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A NOTE CONCERNING THE EFFECT OF GRAVITY
ON AN ATOMIC CLOCK

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The cesium atoms in a beam tube are in free fall (except for magnetic fields). Since the general theory of relativity postulates (and predicts) that effects of external gravitational fields on physical systems can be completely eliminated in a sufficiently small spacetime neighborhood, by allowing them to fall freely, the frequency spacing between the energy levels of the atoms will be unaffected (to a very high order) by the gravitational potential, or its gradient, the field. In sensing this frequency by a radiation field in a tube, a correction must be made for the velocity Doppler shift. There is no other effect on atomic clock rates controlled this way, unless there is an effect on other portions of the equipment due to the fact that they are not in free fall. This does not appear to be the case, however. Such clocks measure their "proper" or metric time even though, as a unit, they are not in free fall.

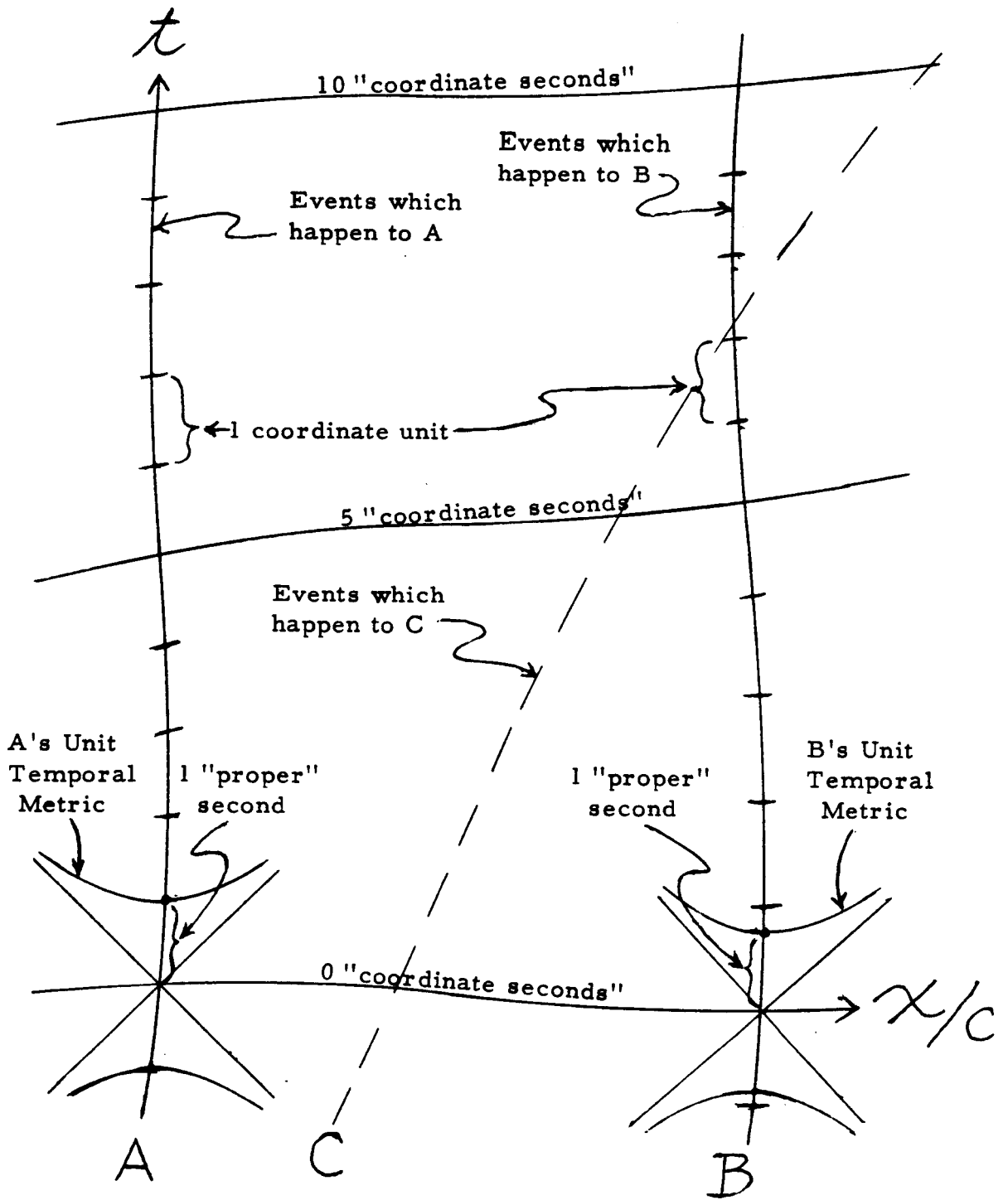
This is not the case for standard coordinate time (and space) systems. Such systems are affected very strongly by the overall field structure, as well as by relative velocity effects. In fact, this is how one can detect spacetime curvatures. Time scales, and distance scales, and the method of disseminating them over large regions in order to construct a standard spacetime coordinate system, must be carefully defined operationally, as I have tried to show in the CIC paper.* There is at least one reference, in astronomical literature, which seems to

*G. E. Hudson, Spacetime Coordinate Systems, Proc. Internat. Chron. Conf. (CIC), June 1964.

indicate that "ephemeris time," as now defined, is best regarded as a coordinate time. (G. C. McVittie, General Relativity and Cosmology, University of Illinois Press, 1965, pp. 89 and ff.) Coordinate time units and metric (proper) time units should be carefully distinguished conceptually.

As an illustration (see Figure), let A set up a time scale using his atomic clock, so that each time coordinate unit for A spans the same time interval as the metric (proper) unit (one second) indicated by his clock. Similarly, B has an atomic clock which also ticks off (proper) seconds. But let A also send signals to B and thus establish a coordinate time scale at B with A being at its spatial origin. This must be done according to some agreed upon procedure which insures the necessary continuity of the coordinate system in both space and time. In the figure, B is shown in a fixed "spatial" relation to this coordinate system, as A is, instead of moving relative to it, as for C. The atomic clock carried by B also records seconds (proper time) but the coordinate time interval units at B obtained from A's signals are generally not one proper second long. This distortion of the coordinate system temporal units relative to the metric (proper) unit depends on the procedure for setting up the coordinate system; for some purposes, it may ultimately prove to be an inescapable one, if gravity is finally concluded to be evidence for a curvature of spacetime.

Different procedures will lead to different (but equally valid) coordinate systems. Each is distorted by gravitational (curvature) effects. Ideal clocks, which record proper metric time, are not affected by these things. Correctly constructed atomic clocks appear to function in this ideal way.



A Comparison of Metric (or Proper)
 and Coordinate Time Units