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E. Buckingham

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LV. *On the Time Scale.* By E. BUCKINGHAM *.

IN the examination of our notion of time which is necessitated by recent speculations, one point hardly seems to receive the attention it merits. This is the evident fact that *in the nature of things* time is not a measurable quantity; that times can be numbered in accordance with any system we please which does not introduce ambiguity into the meanings of "before," "after," and "at the same time"; and that no system has any more justification than another, *a priori*.

We have a simple criterion by which we may decide whether two temperatures are the same or which is the higher. When we go farther and express temperatures or intervals of temperature by numbers, we do so by adopting an arbitrary convention for numbering temperature, in other words, a scale. With regard to time, the case is analogous. We can say that two events are simultaneous, or that one occurs later than the other, and all other observers will agree with us if they are situated as we are with relation to the two events. But when we go farther and say *how much* later one event is than the other, we adopt a scale for numbering time: we do not measure it in any proper sense, for a past interval of time cannot be superposed upon nor substituted for one now elapsing or to come, so that the fundamental operation which lies at the basis of all true measurement is not only absent but in the nature of things impossible. Tomorrow differs *qualitatively* from today, as the warmth of summer does from the chill of winter. As with temperature, our choice of a scale has been and always will be dictated solely by convenience and subject to arbitrary change whenever we change our minds as to what is most convenient.

Why is it that we use mean solar time instead of sundial time? Because if we use mean solar time a body not acted on by any push or pull that we can detect moves "*uniformiter in directum*." We can use Newton's first law if we adopt this mode of numbering time, but not if we adopt an essentially different one. Newton's laws are the simplest and most perspicuous summary of the facts of pure dynamics, and for this reason and this only, we adopt a time scale which shall make them a correct representation of the observed facts. In effect, we use the first law to fix our time scale. It would be an utter absurdity to say that we "assume" that time "really" does progress in this way. An assumption is a proposition of which the truth or falsity can be decided by reference to some independent criterion. A definition is neither true nor false, it is only useful or not

* Communicated by the Author.

useful. We *define* our time scale by saying that Newton's laws *shall* be true, simply because it pleases us to do so; and it pleases us because we prefer simple to complicated statements of fact, when our choice is free.

Now all this has reference to ordinary experience where the observers are all relatively at rest or nearly so. But if we drop this restriction, a different definition of the time scale may be more convenient; if so, we are entirely at liberty to adopt it, if we do not delude ourselves with any nonsense about clocks "running at a constant rate,"—the term "a constant rate" being quite meaningless except in connexion with some time scale outside of and independent of the clock itself.

The notion of time, as defined by reference to Newton's first law and to the measurable quantity length, is so ingrained in us that the symbol " t " in our equations seems to us as if it ought, somehow or other, always to stand for the old familiar mean solar time. In reality it stands for a derived quantity which may be defined by means of true, *i. e.*, measurable, quantities, through the mediation of Newton's laws or Maxwell's equations or any other statement of observed facts which we may happen to be interested in having appear in a particular form. In the past we have paid attention only to Newton's laws, defined the time scale by reference to them, and used the same time scale in all branches of physics. It now turns out that if the usual form of the electromagnetic equations is to be retained when velocities comparable with that of light are in question, the time scale must be defined by those equations, so that the facts of mechanics are no longer expressible by Newton's laws. And since such velocities occur practically only in connexion with electromagnetic experiments, it may quite legitimately be thought better to pay attention to the electromagnetic than to the mechanical equations when, as for these high velocities, a choice must be made.

Whether a quantity can be so defined that it may replace our familiar " t " in *all* the equations of physics, for observations made under all possible circumstances, and without requiring any too serious modifications in the forms of the equations, remains to be seen. If it can, we may find it well to adopt the new quantity and call it "time." But the task will not be accomplished by shutting one's eyes to the fact that any time scale is merely an arbitrary system of numbering successive events, nor by any use of clocks which run "uniformiter," when uniformiter is defined only by reference to the Latin dictionary.

Washington,
February 15th, 1912.