tific theory to another which encompasses it *and* with which it is inconsistent.

We have tried to show just how this thesis is to be understood, and we have tried to support it by suggesting an analysis of just what circumstances do prevail when a term is retained in the transition between scientific theories (iii). In order to deal with claims (i) which run counter to this thesis, we have tried to show (ii) that they are based on inadequate criteria for change of meaning. Beyond these critical remarks, however, no attempt has been made to treat in any substantial way problems of meaning. If one acknowledges the criticism and the analysis and still tries to undermine the above thesis by urging a radical change of meaning, the suspicion is bound to grow that such opposition is founded only in a general skepticism with regard to the stability of meanings. Surely, neither historians nor even philosophers of science need contend with that.

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TIME AND PHYSICAL GEOMETRY *

I THINK that if we attempted to set out the "man on the street's" view of the nature of time, we would find that the main principle underlying his convictions on this subject might be stated somewhat as follows:

(1) All (and only) things that exist *now* are real.

Future things (which do not already exist) are not real (on this view); although, of course they *will* be real when the appropriate time has come to be the present time. Similarly, past things (which have ceased to exist) are not real, although they *were* real in the past.

Obviously, we shall have to make some assumptions about the concept *real* if we are to discuss the "man on the street's" view at all. The assumptions I shall make are as follows:

  i. I-now am real. (Of course, this assumption changes each time I announce that I am making it, since 'I-now' refers to a different instantaneous "me.")

  ii. At least one other observer is real, and it is possible for this other observer to be in motion relative to me.

And, the most important assumption, which will be referred to (when

properly understood) as the principle that There Are No Privileged Observers:

III. If it is the case that all and only the things that stand in a certain relation R to me-now are real, and you-now are also real, then it is also the case that all and only the things that stand in the relation R to you-now are real.

If the assumption III is not to be vacuous, it is necessary to understand the expression 'the things' as referring not just to present things, but to all things past, present, and future, whether we regard all these things as "real" or not. (That is, III is to be understood as stated in "tenseless" language, except for the indexical terms 'me-now' and 'you-now'.) Secondly, R must be restricted to physical relations that are supposed to be independent of the choice of a coordinate system (as simultaneity was in *classical* physics) and to be definable in a "tenseless" way in terms of the fundamental notions of physics. And, lastly, it must not depend on anything *accidental* (physically speaking) that all and only the things that stand in the relation R to me-now are real.

We note that, if we assume classical physics and take the relation R to be the relation of simultaneity, then, on the view (1), it is true that all and only the things that stand in the relation R to me-now are real, and the principle III is satisfied because the relation of simultaneity is transitive.
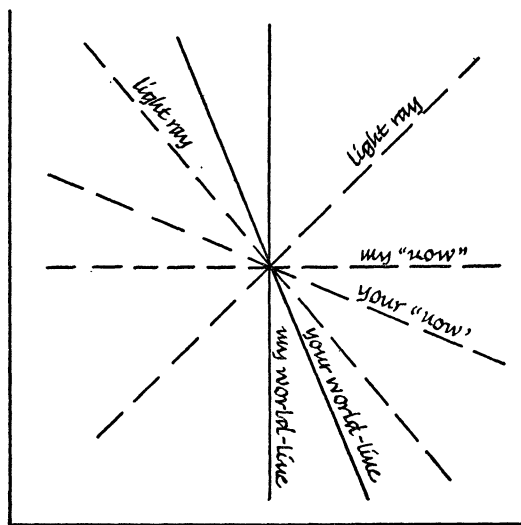

FIGURE 1

Finally, I shall assume Special Relativity.

We now discover something really remarkable. Namely, on every natural choice of the relation R, it turns out that *future* things (or events) are already real! For example, suppose I take the relation R to be the relation of simultaneity (as is suggested by (1)). For the remainder of this paper I shall assume the following (perfectly possible) physical situation to be actual: you-now and I-now are at the same place now, but moving with relative velocities which are very large (relative to the speed of light, which I take to be $= 1$). Thus, our world-lines look as shown in figure 1 (I have also drawn our "light-cone" for the purpose of the later discussion):

Now then, we cannot take the relation of simultaneity-in-my-coordinate-system to be R without violating the way in which the principle that There Are No Privileged Observers is intended to be understood. Rather, we have to take R to be the the relation of simultaneity-in-the-*observer's*-coordinate-system. Then, if I assume that all and only those things which stand in *this* relation R to me-now are real, I find that you-now are also real (since I-now and you-now are simultaneous-at-a-point and, hence, simultaneous in *every* coordinate system). Hence, everything that stands in the relation R to you—everything that is simultaneous to you-now in *your* coordinate system —is also real. But it is well known that, as a consequence of Special Relativity, there are events which lie in "the future" according to *my* coordinate system and which lie in the "present" of you-now according to *your* coordinate system. Since these things stand in the relation R to you-now, and you-now are real, and it was assumed that all and only the things that stand in the relation R to me-now are real, the principle III requires that I call these future things and events real! (But, actually, I now have a contradiction: for these future things do not stand in the relation R to me-now, and so my assumption that all and only the things that stand in *this* relation R to me-now are real was already inconsistent with the principle that There Are No Privileged Observers.)

The difficulty is obvious: what the principle that There Are No Privileged Observers requires is simply that the relation R be *transitive*; i.e., that it have the property that from xRy and yRz it follow that xRz. Simultaneity-in-*my*-coordinate-system has this property, since if x is simultaneous with y in my coordinate system, and y is simultaneous with z in my coordinate system, then x is also simultaneous with z in my coordinate system; but simultaneity-in-*my*-coordinate system is not admissible as a choice of R, because it depends on the coordinate system. And the relation "x is simultaneous with y in the coordinate system of x" (which is essentially the relation we just

considered), while admissible, is not transitive, since, if I-now am simultaneous with you-now in the coordinate system of me-now, and you-now are simultaneous with event X in the coordinate system of you-now, it does *not* follow that I-now am simultaneous with event X in the coordinate system of me-now.

Now then, if we combine the fact that the relation R is required by III to be transitive with our desire to preserve the following principle, which is one-half of (1):

(2) All things that exist now are real.
—then we quickly see that future things must be real.

For, if the relation R satisfies (2)—and I take (2) to mean (at least when *I* assert it) that all things that exist *now* according to *my* coordinate system are real—and you-now are as in figure 1, then you-now must stand in the relation R to me-now, since you exist both *now* and *here*. But, if the relation R always holds between all the events that are on some one "simultaneity line" in my coordinate system and me-at-the-appropriate-time, then (since the laws of nature are invariant under Lorentz transformation, by the principle of Special Relativity), the relation R must also hold between all the events on some one "simultaneity-line" in *any* observer's coordinate system and that-observer-at-the-appropriate-time. Hence, all the events that are simultaneous with you-now in *your* coordinate system must *also* bear the relation R to you-now. Let event X be one such event which is "in the future" according to *my* coordinate system (if our velocities are as shown in figure 1, then such an event X must always exist). Then, since the event X bears the relation R to you-now, and you-now bear the relation R to me-now, the event X bears the relation R to me-now. But we chose R to be such that all and only those events which bear R to me-now are real. So the event X, which is a *future* event according to my coordinate system, is already real!

The Space-fight Tomorrow. A different problem connected with time was studied by Aristotle. Aristotle was what we would today call an "indeterminist." He did not think that the outcome of certain future events—his example was, Who will win the sea-fight tomorrow?—was determined at the present time. Given this assumption, he found it difficult to believe that the statement 'The *A*s will win the sea-fight' *already* has a truth value, that it is already true or already false. Rather he suggested that such "future contingent" statements have *no* truth value.

Some philosophers would say that this belief rested upon a simple *mistake* on Aristotle's part, that 'is true' and 'is false' are *tenseless* predicates, and that statements are "true" and "false" *simpliciter*, not

"already true" or "now true" or "going to be true," etc. But this is begging the question. If any statement that is true at some time is true at every time, then indeed there is some point to dropping this way of speaking and making 'true' and 'false' tenseless (which they clearly are *not* in ordinary language, by the way). But the correctness of this view —whether you express it by saying that truth is eternal or by saying that truth is "tenseless" does not matter—was what Aristotle was challenging. It is unfair to assume a form of language which presupposes that Aristotle was wrong and then to use the assumed correctness of this linguistic formalism as an argument against Aristotle.

It would be easy to write down a list of predicates $P_1, \ldots, P_n$ such that, on Aristotle's view, the statement that any past or (completed) present event has one of the properties $P_1, \ldots, P_n$ always has a truth value, but the statement that a future event has one of the properties P_i does not have a truth value. Thus Aristotle's view is a sort of supplement to what we called the "man on the street's" view of time. The principle (1) asserts a fundamental difference between the present and both the past and the future; but it does not assert any difference between the past and the future; neither past things nor future things can now be called real. Aristotle would perhaps have accepted this, but he would have added that there is a fundamental difference, nonetheless, between the past and the future, viz., that past events are now determined, the relevant statements about them have now acquired truth values which will "stick" for all time; but future events are undetermined, and at least some statements about them are not yet either true or false. (The fact that you can change the future but not the past would have been explained by Aristotle in terms of this fundamental asymmetry between the two.)

Aristotle was wrong. At least he was wrong if Relativity is right; and there is today better reason to believe Relativity than to believe Aristotle, on this point at least. To see this, let us revert to the situation depicted in figure 1, and let there be a space-fight which is "in the future" in my coordinate system (i.e., above the "now" of "me-now") but "in the past" in your coordinate system (i.e., below the "now" of "you-now"). Then, since the space-fight is "in the future" (for me), I must say that the statement 'the *A*s will win or have already won' has no truth value. But, if you say that this same statement *has* a truth value—as you must, if Aristotle is right, since it lies "in the past" for you—then you and I cannot both be right. Nor can just one of us be right, without becoming a Privileged Observer! [1]

[1] Nor can one avoid the difficulty by abandoning the objectivity of truth, and speaking of "truth-for-me" and "truth-for-you." For, if it is even true-for-me that the statement in question *has* a *truth-value–for-you,* then either it is true-for-me

The point becomes even clearer when viewed a bit more abstractly. Let us assume that Aristotle was right. Then I shall show that we can define a relation of Absolute Simultaneity, contradicting Relativity. Namely, I define an event to be Absolutely Future if the statement that it has the property P_i (where P_i is one of the properties in the list alluded to before) has no truth value. I define an event to be Absolutely Present if it is *not* Absolutely Future and if every event that is in its proper future (i.e., occurs later on its world-line—this is relativistically invariant) *is* Absolutely Future. Then two events are Absolutely Simultaneous if and only if there is a time (in the coordinate system of *any* observer) at which they are both Absolutely Present. (Also, one can define *that* observer to be at Absolute Rest.)

It is no criticism of Aristotle's ability to say that he was mistaken, any more than it is a criticism of Newton that he failed to foresee Relativity. Had the world been different than it is, these sorts of objections could not be brought against Aristotle's view. But it is important to see that Aristotle's view depends upon an *absolute* "pastness" and "futurity" just as much as Newtonian physics does, and that it is obsolete for the same reason.

I might try to save the view that "future contingents" have no truth value by saying that even *present*-tense statements have no truth value if they refer to the outcome of events that are so far away that a causal signal informing me of the outcome could not have reached me-now without traveling faster than light. In other words, I might attempt saying that statements about events that are in neither the upper half nor the lower half of my light-cone have no truth value. In addition, statements about events in the upper half of my light-cone have no

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that the statement in question is true-for-you, or it is true-for-me that the statement in question is false-for-you (since 'true-for-you' and 'false-for-you' are the only two truth-values-for-you). But if it is true-for-me that "the As have won or will win the space-fight" is true-for-you, then, to all intents and purposes, "the As have won or will win the space-fight" is true-for-me too, since both facts—the outcome of the space-fight and the truth-value–for-you of this statement—have exactly the same status relative to me; and, likewise, if it is true-for-me that "the As have won or will win the space-fight" is false-for-you, then, to all intents and purposes, "the As have won or will win the space-fight" is false-for-me too. So I must not regard it as true that "the As have won or will win the space-fight" is either true-for-you or false-for-you, if I wish to maintain that this future contingent has no truth value. And hence, if it is true that:

For every contingent statement S and every observer O, (S is true-for-O or S is false-for-O) if and only if S refers to an event in the lower half of O's light-cone.

—then this "truth" cannot itself be stated by any observer on pain of contradiction!

(Here I assume this much concerning the logic of "true-for-me": that, if $p \vee q$ is true-for-me, then either p is true-for-me or else q is true-for-me. Of course, we might try still more radical alterations of logic. But it seems considerably preferable —to me at least—*not* to do this, and rather to concede the objectivity of future contingents.)

truth value, since they are in my future according to every coordinate system. So only statements about events in the lower half of my light-cone have a truth value; only events that are in "my past" according to *all* observers are determined.

This last move, however, flagrantly violates the idea that there are no Privileged Observers. Why should a statement's having or not having a truth value depend upon the relation of the events referred to in the statement to just one special human being, *me*? Moreover, the following highly undesirable consequence flows from this last view: let Oscar be a person whose whole world-line is outside of the light-cone of me-now. Let me-future be a future "stage" of me such that Oscar is in the lower half of the light-cone of me-future. Then, when that future becomes the present, it will become true that Oscar *existed,* although it will never have had a truth value to say in the present tense "Oscar exists now." Things could come to *have been,* without its ever having been true that they *are!*

Morals and Conclusions. What moral should we draw from all this? In the first part of this paper I showed that, if we couple the assumption III with the principle (2), we must say that future things are real, even if they do not exist yet. Strictly speaking, I showed only that *some* future things are real, and that only on the assumption that the situation shown in figure 1 obtains. But the argument can obviously be extended (bringing in certain further assumptions with which virtually no one would argue) to show that *all* future things are real ("things" here includes "events"), and likewise that all *past* things are real, even though they do not exist *now*. To spell this out: If I accept (2), then I must say that all those things are real (but not *only* those things, as we saw) which bear to me the following relation: the relation y bears to x just in case y is simultaneous with x in the coordinate system of x. I must describe the relation this way, and not as "the relation y bears to x just in case y is simultaneous with x *in the coordinate system of me-now,*" because otherwise I would be committed to the view that the real things bear to me-now a relation which is not Lo-rentz-invariant and, hence, that they define an absolute simultaneity. But principle III then requires that I also count every thing and event which bears the *transitive closure* of R to me (i.e., which bears R to me, or which bears R to something that bears R to me, or which bears R to something that bears R to something that bears R to me, or . . . .) as real. But every thing and event in space-time bears the transitive closure of the above relation R to me, at least if there are enough observers. And, if we allow all physical systems (even electromagnetic fields, etc.) as "observers" (as why should we not?) and allow observers

to use coordinate systems in which they are not at rest, then there are certainly "enough observers."

In the second part of this paper I showed that contingent statements about future events already have a truth value. In consequence, the "tenseless" notion of existence (i.e., the notion that amounts to "will exist, or has existed, or exists right now") is perfectly well-defined. This is fortunate, since the upshot of the first part of the paper could also have been stated by saying that the notion of being "real" turns out to be coextensive with the *tenseless* notion of existence.

I conclude that the problem of the reality and the determinateness of future events is now solved. Moreover, it is solved by physics and not by philosophy. We have learned that we live in a four-dimensional and not a three-dimensional world, and that space and time—or, better, space-like separations and time-like separations—are just two aspects of a single four-dimensional continuum with a peculiar metric which sometimes permits distance $(y, x) = 0$ even when $x \neq y$. Indeed, I do not believe that there are any longer any *philosophical* problems about Time; there is only the physical problem of determining the exact physical geometry of the four-dimensional continuum that we inhabit.

In this paper I have talked only about the relativistic aspects of the problem of physical time: there is, of course, also the problem of thermodynamics, and whether the Second Law does or does not explain the existence of "irreversible" processes (the so-called "problem of the direction of time"), and the problem of the existence or nonexistence of true irreversibilities in quantum mechanics, which, I gather, is currently under hot discussion. I have not talked about these problems.

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THE FALSIFIABILITY OF GEOMETRIC THEORIES

IN several articles, and in his recent book on the philosophy of space and time, Adolf Grünbaum has offered a number of observations on the famous thesis of Duhem concerning the nonexistence of "crucial experiments" in physical science.[1] At least three separate theses have been offered by Grünbaum:

1. The Duhem thesis—that no crucial experiment can provide logically compelling grounds for the rejection of a physical hypothesis,

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[1] "Law and Convention in Physical Theory," in H. Feigl and G. Maxwell, eds., *Current Issues in the Philosophy of Science* (New York: Holt, Rinehart and Winston, 1961); and *Philosophical Problems of Space and Time* (New York: Alfred Knopf, 1963), esp. chap. 4.