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September 22, 1971

AEC Contract No. W-7405-eng-48

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The Clock Paradox and Radioactive Decay*

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Mendel Sachs has reopened the old controversy over the clock paradox.[1] Sachs' version of general relatively predicts that the traveling twin is no younger than the one who stays home, contrary to the conventional majority opinion. I will not comment on Sachs' theory. Instead I describe a gedanken experiment that has already been carried out implicitly, with results that verify the conventional opinion. Using experimental facts that everyone including Sachs accepts, I will show that if radioactive decay is a suitable clock, as Sachs believes, then Sachs' theory is wrong.

Start with a group of muons at rest in the laboratory inertial frame. Call half of them Jack and half of them John. Jack and John are the same age, and are at the same place in the same inertial frame. Now accelerate Jack and John together up to some relativistic energy and inject them together into a circular storage ring. We do not worry about how much they have aged so far, since they are together and have aged by the same amount. Their age is continuously monitored by scintillation counters that count radioactive decays; the counters are in the lab frame and completely enclose the storage ring so that every decay is registered. We also monitor the number of muons left in the ring by means of induction electrodes that measure the circulating charge.

John and Jack are both aging more slowly in the ring than they would at rest, because of the well-known time-dilation factor. This has been established hundreds of times by beams of radioactive mesons from accelerators, and to Sachs' satisfaction. ("Many experiments have confirmed the time dilation effect of special relativity.")[1] In particular it has been verified for muons, in the CERN muon storage ring.[2] Thus the counters record a smaller counting rate when the muons are circulating in the storage ring than when they are at rest.

Now turn on a device that decelerates half the muons, John, to rest in the laboratory frame, while allowing the other half, Jack, to continue undisturbed in the ring. This is the first asymmetric treatment of John and Jack. (We could have waited until now to give them their names, if we wished.)

During the deceleration of John there may be some decays of John or of Jack. Our conclusion will be independent of whether or not there are any such decays. For simplicity assume first that neither sample suffers any decays during John's deceleration. (Later we relax that assumption.)

Suppose John and Jack each consist of 100 muons just before decelerating John. Then there are 100 muons in John and 100 in Jack immediately after John comes to rest in the lab (according to our assumption). Now wait until the monitor counters tell us that John, at rest in the lab, has decayed from 100 down to 10 muons. Because of the time-dilation factor, Jack, still circulating in the storage ring, will have decayed down to--let us say--90. (Given these numbers and the

muon lifetime, the reader can calculate the muon momentum in the storage ring.) Next we decelerate Jack to rest in the lab, using the same decelerator as was used for John. Note that Jack and John have now suffered the same sequence of accelerations and decelerations, with the exception of the continuous acceleration suffered by Jack in the extra circuits he made in the storage ring.

Jack and John are together again, at the same place, at rest in the same inertial frame (the lab) where they started. According to Sachs, Jack and John must now exhibit the same age. In order for Jack to have the same age as John he must decay from 90 down to 10 muons during deceleration. Such an anomalous acceleration-induced decay in flight would have been observed long ago, but we do no appeal to that, yet. More important: in spite of the fact that John and Jack experienced the same deceleration in the same device at the same place, Jack must suffer a much larger fraction of acceleration-induced decays than John, in order for him to catch up in age when they reunite. For Sachs' theory to be correct, not only must there be acceleration-induced decays of muons, but the probability of such decays must depend strongly on the previous history of the sample, i.e., how many times it has gone around the storage ring. (We now relax the simplifying assumption that there were no decays during John's deceleration, without affecting the conclusion expressed in the preceding sentence.) There must, therefore, exist a hitherto-undetected hidden variable (internal age) that can distinguish two collections of equal numbers of otherwise identical radioactive mesons. That contradicts our present knowledge of radio-

active particles, according to which their observed behavior under all sorts of accelerations, including the violent ones suffered in elastic nuclear collisions, is independent of their history. (That remark does not hold for a neutral K meson that is a superposition of K_{short} and K_{long}. It does hold for any radioactive particle that exhibits exponential decay.)

There is a possible loophole.—Might not Sachs be right? Might not muons have a hitherto-undiscovered hidden variable that keeps track of the amount of time the muon has spent at a given velocity with respect to any given inertial frame, and then induces the appropriate number of decays when the muon is decelerated to rest in that frame? Such a remarkable discovery, stimulated by the general theory of relativity, would have greatly pleased Einstein, who was dissatisfied with the apparent lack of any internal variable that tells a radioactive atom when it should decay. Could such anomalous acceleration-induced decays have gone undetected? The number of required decays depends on the time spent at a given velocity, independent of the acceleration during that time; i.e., it is independent of the diameter of the storage ring. Therefore we can search for this new hidden variable by looking at high energy muons that have traveled a long distance in a straight line, and then been brought to rest. We can look at energetic cosmic ray muons at sea level. They have been produced high in the earth's atmosphere and would have practically all decayed by the time they reach sea level, if it were not for the time-dilation factor. Thus their hidden variable should tell them to suffer a large number of decays while being brought to rest in an absorber at sea level.

This experiment has been done, by Harold Ticho.[3] Fast incident positive muons triggered a counter system. The muons were decelerated to rest by an absorber. Delayed counts due to radioactive decay at rest were then observed. The experiment was performed at 11 500 ft and at 600 ft (Chicago) with the same apparatus. If there were no asymmetrical aging, Ticho would have observed at Chicago a delayed counting rate anomalously reduced by a factor of about 40. Instead he observed the expected number, both at low altitude and at high altitude.

In summary: Two well established experimental facts guarantee that if our gedanken experiment were actually carried out we would find asymmetric aging. They are the experimentally observed time dilation of radioactive decay of moving particles, and the independence of decay rate on previous history. Thus Sachs' theory of relativity disagrees with experiment.

Footnote and References

*Work done under the auspices of the U.S. Atomic Energy Commission.

1. Mendel Sachs, "A Resolution of the Clock Paradox," Physics Today, September 1971.
2. J. Bailey, W. Bartl, G. Von Bochmann, R. C. A. Brown, F. J. M. Farley, H. Jostlein, E. Picasso, and R. W. Williams, Phys. Letters 28B, 287 (1968).
3. H. Ticho, Phys. Rev. 72, 255 (1947), and private communication to F. Crawford.

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