From: The Physical Origins of Time Asymmetry, eds. J J Halliwell, J Perez-Mercader, and W. H. Zurek, CUP (1994)

27

The Emergence of Time and Its Arrow from Timelessness

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Abstract

An attempt is made to sketch a complete timeless theory of the universe and explain why time can nevertheless appear to flow in such a framework.

27.1 Is Time a Basic Concept?

During the Workshop, I conducted a very informal straw-poll, putting the following question to each of the 42 participants:

Do you believe time is a truly basic concept that must appear in the foundations of any theory of the world, or is it an effective concept that can be derived from more primitive notions in the same way that a notion of temperature can be recovered in statistical mechanics?

The results were as follows: 20 said there was no time at a fundamental level, 12 declared themselves to be undecided or wished to abstain, and 10 believed time did exist at the most basic level. However, among the 12 in the undecided/abstain column, 5 were sympathetic to or inclined to the belief that time should not appear at the most basic level of theory.

Although my straw-poll probably broke all rules of scientific opinion polling, and, as was pointed out to me, the question itself was likely to elicit the response I myself favoured (nonexistence of time at the fundamental level) - for what theoretical physicist will resist the challenge to reduce the world to the minimal number of basic concepts? - I think it was worth establishing that a clear majority was inclined to do away with time.

I also felt that, given the topic of the Workshop, this was a question on which we should be concentrating our minds more actively. I do believe that any theory of the world in which time is truly eliminated as a fundamental concept will have more startling consequences than many of even the most dedicated 'no-timers' appreciate. For example, a proposal made on the final day of our discussions for the cover design of the Workshop proceedings received widespread assent. Now the implication of the proposed design was that the formalism of quantum gravity admits *pairs* of solutions corresponding to expanding and contracting universes. Such an assumption brings with it the problem of why we observe only an expanding world and not a contracting one too. However, as explained below, I suspect this problem is spurious, the result of a failure to exorcise the ghost of Newtonian absolute time from a context in which it is quite inappropriate.

My own contribution to the Workshop, a slightly edited version of which now follows, is an attempt, in part still very qualitative, to sketch a complete timeless theory of the world, including an account of how sentient beings within such an atemporal world could neverless perceive it as intensely temporal. I hope it will foster discussion and clarification of the fundamental issue of timelessness.

27.2 Outline of a Timeless Theory of the World

In the theory of the whole world, time is a redundant concept. One only needs the world's possible relative configurations. Think of them as pictures, a different one for each configuration. They form the *relative configuration space* of the universe, each point of which is a distinct structured whole. The essence of this approach is structure. There is nothing else *at all* but these structured wholes.

Our primitive idea of the passage of time derives from change. If I see one picture and then another, slightly different from the first, that is already enough to give the idea that time has passed. What I want to do in this talk is explore systematically a conceptual world in which time is totally banned as a basic concept and can be recovered as an effective concept solely from differences *between* configurations (at the level of classical physics) or from structure within a single configuration (in quantum physics).

I begin with classical physics.

A *history of the world* is a curve in its relative configuration space. We can define an action between points A and B of that history using data intrinsic to the points of the history and nothing else. Take any two configurations that differ just a little. Match, in some way, all the points of the one to all the points of the other. Choose some quantity that measures the difference between the corresponding pictures at a matched pair of points. Then add up all such quantities for all paired points. The result is a global, or integrated, difference for that trial matching. Do this for all possible trial matchings and choose the *best matching*, the one that makes the global difference extremal.

That defines an action between the compared neighbouring points. Moving along the history and adding the best matching differences as we go, we determine the action of that history between A and B. One such history will have extremal action. I declare it to be the *classical history* of the world between A and B.

Let us take all the pictures corresponding to the points of this classical history and throw them down in a confused heap. Since everything has been done using data intrinsic to the configurations, nothing will be lost. The pictures still tell the same story, and we can easily put them back in their 'right' order.

The advantage of this order is that the pictures tell their story in a manner easier to read. But we can do more. There's a dynamical reason, rooted in the extremalization of intrinsic differences, why the one picture follows the next. Let us bring that out more clearly. Let us start with the picture at one end, calling it the first. Let us then take the next one and move it around on top of the first until we find the position where they are in their best matching positions relative to each other. Then we take No. 3 and move it around on top of 2 until they too are locked into the best matching position. We go on like that all the way to the other end.

To keep them safely in these special positions, we could fit them onto a 'rod', which keeps them locked into the correct mutual positions.

There is one last thing we can do. We can space the pictures out along the rod in such a way that, as we move along it, the pictures seem to change in the *steadiest* possible way. When you do this properly with the mathematical equations (Barbour & Bertotti, 1982) there is a certain spacing which is uniquely convenient. It establishes distinguished spacings between the successive pictures.

Newton called these spacings the intervals of absolute time, but in the approach being developed here his time doesn't exist at all. It's a mere convenience to think of things that way.

The thing I most want to insist on is this. Newton supposed that the different configurations of the world are realized at different instants of time. That, I believe, is a pernicious misconception. The pictures do not occur *at* instants of time. They *are* the instants of time.

Now what about the conceptual 'rod' introduced to hold the pictures in the dynamically most revealing relative positions? Newton called it absolute space. Today we call it the rest inertial frame of reference. It's just as convenient and just as redundant.

Let me summarize: If from the very outset we consider the entire world, then all of dynamics, including general relativity (*ibid*), can be recovered in this timeless and frameless fashion. Pure configuration is enough. In particular, the passage of time is nothing but the *difference* between configurations, measured and parametrized in a more or less unique manner dictated by the same action that creates extremal histories.

What then are the consequences of the nonexistence of time? An important one is this: The classical theory we have constructed has no sense of direction coded into it. Curves in the configuration space do not carry the names *past* and *future* at their ends.

This simple fact has uncomfortable implications. Despite the widespread intuitive acceptance of the contrary, there is not a double set of possible motions of the complete universe with every motion going one way matched by another going the other.

In a timeless theory, that is simply wrong. Curves are curves. They don't have arrows on them. We do not have a BIG BANG nor a BIG CRUNCH nor even their superposition, the BIG BRUNCH, but simply curves in the configuration space of the world.

How then do we have the firm conviction we live in an expanding universe? Why indeed do I think I got up this morning?

It is no answer to say that in consciousness we are somehow directly aware of the passage of time and can therefore tell which way we travel through it. No: Not only dynamics but also the sense of the passage of time must come from the bare idea of configuration.

We need the concept of *time capsules*, which I first introduce qualitatively.

A *single* photograph of a geological section shows fossils at different levels. This is history compressed into now. For those trained to see it, the apparent evidence of temporal evolution from a less structured past over a vast period of time to a more structured present is literally set in rock. All this can be present in just one configuration. Any piece of rock on the earth is a time capsule. In fact, almost anything one can get ones hands on in the real universe is a time capsule, including all matter within stars (the chemical composition of which tells a history).

A formal definition will now be helpful. A *time capsule* is a single configuration (either of the entire universe or part of it) that seems to be the outcome of a dynamical process of evolution through time in accordance with definite laws. It appears to contain records of the past, and these records are mutually consistent. By means of these records contained within a single configuration, it is in principle possible to *date* the configuration (an example that illustrates the sense in which this is meant will be given later).

I believe that the ubiquity of time capsules has not been accorded the significance it warrants. My suggestion is that the belief in time and its pasage is *solely* a consequence of the fact that, at any instant, we find ourselves within a time capsule. If there were no time capsules, there would be no notion of time.

Indeed, it is a fact that what we experience psychologically is always a time capsule; for our memory is like a progress book, with snapshots taken every day and faithfully pasted in, one next to another, the brightest and clearest from what we think was yesterday, the ones in the supposed past getting fainter and fainter. All this is coded into the brain's now. It is at least plausible that what we take to be the direct perception of motion of images in consciousness is created in our mind by the juxtaposition of several different images, like successive movie stills, in a single structure.

I will not expand here further on this question, but I think it must be addressed and at least answered in outline to make plausible the idea that a completely timeless world could still be experienced as temporal.

Let me now start on this project.

I first introduce the *heap hypothesis*. There are two heaps: the heap of all possible configurations, the *heap of possibilities*, and the heap of realized configurations, the *heap of actualities*. I use the word *heap* because the individual objects in a heap are entities in their own right. They can be picked up and examined and have an intrinsic structure which exists independently of the fact that they belong to the heap.

We have two heaps. The next question is: what are our most basic theories, those of classical mechanics and quantum mechanics, actually telling us? The heap hypothesis is that these theories are simply rules to establish which configurations from the heap of possibilities go into the heap of actualities.

The fundamental law of classical mechanics, $\mathbf{F} = m\mathbf{a}$, tells us that the heap of actualities consists of a single curve lifted from the heap of possibilities. It says nothing about *which* particular curve that will be. It merely says there will be one and only one such curve of actualities.

How are we to save the appearances in such a framework? In particular, how are we to recover that most powerful appearance, the appearance that we move forward in time in one definite direction along such a curve?

I take up one picture at random from the curve. It may well be - and there is nothing in classical mechanics to deny the possiblity - that within this single picture there are self-sentient time capsules who deduce, from everything of which they are aware in their instant, that they occur at a certain time and place on that picture-carrying 'rod' which is such a useful device for representing in a transparent way the heap of actualities as it is conceived by classical physics.

What classical physics can never do is make these experiences, which do occur, seem at all likely. For histories containing time capsules of the type we need to explain our own experiences - to say nothing of the structure we see all around us - form the minutest fraction of the set of all possible histories. It is only a partial explanation to say that exceptional conditions at a boundary selected such a history of actualities. Classical physics can never provide a complete explanation and say why a particular solution is selected.

It is the presumed *linearity of time*, the assumption that instants are realized in a one-dimensional continuum, that makes classical physics forever impotent in this question. But if we once recognize that configurations do not occur at instants of time *but are the instants themselves* and reside, not in a puny one-dimensional line, but in a huge multidimensional space of configurations, the arena is transformed.

How are we to conceive quantum mechanics in this timeless arena? In ordinary quantum mechanics, the wave function is defined on the possible configurations, which are defined in a definite inertial frame of reference, at different times.

Nothing like this can happen in the wave mechanics of the world. There is neither time nor frame, just the heap of possibilities. The wave function Ψ of the universe must be a function that takes values on the possible configurations in that heap, nothing else. This is, in fact, exactly the message of canonical quantum gravity (DeWitt, 1967). The Wheeler-DeWitt equation does not take the form of Schrödinger's time-dependent equation $i\hbar\partial\Psi/\partial t = \hat{H}\Psi$, but the form of his time- independent equation $\hat{H}\Psi = 0$. Moreover, the probabilities are for complete three-geometries and the values of the matter fields on them (i.e., for complete configurations of the universe), not for values of the metric on some underlying manifold.

What does the Ψ obtained by solution of the Wheeler-DeWitt equation mean? I go for the so-called naive Schrödinger interpretation (Kuchař, 1992). A solution of the Wheeler-DeWitt equation puts a value of Ψ and, with it, the Schrödinger density $\Psi^*\Psi$ on each configuration in the heap of possibilities. Let us then suppose that whoever or whatever creates the world puts a corresponding number of identical copies of that configuration into the heap of actualities.

The theory will have genuine predictive power if the Schrödinger density always has large values on configurations containing lots of time capsules with a structure such as we actually observe in the universe. For then, making the assumption that what we experience is probable, we shall have an explanation for our own actual experiences and the apparent emergence of time and its arrow from the timelessless of pure configuration, i.e., the theory predicts copious production of just the sort of configurations that we do actually experience.

Before outlining how this could work, let me draw the quantum parallel to my insistence that in classical mechanics there are just curves and neither BANG nor CRUNCH, which are simply not present in a timeless formalism.

In the quantum mechanics of subsystems of the world we are familiar with plane wave solutions of two forms: $e^{-i\omega t}e^{ikx}$ and $e^{-i\omega t}e^{-ikx}$. Out of them we can construct wave packets that move to the right and to the left. This has a good meaning in ordinary quantum mechanics because there is an external time and frame in which we can see, more or less literally, that the packets really do move in those directions.

But in the quantum mechanics of the universe it is quite common to set up a Wheeler-DeWitt equation for the scale factor a of a Friedmann universe and obtain for it two fundamental solutions of the form $e^{-iS(a)}$ and $e^{iS(a)}$, where $S(a)$ is a solution of the corresponding Hamilton-Jacobi equation.

These are said to represent expanding and contracting universes, respectively. There are two severe problems with this.

First, there is no additional factor containing the time, which is what gives genuine motionic content to wave packets in ordinary quantum mechanics.

Second, the fact that the two solutions exist at all as simultaneously valid solutions is solely a consequence of the fact that the Wheeler-DeWitt equation has been taken to be a real equation but has been allowed to have complex solutions. However, I believe that a real equation should have real solutions, and then the above alleged distinction between expanding and contracting universes cannot be expressed. One may also ask whether a real equation gives a true representation of the full Wheeler-DeWitt equation for the universe when all known interactions are taken into account. In fact, I think the Wheeler-DeWitt equation must be essentially complex (Barbour, 1993). But a function and its complex conjugate cannot simultaneously be solutions of a complex linear equation. One way or another, the possibility of associating directions of motion with phase relationships in complex solutions seems to me most questionable if used in the context of the complete universe, though it is obviously valid for subsystems. On this particular point, my approach is radically different from the approach that seems to be taken thoughout the literature, including Halliwell's contribution to these proceedings.

To summarize, my conclusion is this: If we take the timeless approach seriously, then in neither the classical nor the quantum dynamics of the whole world does the theoretical formalism say anything about directions of motion of the complete world. Any conclusions of that type must be drawn from the *intrinsic structure of individual configurations*; they cannot be based on conjectured external structures. That is why the notion of time capsule is essential in a timeless theory. An arrow of time or motion can emerge only through the preferred selection of time capsules.

Now is that likely to happen? This brings me to what, so far as I know, is a new proposal (however, see Zeh, 1989). It is, I believe, the first attempt made at this workshop to find a genuine explanation of the arrow of time, as opposed to a description of it.

My conjecture is that the ultimate origin of the arrow of time is the *asymmetric structure* of the configuration space of the world. Let me note first that this configuration space is a vast and curious place. It has what in atomic physics Schrödinger (1926) called *natural boundaries*. In the cosmic context, these are, on the one side, the boundaries of zero size of the world and zero intensity of the fields in it. On the other side, they are the frontiers of infinite size and infinite field strength. Moreover, because the scale factor can have only positive values, the configuration space is decidedly lopsided! And that is just on the basis of the configurations that make up its points. We must also consider the effect of the variational principle defined on it. I think of the configuration space as a curiously shaped continent in the sea of nothing and the variational principle as putting a rich and even more asymmetric topography on that continent. Potentials are always represented as hills, valleys, wells, and walls. The configuration space of the world must be criss-crossed by the most extraordinary mountain ranges, ocean troughs, odd shaped obstacles, and so forth.

Above all, superimposed on everything is one prevailing direction, arrow if you like: from the small to the large and from low to high intensity. Pronounced structure and inhomogeneity (through still with a centre of symmetry that is absent in the cosmological case) is already clearly expressed in the picture of a far less exotic configuration space shown in Fig. 27.1. It is a projection of the configuration space of four particles on a line that interact through short-range forces. The fourth particle is at the origin. The pronounced structure is built into the configuration space by the existence of a natural origin, where all the particles sit on top of each other, and the barriers that spring up whenever two particles meet.

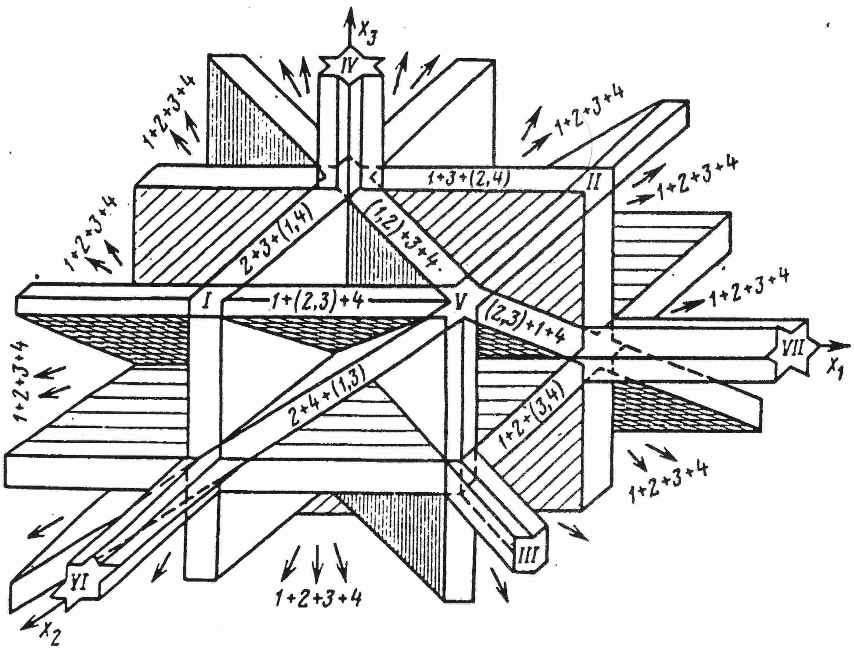

Fig. 27.1. Regions of (short-range) interaction of four particles in one-dimensional motion. Particle 4 is fixed at the origin. [Reproduced from: Zakhar'ev, B. N., Kostov, N. A., & E. B. Plekanov (1990) Exactly solvable single-channel and multichannel models (lessons in quantum intution). *Soviet Journal of Particles and Nuclei*, **21**, 384–405].

Now my conjecture: Any allowed solution of the Wheeler-DeWitt equation will be characterized by a very strong asymmetry which is imposed on it by the profound asymmetry of the configuration space on which it is defined. This asymmetry will be expressed in the preferential concentration of high values of the Schrödinger density on configurations that contain time capsules. If this is correct, the asymmetry of the world's configuration space is the ultimate origin of our belief that time exists, flows, and has an arrow at whose tip we now sit.

To make this more plausible, it will be necessary to show how the time-dependent Schrödinger equation can emerge together with classical worlds out of the timelessness of the Wheeler-DeWitt equation (discussed by Halliwell in these proceedings). It will also be necessary to explain how quantum mechanics can be interpreted on the basis of the two heaps - those of possibilities and those of actualities and to show how there is no need for collapse of the wave function in a cosmic context. That will also show why time is not an operator in ordinary quantum mechanics. If all this succeeds, the end result will be a modification of Everett's idea: not a many-worlds but a *many-instants* interpretation of quantum mechanics.

This task will be taken up elsewhere (Barbour unpublished).

Note added in revision (August 1992). Several months after the Workshop, I

was lucky to have some extensive discussions with Dieter Zeh about the ideas expressed above. I should like to thank him for the suggestion, adopted here, to emphasize in the formal definition of a time capsule that it must contain *mutually consistent* records. He also drew my attention to many close parallels between my configuration-based many-instants interpretation of quantum mechanics (and my insistence that the notion of a past and a future arises exclusively from juxtaposition of mutually consistent records in the now) and J. S. Bell's gloss of Everett's many-worlds interpretation in his paper "Quantum mechanics for cosmologists" (Bell, 1981). In fact, Bell regarded the really novel element of Everett's theory as the "repudiation of the concept of the 'past' " and said that it could be considered "in the same liberating tradition as Einstein's repudiation of absolute simultaneity." Despite this, later in the same paper Bell declared Everett's replacement of the past by memories to be a "radical solipsism" and rejected it for that reason.

However, neither Everett's proposal nor mine is any more solipsistic than more conventional interpretations. They merely postulate a different external reality. It may also be noted that Bell did not discuss the Wheeler-DeWitt equation; had he done so, he might have been forced to take timelessness more seriously.

I would also like to take this opportunity to mention that, since the Workshop, I have discovered the notion of a time capsule (the significance of which I postulated purely speculatively at Huelva as the only possible way in which a notion of time can arise in a timeless context) is beautifully realized in Mott's account of the formation of straight tracks of alpha particles in cloud chambers (Mott, 1929). Mott's paper [the great importance of which for the interpretation of quantum mechanics is underlined by Bell (*ibid*)] shows clearly that solutions of the *time-independent* Schrödinger equation can be concentrated to an extraordinary degree on configurations that are time capsules in the sense of my definition. (Any photograph of a track in a cloud chamber is a time capsule. Moreover, it carries its *own date*, so to speak: from the configurations of the tracks in a photograph of a cloud chamber one can in principle determine the time that elapsed between the interaction event that produced the particles and the photographing of the tracks they produced.) It should be said that Mott obtained his solution by making important tacit assumptions (essentially, the assumptions under which time-independent scattering theory is equivalent to the time-dependent theory). I believe that the elucidation of the conditions under which Mott-type solutions can be obtained in the context of the Wheeler-DeWitt equation will cast much light on the origin of time and its arrow. This work is in hand.

Finally, I should like to thank Jonathan Halliwell for several helpful suggestions for revision of this paper.

Discussion

Gell-Mann Do the configurations come with an ordering?

Barbour No, if by ordering you mean in a one-dimensional continuum, but yes if you mean ordering as the points of a multidimensional space. The example I give is the set of all possible relative configurations of N particles in Euclidean space. Each distinct configuration of the N particles is a point of the configuration space. Another example is DeWitt's superspace of all possible closed Riemannian three-geometries. Except at the frontiers of the exceptional configurations that exhibit symmetries, such configurations can be ordered.

Unruh 1) What is the measure you take over the configurations? The Born-Oppenheimer density means nothing unless you also have that measure. 2) What about alternatives like momenta, or do you believe that they are also figments of our imagination?

Barbour 1) As yet I have no definite proposal, but you are, of course, right that a choice must be made. I believe this is an important but secondary matter. 2) In the attempt to set up a timeless formulation of quantum mechanics, I do incline to think of configurations as ontologically primary and concepts like momentum as elements of the theory which explain why there is a high probability of realization of certain configurations. (For me, a theory such as quantum mechanics does not exist in any material sense, but I certainly would not regard it as a figment of my imagination.)

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