Relativity Theory may not have the last Word on the Nature of Time: Quantum Theory and Probabilism

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Abstract
Two radically different views about time are possible. According to the first, the universe is three dimensional. It has a past and a future, but that does not mean it is spread out in time as it is spread out in the three dimensions of space. This view requires that there is an unambiguous, absolute, cosmic-wide "now" at each instant. According to the second view about time, the universe is four dimensional. It is spread out in both space and time - in space-time in short. Special and general relativity rule out the first view. There is, according to relativity theory, no such thing as an unambiguous, absolute cosmic-wide "now" at each instant. However, we have every reason to hold that both special and general relativity are false. Not only does the historical record tell us that physics advances from one false theory to another. Furthermore, elsewhere I have shown that we must interpret physics as having established physicalism - in so far as physics can ever establish anything theoretical. Physicalism, here, is to be interpreted as the thesis that the universe is such that some unified "theory of everything" is true. Granted physicalism, it follows immediately that any physical theory that is about a restricted range of phenomena only, cannot be true, whatever its empirical success may be. It follows that both special and general relativity are false. This does not mean of course that the *implication* of these two theories that there is no unambiguous cosmic-wide "now" at each instant is false. It still may be the case that the first view of time, indicated at the outset, is false. Are there grounds for holding that an unambiguous cosmic-wide "now" does exist, despite special and general relativity, both of which imply that it does not exist? There are such grounds. Elsewhere I have argued that, in order to solve the quantum wave/particle problem and make sense of the quantum domain we need to interpret quantum theory as a fundamentally *probabilistic* theory, a theory which specifies how quantum entities - electrons, photons, atoms - interact with one another probabilistically. It is conceivable that this is correct, and the ultimate laws of the universe are probabilistic in character. If so, probabilistic transitions could define unambiguous, absolute cosmic-wide "nows" at each instant. It is entirely unsurprising that special and general relativity have nothing to say about the matter. Both theories are pre-quantum mechanical, classical theories, and general relativity in particular is deterministic. The universe may indeed be three dimensional, with a past and a future, but not spread out in four dimensional space-time, despite the fact that relativity theories appear to rule this out. These considerations, finally, have implications for views about the arrow of time and free will.

1 Two Views about The World

Ordinarily we think of the world as a three-dimensional place, with a past and a future. Things change. Time passes. Future events, after a time, occur now, and then become a part of the past, but none of this means that we ordinarily think of the universe as spread out in both space and time, objects having temporal parts and temporal extension in the same way that they have spatial parts and spatial extension.

Only when we think of the distant past - and perhaps the distant future - is there a temptation to think of time in spatial terms, so that the distant past is, as it were, "another place". Science fiction about time travel exploits this tendency. It exploits our tendency to think of the distant past, and distant future, as distant "places" which we might travel to, for example in H.G. Well's Time Machine.

Why are we prone to think of distant times on analogy with distant places? This, I think, is the reason. When we travel through space, we encounter new objects - new houses, cities, landscapes. But this is ordinarily hardly the case if we stay in the same place, and allow minutes or an hour or two to pass. The distant past - or the distant future - is, however, likely to contain objects quite different from those around us now (unless, perhaps, we are in some very ancient building). Hence, there is the temptation to think of distant times as "distant places" which we might visit if only we could discover how to create a viable time machine.

Much of the apparently baffling nature of time arises, I think, from a common sense tendency (to which some philosophers seem prone) to try to combine these two ways of thinking about time - or rather, two ways of thinking about the nature of the world, the three-dimensional view[1], and the four-dimensional view.[2] We entertain the broadest possible perspective, and consider the entire history of the universe, from its beginning in the big bang to its end in the big crunch, or from eternity to eternity (if eternal it should be). There is all of reality stretched out before the mind's eye, from the most distant past to the most distant future, and encompassing our present existence and time, now. But then we become aware of something missing: the present. If the universe really is stretched out in time, as it is stretched out in space, the vital *now* of present existence seems somehow to be missing. And so we attempt to add it, by adding a moving "now" along the time line, a brilliant light of existence, moving steadily from past to future.[3]

At once a host of baffling questions arise. Why is the dimension of time so profoundly different from the other dimensions of space? What is it that marks out "the present moment" from all other moments, past and future? What is it that causes "the present" to be so different from all other times? Why does "the present" move as it does, from past to future? What causes it so to move? How fast does it move? Do we need another dimension of time to mark the movement of the present along the time line? How long does "the present" endure? Does "the present" exist objectively, or is it no more than a subjective experience? Is time travel, back into the past, or forward into the future ahead of the passage of "the present", possible? What is it about time that enables it steadily to digest the future, turning it first into the present, and then into the past? What exactly do these mysterious transformations consist in? What keeps the present remorselessly travelling into the future and away from the past? There is, in the constitution of things, it seems, a mysterious process of *absolute becoming,* when events in the future enter the present and become *actualized*; for an instant they blaze into existence before disappearing into the shadows of the past. But what is this process of *absolute becoming*? How is it to be understood?

All these baffling questions only arise because, probably without even being aware of it, we have tried to combine two views about time, or rather two views about the nature of the universe, that are in flat contradiction with one another, and cannot be combined. The two views are the three-dimensional view of the universe, and the four dimensional view. Granted the four-dimensional view, "now" is like "here": it is just where you happen to be. There is no such thing as "the objective now" - or rather, all moments are equally entitled to be called "the objective now". Granted the three-dimensional view, there is no such thing as "the objective now" either. There is just the three-dimensional universe as it is *now*. That is indeed all there is. The past and the future are not "places" separated from us by temporal "distance". In speaking of events "that lie in the past", or "in the future" we are speaking metaphorically about what has been and what will be: no more. Objects are spread out in space, but not in time; it is facts about objects, their histories, that can be represented as being spread out in time. Such space-time representations depict, not objects, not the world, but facts about objects, facts about the world. And whereas the four-dimensional view needs to appeal to distinctive phenomena - irreversible processes, the second law of thermodynamics - in order to account for the direction of time, the distinction between the future and the past, the three-dimensional view does not need to make any such appeal. That time goes by in one direction, and the future becomes the past, is built into the nature of time, according to this view. Even if the universe one day degenerates into a state such that no irreversible processes occur, still time would pass from the future to the past.

2 The Impact of Relativity Theory

Up until 1905, it seemed as if science was indifferent between the two views, three and four dimensional. Then along came Einstein's special and general relativity, in 1905 and 1915, and it seemed that theoretical physics had declared unequivocally in favour of the four-dimensional view.[4] The three-dimensional view, sometimes called *presentism*, was, it seemed, decisively refuted.

Let E_1 and E_2 be any two events separated in space and time in such a way that light cannot travel from one to the other. E_1 might be the event of me typing "E_1" into my computer, while E_2 might be a short-lived flare occurring abruptly on the surface of the sun at a time that is simultaneous, for me, with me typing "E_1". Einstein's theory of special relativity now tells us the following. In some reference frames, E_1 occurs *before* E_2; in other reference frames, all moving with respect to the first set, E_1 occurs *after* E_2; and in a third set of reference frames, all stationary with respect to me, E_1 and E_2 occur simultaneously, at the same moment. Furthermore, according to special relativity, all these reference frames are equally viable. No one reference frame can be picked out as the proper, unique, objectively correct one.

The consequences for the three-dimensional view - presentism - are devastating. For the three-dimensional view only makes sense if there is, at every instant, a unique, cosmic-wide "now" - the three-dimensional universe as it is at this instant. If this does not exist - if there is no such thing as the unique, cosmic-wide "now" at each instant - as special relativity tells us, then the three-dimensional view becomes incoherent. What is required to exist for it to be viable does not obtain. The three-dimensional view is refuted by special relativity. And general relativity just confirms the point. Modern theoretical physics obliges us, it seems, to accept the four-dimensional view, with all its disturbing implications. The universe just *is*. The passage of time is an illusion. There is no such thing as the objective "now". All instants, everywhere, at all times and places, are equally entitled to be regarded as "now", just as all places are equally entitled to be regarded as "here". Free will becomes no more than an illusion since, if everything, past, present and future, just (tenselessly) *is*, what we do now cannot affect in any way what will come to be, in the future. Even more seriously, perhaps, our whole world - or at least the way we ordinarily conceive of the world in terms of the three-dimensional view - turns out to be an illusion. The four-dimensional "block universe" (as it is sometimes called) is very different from the three-dimensional world of human actions, persisting and changing things.

3 Special and General Relativity are both False

If general relativity is true, then special relativity is false. Special relativity requires space-time to be flat. General relativity, however, tells us that space-time becomes curved in the presence of matter, or energy-density more generally - energy associated with radiation as well as matter. Wherever you go in the universe, however far from stars and galaxies, the presence of matter, or energy-density, even if distant, still curves space-time very slightly, according to general relativity. Special relativity is thus false everywhere; and in some places, near black holes for example, where space-time is subjected to marked curvature, special relativity will be quite badly false.

But what of general relativity? Is it false? There are three grounds for holding that it is.

First, general relativity seems to be incompatible with quantum theory. Attempts to unify the two theories so far have failed. Many theoretical physicists believe string theory will unify relativity theory and quantum theory.[5] Other theoretical physicists strongly disagree.[6] So far, string theory has not been confirmed experimentally.

But even if string theory, or some other theory, does succeed in unifying general relativity and quantum theory - or the standard model, the quantum field theory of fundamental particles and the forces between them - in all likelihood, the unifying theory will reveal that general relativity is false. Almost always when two theories, T_1 and T_2 are unified by a new theory, T_3, it emerges that T_3 is incompatible with the predecessor theories, T_1 and T_2, and reveals these theories to be false.[7] Here, then, are grounds for holding that general relativity will eventually turn out to be false.

Second, almost all fundamental physical theories so far proposed that have been accepted because of their immense empirical success, have turned out subsequently to be, strictly speaking false. This is true of Kepler's laws of planetary motion, and Galileo's laws of terrestrial motion: see note 7. Special and general relativity reveal that Newtonian theory is false. James Clerk Maxwell's classical theory of the electromagnetic field reveals that predecessor laws of the electric force between charged particles, and the magnetic force between magnetic poles, are false. Quantum theory reveals that the whole of classical physics is false (Newtonian and Maxwellian theory). Relativistic quantum theory (quantum field theory) reveals that non-relativistic quantum theory is false. It is all too likely, then that current accepted fundamental theories of physics, general relativity and the standard model, will turn out to be false too, when a better theory emerges that unifies these current theories.

Third, there is an argument which provides strong grounds for holding that any dynamical theory of physics, which is about a restricted range of phenomena only, must be false. It goes like this. Theoretical physics only ever accepts *unified* fundamental dynamical theories, even though endlessly many empirically more successful disunified rivals are always available. This means that physics accepts a substantial metaphysical assumption about the nature of the universe: it is such that all (precise) disunified dynamical theories are false. The universe is such that some kind of unified pattern of physical law runs through all phenomena. Some such thesis as this is as secure an item of theoretical scientific knowledge as anything theoretical can be in physics. It is so secure, indeed, that physical theories that clash with it are rejected out of hand - not even considered - whatever their empirical success might be if they were considered.

Despite the validity of this argument, and its widespread dissemination in the literature since it was first published over 40 years ago in 1974,[8] it is still almost universally ignored. This is because it clashes with the orthodox conception of science firmly and almost unthinkingly taken for granted by scientists, philosophers of science and the public alike. This conception holds that, in science, evidence alone decides what theories are to be accepted and rejected. Considerations that have to do with simplicity, unity or explanatory power may influence choice of theory too, to a limited extent, but not in such a way that the world itself, or the phenomena, are permanently assumed to be simple, unified, or comprehensible. The decisive point is this: *no factual thesis about the nature of the universe can be accepted permanently, as a part of scientific knowledge independently of, and certainly not in violation of, the evidence*. This orthodox view, widely taken for granted, I call *standard empiricism*.

The above argument concerning persistent acceptance of unified theories demonstrates, however, that standard empiricism is false. Persistent acceptance of unified theories when endlessly many empirically more successful disunified rivals are available means that science *does* make a big, persistent assumption about the universe independent of the evidence (even

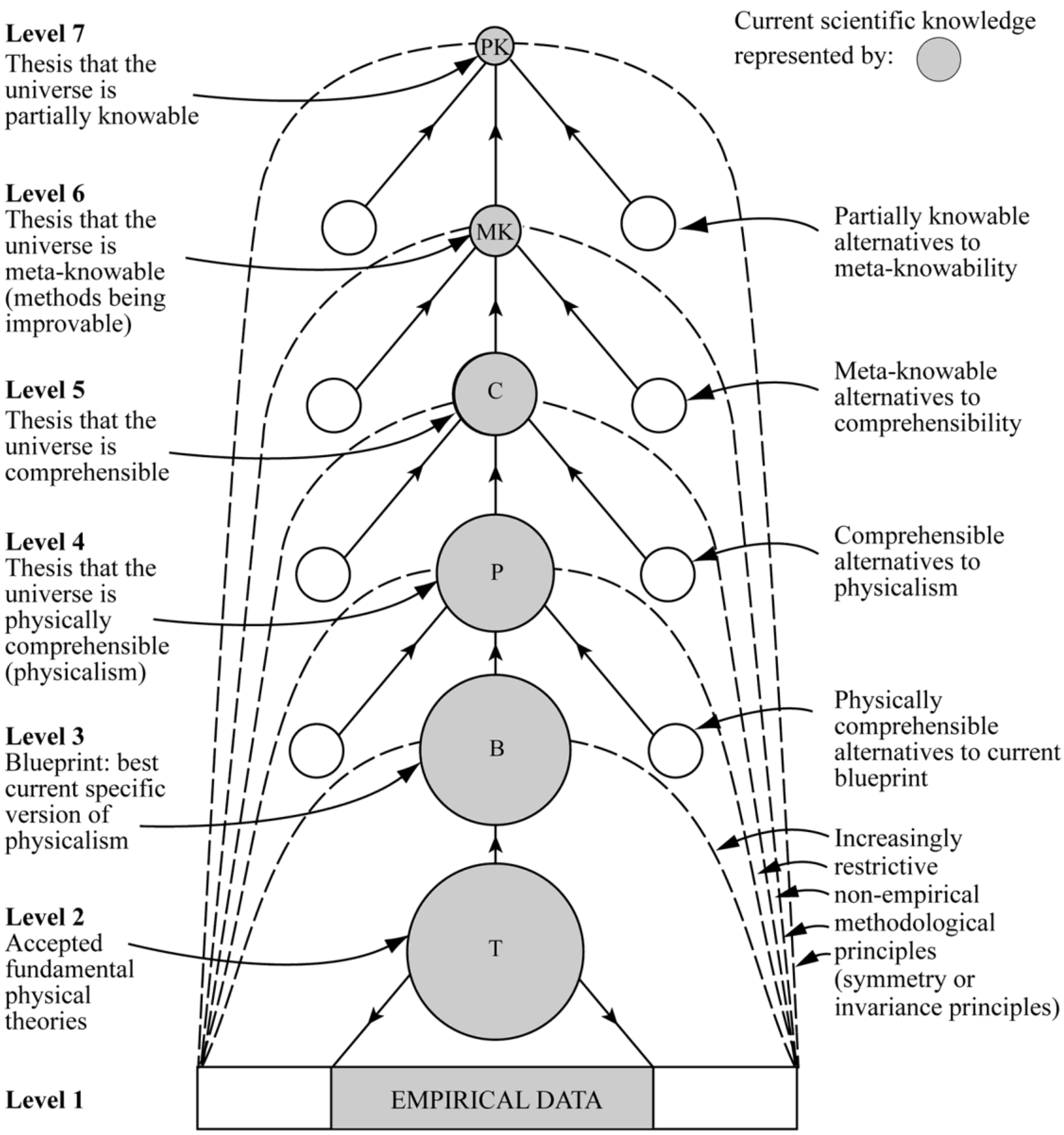

Figure 1: Aim-Oriented Empiricism (AOE)

in a sense in violation of the evidence): the universe is such that some kind of unified pattern of physical law runs through all phenomena.

This thesis is, however, profoundly problematic. We have no reason to suppose that it is true. Even if it is true, the specific version of it that we hold at any stage in the development of physics is almost bound to be false. A glance at the history of physics reveals that we have changed our ideas a number of times as to what kind of unified pattern does run through all phenomena. I argue that we need a new conception of scientific method which facilitates the *improvement* of the big, problematic, metaphysical assumption physics is obliged to make. We need to represent this assumption in the form of a hierarchy of assumptions, these becoming less and less substantial as one goes up the hierarchy, and so more and more likely to be true, and more nearly such that the given assumption needs to be true for science, or the pursuit of knowledge, to be possible at all: see Figure 1. As we descend the hierarchy, from level 7 to 3, assumptions become increasingly substantial, and increasingly likely to be false and in need of revision. At levels 6 to 3, we choose that assumption which (a) accords best with what is above in the hierarchy, and (b) has led to, or promises to lead to, the greatest empirical growth at levels 1 and 2, the levels of experimental results and testable theory. As physics advances, and we improve our knowledge and understanding of the universe, we improve assumptions and associated methods at levels 3 and 4; improving knowledge leads to improving assumptions and methods - improving knowledge about how to improve knowledge. There is something like positive feedback between improving scientific knowledge at levels 1 and 2, and improving knowledge about how to improve knowledge. Science adapts its nature to what it finds out about the nature of the universe - the key to scientific rationality which helps explain the astonishing, explosive growth in scientific knowledge. I call this hierarchical view of science *aim-oriented empiricism*.[9] One day, aim-oriented empiricism will replace the untenable but at present orthodox view of standard empiricism. In what follows, I take aim-oriented empiricism for granted.

At level 4 in the hierarchy of theses there is the thesis that the universe is such that a unified pattern of physical law runs through all phenomena. I call this thesis *physicalism*. According to aim-oriented empiricism, physicalism is a pretty secure item of theoretical scientific knowledge. So secure, indeed, that any physical theory that clashes with it is to be rejected on that account, whatever its empirical success may be.

Physicalism tells us that, whatever it is that determines precisely the way some specific kind of phenomenon evolves in space and time is precisely the same as that which determines the way *all* phenomena evolve, whether they be at the centre of the earth, inside our heads, or inside the sun. This has the consequence that a theory that is precisely correct about the way any specific phenomenon, or any limited range of phenomena, evolve must thereby be correct about the way *all* phenomena evolve. This in turn means that a theory that is about a restricted range of phenomena only - so that it cannot be generalized to apply to all phenomena - must be only approximately valid about the phenomena to which it does apply. That is, it must be false. As far as fundamental physics is concerned, in order to be true about *anything* a theory must be true about *everything*. The only serious candidates for truth are so-called "theories of everything" - theories about all physical phenomena.

All physical theories so far developed (with the possible exception of string theory) are about restricted ranges of phenomena only. Hence, they are all false - even if some, such as quantum theory, are incredibly successful empirically, in making accurate predictions about a vast range of diverse phenomena. In particular, then, general relativity is false - despite its unity, and its empirical success.

Both special and general relativity are false.

4 Is The Three Dimensional View Viable Given that Relativity Theory is False?

Does the falsity of relativity theory mean that the three dimensional view can be salvaged after all? That is by no means obvious. The falsity of relativity theory does not mean that all the empirical predictions of the theory are false as well. Indeed, we know that this is not the case. Special relativity is astonishingly successful empirically, and is integral to quantum electrodynamics, quantum electroweak theory, quantum chromodynamics, and the so-called *standard model* that puts these three theories together. And general relativity has met with predictive success as well. If special and general relativity imply that the 4 dimensional, spacetime view is true, then this implication may well be true even though the theories, from which it is derived, are ultimately false.

Everything depends on *how*, *in what way*, relativity theory is false.

Here, I explore the possibility that general relativity is false because it is a deterministic theory but the basic laws of nature are fundamentally probabilistic.[10]

5 Probabilism, Quantum Theory and The Three Dimensional View

Orthodox quantum theory (OQT) fudges two basic questions about the quantum domain:

1. What sort of entities are the objects of the quantum domain: electrons, photons, atoms?
2. Is the quantum domain fundamentally deterministic or probabilistic?

The first problem arises because electrons, atoms and other quantum entities seem, mysteriously to have both wave-like and particle-like properties. Niels Bohr, Werner Heisenberg, in developing quantum theory (QT), decided that the quantum wave/particle problem could not be solved and, as a result, developed QT as a theory, not about quantum entities as such, but rather about the results of performing measurements on quantum entities. The version of quantum theory that emerged - OQT - avoids specifying what sort of entities electrons and atoms are when not being observed, but pays a very heavy price as a result. OQT is obliged to call upon some part of classical physics for a treatment of the measuring process. OQT cannot predict the outcome of measurement without classical physics, for that would require OQT to be able to specify, in a consistent way, what quantum entities are, and it is just this that OQT cannot do. (If OQT is applied to the measuring process, a further measurement must be made before OQT can issue in physical predictions.) Thus, the theory that makes physical predictions is quantum theory *plus some part of classical physics*. And this theory is unacceptably *ad hoc* and disunified, precisely because it is made up of two incompatible parts that are only rendered compatible by arbitrarily restricting their respective ranges of application (quantum postulates to quantum states, classical physics to macro measuring instruments).[11] As we saw in section 3 above, a physical theory, in order to be acceptable, must be (a) sufficiently empirically successful and (b) sufficiently unified. OQT satisfies condition (a) magnificently, but fails dismally to satisfy condition (b).

Failure to solve the quantum wave/particle problem also leads to the failure of OQT to answer unambiguously whether the quantum domain is deterministic or probabilistic. According to OQT, quantum states evolve deterministically, in accordance with Schrödinger's time-dependent equation. Probabilism only enters in when measurements are made. But OQT is wholly ambiguous as to whether measurement really does involve the occurrence of objective probabilistic events. On the one hand, OQT in general makes probabilistic predictions about the outcome of measurements. But, on the other hand, OQT can hardly be interpreted as asserting that probabilistic events really do occur when, and only when, measurements are made. Is it conceivable that the universe would have had to wait for billions of years for physicists to make measurements, and thus provoke probabilistic events to occur for the first time? Secondly, if Schrödinger's equation is applied to the measuring process, everything proceeds *deterministically*!

In order to develop an acceptable version of quantum theory (QT), the above two questions must be clearly answered, and not just fudged. Granted that both determinism and probabilism are possible, are there any grounds for favouring one over the other?

There are. OQT, despite being unacceptably disunified, is nevertheless quite astonishingly successful empirically. OQT predicts a greater variety of phenomena with greater accuracy than any other physical theory. It has never been refuted. OQT has evidently got a great deal right about the quantum domain; it is just that it fails to solve the wave/particle problem, and thus must incorporate measurement into the theory, thus rendering it unacceptably disunified.

What all this suggests is that we should, initially, seek to keep as close to the structure of OQT as possible, and modify the theory just sufficiently to eliminate the devastating defects of the theory: the failure to solve the wave/particle problem, the resulting need to call upon measurement in an essential way, and the failure to answer the question: Is nature deterministic or probabilistic?

In order to do this, the decisive step we need to take is to eliminate "measurement" from the basic postulates of the theory.[12] That in turn requires that we solve the wave/particle problem. Probabilism, dramatically, enables us to do both!

OQT says: quantum states evolve deterministically, in accordance with Schrödinger's equation, until a measurement is made, when (in general) something ostensibly probabilistic occurs. If we adopt the conjecture of probabilism, we can modify this very slightly (implementing the above plan), so that QT asserts: quantum states evolve deterministically, in accordance with Schrödinger's equation, until *specific quantum mechanical physical conditions* arise, and an *objectively probabilistic event* occurs.

At once we have a solution to the wave/particle problem! Given probabilism, "Are quantum entities waves or particles?" is the wrong problem. Waves (or fields) and particles come from *deterministic* classical physics. If probabilism holds, and quantum entities interact with one another *probabilistically*, they ought to be quite different from classical deterministic entities, such as classical waves or particles. Granted probabilism, the wrong, traditional question "Waves or particles?" needs to be replaced by the two correct questions: "What kind of unproblematic, fundamentally probabilistic entities are there, as possibilities?" "Can we see quantum entities as some variety of these possible, unproblematic, fundamentally probabilistic entities?" Fundamentally probabilistic entities may be called *propensitons*.

Propensitons could be such that probabilistic events occur continuously in time, or they could be such that their physical state evolves deterministically until specific physical states of affairs arise, when and only when a probabilistic transition occurs. We may call the latter *intermittent propensitons*. Our strategy is to stick as close to the structure of OQT as possible. This requires that we hold that electrons, atoms and the rest are intermittent propensitons.

The simplest, most elementary example of an intermittent propensiton that one can think of is the following. It is, initially, a tiny sphere, of a definite radius. This expands, at some fixed rate until it touches another such sphere. That is the condition for both spheres to shrink instantaneously into the initial tiny spheres, each to be located probabilistically somewhere within the volume of its big sphere state.

We can now make this intermittent propensiton a bit more interesting by postulating that each sphere has within it a "stuff", which varies in density in a wave-like way. The density of this "stuff" determines the probability of location of the tiny sphere. Already we have an entity which can begin to mimic the behaviour of quantum entities. We can imagine sending a stream of these "spheres" at a two-slitted screen: most of the sphere's "stuff " is reflected from the screen, but some passes through both slits. The waviness of the "stuff" then interferes, producing bands on a second screen, where conditions are such as to localize probabilistically the spheres. This elementary intermittent propensiton is able to mimic the results of the two-slit experiment, generally held to illustrate most strikingly the enigmatic "wave/particle" behaviour of quantum entities.

There is just one final modification that needs to be made to our elementary intermittent propensiton, and we have full quantum theory. We specify that the propensity state of the propensiton is specified by $\Psi(r,t)$, a complex function that attributes a complex number to each point in space, r, at a given time, t. We specify (a) that $\Psi(r,t)$ evolves in time in accordance with Schrödinger's equation, and (b) that $|\Psi(r,t)|^2dV$ gives the probability of the propensiton being localized in the volume element dV. We have all but recovered quantum theory, but with this difference: quantum theory has become a fully realistic, fundamentally probabilistic theory about the evolution and probabilistic interactions of intermittent propensitons. This version of QT - *propensiton quantum theory* (PQT) as we may call it -

solves the wave/particle problem by declaring that electrons, photons, atoms, etc., are *intermittent propensitons*.

But a key problem remains to be solved: What is the quantum mechanical condition for probabilistic transitions to occur? My proposal here, first put forward in 1982, is that probabilistic transitions occur if and only if "particles", or bound systems are created or destroyed as a result of inelastic interactions. [13] For example if an electron collides with a hydrogen atom so that the system goes into a superposition of (a) an electron and hydrogen atom and (b) two electrons and one proton (the hydrogen atom being dissociated), then, although this superposition exists, it does not persist. Entirely in the absence of measurement, or interaction with an external environment, when the interaction is very nearly at an end, the superposition jumps probabilistically into *either* (a) the electron plus hydrogen atom state, *or* (b) the two electron and one proton state, the probabilities being those predicted by OQT (if a measurement were made). As I have shown elsewhere, this version of PQT recovers all the empirical success of OQT but nevertheless differs from OQT for as yet unperformed experiments.

Some years after I first put forward this version of PQT, Roger Penrose proposed another version. Both versions hold that probabilistic transitions are associated with superpositions involving mass. But whereas I hold that what is required is a superposition of states, each with different particles or bound systems associated with them (of different mass), Penrose's idea is that what is required is that a sufficiently massive body evolves into a state that is a superposition of different *positions* in space.[14]

Just conceivably, my version of PQT, Penrose's version, or some other version, may be correct. Let us, in any case, conjecture that this is so. The quantum domain is such that, when specific quantum mechanical conditions arise, quantum states undergo instantaneous probabilistic transitions.

At once PQT comes into sharp conflict with special relativity.[15] Probabilistic changes of quantum state, of the kind required by PQT, will be such that the quantum state changes *instantaneously* throughout a region of space. But such a change will only be instantaneous in one reference frame.[16] In all other reference frames in motion with respect to this one frame, the change of state will not be instantaneous: it will travel at a faster than light, but finite, velocity, from one spatial position to another. If the change of state is caused by an interaction occurring in a relatively small spatial region, dV, then in some reference frames, a part of the quantum state far away spatially from dV, will begin to change, and to travel towards dV, before the event has occurred which causes the probabilistic transition. In these frames we have the absurdity that changes of quantum states *anticipate* future events!

Instantaneous probabilistic changes of quantum state, required by PQT, conflict with special relativity because they pick out a privileged reference frame, in which the change of state *is* instantaneous. Special relativity, however, demands that all inertial reference frames are equivalent, no one frame being uniquely privileged in representing the laws of nature.

Here, then, is a way in which relativity theory might be false in such a manner that the three dimensional view of the universe can be salvaged. Instantaneous probabilistic changes of quantum state pick out the unique cosmic "now" required to exist by the three dimensional view.

5 Ontological Probabilism and Relativity Theory Reconciled

It may be, however, that probabilism, if true, does not just *falsify* relativity theory. There is the possibility that a kind of *partial reconciliation* can be brought about between probabilism and relativity theory. Both might, in a sense, be true. Perhaps we can have our cake and eat it.

Let us conjecture that ontological probabilism is true, and hence the three dimensional view is true as well. Some version of PQT is correct: probabilistic changes of quantum state occur instantaneously across vast regions of space. These spatial regions may, incidentally, be very big indeed. Consider a photon emitted by an early star some tens of millions of years after the big bang. This has travelled in opposite directions for some 13 billion years, to be absorbed by the eye of someone gazing at the night sky. Instantaneously, the photon is annihilated. One instant it fills a region of space over 26 billion light years across; the next instant it has ceased to exist. Such an instantaneous collapse of state picks out a privileged reference, and an instantaneous "now", with a vengeance.

But let us suppose that such probabilistic collapses of quantum state are *all that there is in the constitution of things* to pick out "the reference frame at rest", and thus "the cosmic now". There is nothing else in the physical constitution of things that picks out the privileged reference frame to be the frame at rest. In particular, *that which determines how physical states of affairs evolve deterministically in time in between probabilistic transitions has nothing associated with it which can determine which frames are at rest, which in motion*. As far as deterministic evolutions of physical states are concerned, any inertial reference frame or, more generally, any coordinate system, is as good as any other. To a first approximation, special and general relativity are correct. Only probabilistic transitions reveal the serious inadequacy in relativity theory, in that they pick out the "cosmic-wide now" at each instant, thus picking out one frame of reference to be the privileged rest frame.

Our supposition is, then, that this state of affairs will be a feature of the yet-to-be-discovered true, unified "theory of everything" - a unification of probabilistic quantum theory (or the standard model) and deterministic general relativity which we may call *probabilistic quantum gravity* (PQG). This theory comes in two parts. There is (1) the *deterministic* part which specifies how physical states of affairs, propensity states, evolve in time in between probabilistic transitions; and there is (2) the *probabilistic* part which specifies the physical conditions that must obtain if probabilistic transitions are to occur, with the actualization of propensites, just one of many possible states of affairs becoming actual with such and such probability.

As far as part (1) is concerned, special and general relativity both hold, to a first approximation; only part (2) reveals the serious inadequacy in both theories.

The viewpoint just outlined is to be contrasted with the neo-Lorentzian view defended by William Lane Craig (2001), and very effectively criticized by Yuri Balashov and Michel Janssen (2003). According to special relativity, a body, A, set in motion with respect to another one, B, will be such that lengths in the direction of motion are contracted, clocks go slow, and masses increase, as measured by B. And all this will be true as well of lengths, clocks and masses travelling with B, as measured by A. These results follow from the basic postulates of special relativity: all inertial reference frames are equivalent, light has the same velocity c in all inertial reference frames, and space is homogeneous and isotropic. The neo-Lorentzian view supported by Craig rejects the first of these postulates, even as far as the deterministic evolution of physical states of affairs is concerned. Such evolutions of physical states pick out a unique reference frame to be the one at rest. Neo-Lorentzianism, as a result, faces two problems: (1) What exists physically that provides a basis for picking out that unique reference frame that is, objectively, at rest? (2) How can the behaviour of rods, clocks and masses in motion, successfully predicted and explained by special relativity, be explained by neo-Lorentzianism? Neo-Lorentzianism fails to answer these two questions - especially question (2). In connection with question (1), Craig suggests that, given general relativity, and given the homogeneity and isotropy of the cosmos, a uniquely natural foliation of spacetime into space and time emerges which provides a rest frame at each point in space, and a unique cosmic time.[17] Neo-Lorentzianism provides no satisfactory answer to (2), no explanation for the behaviour of rods clocks and masses in motion so beautifully explained by special relativity. It fails, especially, to explain, given two bodies, A and B, in relative motion, why A observes B's lengths to shrink, clocks to go slow, and masses to increase, and B observes precisely the same of A!

The *reconciliation* viewpoint, indicated above, faces none of these difficulties. According to this view, *only quantum probabilistic transitions* determine, physically, that frame uniquely at rest. Furthermore, as far as deterministic evolutions of physical states of affairs are concerned, nothing exists that can pick out the rest frame. All inertial reference frames are equivalent. The postulates of special relativity hold (to a first approximation), and so the consequences of those postulates hold as well. The problem of *explaining* why rods, clocks and masses in motion behave as predicted by special relativity, which poses an insuperable problem for neo-Lorentzianism, poses no problem at all for the reconciliation view, indicated above.

If we are to pursue this "reconciliation" view with complete integrity, we must acknowledge, it seems, that deterministically evolving physical states, being inherently indifferent to whether they are moving or at rest (in an absolute sense), have no way of determining what space-like hyperplane or hypersurface the instantaneous probabilistic change of physical state occurs, when conditions for it to occur obtain. The equations of motion, and the conditions for probabilistic collapse to occur, leave open in what hyperplane the collapse occurs. This is determined by "the cosmic now" of the three dimensional universe.

Can the hyperplane (or hypersurface) of probabilistic collapse be determined experimentally? What answer is to be given to that question will depend, I take it, on the specific form *probabilistic quantum gravity* takes.

References

Balashov, Y. and M. Janssen, 2003, Presentism and Relativity, *British Journal for the Philosophy of Science*, 54, pp. 327-346.

Bell, J., 1973, Subject and Object, in J. Mehra, ed., *The Physicist's Conception of Nature*, Reidel, Dordrecht, pp. 687-690.

Craig, W. L., 2001, *Time and the Metaphysics of Relativity*, Kluwer, Dordrecht.

Ghirardi, G. C., Rimini, A. and Weber, T., 1986, Unified dynamics for microscopic and macroscopic systems, *Physical Review D, 34,* pp. 470-91.

Greene, B., 1999, *The Elegant Universe*, W.W. Norton, London.

Maudlin, T., 2011, *Quantum Non-Locality & Relativity*, Wiley-Blackwell, Chichester.

Maxwell, N., 1968, Can there be Necessary Connections between Successive Events?, *British Journal for the Philosophy of Science*, 19, pp. 1-25.

______, 1972, A New Look at the Quantum Mechanical Problem of Measurement, *American Journal of Physics*, vol. 40, pp. 1431-1435.

______, 1974, The Rationality of Scientific Discovery, *Philosophy of Science*, 41, pp. 123-153 and 247-295.

______, 1976, Towards a Micro Realistic Version of Quantum Mechanics, *Foundations of Physics*, 6, pp. 275-292 and 661-676.

______, 1982, Instead of Particles and Fields, *Foundations of Physics*, vol. 12, pp. 607-31.

______, 1985, Are Probabilism and Special Relativity Incompatible?, Philosophy of Science, 52, pp. 23-43.

______, 1992, Beyond "FAPP": Three Approaches to Improving Quantum Theory and an Experimental Test, in A. van der Merwe *et al.*, eds., *Bell's Theorem and the Foundations of Modern Physics*, World Scientific, Singapore, pp. 362-370.

______, 1993, Induction and Scientific Realism: Einstein versus van Fraassen, *British Journal for the Philosophy of Science*, 44, pp. 61-79, 81-101 and 275-305.
______, 1994, Particle Creation as the Quantum Condition for Probabilistic Events to Occur, *Physics Letters*, A 187, pp. 351-355.
______, 1998, *The Comprehensibility of the Universe*, Oxford University Press, Oxford.
______, 2004a, *Is Science Neurotic?*, Imperial College Press, London, chs. 1 and 2, and appendix.
______, 2004b, Does Probabilism Solve the Great Quantum Mystery?, *Theoria*, vol. 19/3, no. 51, pp. 321-336.
______, 1988, Quantum Propensiton Theory: A Testable Resolution of the Wave/Particle Dilemma, *British Journal for the Philosophy of Science*, 39, pp. 1-50.
______, 2006, Special Relativity, Time, Probabilism, and Ultimate Reality, in D. Dieks, ed., *The Ontology of Spacetime*, Elsevier, pp. 229-245.
______, 2011, Is the Quantum World Composed of Propensitons?, in M. Suárez, ed., *Probabilities, Causes and Propensities in Physics*, Synthese Library, Springer, Dordrecht, pp. 221-243.
______, 2013, Has Science Established that the Cosmos is Physically Comprehensible?, *Recent Advances in Cosmology*, in A. Travena and B. Soen, eds., Nova Publishers Inc, New York, Chapter One, pp. 1-56 (available online at http://discovery.ucl.ac.uk/view/people/ANMAX22.date.html).
______, 2017, *Understanding Scientific Progress*, Paragon House, Saint Paul, Minnesota.
McTaggart, J.M.E., 1906, The Unreality of Time, *Mind*, 17, pp. 457-473.
Minkowski, H., 1952, Space and Time, in A. Sommerfeld, ed., *Einstein: The Principle of Relativity*, Dover, New York, pp. 75-91.
Penrose, R., 1986, Gravity and State Reduction, in R. Penrose and C. J. Isham, eds., *Quantum Concepts of Space and Time*, Oxford University Press, Oxford, pp. 129-146.
Smolin, L., 2007, *The Trouble with Physics*, Allen Lane, London.
Tumulka, R., 2006, A Relativistic Version of the Ghiraardi-Rimini-Weber Model, *Journal of Statistical Physics*, 125, pp. 821-840.
Woit, P., 2006, *Not Even Wrong*, Jonathan Cape, London.

Notes

[1] If string theory is correct, there may be 9 or 10 spatial dimensions. The "three dimensional view" becomes the nine or ten dimensional view. The crucial tenet of this view is, not the number of spatial dimensions, but rather that the world is not spread out in time in the way in which it is spread out in space.

[2] See Maxwell (1968), where I referred to the three and four dimensional views as C_2 and C_1 respectively, and briefly made the point that much confusion about time stems from attempting to combine these two incompatible views. The main point of the article was to argue that necessary connections between successive states of affairs *are* possible, despite Hume's arguments to the contrary, but only if the three-dimensional, C_2, view is true.

[3] This incoherent view would seem to be implicit in McTaggart's A-series, according to which events are initially future, then present, then past, future events being converted into past ones by the passage of the present along time: see McTaggart (1908). It is explicit in all those attempts to rectify the perceived inadequacy of the spacetime view (or McTaggart's B-series) by adding "the present" to it, or "objective becoming", which is supposed to move steadily from past to future.

[4] It is really Hermann Minkowski who first interpreted special relativity in terms of the four-dimensional, space-time view in 1908: see Minkowski (1952). Einstein's 1905 paper implicitly takes the three-dimensional view for granted.
[5] For a popular exposition and defence of string theory see Greene (1999).
[6] For criticisms of string theory see Woit (2006) and Smolin (2007).
[7] The first great unifying theory in physics was Newtonian theory. This theory unifies Kepler's laws of planetary motion, and Galileo's laws of terrestrial motion. But in doing so, it reveals that both Kepler's and Galileo's laws are, strictly speaking, false. Granted Newtonian theory, planets deviate from precise Keplerian, elliptical motion because the planets attract each other gravitationally, and attract the sun, which leads to deviations. Again, granted Newtonian theory, a stone falling near the earth's surface does not fall with constant gravitation precisely because, as it falls, it gets closer to the centre of the earth, and thus the gravitational attraction on the stone increases very slightly, which means in turn that its acceleration increases very slightly. Newtonian theory explains why there are deviations from Kepler's and Galileo's laws. This almost always occurs whenever a new theory, T_3, unifies two predecessor theories, T_1 and T_2.
[8] See, for example, Maxwell (1974; 1993; 1998; 2004a; 2013; 2017).
[9] For detailed expositions and defence of aim-oriented empiricism see works referred to in note 8, especially Maxwell (2017).
[10] For earlier discussion of this idea see Maxwell (1985; 2006). For a much more detailed discussion of the closely related issue of relativity and quantum non-locality see Maudlin (2011).
[11] This argument is spelled out in greater detail in Maxwell (1972; 1976). See also Bell (1973) and Maxwell (1992).
[12] I first made this point in Maxwell (1972).
[13] See Maxwell (1982; 1988; 1994; 2004b; 2011).
[14] Penrose (1986). For a quite different proposal for probabilistic collapse see Ghirardi, Rimini and Weber (1986).
[15] Probabilism and special relativity do not inevitably contradict one another, a point I made in Maxwell (1985). This point is borne out by the existence of a fundamentally probabilistic, Lorentz invariant version of quantum theory developed by Roderick Tumulka (2006). This is a version of the theory of Ghirardi, Rimini and Weber (1986). Tumulka's theory suffers, however, from severe limitations: its ontology is that of discrete spacetime points, there are no interactions between "particles" and, most serious of all, nothing corresponds physically, in reality, to the quantum state.
[16] Here, and in what follows, I take "one rest frame" to mean "one set of reference frames all at rest with respect to each other".
[17] Craig (2001, ch. 10).