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ARE PROBABILISM AND SPECIAL RELATIVITY INCOMPATIBLE?*

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In this paper I expound an argument which seems to establish that probabilism and special relativity are incompatible. I examine the argument critically, and consider its implications for interpretative problems of quantum theory, and for theoretical physics as a whole.

1. The Argument. I begin with a simple and, I hope, intuitively clear exposition of my basic argument, designed to establish that probabilism and special relativity are incompatible. I then go on to add some refinements to the argument, in an attempt to ensure its validity, before considering its implications for interpretative problems of quantum theory, and for theoretical physics as a whole.

Probabilism, as understood here, is the thesis that the universe is such that, at any instant, there is only one past but many alternative possible futures—the fundamental laws of the universe being probabilistic and not deterministic. According to probabilism, then, there is a physically real difference between past and future events—the future alone containing physically, ontologically real alternative possibilities. Because of this physically real difference between past and future, probabilism requires that, at any instant, there be a universal, absolute, unambiguous distinction between past and future—to divide off the *one* past from the *many* alternative possible futures. Probabilism, in short, is only true if there does exist such an absolute distinction between one past and many possible futures.

Special relativity, on the other hand, is only true if there is *no* universal, absolute, unambiguous distinction between past and future. According to special relativity, given any two physical events, E_1 and E_2, having space-like separation from each other (so that they lie outside each other's past and future light cones), then there is no absolute, frame-independent way in which E_1 is unambiguously either earlier than, simultaneous with, or later than E_2. Which relationship holds depends on the choice of inertial reference frame, all such choices being physically

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equivalent. Thus special relativity denies that there exists the kind of absolute, universal, frame-independent distinction between past and future, which must exist if probabilism is to be true.

Hence probabilism and special relativity cannot both be true.

It deserves to be noted that this objection to combining probabilism and special relativity does not arise if we seek to combine probabilism and Newtonian conceptions of space and time. This is because the 'universal, absolute present' of Newtonian space-time does unambiguously separate off the *one* past from the *many* alternative possible futures of probabilism. Granted that the physical event E_1 is here and now, any other physical event E_2 is *either* (1) in the past or present, *or* (2) it is in the future. If (1) holds, then E_2 is ontologically fixed and definite, devoid of physically real alternatives. If (2) holds, then E_2 may well be ontologically indefinite, there being many physically real alternative possibilities associated with the space-time location of E_2. The Newtonian universal 'now' ensures that there can be no ambiguity as to which of these two cases holds.

It is the relativistic denial of the Newtonian absolute, universal 'now' which renders relativistic space-time incompatible with probabilism.

2. Two Restrictions of the Argument Accepted. Two restrictions need to be placed on the *scope* of the argument just expounded.

In the first place, one might suppose that the argument establishes that probabilism is incompatible with special relativity however the latter theory is interpreted. But this is not correct. Special relativity may be interpreted to assert only that all causally connected chains of events, that actually occur, and that are capable in principle of being used to transmit signals, occur in such a way that they can be construed to take place in a Lorentz invariant fashion. The fact that future possibilities and potentialities are eliminated, as time passes, in a non-Lorentz invariant fashion, does not contradict special relativity, interpreted in this somewhat phenomenalistic way, as long as all actual causal evolutions of physical states can be construed to take place in a Lorentz invariant manner.

What we must conclude, then, is this. Probabilism *is* incompatible with special relativity interpreted realistically, to assert that all inertial reference frames are physically, ontologically equivalent, there existing nothing physical (such as an ether, or instantaneous annihilation of spatially separated physically real possibilities) to distinguish *one* such frame from the others. Probabilism is not, however, incompatible with a more modest, phenomenalistic version of special relativity which asserts merely the Lorentz invariant character of all actual causal chains of events (such as particles or light).

In the second place, one might suppose that the argument of section 1 establishes that special relativity (realistically interpreted) must be false if the basic laws of nature are probabilistic in character, and not deterministic. Once again, this is not correct. Special relativity might be true even though the basic laws are probabilistic. The truth is that two distinct versions of probabilism need to be distinguished. On the one hand there is probabilism as this has been defined above, a view which asserts that the basic laws are probabilistic *and that the future is now in reality open with many ontologically real alternative possibilities* whereas the past is not. This view may be renamed *ontological probabilism*. On the other hand there is *predictive probabilism* (as it may be called), a view which asserts that the future, like the past, is now in reality entirely fixed and determined even though the basic laws are probabilistic and not deterministic. According to predictive probabilism, alternative possible futures represent no more than alternative possibilities relative to what can in principle be predicted on the basis of a complete specification of the present, and the basic laws: they are not alternatives *in reality*. Whereas ontological probabilism asserts that the future is open and undecided in reality, predictive probabilism asserts that the future is now in reality fixed and decided, the present state of affairs plus the basic laws of nature being insufficient however to determine this unique future.

This difference between ontological and predictive probabilism, fine though it is, crucially affects the question of the compatibility of special relativity and probabilism. The argument of section 1 presupposes *ontological* probabilism. It fails if *predictive* probabilism is presupposed. We may thus conclude that special relativity is incompatible with ontological probabilism, but compatible with predictive probabilism.

In brief, the argument of section 1 establishes only that *ontological probabilism and realistically interpreted special relativity cannot both be true*.

3. Four Objections to the Argument Rejected. In order to discuss objections to this reformulated version of the argument, let us examine in a little more detail ways in which one might attempt to combine (realistic) special relativity and (ontological) probabilism.

Granted, as before, that E_1 is here and now, if E_2 lies in the past light cone of E_1, then E_2 can be held to be ontologically fixed and definite. If E_2 lies in the future light cone of E_1, then E_2 may well be ontologically indefinite, there being many physically real alternative possibilities associated with (or corresponding to) the space-time location of E_2. So far there appears to be no problem. The problem arises if E_2 lies outside both the past and future light cones of E_1, so that E_1 and E_2 have space-like separation.

Let us now stipulate that E_2 is at least a candidate for ontological indefiniteness in the following sense. Consider any inertial reference frame which defines an 'instantaneous now' (a space-like hyperplane in Minkowskian space-time), which passes through E_1, and through the past light cone of E_2. Consider that part of the 'instantaneous now' which lies in the past light cone of E_2. Suppose that, relative to any consistent choice of what exists here (from possible probabilistic alternatives), a specification of this, together with the basic probabilistic laws, makes only probabilistic predictions about what exists at the space-time point at E_2. If such a reference frame and associated 'instantaneous now' exists, with these properties, then E_2 can be declared to be at least a candidate for ontological indefiniteness.

Is E_2 ontologically definite, indefinite, or what? This is the question that must be answered if (ontological) probabilism and (realistic) special relativity are to be reconciled, in opposition to the argument of section 1. There are just four suggestions to consider.

In the first place, it may be suggested that the question of whether E_2 is ontologically definite (like events in the past light cone of E_1) or ontologically indefinite (like events in the future light cone of E_1) depends on what reference frame is chosen. The existence or non-existence of alternatives to E_2 is a frame-dependent matter, like values of mass, length and time. If E_2 is in the past or present with respect to reference frame R_1, then E_2 is ontologically fixed; if it is sufficiently in the future with respect to R_2, then it is ontologically unfixed.

This suggestion succeeds as long as *predictive* probabilism is presupposed. For then the definiteness or indefiniteness of E_2 is *solely* a *relational* matter. It depends solely on what reference frame and 'instantaneous now' is chosen. There is, according to predictive probabilism, no absolute, nonrelational sense in which E_2 is either definite or indefinite. But in sharp contrast to this, ontological probabilism asserts that the definiteness or indefiniteness of any event such as E_2—the non-existence or existence of alternative possibilities—is an absolute matter, and not *merely* a matter of when or where one is in relation to E_2. If ontological probabilism is true, there must be a wholly unambiguous, absolute answer to the question 'Do alternative possibilities to E_2 exist or not?' It cannot be merely a relative, relational, or frame-dependent matter (like values of mass or length). Thus the ontological definiteness or indefiniteness of E_2 cannot depend merely on choice of reference frame.

This argument can be reformulated as follows. Special relativity requires that all inertial reference frames are physically equivalent—so that anything which is true in one reference frame has its equivalent truth in any other reference frame. Predictive probabilism permits reference frames to be physically equivalent in this way—since the view permits us to conceive of the world as spread out in Minkowskian space-time, successive instantaneous states of affairs (in any reference frame) being probabilistically interconnected. Ontological probabilism, in sharp contrast, asserts that future events have physically, ontologically real alternative possibilities associated with them which are progressively annihilated as the future becomes the present and the past. Whether or not E_2 has alternative possibilities associated with it does depend on whether E_2 lies in one's (absolute) future or past; but it is not equivalent to, or reducible to, E_2 being in one's (absolute) future or past. Future alternative possibilities really do exist, absolutely; and they really are annihilated as time passes. Thus a reference frame which puts E_2 into the future, with associated physically real alternative possibilities, cannot be equivalent to a reference frame which puts E_2 into the past, devoid of real alternative possibilities. Given ontological probabilism, the world cannot be conceived of as spread out in Minkowskian space-time, as it can given predictive probabilism, just because this ignores the physical reality of future alternative possibilities. Thus this first suggestion that the existence or nonexistence of alternative possibilities associated with E_2 is a frame-dependent matter collapses.

In the second place, it may be suggested that the question of whether E_2 is ontologically definite or indefinite is, from the standpoint of the here and now, E_1, *meaningless*, since neither answer can even in principle be verified or falsified empirically, here and now at E_1. This suggestion is acceptable if, and only if, the logical empiricist verificationist criterion of meaningfulness, to which it appeals, is acceptable. There are, however, well known and decisive objections to this logical positivist criterion of meaningfulness.

In the third place, it may be suggested that E_2 is ontologically fixed and definite absolutely, like events in the past light cone of E_1. This suggestion faces the fatal objection that it annihilates ontological probabilism. For if E_2 is fixed and definite from the standpoint of E_1, then from the standpoint of E_2 (and thus also from the standpoint of E_1), all events in the future light cone of E_1 that lie outside the future light cone of E_2 are also ontologically fixed and definite. As much as we please of the absolute future of E_1 can be rendered ontologically definite merely by considering an E_2 far enough away from E_1. Thus ontological probabilism collapses.

In the fourth place, and finally, it may be suggested that E_2 is ontologically indefinite absolutely, like events in the future light cone of E_1. But this suggestion faces the fatal objection that it postulates not just future alternative *possibilities*, but present alternative *actualities*—a full-fledged multi-universe view. If E_2 consists of many alternative possibilities from the standpoint of E_1, then similarly E_1 itself consists of many alternative possibilities from the standpoint of E_2, and thus from the standpoint of E_1 itself. This fourth suggestion thus commits us to the view that whenever anything probabilistic occurs, there being N equally probable outcomes, three-dimensional space splits up into N distinct three-dimensional spaces, each space containing one of the N outcomes. Any such branching-universe or multi-universe view is, however, far too grotesquely *ad hoc* to be taken seriously. Ontological probabilism combined with Newtonian space-time does not, it should be noted, face this objection since in this case alternative possibilities are all in the future; and they can thus be regarded as alternative *possibilities* only, and not alternative *actualities*. In the relativistic case, this option is not open to us; granted that E_1 and E_2 are outside each other's light cones, and each is ontologically indefinite from the other's standpoint.

However, this fourth suggestion does indicate, it must be admitted, how ontological probabilism and realistic special relativity can be combined in at least a logically consistent way. As we have just seen, ontological probabilism can be represented as a multi-universe view, all possibilities being realized, probabilism being converted into a kind of determinism. In the Newtonian case, this involves postulating that whenever a probabilistic event occurs with N equally probable outcomes, then instantaneously the entire universe branches into N distinct universes, between which there is no subsequent communication, each universe containing one of the N outcomes. In the relativistic case, this involves postulating that whenever such a probabilistic event occurs, three-dimensional space in the immediate vicinity splits into N distinct three-dimensional spaces, each space containing one outcome. The splitting of space into N distinct spaces then travels outwards in all directions at the velocity of light—the N distinct spaces joining at a closed surface which expands at the velocity of light. If another such splitting of space into M spaces is encountered, $N \cdot M$ spaces result. Once space has branched in this way, all communication between the distinct spaces is impossible. Probabilism results from the illusion of being invariably confined to just one branch.

This is consistent but, to repeat, far too grotesquely *ad hoc* to be taken seriously. And yet only by adopting this space-splitting view can ontological probabilism be combined consistently with realistic special relativity.

I conclude that all suggestions as to how ontological probabilism and realistic special relativity are to be combined fail.

4. Choosing between Ontological and Predictive Probabilism. What arguments can be given to help us choose between predictive and ontological probabilism?

On the one hand, it may be argued that predictive probabilism is to be preferred on straightforward *physical* grounds. Special relativity is an extraordinarily successful physical theory, firmly built into the framework of theoretical knowledge in physics today. Ontological probabilism deserves to be rejected just because it is incompatible with this especially secure part of current scientific knowledge.

On the other hand, it may be argued that as our theoretical knowledge and understanding of the physical universe develops, it is to be expected that new theories will revise and correct their predecessors. Just as Newton corrects Kepler and Galileo, and Einstein corrects Newton, so future theories will no doubt correct Einstein. Ontological probabilism should not be condemned out of hand merely because it subtly contradicts special relativity. In seeking to improve our knowledge and understanding of the structure of the physical universe, we ought indeed to seek to transform untestable metaphysical theories (such as ontological probabilism), incompatible with existing theoretical scientific knowledge, into testable theories, since it is along some such path as this that progress is to be made. If positive reasons can be given for preferring ontological to predictive probabilism, the incompatibility of ontological probabilism and special relativity may be deemed not to tell too much against the acceptability of the view.

5. Objectism versus Eventism. In choosing between ontological and predictive probabilism, we are almost bound to be influenced by the way we choose between two other, more general, rival metaphysical positions, which may be called *objectism* and *eventism* (referred to as C_2 and C_1 respectively in Maxwell 1968, pp. 5–9).

According to objectism, the world is three dimensional and not four dimensional. The basic entities—objects—are spread out in space, but not in time. Objects change; they have a past and a future: but it is facts about objects, rather than objects themselves, that are (or can be construed to be) spread out in time. Spatial relations are between objects, but temporal relations are between facts-about-objects. This constitutes a fundamental difference between space and time. It is not objects, but rather the history of objects, that can be conceived as being spread out in time: and histories exist only insofar as objects persist and change. Space-time diagrams do not depict objects or the world at all: they depict facts about objects, much as any graph relating, for example, temperature and pressure, depicts not objects but facts about objects.

Eventism rejects almost everything that objectism affirms. According to eventism, the world *is* spread out in both space and time. The basic entities are four-dimensional events, not three-dimensional objects. What would ordinarily be conceived of as persisting objects—tables, atoms, electrons—are in reality large collections of similar events spread out continuously in space-time. Objects are thus made up of events, as opposed to events being made up of objects. Events are spatially *and* temporally related: in this respect there is no difference between space and time, and time may be conceived in quasispatial terms. Space-time diagrams depict the four-dimensional world as it really is, compounded of events imbedded in space-time.

It deserves to be noted in passing that common sense tends to amount to an inconsistent combination of objectism and eventism. We ordinarily tend to think of the present, the immediate past, and the immediate future in terms of objectism: the immediate past is what has just happened to objects that now exist, and is not a *place* where other entities (events), resembling present entities, exist. The distant past (and to a lesser extent the distant future) does tend, however, to be conceived of in terms of eventism: a distant place, existing elsewhere in the dimension of time, stocked with different things. This common sense inconsistent jumble of objectism and eventism accounts for much of our ordinary confusion about time. We conceive of time in eventist, space-time terms and then, discerning that something has been left out, we seek to make good the omission by adding the instantaneous 'now', flowing along time, creating 'becoming', the world as we ordinarily experience and conceive of it. Versions of this view have been propounded by such diverse authors as Weyl, Reichenbach, Eddington, Bondi, Whitrow, Bergmann, James, Bergson, Capek, and Grünbaum (see Grünbaum 1963, chap. 10). All such views, which seek to add the 'now', the 'flow of time', and 'becoming' to the world conceived of in space-time terms, amount, I suggest, to nothing more than a hopelessly confused attempt to do justice to the inconsistent combination of eventism and objectism of common sense. From the perspective of objectism, eventism and space-time diagrams are not inadequate or incomplete because they leave out the instantaneous 'now', the specious present, becoming, etc.; they are inadequate or incomplete because they leave *everything* out, depicting facts about objects but not persisting, changing objects themselves. The common sense combination of eventism and objectism needs to be recognized for what it is, an inconsistent picture that must be rejected. Nothing but confusion is created by transforming this inconsistent common sense combination of eventism-plus-objectism into eventism-plus-the-instantaneous-'now'-and-becoming.

It also deserves to be noted that special relativity may be formulated in terms of either objectism or eventism. Einstein originally formulated special relativity in such a way that objectism is presupposed; it was Minkowski who was responsible subsequently for the space-time, eventism formulation. After some initial dismay, this interpretation was taken up by Einstein in developing general relativity, which, as a result, has subsequently usually been interpreted in terms of eventism. Presumably, however, general relativity is open to being interpreted in terms of objectism, just as special relativity is.

It might be thought that the fact that all ordinary physical objects—human bodies, rocks, tables, and even molecules and atoms—are processes rather than unchanging objects, in itself tells against objectism. But this is wrong. Objectism might well be true—fundamental physical entities being *objects* in the sense of objectism, these entities interacting in persisting ways to form enduring processes we ordinarily conceive of as macroscopic objects.

Choosing between objectism and eventism is relevant to choosing between ontological and predictive probabilism in the following way. If eventism is true, then ontological probabilism cannot be true. Eventism plus probabilism implies *predictive* probabilism. For eventism asserts that the future exists, like the past, and like states of affairs at other places. Eventism denies that the future is really, ontologically open and undecided; it is at most open only with respect to what can be in principle predicted on the basis of a full specification of the present, and basic (probabilistic) laws of nature.

If objectism is true, on the other hand, then it is possible for ontological probabilism to be true. Objectism, in rejecting the eventist picture of a four-dimensional universe spread out in space and time, makes it possible for the future to be genuinely, ontologically open and undecided. We might even conclude that objectism plus probabilism implies ontological probabilism—given that objectism and probabilism together are taken to assert that nothing exists to determine the shape of the future over and above the basic probabilistic laws of nature, and the state of affairs that obtains in the present.

The conclusion of the above argument can be put like this. Let *probabilism* be the thesis that the basic laws of nature are probabilistic in character, it being left entirely open whether ontological or predictive probabilism holds. We then have: (i) probabilism plus objectism implies ontological probabilism; (ii) probabilism plus eventism implies predictive probabilism. Thus, granted probabilism, if strong arguments can be given for preferring objectism to eventism, then these are also strong arguments for preferring ontological to predictive probabilism.

6. Arguments for Objectism and against Eventism. I have two very different arguments for preferring objectism to eventism.

The first amounts to this. If objectism is true, then it is possible for there to be necessary connections (deterministic or probabilistic) between successive states of affairs. If eventism is true, such necessary connections are impossible. This provides decisive grounds for accepting objectism and rejecting eventism.

Hume, notoriously, denied that it is possible for there to exist logically (or analytically) necessary connections between successive states of affairs. He held that "... *there is nothing in any object considered in itself, which can afford us a reason for drawing a conclusion beyond it*" (Hume 1959, p. 139), and that "We can at least conceive a change in the course of nature, which sufficiently proves that such a change is not absolutely impossible" (Hume 1959, p. 91).

Given eventism, Hume is right. Basic entities—events—are spread out both in space and time. Just as statements exclusively about what exists at one *place* cannot have implications for what exists at other places, so too statements exclusively about what exists at one *time* cannot have implications for what exists at other times.

Given objectism, however, Hume is no longer correct. For, according to objectism, basic entities are spread out in space, but *not* in time. The analogy between space and time breaks down. It is facts about objects, as it were, not objects themselves, that are spread out in time. It is thus possible for logical relationships to exist between facts 'spread out in time' about one and the same set of objects. Statements exclusively about objects existing at one place cannot have implications for different objects (or different parts of the same spatially extended objects) existing at other places. Statements exclusively about objects, and their instantaneous states, at one instant, may well have implications for the subsequent states *of the very same objects* at subsequent times. For objects may possess unchanging powers, necessitating properties, dispositional properties or propensities (deterministic or probabilistic)—analogous to such physical properties as inflammability, solidity, elasticity, gravitational and electric charge—which determine necessarily (deterministically or probabilistically) how the objects change in certain respects in certain circumstances. Thus two particles, possessing Newtonian gravitational charge, of necessity accelerate towards each other at a rate inversely proportional to the square of their distance apart; if they do not, then, *ipso facto*, they do not possess Newtonian gravitational charge. On this view, Newtonian gravitational charge is such that it can only be fully described (or attributed to objects) by a term 'gravitational charge' whose *meaning* is such that 'particles 1 and 2 are gravitationally charged and distance d apart' *analytically* implies '1 and 2 accelerate towards each other at a rate inversely proportional to d^2 (assuming the absence of other forces)'. When Newtonian theory is interpreted in this way—in accordance with what may be called *conjectural essentialism*—so that the theory attributes powers or necessitating properties to objects, then all the *laws* of Newtonian theory, such as $F = G \cdot m_1 \cdot m_2/d^2$ and $F = m \cdot a$, are interpreted as *analytic* statements, all the factual and empirical content of the theory being contained in the assertion that all objects everywhere possess unchanging Newtonian mass and gravitational charge.[1]

Unchanging powers or necessitating properties of this type are possible given objectism, impossible given eventism. We cannot of course know for certain that any such invariant necessitating properties do actually exist; equally, we cannot know for certain that such properties do not exist. If they exist universally, then what exists at one instant determines necessarily (probabilistically or deterministically) what occurs subsequently, in the sense that a full specification of what exists at one instant analytically implies[2] what occurs subsequently. In this case the world is such that if the full specification of what exists at one instant is weakened, so that it no longer analytically implies what occurs subsequently, then inevitably it ceases to be a *full* specification of what exists exclusively at the first instant. Real physical properties possessed by objects at the instant in question are no longer fully described. If there are universal necessary connections between successive states of affairs in *this* world, then it is not possible to conceive consistently that *this* world, with all its objects and necessitating properties, suffers an abrupt change in the laws of nature in the future—even though of course it is possible to conceive consistently that a world that has so far *behaved* like this world, but lacks this world's necessitating properties, does suffer a change in its laws in the future. (A more detailed argument along these lines for the possibility of necessary connections between successive states of affairs is given in Maxwell [1968], reprinted in Swinburne [1974], and briefly discussed in Harré [1970]; somewhat similar arguments are to be found in Harré and Madden [1975].)

In brief, it is possible for there to exist powers, necessitating properties, and (analytically) necessary connections between successive states of affairs if objectism is true; all this is impossible if eventism is true.

There is a further point. In a universe in which (as far as it is known)

[1]It may be objected that this constitutes a *reductio ad absurdum* of conjectural essentialism in that, if physical laws are true *analytically*, they cannot be refuted empirically and revised. The reply to this of course is that from the standpoint of conjectural essentialism it is factual and falsifiable assertions attributing necessitating properties to physical entities that can be empirically refuted and revised as physics progresses. A refutation of essentialistic Newtonian theory may be held to disclose that nothing has gravitational charge, as explicated by the analytically true statement $F = G \cdot g_1 \cdot g_2/d^2$ (with gravitational charge equal to inertial mass). If this is correct, then the analytic statement is discovered not to be (precisely) applicable to anything in the world, and new analytic statements need to be formulated to specify precisely the meaning of theoretical terms to be employed to attribute new necessitating properties to entities (such as the capacity of matter to curve space-time).

[2]p 'analytically' implies q (as I am using the term) if and only if p plus relevant *analytic* statements, true in virtue of the meaning of terms in p, *logically* imply q. In other words p analytically implies q iff '$p \supset q$' is analytic.

all events unfold in accordance with some fixed pattern of natural law, if it is meaningful and possible for necessitating properties and connections to exist, then it is absurd not to postulate the actual existence of such necessitating properties and connections. The only rationale that there can be for not postulating such necessitating properties and connections is that the very idea of such necessitating properties and connections does not make sense.

Hume's rejection of the existence of necessitating properties and causal connections (as these have been understood here) may well, when one first encounters it, seem too absurd to be taken seriously. For if Hume were right, all lawfulness in the world could, it seems, amount to nothing more than an utterly incredible stream of coincidences at every place and time. For if Hume were right, nothing could exist that is, in any sense, *responsible* for the persistence of natural regularities. Anything could follow anything in time; and if only those events occur which obey fixed regularities, this must be due to nothing more than a sustained, infinitely improbable stream of coincidences.

This argument is valid just as long as necessitating properties and connections are meaningful and possible. For in this case it is meaningful and possible to make the required distinction between (i) a universe in which lawfulness is due to the existence of necessitating properties and connections; and (ii) a universe in which precisely the same lawfulness is due to nothing more than infinitely improbable coincidence, there being no necessitating properties and connections in existence. But if Hume is correct in holding that no meaning whatsoever can be given to 'necessitating properties and connections' (as interpreted here), then the distinction between (i) and (ii) above collapses. The intuitive idea or feeling that *mere* natural regularity (postulated by [ii]) is utterly inexplicable and infinitely improbable because nothing exists that is responsible for the persistence of regularity, is unfounded because the very notion of something in existence in the natural world being 'responsible' for regularity is *meaningless*. (Within the Humean position one can, it may be noted in passing, even distinguish between 'true natural laws' and 'true accidental generalizations': the former, by definition, cohere into a deductive structure, whereas the latter, by definition, do not.)

The decisive point to recognize is that it is only reasonable to postulate natural laws or regularities devoid of necessitating properties and connections responsible for them just as long as Hume is correct in holding these 'necessitating' notions to be meaningless. If Hume is wrong here—necessitating properties and connections being both meaningful and possible—then it at once becomes utterly absurd to postulate natural regularities in such a way that the existence of any necessitating properties responsible for the regularities is simultaneously denied. To do this is to postulate infinitely many, infinitely improbable coincidences.

But Hume *is* wrong. The notions of necessitating properties and connections (as explicated here) *are* meaningful. Such properties and connections may exist. It thus *is* absurd to postulate natural law and at the same time exclude the possibility that there exist necessitating properties and connections responsible for such lawfulness.[3]

But eventism does exclude the possibility that such necessitating properties and connections exist. Only objectism permits them to exist.

Therefore, it is absurd to presuppose anything other than objectism in pursuing physics—and natural science more generally. Eventism must be rejected.

This concludes my first argument in support of objectism and against eventism.

My second argument is that objectism allows, and eventism prohibits, free will.

If objectism is true, then it is at least possible that the future is open and undecided (if ontological probabilism is true). It is thus possible that free will exists in the strong sense that in order to have free will (in this sense) it is *necessary* (i) that all our actions were not ontologically fixed and determined in the past (e.g., before we were born); and (ii) that some of the future depends crucially on whether we do, or do not, perform certain actions (ontologically undetermined in the past). Whereas free will, in this strong sense, *is* possible given objectism, it is not possible given eventism, even if probabilism obtains, just because eventism excludes the possibility that the future is genuinely, ontologically open and undecided. The assumption that we do have some genuine free will—some genuine power to decide the future—is not one that can be readily laid aside in any sphere of human life and action, including the sphere of scientific inquiry. Our assumption that we have the capacity to assess scientific theories rationally, and to make progress towards a greater scientific knowledge and understanding of the world, presupposes, it may be held, that we have some genuine control of, and responsibility for, our scientific thoughts, judgments, and deeds. Thus eventism, which makes all this impossible, is to be rejected; and objectism, which makes free will possible, is to be accepted instead.

[3]This argument, incidentally, provides decisive grounds for rejecting anti-realist views of science such as those of van Fraassen (1980) and Laudan (1981), insofar as these views are opposed to the thesis that theoretical physics needs to be committed to an overall essentialistic, and thus realist, research program if genuine explanations and understanding of phenomena are to be achieved. The argument also provides grounds for rejecting realist but anti-essentialist views of science such as those of Popper (1963).

It might be thought that any argument in support of necessary connections between successive events must be diametrically opposed to any argument in support of free will. Strikingly enough, the above two arguments, apparently diametrically opposed in this way, work together to support objectism.

I conclude that objectism is to be accepted and eventism is to be rejected. Thus, given probabilism, predictive probabilism is to be rejected and ontological probabilism is to be accepted. This gives strong grounds for holding that *probabilism as such, and not just ontological probabilism, is incompatible with special relativity.*

I turn now to a discussion of the implications and significance of this conclusion.

7. Implications of the Argument for Quantum Theory. The above argument dramatically affects the way we assess those versions of quantum theory that postulate the instantaneous, nonrelativistic wave packet collapse of spatially smeared out wave packets as an objectively real physical phenomenon.

For some years now, I have sought to develop and advocate a 'microrealistic, propensity' version of quantum theory (1972, 1973, 1975, 1976a, 1982). My aim has been to solve the quantum wave/particle problem in such a way that a version of quantum theory (QT) can be formulated which can be interpreted as being, in the first instance, exclusively about microsystems such as electrons—about how they evolve and interact in physical space and time wholly independent of preparation and measurement. Given the main argument of section 6 above in support of objectism and conjectural essentialism, it becomes an urgent matter to try to develop a microrealistic, essentialistic version of QT. Orthodox QT cannot be interpreted essentialistically, as attributing powers or necessitating properties to electrons, protons, etc., just because it does not provide a consistent theory of the nature of these entities in the absence of measurement, there being within orthodox QT no microrealistic solution to the quantum wave/particle problem. Orthodox QT specifies regularities, but cannot explain why these regularities obtain in terms of (conjectured) powers or necessitating properties possessed by fundamental physical entities. Orthodox QT can only offer miraculous coincidence, not explanation and understanding.

In seeking to develop a microrealistic, essentialistic version of QT, my approach has been—modifying an idea of Popper (1957, 1959)—to interpret QT as attributing *propensities* to microsystems. A propensity, as understood here, is a physical property—a probabilistic power or necessitating property (of the kind discussed in section 6 above). In other words, the notion of 'propensity' is a *probabilistic generalization* of the *deter-*

ministic notion of physical power or necessitating property of the kind that deterministic theories of classical physics, essentialistically interpreted, can be regarded as attributing to classical physical entities such as particles and fields. (See Maxwell 1976a, pp. 283–89 for a more detailed development of this point.) This approach requires that precise, microrealistic, quantum conditions be specified for propensities to be 'actualized'—for probabilistic events to occur in quantum systems even in the absence of measurement. My proposed solution to this key problem is that probabilistic 'actualizations' occur whenever, as a result of potential particle creation or annihilation, a composite quantum system evolves into a superposition of two states with rest masses that differ by δm. Reinterpreting the time/energy uncertainty relations, I suggest that such a superposition persists only for a time $\delta t = h/\delta m \cdot c^2$, and then jumps to one or other rest mass state. All quantum measurements can, I argue, be interpreted as special cases of this kind of probabilistic occurrence (see Maxwell 1976a, 1982).

According to this approach, then, the strange wave/particle features of quantum entities such as electrons are due to the fact that these entities have *propensities* as fundamental physical properties, thus being unlike anything we seem to encounter in the macroscopic world. The propensity of an electron to interact in a particle-like way evolves in a wave-like fashion in accordance with Schrödinger's time-dependent equation (to a first approximation)—just as long as this propensity is not (probabilistically) actualized. An electron is quite unlike a classical wave or particle; it may be called a 'wavicle', 'smearon' or 'propensiton'.

This 'propensiton' version of QT can in principle reproduce all the empirical success of orthodox QT. It is much less *ad hoc*, much more explanatory, than orthodox QT in that it can (in principle) explain macrophenomena arising solely as a result of interactions between microsystems (whereas orthodox QT cannot in that it presupposes the existence of macromeasuring instruments in its basic formulation). It is much more precise than orthodox QT, in that the physical conditions for probabilistic events to occur are much more precisely specified (orthodox QT asserting only that probabilistic events occur if and only if a measurement is made, 'measurement' here being an extremely imprecise notion). Finally, propensiton QT differs empirically from orthodox QT, in principle and perhaps in practice. This is because of the fact that propensiton QT asserts that probabilistic events occur even in the absence of measurement, whereas orthodox QT denies this. In particular, the two versions of QT ought to be empirically distinguishable by means of experiments performed on decaying systems, such as radioactive nuclei, of the kind discussed by Fonda et al. (1978). Orthodox QT predicts that such systems decay continuously in the absence of measurement, the systems persisting in a superposition of the decayed and undecayed state. Propensiton QT predicts that such systems persist as superpositions of the decayed and undecayed states only for limited times, after which each system jumps abruptly and probabilistically into *either* the decayed *or* undecayed state, even in the absence of measurement. The two versions of QT predict the same rate of decay, in the absence of measurement, if and only if the decay rate is exponential. For short and long times, QT predicts departure from exponential rates of decay (in the absence of measurement). Thus there is here a basis—certainly in principle, and perhaps in practice—for crucial experiments designed to decide between orthodox and propensiton versions of QT. (For further details concerning the points of this paragraph, see Maxwell 1976a, 1982, 1984, chap. 10; and Fonda et al. 1978.)

Despite these impressive credentials, propensiton QT may well be judged to be wholly unacceptable for one reason alone. The theory is irreparably incompatible with special relativity. For propensiton QT postulates that, in appropriate physical conditions, propensitons—which may be smeared out in space over large volumes—collapse *instantaneously* into very small volumes; and this contradicts special relativity. This contradiction is not merely because of the fact that propensiton QT postulates a faster-than-light collapse of wave packets, or propensitons. Many have argued that faster-than-light particles—tachyons—are permitted by special relativity, as long as it is conceded that such particles move in one direction in some reference frames, and in the opposite direction in others. Much more seriously, it is the demand that propensiton collapse be *instantaneous* which irreparably contradicts special relativity. For special relativity asserts that all inertial reference frames are physically equivalent. In only one reference frame, however, will any given probabilistic collapse of propensiton state be instantaneous; in other, relatively moving inertial reference frames the collapse will not, according to special relativity, be instantaneous (though always faster-than-light).

There are, it may be argued, three reasons why propensiton QT needs to be interpreted as being irrevocably committed to *instantaneous* propensiton collapse.

First, it may be argued that instantaneous collapse is implicit in the basic idea of propensities becoming probabilistically 'actualized', of the potential becoming actual. Either propensities evolve smoothly and deterministically (in accordance with Schrödinger's time-dependent equation); or there is the abrupt, instantaneous probabilistic actualization of propensities. Any theory which described propensities as being actualized smoothly and gradually in time (in accordance with some sort of time reversal of Schrödinger's equation) abandons altogether the basic propensity idea.

Second, the very requirement for a probabilistic event to occur, postulated by propensiton QT, appeals to the notion of *rest mass*, and hence appeals to the existence of a privileged reference frame at rest, in terms of which the probabilistic event is to be described. This is compatible with the postulate of instantaneous wave packet collapse, and incompatible with the thesis that wave packet collapse occurs in a faster-than-light, Lorentz invariant manner.

Third, and much the most serious, propensiton collapse must be instantaneous if causal anomalies are to be avoided. Suppose a wave packet or propensiton, spread throughout a large region of space R, collapses instantaneously, relative to reference frame F_0 into a small region δR_0 because of a physical interaction that occurs in δR_0. If this collapse is Lorentz invariant then in some other reference frame, F_1, the propensiton begins to collapse in δR_1 in R a long way away from δR_0, the collapse travelling faster than light for some time towards δR_0. In this case physical events in δR_1, far from δR_0, *anticipate* an interaction that will occur in the future in δR_0. The future influences the past. In order to avoid this absurdity, it is necessary to stipulate that such probabilistic collapses of propensities occur instantaneously, in a non-Lorentz invariant way.

Recent experimental results, such as those of Aspect, Grangier, and Roger (1982), appear to confirm that wave packet collapsing events, associated with measurement, occur in a faster-than-light way. This is a great experimental success for propensiton QT. The experimental results do not, however, in themselves decisively refute special relativity and establish the instantaneous character of wave packet collapse. As Redhead (1983) has argued, there are at least two alternatives to this view. In the first place, upholders of orthodox QT may argue that 'wave packet collapse', associated with measurement, is not a physical phenomenon at all; it cannot, therefore, conflict with special relativity. Secondly, there is the possibility that a Lorentz invariant, tachyon-like theory of wave packet collapse may be developed. The experimental results in themselves do not exclude these possibilities, and thus do not establish that special relativity (realistically interpreted) is false. Those who uphold the orthodox interpretation of QT (still the majority of physicists today), and those who seek to develop a Lorentz invariant theory of wave packet collapse, such as Fox (1972), will continue to regard propensiton QT as highly implausible, despite the results of Aspect et al.

The standing of propensiton QT changes dramatically however if the main argument of this paper is correct, and *probabilism in general* contradicts special relativity. For in this case *any* fundamentally probabilistic physical theory must contradict special relativity. In particular, all interpretations and versions of QT which hold QT to be fundamentally probabilistic must contradict special relativity. Thus the fact that propensiton QT contradicts special relativity in the way indicated—as a result of its fundamentally probabilistic character—cannot tell in any way at all against the theory.[4]

Propensiton QT deserves, I conclude, serious attention from the physics community. Only the accidents of intellectual history have, I suggest, prevented propensiton QT from being adopted decades ago as the official, dominant version and interpretation of quantum mechanics, the orthodox, Copenhagen interpretation generally being regarded as a highly unsatisfactory, implausible, minority viewpoint. In particular, it is important that propensiton QT be tested experimentally against orthodox QT, for example, in the way indicated above. I conclude also that all those who, like Fox, seek a Lorentz invariant theory of wave packet collapse are—if the argument of this paper is correct—engaging in a misguided endeavor.

8. Implications of the Argument for Theoretical Physics as a Whole. The deepest problem confronting theoretical physics today, in seeking to discover the underlying *unity* inherent in the laws of nature—a unity we conjecture to exist—is the problem of how to unify general relativity and quantum theory. In seeking to solve this problem, it is important to try to extract the most basic, general aspects of the problem from those aspects that are secondary and peripheral. We need to do this if we are to find guidelines towards the development of a new unifying theory, guidelines of the kind found by Einstein in developing special and general relativity in the first place.

If the main argument of this paper is correct, then it provides grounds for holding that the most basic aspect of the conflict between general relativity and quantum theory is that the former theory is incompatible with *probabilism*. The first, and most elementary, change that needs to be made to general relativity, as a step towards transforming it into unified, general relativistic quantum theory, is to render it *compatible* with probabilism. This requires at least that a version of general relativity be formulated in which there exists in space-time a unique set of temporally successive, spacelike hypersurfaces, to constitute successive cosmic or universal 'nows'. These hypersurfaces then need to be related to the presence of *matter*, in a way to be specified by some generalization of the propensiton QT requirement for probabilistic actualization of propensities to occur. In this way one can perhaps discern a possible route to the unification of general relativity and quantum theory—a route almost certainly not being considered by any theoretical physicist today, because

[4]Deterministic evolutions of propensities can be Lorentz invariant; it is only probabilistic actualizations of propensities that must violate special relativity.

of a general failure to take into account the import of the main argument of this paper.

One final point. The argument of this paper is put forward in part with the intention of putting into practice and illustrating the aim-oriented, empiricist methodology of discovery, involving an interplay of physical and metaphysical considerations, which needs to be put into practice if natural philosophy is to be pursued rationally—as I have argued at length elsewhere (see Maxwell 1974, 1976b, 1979, 1984).

APPENDIX

The idea that interpretative problems of QT can be solved, and realism be upheld, by means of a propensity interpretation of the theory we owe primarily to Popper (1957, 1967, 1982), even though as Popper himself has pointed out Born, Heisenberg, Dirac, Eddington, Jeans, and Landé have on occasions made remarks in this direction (Popper 1982, pp. 130–35); and Margenau's *latency* view may be held to amount to a propensity interpretation of QT; see Margenau (1950). In the circumstances, I ought perhaps to explain how, and why, my propensity interpretation of QT differs from Popper's. Some basic differences are the following.

According to Popper: "*Propensities are properties of neither particles nor photons nor electrons nor pennies*. They are *properties of the repeatable experimental* arrangement . . ." (Popper 1967, p. 38). Subsequently, partly in response to criticism, Popper (1982, p. 71) has emphasized that: "Propensities are . . . not properties of the particle but of the objective physical situation" which may, but usually will not, be a repeatable experimental arrangement created by man. Popper also asserts that propensities are *relational* properties of objects and whole physical situations that serve to actualize propensities. Quite clearly, Popper rejects my view that propensities are to be understood as essentialistic powers or necessitating properties of objects *per se*, e.g., electrons, which determine (probabilistically) how these objects interact with one another, analogously to the way in which deterministic necessitating properties like solidity or charge do this.

There is, closely related to this basic difference in the way propensities are conceived, a dramatic difference in the way in which the entities of the quantum domain are conceived. For Popper, electrons, protons, etc., are particles with definite trajectories. For me, electrons are neither particles nor waves but 'smearons' or 'propensitons'—roughly speaking, spatially smeared out wave packets interpreted as determining propensities to interact. The strange features of smearons or propensitons are owing to the fact that these entities have propensities as basic physical properties. In contrast, pennies and dice have nonbasic propensities that can be explained away in terms of nonpropensity-like deterministic physical properties, and initial conditions that vary, in a statistically determinate way, from toss to toss.

Again, for Popper the reduction of the wave packet is not a *physical* phenomenon at all; it "is not an effect characteristic of quantum theory but of probability theory in general" (Popper 1967, p. 34), which arises just as much when a tossed penny comes to rest as when a quantum measurement is made. For me, the reduction of the wave packet is a real physical phenomenon, peculiar to the quantum domain, and unlike what occurs when a penny comes to rest. Wave packet reductions are probabilistic actualizations of propensities of smearons, as opposed to deterministic evolutions of propensities of smearons (in accordance with Schrödinger's time-dependent equation). For Popper, there is no general, fundamental problem of specifying the precise physical conditions for wave packet reductions to occur—just because this is not, for Popper, a distinctive kind of physical phenomenon. For me, the basic problem confronting any attempt to develop a microrealistic propensity interpretation of QT is just to specify, in exclusively microrealistic terms, precise, necessary, and sufficient physical conditions for propensities to be actualized, for wave packets to 'collapse'—no surreptitious reference being made to observables, measurement, or vague 'irreversibility'. In putting forward a possible solution to this problem (indicated above), I have succeeded in providing a fully microrealistic interpretation of QT—one which interprets QT as being, in the first instance, exclusively about microsystems and their mutual interactions. This interpretation of QT is, as a result, (i) experimentally distinguishable from orthodox QT; (ii) free from the grotesque *ad hoc*ness of orthodox QT arising from the fact that orthodox QT must presuppose in its basic postulates the existence of macroscopic measuring instruments, and some part of classical physics to describe such instruments, it thus being impossible for orthodox QT to explain macrophenomena and classical physics from quantum postulates alone. As a result of failing to solve the problem of specifying microphysical conditions for wave packets to collapse—as a result, indeed, of failing even to recognize the existence of the problem—Popper's propensity version of QT fails to be microrealistic in the above sense; it is thus just as grotesquely *ad hoc* as orthodox QT, and it is not experimentally distinguishable from orthodox QT.

The differences just indicated all stem, I suggest, from two general philosophical differences. First, whereas I uphold conjectural essentialism, Popper vehemently opposes essentialism; see Popper 1963. Second, whereas I seek a microrealistic version of QT—a version capable in principle of explaining macrophenomena *solely* in terms of microphenomena which alone, for me, can be non-*ad hoc* and genuinely explanatory—Popper appears to seek only a realistic interpretation of QT, the need to explain macrophenomena and properties solely in terms of microphenomena and properties being nowhere asserted.

It is Popper's anti-essentialism, I suggest, which leads him to adopt his nonessentialistic interpretation, (i) of propensities in general, and (ii) of QT in particular. Popper's anti-essentialistic, relational way of understanding quantum propensities allows him to conceive of quantum entities as particles, and to dismiss wave packet reductions as nonphysical. (Conjectural) essentialism holds, by contrast, that the physical properties and character of physical entities are given by the physical laws these entities obey; it thus becomes highly implausible to suppose that electrons, obeying fundamentally probabilistic laws, and having propensities as basic physical properties, might be *particles*—entities of classical, deterministic physics. In addition, Popper's failure to give priority to the task of developing a fully microrealistic version of QT has led him to overlook the serious inadequacies of his interpretation of QT. For further criticisms of Popper's viewpoint see Feyerabend (1968), Gardner (1972), and Maxwell (1975).

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