ter how small in the relation between acceleration relative to the fixed stars and the inertial forces that result. According to Newton, the inertial effects are the result of acceleration relative to a totally unmodifiable substantival space, and nothing we do can ever change their lawlike association with acceleration. So the possibility of a crucial experiment is not ruled out entirely. In addition, it may be that a general theory that we believe for independent empirical reasons will have theoretical consequences that differentially support the Machian or the Newtonian theory. We shall see how this direction of investigation goes when I ask whether general relativity supports a Machian or Newtonian world-view in (III,E) below.

I might note at this point that in some versions of his theory Mach denies any distance dependence of his new force at all, thereby making the test between Mach and Newton, which depends upon local variation in the inertial forces with local variation in the distribution of the surrounding matter, impossible. But for the future, I will stick with the version of the Machian theory which allows at least a weak dependence of the force upon the separation of the interacting objects.

3. *Neo-Newtonian Spacetime*

In this section and in the next one we will see how the notions of absolute position, velocity, and acceleration fare in the light of two doctrines about the structure of spacetime whose very nature was quite unimagined by Newton or his critics throughout the seventeenth through nineteenth centuries. Both of these accounts do assume, at least on the surface, the reality of spacetime as an "entity" over and above the material things that may happen to be located in it. Once again one must reflect upon the fact that the critical examination of Newton is two-staged: (1) To what extent was Newton correct in thinking that the facts required the postulation of absolute motions, as opposed to motions merely relative to other material objects? (2) To what extent was Newton correct in believing that the existence of absolute motions requires the postulation of a substantival space, or of spacetime in general, as an independent existent?

Both the theory of neo-Newtonian spacetime and the spacetime theory of special relativity postulate spacetime structures radically different from Newton's "substantival space persisting through time." And the notion of absolute acceleration becomes quite different from Newton's in these accounts. While the accounts agree with Newton that absolute acceleration exists, and that an object absolutely accelerated is accelerated relative to some entity, both deny this "reference entity" the status of a *thing* possessed by Newton's substantival space.

Both theories would give some comfort to a verificationist, for in both of them some of the features of the world which Newton postulates to exist but to have no observable consequences are denied existence. But neither theory would fully satisfy a pure relationist, for in both cases the theories, at least superficially, speak of a spacetime whose existence is postulated to be independent of the existence of any material objects whatever and whose features are postulated to be real and independent of the material objects that happen to occupy the spacetime arena. In (III,F) I shall once again examine in detail the relation between a theory's view about absolute motions and its metaphysical commitment to a substantival spacetime.

The structure of neo-Newtonian spacetime looks like this: The basic entities of which the spacetime is constituted, as a whole is constituted of its parts, are event locations, which as before we will call events, hoping that the reader will not confuse events as locations with events as possible or actual happenings at the locations. Between any pair of events there is a relation that generates the temporal separation of the events. As in Newton's theory, this is an absolute notion. Any two events have a definite temporal separation, which may be zero, and their separation in time is not relative to any particular reference frame, state of motion, or whatever.

A class of events that are simultaneous forms a space. It is assumed as in Newtonian spacetime that the relation of simultaneity, of having a temporal separation of zero, is an equivalence relation: every event is simultaneous with itself; if a is simultaneous with b then b is simultaneous with a; and if a is simultaneous with b and b with c, then a is simultaneous with c. One can, therefore, divide up the class of all events into "equivalence classes" under the relation of simultaneity, i.e., into classes that are disjoint (have no members in common) and when taken together exhaust the class of all events. Each such equivalence class of simultaneous events is called a space.

The structure of each space is assumed to be that of Euclidean three-space. So far the theory parallels Newton's in every detail. But where neo-Newtonian spacetime differs from that of Newtonian is in the way that the spaces are "glued together" to form a spacetime. In Newton's theory of space-through-time, we can keep track of any given spatial point through time. That is, at t_1 we can ask of a point of the space at

t_1 whether it is identical with some point of the space at t_0. In neo-Newtonian spacetime this is impossible. The points of the spaces are events. For simultaneous events *a* and *b* we can ask whether they are the same event--two events at different times are, obviously, different events—but we cannot ask, as one can in Newton's theory, whether the two events occur at the same place in substantival space. In Newton's theory we can view places in substantival space as classes of events that occur at different times but are related to one another by the equivalence relation of being spatially coincident. In neo-Newtonian spacetime, the notion of spatial coincidence holds only for events that are simultaneous. There is no spatial coincidence or spatial noncoincidence for events that occur at different times.

Now in the Newtonian theory it makes sense to ask for the average velocity of a material particle between two events in its history. In the neo-Newtonian theory it is still coherent, of course, to ask for the velocity of a particle between two events in its history, if it is the velocity relative to some particular material frame which is in question. For we can ask whether the position of the particle relative to some other material particle at the later time is the same as or different from its relative position at the earlier time. But since we cannot ask whether the absolute position at the later time is even the same as or different from its absolution position at the earlier time, the notion of "absolute velocity" for a particle is just not defined in the theory. Since the spaces fit together to form spacetime in a way that forbids inquiry into the sameness or difference of position for events at different times, there is simply no such thing as "the" change of position of a particle through time, and, hence, no such thing as "the" velocity of a particle through an interval of time. And since there is no such thing as "the" average velocity of a particle through an interval of time, there is no such thing as "the" instantaneous velocity of a particle at a time, since this notion is defined as a limit of a series of average velocities. So neo-Newtonian spacetime satisfies at least one verificationist objection to the Newtonian theory. There is no longer in this view an absolute velocity of a particle existing as a real but totally unobservable feature of the world.

But if absolute velocity simply does not exist in the neo-Newtonian view, how can there be such a thing as absolute acceleration in this account? The answer is simple. We simply build in enough additional structure to the spacetime to allow for the definition of noninertial motion. It works like this: So far the only relation nonsimultaneous events have to one another is their temporal separation. I now introduce a new three-place relation, that of three nonsimultaneous events being inertial, or if we wish, the relation of c being inertial relative to a and b. I assume that there is such a relation. The empirical correlate of this relation is clear. Suppose that we have three events, a, b, and c, none of which is simultaneous with one of the others. How can we test to see if the third is inertial relative to the first two? We look to see if there is a possible path of a particle such that: (1) Three events in the particle's history are located at a, b, and c, and (2) the particle is at rest in an inertial frame, i.e., in a frame such that any system at rest in that frame has no inertial forces acting upon it. Essentially, collections of events, all of which are nonsimultaneous with any other event in the class, constitute inertial classes of events if they are all related to one another by being locations of events in the history of some particle moving free of forces, moving "inertially."

With this additional structure built into the spacetime, it is easy to see how absolute accelerations are both definable and measurable. What is the average acceleration of a particle over an interval of its trajectory? Take the particle at the beginning of the interval. Find a reference frame that is (1) inertial and (2) such that at the initial time the test particle is at rest in this inertial frame. At the end of the interval, find the new inertial frame in which the particle is at rest. Now find the *relative* velocity of the second frame relative to the first at the end of the time interval. We don't know what the absolute velocity of the first frame is; indeed, there is no such thing as its absolute velocity. But we do know that the first inertial frame has had no *change* in its velocity throughout the interval, since it is an inertial frame and these, by definition, fix the meaning of "frame that suffers no velocity change over an interval." So the relative velocity of the second frame to the first at the end of the interval gives the "absolute velocity change" of the particle over the interval, since the particle was at rest in the first frame at the beginning of the interval and at rest in the second at the end. Now take this absolute velocity change and divide it by the temporal separation between the events at the beginning and end of the intervals. This is the "average absolute acceleration" of the particle over the interval. By the usual limiting process we generate the notion of instantaneous absolute acceleration.

In this neo-Newtonian view, then, absolute accelerations are both real and empirically measurable. Absolute velocities are not measurable, but that is because they simply do not exist. It is clear that neo-Newtonian spacetime is somewhat more appropriate to the facts that led Newton to postulate substantival space-through-time as his model of spacetime. It makes fewer unnecessary postulations about the structure of spacetime, in the sense that it puts into the structure of spacetime only those features that have empirical consequences.

Well, not quite. To be sure, the old verificationist objection to Newtonian spacetime, that it postulated the existence of absolute velocities with no observable consequences, is now vitiated. But the very hard-nosed verificationist is still likely to be dissatisfied. Consider the world at a given moment in time. According to the neo-Newtonian theory there is a set of spacetime locations which are simultaneous and constitute the space of the world at this time. The material objects of the world are situated at various "places" in this space. But would it make any observational difference, we can hear Leibniz object, if the world were situated at the time at some other location in "space itself," all spatial relations of material objects relative to one another kept unchanged? No it would not. Once again this extreme version of verificationism is contravened, as indeed it must be by any spacetime theory that postulates a spacetime with an existence over and above the existence of the material objects "in" the spacetime and yet denies any direct observability of the spacetime locations themselves.

4. *The Spacetime of Special Relativity and Absolute Acceleration*

I have already described the spacetime appropriate to special relativity, Minkowski spacetime, in some detail in (II,C,1), and here I will only rehearse its most crucial features. My concern in this section is not to motivate the adoption of this spacetime model, I leave that to Chapter IV below, but only to see how the notion of absolute motion fares in the light of this new spacetime theory.

As in the case of Newtonian and neo-Newtonian spacetime, the spacetime of special relativity is postulated, at least on the surface level, as an independent entity having its own existence and its own structure and, as in the other cases, being totally unaffected by the presence of whatever events happen to take place in its arena. It goes without saying, I think, that the theory is going to fall prey to just those objections of the extreme verificationist to neo-Newtonian spacetime which I brought out at the end of the last section. In this case, however, the objection will be stated slightly differently. In Minkowski spacetime there is no such thing as "the space at a time," since, as we saw in (II,C,1) the notion of simultaneity of events or event locations is no longer invariant. The hard-