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THE PHYSICS AND METAPHYSICS OF TIME

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ABSTRACT

We review the current situation in the philosophy of time, partly to investigate Michael Dummett's complaint that the philosophy of physics has become too specialized and technical to be able to communicate with mainstream philosophy. We conclude that the situation in this case is different: there is no special difficulty of intelligibility – the obstacle for communication between science and philosophy here is rather that what physics, or science in general, tells us is prima facie in conflict with common sense and intuition. We argue that this difficulty is indeed prima facie: on closer inspection it appears that the scientific B-theory may explain our intuition better than the A-theory, even though the latter at first sight seems to completely mirror our direct experience.

Keywords: philosophy of time, physics and metaphysics, flow of time, block universe

1. Introduction

Michael Dummett (2007, 25; 2012, 19) has complained that "philosophers of physics speak a technical language among themselves, and fail to communicate with other philosophers in the mainstream." There is no denying that examples exist to which this characterization of the philosophy of physics applies. Still, as a general claim it is unjust; and one may even wonder whether it is not more appropriate to complain that many mainstream philosophers take uneducated intuition more seriously than the results of modern science. To illustrate this counter position, we may take the current situation in the philosophy of time as a case in point. No high-brow technical knowledge is necessary to understand what modern physics has to tell us about time. But the mere tension with immediate intuition seems sufficient for many philosophers to push this physical picture aside.

The most striking difference between time and space is the dynamic character of time. Space is static, but in direct experience time is fleeting: time passes. This characteristic feature of experiential time is taken as metaphysically basic in the A-theory of time, in McTaggart's famous terminology. According to this A-theory the passage of time is not only a feature of our experience, but also characterizes time itself, independently of any experience of it: time really flows, with a Now that constantly shifts the boundary between Past and Future. By contrast, the B-theory of time only recognizes temporal *relations*, like "earlier than" and "later than", without the identification of a moving Now (McTaggart 1908; Dummett 1978; Oaklander 2004; Dolev 2007; Dainton 2010).

In theoretical physics, both classical and relativistic, time is used in the spirit of the B-theory. The four-dimensional Minkowski diagrams of special relativity are typical: they represent (parts of) the history of the universe, extended both in time and space, by specifying all events at their dates and locations, together with their spatial and temporal interrelations. The important point is that there is no preferred Now in these diagrams, let alone a flowing Now.

Because of this use of B-type notions, the objection is not uncommon in philosophical circles that theoretical physics, and more generally fundamental science, omits essential features of real time: it does not do justice to time's dynamism. Moreover, it is sometimes suggested, the reason may be one of principle – perhaps fundamental science just *cannot* deal with the Now (e.g., Zimmerman 2008), because its methodology makes it blind for this aspect of reality. The argument is that it is an essential aim of fundamental science to formulate universal laws, which automatically implies a restrictive focus on those features of the world that do not depend on what time it is *now*. Physics only pays attention to features that apply to all places and times, and by this narrowing of vision throws away the possibility of understanding the peculiarity of the Now.

By contrast, the A-theory does not neglect the Now and moreover appears to fully account for our experience of passage. The explanation it offers is simply that our experience is faithful to reality itself: time actually passes. So there may appear to be a strong argument here for the priority of the A-theory: the A-theory is both descriptively and explanatorily more complete (cf. Zimmerman, 2008). As soon as we leave the restricted and impoverished domain of scientific methodology and physical representations, and turn to reality in the fullness of its real properties, we automatically arrive at the A-theory of time.

It is the purpose of this article to critically analyze the just-sketched plea for the A-theory. First we shall review in some detail the way physics deals with time, both in classical mechanics and in relativity theory, in order to have a better look at the reasons why physics makes use of the B-theory. Then we shall explore the explanatory resources of physics (and fundamental science in general) *cum* B-theory with respect to our temporal experience, in particular our experience of passage. We shall argue that the above-mentioned explanatory incompleteness of the B-theory is illusory: there is no reason to think that the B-theory cannot explain our experience of passage and the intuitions we have about the Now. Then we shall return to the A-theory and investigate its possibilities of explanation. Perhaps surprisingly, it will turn out that it is unclear how the A-theory can live up to its promises here. Even if time were exactly as the

A-theory says it is, with a moving Now, it would remain obscure how this should figure in an explanation of our *experience* of passage. On balance then, the B-theory will turn out to fare better than the A-theory *vis-à-vis* the explanation of our temporal experience.

This then leads us to the question of whether, and if so in what way, physics may be able to determine, and change, our metaphysical conception of time. We shall defend the stance that if it is correct that physics and the B-theory can explain the very experiences and intuitions on which the A-theory is predicated, without the additional theoretical superstructure introduced by the A-theory, there is no justification for accepting the A-theory as metaphysically preferable. In this case we should overcome our intuitive inclinations and opt for the B-theory.

2. Time According to Physics

Present-day discussions about physics and time are typically conducted within the framework of relativity theory. Let us first consider special relativity: this theory positions all events in the history of the universe in a four-dimensional manifold of points, Minkowski spacetime. Minkowski spacetime possesses a definite geometrical structure, deriving from a distance function *ds* between neighboring spacetime points. This distance function is well-defined regardless of whether or not actual physical events, matter or fields are present. Even in completely empty Minkowski spacetime there thus exists a definite spatiotemporal structure. Just as in ordinary Euclidean geometry, comparisons of distances makes it possible to distinguish between curved lines and straight lines (although there are technical differences: straight "time-like" lines in Minkowski spacetime realize the *longest* distance between points, instead of the shortest distance of Euclidean geometry). Straight time-like lines in Minkowski spacetime represent uniform inertial motion of material bodies; straight lines that realize null-intervals represent rays of light ("light-like" world lines). Curved (i.e. not straight) time-like world lines correspond to accelerated motions of particles. Given any particular point in Minkowski spacetime, the straight world lines going through it and representing light form two cones, the future and past light cone, respectively.

It is an essential characteristic of this Minkowski spacetime structure that no time function is defined on it. This is quite different from the situation in classical, pre-relativistic physics. According to Newtonian theory, once we have chosen any particular event as our time origin, and have decided on a time unit, each event in the history of the universe can be assigned a definite time; this defines a time function on spacetime points. But according to relativity theory we cannot consistently assign one physically meaningful time value to events in this manner. In relativity theory time appears in a new form: the theory operates with the integral of the distance function, $\int ds$, between pairs of points on time-like world lines in order to represent *time intervals*. That is, take any pair of points on a time-like world line, and calculate $\int ds$ between them along this world line. The resulting number has the physical interpretation of the lapse of time that would be measured by a clock whose motion between the two point events is represented by the world line in question. Time therefore enters in special relativity in the form of the *duration* of processes: the time taken up by a process between two points in its existence. It is only this time that occurs in the equations and is relevant for the evolution of physical processes.

As a consequence of this lack of a time function, no definite answer can be given to the question of what the time difference is between any two given events. Everything depends on which world line – a curve in Minkowski spacetime – between the events in question is considered, or in other words, which process between the two events we look at. Different world lines lead to different values of $\int ds$ calculated along them, and this means that different processes connecting the same two events consume different amounts of time. An illustration of this basic feature of relativistic time is the notorious case of the twins, one of whom stays on Earth while the other departs on a space journey and subsequently returns: there is no fixed amount of time between the events of the parting and reunion, respectively, of the two twins. In accordance with what was said above about the longest distance being realized by straight lines in Minkowski spacetime, the amount of time along the world line of the Earth (taken to be an approximately straight line, i.e. a world line representing inertial motion) is greater than the time interval along the world line of the space traveler. The traveler therefore returns younger than his or her twin brother or sister.

This peculiar structure of relativistic time has an immediate consequence for the notion of *simultaneity* in relativity theory. Suppose we take any given event as our origin, and ask for all events that happen one unit of time later. In Newtonian spacetime the answer to this question is given by a collection of *simultaneous* events, all being one time unit later than the original event. These events cannot be mutually connected by ordinary signals (these take time, which would make one event later than another) but can only interact via *infinitely fast* processes (that do not need time for their propagation). In relativity theory the situation is very different, however, as we can see by considering the twin case again. By travelling fast enough (with a speed arbitrarily close to the speed of light) along a non-inertial path we can push the events at which one time unit has lapsed arbitrarily far into the future of events that are one time unit later from the origin as measured along a straight inertial world line. So the collection of events "one time unit later than a given event" does not define a sensible notion of simultaneity: actually, these events fill almost the whole future light cone of the originally given event (more precisely: it is the set of all points within the future light cone that are to the future of the hyperbola with Minkowski distance 1 from the origin).

In fact, there is every reason to be suspicious about the physical relevance of any notion of simultaneity at all that could be proposed within relativity theory. At the very least such a notion should satisfy the requirement that any two events that are simultaneous cannot be connected by a causal signal (signals cannot have infinite speeds in relativity: the maximum signal speed is the speed of light – causally connected events stand therefore in the "earlier-later" relation to each other). But this means that by definition in relativity theory simultaneous events should be unable to "feel" each other: no physical contact is possible between them. In other words, any viable notion of simultaneity can only group together events that are causally cut off from each other. These events consequently cannot work together and will not function as a physically coherent whole (more precisely, they cannot do so by virtue of being simultaneous; it could be, of course, that there are relations between them because of common causes in the past).

The rigorous background of what was just said is provided by the *locality* of all physical interactions in relativistic physics. According to the relativistic laws governing the evolution of physical processes, material bodies and fields can only feel and influence each other per space-time point at which they are co-present. What physical changes are brought about by the interaction at a space-time point is independent of what goes on elsewhere but only depends on the local situation (which in turn depends on events in the past lightcone). How one groups distant events together under the denominator "simultaneous" is therefore immaterial for what happens in physical processes. In accordance with this, simultaneity does not play any role in the laws of relativistic physics.

Nevertheless, it is possible to split up four-dimensional Minkowski space-time as a stack of three dimensional spaces (so-called "foliations" of Minkowski space-time), and one may think of these three dimensional spaces as "spaces at one instant of time". Some of these ways of taking the four-dimensional manifold apart so that a stack of "spaces-at-a-time" results are more natural than others, given the symmetries of Minkowski space-time. In particular, a natural foliation is given by cutting Minkowski space-time up in slices that are perpendicular (in the Minkowski-geometrical sense) to a set of parallel inertial world lines. This leads to what is known in the literature as "standard simultaneity": Minkowski orthogonality with respect to inertial, straight world lines. Each inertially moving system (or "observer" as the tradition often wants it) thus has its own standard simultaneity.

Since the beginning days of special relativity there have been debates about whether this standard simultaneity is merely conventional or possesses an objective status (cf. Dieks, 2010). For the purposes of this article we do not need to enter into this discussion, however. For us it is sufficient to note again that simultaneity, in whatever way defined, cannot play a causal role in the laws of relativistic physics. By virtue of their locality these laws can be written down without employing any concept of simultaneity at all. Empirical predictions made with these laws are consequently independent of which events one considers to be simultaneous. (In fact, exactly this latter observation grounds the idea that relativistic simultaneity is merely conventional. As already alluded to, one may object to this conventionality claim on the basis of symmetry considerations relevant to foliations of space-time – but this does not touch the point we are making here, which is about the *dynamical* irrelevance of any notion of simultaneity.)

Special relativity is not the latest word in space-time physics, and we should at least glance at the changes that are made necessary by the general theory of relativity. We can be brief about this, however, at least for the purposes of our present discussion. It is true that the space-time structure of cosmological models allowed by general relativity may deviate very much from that of Minkowski space-time. Intuitively, the space-time structure of general relativity stands to the space-time structure of special relativity as the geometry of a curved two-dimensional surface (perhaps with a non-standard topology, for example with holes in it) to the Euclidean geometry of the plane. One may imagine a general relativistic space-time to be formed from Minkowski space-time by cutting away pieces of it, and/or applying deformations that introduce curvature. In small pieces of general relativistic space-time, however, the relations between events remain like those in Minkowski space-time. This is analogous to the fact that in small portions of curved two-dimensional surfaces Euclidean relations hold to good approximation: small portions of such a curved surface can be approximated by the Euclidean plane that is tangent to the curved surface at the position of the portion. It follows that our earlier conclusions concerning time in relativity also apply to the situation in general relativity. Because the laws are still local, it is sufficient to consider small portions of space-time to study the nature of causal relations, and we find that these exhibit the same structure as in special relativity. Material bodies have world lines that are contained within the light cone, light is represented by the light cone itself, time enters as the duration $\int ds$ along world lines, and simultaneity still plays no role in determining the outcome of physical processes.

It is worth-while to compare this situation in relativity theory with the one in classical, Newtonian physics. As we have seen, in special relativity no time function on space-time points can be defined that corresponds to the time governing physical processes. The same is true in general relativity. But in Newtonian physics there **is** such a function: Newtonian space-time is a stack of spaces-at-a-time, with the foliation provided by Newtonian absolute simultaneity. This foliation is causally significant, because a clock travelling at an arbitrary velocity, i.e. a clock whose world line has an arbitrary slant in a space-time diagram, will measure the time corresponding to these hyperplanes of simultaneity. That is, the next tick of this clock will occur when its world line crosses the simultaneity hyperplane that lies one time unit to the future. The time that can be measured this way governs the evolution of physical processes in Newtonian theory. So time has a global significance in classical physics, whereas it is only local in relativity theory.

But there are also similarities between relativity theory and pre-relativistic physics. Causal signals in Newtonian physics are propagated by physical processes, and the standard example of these are moving material bodies. Processes of this kind are local: a moving particle can only influence a physical situation where it is, and it needs a finite time to go from one place to another. Of course, an important difference with relativity theory is that in classical physics there is no maximum signal velocity. However, any specific material body will move at some finite velocity and will therefore take time to transfer information. That means that events that are *simultaneous* cannot receive direct information about each other via such traveling material systems. Nevertheless, instantaneous information exchange *is* possible in Newtonian theory, by virtue of the existence of action-at-a-distance. The prime example is provided by gravitation: changes in the gravitational field do not take time to propagate, they make themselves felt instantaneously over the whole universe. It is therefore possible after all, in classical physics, to feel what is simultaneously going on at other places. But this is so only because of the supposed existence of a peculiar class of causal signals that propagate infinitely fast, along hyperplanes of simultaneity. In other words, even in classical physics there is no possibility for the global present to make itself felt *per se* at a particular location, just by representing the same instant of time. The causal and dynamical relevance of the present in Newtonian physics entirely derives from the existence of specific physical processes, namely action-at-a-distance signals.

3. Why the B-Theory is Supported by Physics

Suppose the A-theory of time were right. Should we in that case expect physicists to no longer use their four-dimensional representations, e.g. the Minkowski diagrams from special relativity? Would they be compelled to insert a privileged Now? Certainly not. Four-dimensional representations can be used completely independently of the question whether the A or the B-theory is correct, and such representations are widely used also outside of physics. Any history book contains examples through its specification of events at certain places and times – the truth of such a historical account is independent of what time it is now. The same applies to the television guide for next week, or the railway timetable for next year. Any representation of the history of the universe during part of its existence can do without the specification of a Now. Such a representation, if correct, will be reliable quite regardless of what time it is. This is evidently completely independent of the validity of relativity theory and the appropriateness of Minkowski space-time. Even in classical Newtonian physics it is standard to represent (parts of) the history of the universe in a four-dimensional picture without a privileged Now, in this case by means of events placed in Newtonian space-time.

Therefore, the "eternalist" or "block universe" representations are not confined to physics and are not immediately linked to the B-theory. Within physics the block is not specific for relativity theory but can equally be applied in classical physics (or Aristotelian physics, for that matter). In all these cases its use is independent of any argument that the Now does not exist. Conversely, the fact that a four-dimensional block representation is used does not speak immediately against the Now and the A-theory of time.

In the Introduction the argument was mentioned that physics is only interested in relationships that hold independently of time and place and can therefore only be expected to operate without a Now. Physical laws express connections that hold universally throughout the history of the universe; the Now is therefore by definition irrelevant to physics, so the argument goes. This diagnosis of the absence of the Now from physics boils down to the assertion that the physics is the same at different temporal positions of the Now. An absence of the Now from physics for this reason would of course not count against the Now's existence. Moreover, a moment of reflection shows that time invariance is not essential to our topic at all: even if physical laws were time and position dependent, physics could still do without any privileged instant in time, with four-dimensional pictures that would look the same as the usual ones. The only difference with our actual situation, in which the laws are supposedly time invariant, is that a time dependence of the laws would have to be introduced in the block universe. But this can obviously be done in a tenseless way, without the introduction of a shifting Past, Future and Present. Both the A and the B series are compatible with time independent as well as time dependent laws – the issue of time invariance is logically independent of the question of whether or not there exists a moving Now.

The upshot of the foregoing is that the mere absence of a privileged Now from the four-dimensional representations of the history of the universe, or from physical theory, does not tell us much. It certainly does not prove the non-existence of a moving Now. What, then, is the reason for thinking that physics lends support to the B-theory of time?

The reason is that physics *cum* B-theory is explanatorily complete, or at least promises to be so. There is no reason to think that physics is unable to explain, within the framework of the B-theory, anything one could ask it to explain. Moreover, there is every reason to think that the A-theory cannot add to the explanatory resources provided by the B-theory. As we shall see more clearly in a moment, the A-theory necessarily introduces concepts that are foreign to physics and complicate the description of events; but it does so without bearing new explanatory fruit. If this is correct, the B-theory is better supported than the A-theory. Indeed, in this case the B-theory is part of the conceptual machinery needed to arrive at the explanatory successes of physics, and is therefore (at least partly) supported by these successes. The A-theory adds conceptual wheels without additional proceeds: the extra wheels (i.e., precisely the features that define the differences between A and B time) consequently remain without support.

In order to argue this point in more detail we need to be explicit about what needs to be explained. I take it that physics needs to account for, in principle, all physical properties that are instantiated during the history of the universe. This includes the details of the states of physical systems at all times and positions, and the causal relations between them. It also includes the differences between past, present and future that we observe: physical things now should be distinguishable from physical things in the past and future (taking into account temporal asymmetries, e.g. those relating to differences in entropy).

The actual explaining here is evidently an immense task, and moreover we must assume it to be impossible, strictly speaking, with the theories we have at our current disposal – these theories will undoubtedly prove wrong in their details, just as Newtonian theory has been shown wrong by relativity and quantum theory. But we can still investigate the possibilities of principle here. In particular, we can look at what kind of things theories like Newtonian mechanics, special relativity and general relativity together with the B-theory can explain, and whether we can be satisfied with the general nature of these explanations.

It is easy to see that the laws of physics, together with boundary or initial conditions (that do not need any appeal to the Now as the time to which they refer!) lead to exactly the kind of four-dimensional picture that we discussed above. The laws propagate data from one Cauchy surface to another, regardless of how these surfaces are situated with respect to a supposed Now (a Cauchy surface is a hyperplane on which initial/boundary conditions fix a unique solution of the differential equations that represent physical laws). In Newtonian physics the time dependence of the laws is, as we have pointed out above, such that processes will measure the time lapse between hyperplanes of absolute Newtonian simultaneity; in special and general relativity the *time intervals along world lines* govern processes. This leads to a difference in temporal structure: in Newtonian physics events are totally ordered in time, whereas in relativistic physics the order is only partial. But in both cases all usual distinctions between events can be made: all events occur at their own positions and times, they differ from events at other positions, and also differ from earlier and later events. There is becoming and change in this picture in the following sense: events occur after each other in time, displaying different qualities at different instants.

The argument for the B-theory announced above is that this picture is explanatorily complete. This may sound as a sleight of hand: it may seem that the argument is question-begging, because the Now was not among the things for which an explanation was required to start with. Small wonder then that the explanatorily complete picture that results lacks a Now. Against this we maintain that everything for whose existence there is empirical support is contained in this four-dimensional B-picture. The picture comprises all earlier-later relations, all causal links, and – we contend – all processes of change and becoming. Everything that happens in the history of the universe has its counterpart in the four-dimensional representation.

This will probably not convince the critic, who will repeat that there *is* something that remains unexplained in the four-dimensional picture, namely exactly the Now. In the next two sections we shall respond to this claim in two ways. First, we shall argue that our *intuition* that there is a moving Now is explainable with the resources of standard physics, within the four-dimensional block. Second, we shall elaborate on the point that to make metaphysical sense of a Now and its motion, new concepts – foreign to science – have to be introduced, but that this additional conceptual machinery remains explanatorily empty, even as far as the explanation of our experience is concerned. On balance then, there are no good reasons for doubting that everything for which we have empirical warrant will turn out to be explainable within the B-theory; introduction of the A-theory does not enhance our arsenal of acceptable explanations.

4. Physics, Experiential Time and the B-Theory

By virtue of the locality of the laws of relativistic physics there are no causal connections between what happens in a point of space-time and what goes on at space-like separation from this point. That means that for purposes of physical explanation extended nows, i.e. hyperplanes of simultaneity, are irrelevant. Events at any space-time point should be explained by an appeal to events at that point or within its past light cone (why the *past* light cone is relevant, instead of the future light cone or both light cones, is an important question in itself – but in this article we accept this asymmetry as given). Signals that reach a space-time point come from the past, not from distant events located in the same present.

The same type of observation applies to the physical explanation of events in a finite region of space-time: only the past of such a region is explanatorily relevant. A notion of time passage that makes contact with physics, in particular the dynamics governed by physical law, should therefore not make use of distant simultaneity. Rather, any physically respectable notion of passage, or time flow, should be *local* (Dieks 2006).

A fortiori, when we attempt to find a physical explanation of human time experience, simultaneity and an extended Now can only be irrelevant notions. Any physical explanation of the way we "feel" time should make use of our local situation in space-time and the antecedent conditions in our past light cone. It is consequently not important for the purposes of such a physical explanation whether or not a global foliation of space-time is possible at all and, if so, whether or not there is a unique preferred foliation. From the perspective of physics it is irrelevant for the explanation of our temporal experiences and, in particular, our intuition that we are living in a privileged extended Now, whether or not there is some preferred physical simultaneity hyperplane.

This is true in special relativity, with the consequence that the notorious debates about the observer dependence of special relativistic standard simultaneity have no relevance for the physical analysis of our intuition of an extended Now. The same diagnosis applies to attempts that introduce preferred simultaneity hyperplanes in Minkowski space-time by hand (resulting in a neo-Lorentzian space-time). Such attempts are often criticized for the arbitrariness that is involved in the definition of the hyperplanes in question, but this is already doing them too much honor: to the extent that such projects are motivated by the desire to make contact with experienced time and our temporal intuitions, they are non-starters.

The situation in general relativity is basically the same. Certain general relativistic universes (cosmological models; solutions of the Einstein equations) can be foliated; others cannot. Of the universes that can be foliated certain types possess a foliation that may be called preferred because of its simplicity and symmetry (this is the case, e.g., in Robertson-Walker cosmological models). It is frequently suggested that these distinctions are of great significance for the analysis of the status of time in the corresponding universes, but from what we have argued it should be clear that this is incorrect as far as experienced time is concerned. For experienced time the backward lightcone is the only explanatorily relevant region of space-time, both in general and special relativity.

Even in Newtonian space-time the significance of distant simultaneity for experienced time is doubtful. It is true that action-at-a-distance exists according to Newtonian physics, and that causal influences can therefore propagate along hyperplanes of absolute simultaneity. But in Newton's mechanics it is only gravitation that propagates infinitely fast in this way; and it is hardly plausible that our time awareness has anything to do with gravitational interactions between us and far-away masses. The addition of electric signals (Coulomb's law) does not help: positive and negative charges shield each other off, so that in practice no effects of long-range Coulomb forces can be felt. So even within the Newtonian world picture the explanation of our intuition that there is an extended Now with which we are in immediate contact cannot be directly grounded in the existence of a relation of distant simultaneity.

What is more, this intuition *can* be explained in a completely different way. The immediate contact we seem to have with spatially distant regions is in fact mediated by light: we *see* the extended Now (Butterfield 1984). Our strong feeling of immediacy is due to the fact that the speed of light is huge compared to other speeds we encounter in daily life and to the circumstance that objects around us typically do not change that much during the time that light needs to reach us. We know that the speed of light is actually finite, but it is so enormous compared to the speeds of ordinary processes that we are familiar with, that it seems infinite. Put differently, we cannot easily obtain information showing us that the things that we see are past. Signals coming from distant objects reach us from longer ago than signals from objects that are nearby, but under ordinary conditions these time differences are too small to be translated into perceptible changes (cf. Callender 2008).

The physical structure that plays an explanatory role with respect to our intuition of a spatially extended Now thus is the backward light cone. If we represent our own lives in Minkowski space-time by means of world lines (this is obviously an idealization; but using world tubes of finite width, while being more accurate, does not change the general picture), this backward light cone is well-defined at each point of our world lines – that is, at each instant of our lives. Physics thus possesses the conceptual means for explaining that during our lives we always have the impression to be in direct simultaneous contact with distant regions. The explanation here is a typical B-theory explanation. No special instant is singled out: the same explanatory story applies to each and every point on our world lines. As we shall see, this is also characteristic of the physical explanations that may be given of other temporal experiences and intuitions.

Our awareness extends over a brief interval of time, of the order of magnitude of one second (or a bit less, depending on the person – the *specious present*). So what we experience as one moment is in fact extended in physical time. It has often been suggested that the brief duration of this specious present can be explained with the help of arguments from evolutionary biology: the amount of information that can be gathered during such a relatively short time interval is sufficient as a basis for the expectations and actions needed in ordinary life. If our time awareness were restricted to a single point instant, it would be impossible to be directly (i.e., without invoking memory) aware of change because there could be no comparison, in direct experience, of states of objects at different physical instants. On the other hand, a specious present longer than the actual one would need more storage room in our brain without a compensating appreciable gain in useful information, and would therefore constitute an evolutionary disadvantage. Of course, this is only an outline of an explanation; but still, it is clear that B-type arguments of this kind can be applied to the situation. Accounts of this type lead to a picture in which there are short temporal spans of awareness (specious presents), strung all along the world line of a sentient being. There is no preferred Now in this picture: the specious presents are all there in one and the same four-dimensional diagram, each centering on its own central instant along the world line. Given their lengths of something like one second, we must assume that these specious presents overlap (compare Dainton 2010, ch.7).

Obviously, there are many biological/physiological questions concerning the precise mechanisms to be answered here, but these scientific questions would not change if we introduced a preferred Now along the world line. If anything, the situation would become more complicated by the introduction of such a Now, given the extendedness in physical time of the specious present. In particular, if presentist notions were to be connected with the preferred Now, we would have to face the consequence that part of our temporal awareness refers to non-existing states of affairs. The tenseless presence of all specious presents along the world line of a conscious organism avoids all complications of this kind.

The situation is similar with respect to our feeling of flow and passage, the experienced dynamism of time. There is strong empirical evidence that differences in sensory input at different instants can result in a perceived feeling of flow, or of continuous motion. For example, the repetition of a brief sequence of pictures of a road, punctuated by a blank picture, creates the impression of continuous motion along the road (Mather 2010). In this case there is obviously no special “flow quality” in the input itself: there just is a brief period of time during which one picture is visible, later a similar period with a second picture, and so on; this can all be described in the B-manner. But the *perception* of this sequence is characterized by a feeling of dynamism, of continuous change and flow, at each instant. There are also many examples in which one and the same picture is presented to an observer during a longer period of time. If there is spatial variation in the picture, a strong feeling of motion may result (a so-called “motion illusion”). Apparently, the combination within the specious present of focuses on different spatial parts of the picture can produce this feeling of continuous change. One of the interesting things is that the experienced feeling of change and flow in these cases is constant: although the physical input consists of different pictures at different instants, the perception is one of permanent flow.

It appears therefore that our brain responds with a continuous feeling of change if its specious presents are filled with sensory input that is not temporally uniform. Again, there are a lot of questions here about details that need to be answered, but these are questions about the mechanisms of perception in the ordinary scientific sense: they do not require assumptions about preferred instants and their motion (see Dainton 2010, chapter 7 for more details). Of course, a consequence of the B-like approach is that what is explained here, our feeling of flow, does not refer to any specific privileged instant. All B-type explanations apply tenselessly, in this case to each and every "present" along the world line of a sentient being. But combined with the result that our awareness is coupled to brief specious presents, brief time intervals that are perceived as undivided wholes, this reproduces exactly what we know from direct experience: our being in one now that is characterized by a perceived quality of transience. The addition to this story of an objective, mind independent preferred Now that is really shifting would not increase our possibilities of explanation. Because this Now and its motion are not part of physical theory they cannot help us in constructing a scientifically acceptable explanation of our perception.

5. The Explanatory Resources of the A-Theory.

As mentioned in the Introduction, the main motivation for the A-theory comes from the expectation that this theory will be able to provide a quick and convincing explanation of our experience of flow. As Le Poidevin (2009) writes:

> Now one very serious challenge to the tenseless theorist is to explain why, if time does not pass in reality, it appears to do so. What, in tenseless terms, is the basis for our experience as-of the passage of time?

and:

> Even if the tenseless theorist can discharge his obligation, the doubt remains that the tensed theorist can produce a simpler explanation of our experience.

In the foregoing we have argued that there is no problem of principle for the tenseless B-theory in explaining our experience of passage. But we should also comment on the second challenge, that even if the B-theory is successful here, the A-theory still does better.

We have already noted an important problem with this claim: the central concept occurring in the A-theory (the Flowing Now) does not make contact with the physical description of the world and cannot function in physical explanations (cf. Price 2011). Even if we forget about the Flow and just associate the Now with some notion of simultaneity, we face the problem that distant simultaneity is causally insignificant and therefore meaningless for the physical explanation of our experience, as we have noted before. It is true that a *local* now *can* play an explanatory role in physics, but it does so without any Flow associated with it. As we have seen, the consequence is that all physical explanations apply equally to each point along the world line of an organism that experiences time, without singling out any preferred now. Because science (in particular evolutionary biology) also tells us that the temporal extension of our time consciousness is finite but limited, we end up with a scientific account according to which we feel time passing at each (specious) present of our lives. What more could we wish? This question epitomizes the dilemma for the A-theory: there does not seem to be any empirical evidence that is not covered by the B-theory, and there is no reason to think that the B-theory cannot be explanatorily complete with respect to our experience – if this is true, what can be added or simplified by the A-theory? By definition, any such addition or simplification must be independent of scientific theorizing. But in this case it becomes a truism that application of the A-theory can never lead to adding to or simplifying a *scientific* explanation.

Evidently, there are reasons here for the suspicion that A-theory explanations merely introduce additional "wheels" compared to scientific explanations, without adding substantive content. There certainly will not be any new empirical content coming from the A-theory, or a new light on physical mechanisms, so isn't the A-theory's function just to tell a story that is reassuring to pre-scientific intuition? Perhaps unfortunately, this fear is not removed by looking at examples of A-explanations given in the literature (e.g., Maudlin 2007, criticized by Price 2011; a further sample from recent defenses of the A-theory is: Hinchliff 1996, 2000; Markosian 2004; Skow 2009, 2011; Tallant 2010; Zimmerman 2005, 2008; and references cited therein).

First the A-theory faces the notorious problem of making sense of the motion of the Now at all: ordinary motion consists in spatial variation as a function of the independent variable "time", but this definition is obviously unavailable in the case of motion of the now itself. In the literature one finds basically two sorts of attempts at solving this problem. In the first a "supertime" T is introduced: the Now is located at time t_1 at supertime T_1. This supertime T can now serve as an independent variable: the Now is flowing at the speed $\mathrm{d}t/\mathrm{d}T$. The second, more common, attempt consists in the introduction of primitive tense operators. As pointed out by Skow (2009) however, these tense operators mimic the results of the supertime approach, although without the explicit introduction of supertime. For example, the following statement using the primitive tense operator "it will be the case", "*It will be the case* that the Now is located at t", is equivalent to "Relative to a point of supertime Later than the Current one, the Now is located at t" (in which Later and Current, with initial capitals, refer to instants of Supertime rather than time). So these two seemingly different approaches are really equivalent. Both clearly introduce elements foreign to scientific theory, either in the guise of supertime or in that of primitive tenses. To reiterate our earlier question: How could such concepts explain anything about time as it is known from experience and science? It soon turns out that they are not really intended to do so. Listen to Skow (2011), who explains and defends the achievements of the A-theory:

> "B-theorists say that change is variation in ***time***. But I say:

> ***Real*** *change* is variation in ***supertime***."

So the very explanandum is redefined, in a way that depends crucially on the new primitive terms (supertime or primitive tense) – whose meaning obviously cannot be reduced to that of concepts we already know, since they are primitive. Small wonder that the explanations for the motion of the now that are subsequently offered strike one as freely floating in thin air. After having posited the basic explanatory principle "Change is the engine that pushes the Now into the future", Skow (2011) explains the motion of the Now as follows:

> "There is irresistible pressure for the universe to change; but the universe cannot change if the Now remains at one time";
>
> "The pressure forcing the universe to change, then pushes the Now into the future."

Both explanandum and explanans here are metaphysical in the bad sense that they do not relate to anything empirical and are fully detached from science. An account of this kind can have no explanatory relevance for our experience of time.

6. Conclusion: The Physics and Metaphysics of Time

Metaphysics in connection with scientific theorizing has become a popular subject during the last couple of decades. Think of the debates surrounding the interpretation of quantum mechanics; e.g. the discussions about the nature of measurement, or about the nature of identical particles, or about the question of whether particles exist at all. What is at stake in these debates is the construction of a consistent picture of fundamental physical reality, constrained by what we know from physical theory. In order to make this project possible, there must be relations between the metaphysics and the physics: they must be dealing with the same subject matter. In the cases just mentioned, physical theory *underdetermines* the structure of the not directly observable parts of reality, which creates room for non-empirical factors in the evaluation of rival world pictures. The closeness of fit with the structure of mathematical physics, the simplicity and elegance of this fit, and the explanatory power that is produced are some of the non-empirical virtues to consider here.

Although the Flowing Now A-metaphysics of time is usually presented as a project of the same kind (in particular, it is often discussed in connection with relativity), the situation here is significantly different. The central concepts and explanatory principles of the metaphysics of the Flowing Now do not connect to physical theory at all, and are unable to produce explanations in combination with the theoretical framework of physics. To use perhaps old-fashioned terminology, the Flowing Now appears to lack cognitive significance, and one is reminded of Carnap's notorious criticism of Heidegger (in connection with the Nothing).

On the basis of criteria like those just-mentioned (closeness of fit with science, simplicity, explanatory power) one can only conclude that the A-theory does not perform adequately.

The B-theory does much better. It is able to operate with terms that have a meaning within the conceptual framework of physics and the rest of science, and is in a position to provide explanations for our temporal intuitions. The version without an extended now, i.e. the version in which the now is local, is particularly convincing: it fits modern physics closely, and shares the simplicity and elegance of relativity. Isn't it time to adapt our intuitions, and to do away with the Flow of the Now?

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