modes of vibration corresponds to different possible particles : one mode corresponds to the electron, another to the neutrino, another to the quark etc. The familiar particles correspond to the modes whose frequencies are the lowest. Other particles, which your accelerators may soon discover, would correspond to modes of higher frequencies.

To understand how the idea of increasing the number of space-time dimensions appeared, it is necessary to go back to the twenties. Einstein was wondering whether electromagnetic effects could be considered to be a geometrical property of the space-time. This approach had worked well for gravitation, that Einstein himself had rendered geometrical by means of his general relativity. Indeed electromagnetism and gravitation are somewhat similar, for example in the fact that their force law is the inverse of the square of the distance. With a view to unifying them, Theodor Kaluza and Oscar Klein suggested a theory by which electromagnetism and gravitation could be connected. They noticed that when general relativity equations were written in space time with five dimensions (four for space and one for time), it was possible to obtain both the usual equations of general relativity and also additional equations equivalent to Maxwell’s equations. A single force in a space time with five dimensions thus appeared to be equivalent to two interactions in a four-dimension space-time. Hence the idea that unification of the interactions might necessitate “enriching” the space-time topology.

The superstring theory uses the Kaluza and Klein hypothesis with a space-time with ten dimensions. Six of them would be “compacted”. They would be folded back on themselves in such a way as to be imperceptible at our scale. For a long time, it was considered that the size of the additional dimensions could not be greater than the Planck length, of around 10^{-35} metre. However, a few years ago, Edward Witten showed that the size of superstrings could be a free parameter in the theory. Since that time, more and more theoreticians consider that additional dimensions could be not as small as the Planck length. If they were of the order of 10^{-18} metre, then some of their effects could be detected by the LHC. If this is the case, accelerators would explore the deep structure of the space-time and may be show that space and time have nothing to do with our standard conception of them.

I would like to add something : in principle, it could be conceivable that one of the extra-dimensions might be temporal and not spatial. This would mean that time has several dimensions, and not only one. Only one of them, that corresponding to normal physical time, would not be rolled back on itself. But this approach is not very popular, as it would necessitate a very strong changing of our intuition. Indeed, how could we understand the existence of a number of time systems? This question becomes even harder to answer if the extratemporal dimensions are postulated to be rolled up. They would form loops, so their very structure would contradict causality, forcing particles to periodically go back in time.

They would thus constitute efficient time machines, if not for ourselves, at least for certain particles.

As can be seen, if equations continue to be daring, time may cease to be what it was, at least in the calculations of physicists.

8 IS TIME ACCELERATING?

Astrophysical data collected in recent years indicate that the expansion of the universe is now accelerating. There are in fact two types of measurements which suggest this conclusion. First of all, the analysis of the light emitted by distant supernovae. The results obtained require giving a positive value to the cosmological constant. In April 2002, this result was confirmed using another method. This method consisted in comparing the observable structures in the cosmic background noise with that of the 250,000 galaxies forming clusters identified in a systematic observation programme. The results show that the cosmological constant is between 0.65 and 0.85. The “matter” responsible for this acceleration should have non-standard physical properties. For example, it should have a negative pressure. This raises the question of its physical nature. One candidate is vacuum energy. Another is the cosmological constant itself. There are other possible candidates such as a scalar field sometimes referred to as “quintessence”. This scalar field would be the cosmic equivalent of your superconducting cavities.

The link between these new data and the passage of time seems to be non-existent. But according to some emerging theories, particularly in quantum cosmology, the passage of time is directly related to the expansion of the universe. If this expansion accelerates, the course of time should also accelerate. But it is certainly not this phenomenon that is causing the impression (that we all have) that time is now “accelerating”. As a result of doing everything we do faster and that everything is accelerating around us, we get the impression that it is time itself which is “accelerating”. Of course, this is an illusion: it is not because the time we need to do something is shorter that time itself is running faster. The course of time does not accelerate. It is what it is, irrespective of our actions : an hour lasts an hour, whatever we do. The course of time is unaffected by our *use* of time.

There is however one special field in which we are capable of accelerating time, and that is the transmutation of certain nuclear waste. As you know, this technique requires the use of accelerators. The idea is to modify certain long-lived radioactive nuclei in order to transform them into stable nuclei or radioactive nuclei with much shorter lives. The most promising approach appears to be irradiation with neutrons produced by spallation by means of proton beams impinging on a target.

With this technology, it becomes possible to assert that accelerators do not only accelerate particles. For certain nuclei that are unwilling to disappear, they will also accelerate the course of time.