ATOMIC CLOCKS COMING AND GOING†

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The results obtained by Hafele and Keating[1] are so important that they merit a more critical examination than that made by W. B. in *Nature*.[2] He gave the final result that the clocks lost 59 ± 10 ns** during their eastward flight and gained 273 ± 7 ns during their westward flight. These results correspond to frequency changes of -25×10^{-14} and 94×10^{-14} respectively, with limits of error of 4×10^{-14} and 3×10^{-14}, and indicate the use of clocks of unusually high stability. The time difference from standard time of the four clocks used are shown graphically in Figure 1 of the authors' paper; and it is clear that they varied in frequency by amounts which are normal for such clocks. In particular three of them suffered changes of about 1 part in 10^{12} during the eastward flight which persisted after the flight. It is necessary to know when these changes occurred before any conclusions can be drawn about the possible changes caused by the flight itself; but by a fortunate chance the persistent changes are in opposite directions for different clocks and on the average nearly cancel out. If we can assume with the authors that they occurred at the mid-point of the flight, the results for the individual clocks, as read from the graphs are then as shown in Table 1.

In view of the differences between the results for individual clocks, the mean value is of doubtful significance but there is an indication of equal and opposite time differences for the two directions of travel.

In Figure 2 of the authors' paper the measurements are reproduced for only 35 hrs before the eastward flight and those for only 25 hrs are used, before and after each journey. This seems to be a strange thing to do because it is well known that such clocks can vary by 1 part in 10^{12} when averaged from day to day. The time differences obtained from this graph are changed from −132 ns to −66 ns and from +134 ns to +205 ns. If the whole of the 35 hrs observation were used it is clear from Figure 2 that the result for the eastward journey would be further reduced to about 30 ns. The result depends markedly on the period of observation used, and one would expect the most reliable value to be that in Table 1 based on the full period.

The authors then proceed to make a statistical analysis of the frequency comparisons made between the clocks, to obtain their final results. No details of these comparisons are given, but the analysis is based on the assumption that the frequency variations are random in nature, which appears to be unlikely and is not in accord with my own experience.

Table 1. Time difference from standard time during the journey round the Earth. Unit = 1 nanosecond.

clock no.	eastward flight	westward flight
120	−80	+180
361	−350	+55
408	0	+300
447	−100	0
mean clock	−132	+134

In their theoretical discussion[3] the authors ignore detailed and fully documented criticisms of Einstein's relativity theory which have been made and have not been refuted.[4,5] I suggest therefore that the theoretical basis of their predictions needs careful scrutiny and that the experimental results given in their paper do not support these predictions.

References

[1]Hafele, J. C. and R. E. Keating 1972. Around-the-world atomic clocks, observed relativistic time gains, *Science* 177(4044):168-170.
[2]W. B., 1972. News and views. Atomic clocks coming and going, *Nature* 238(5362):244-245.
[3]Hafele, J. C. and R. E. Keating 1972. Around-the-world atomic clocks, predicted relativistic time gains, *Science* 177(4044):166-167.
[4]Essen, L. 1971. The special theory of relativity. A critical analysis. Oxford Science Research Papers and The Clarendon Press, Oxford.
[5]Essen, L. 1972. Einstein's special theory of relativity, *Proceedings of the Royal Institution of Great Britain* 45, 141-160.

†This critical note was writtin about the time that the experiment discussed in it was published, and submitted to a journal which had published something about the experiment; but the note was rejected. It is published here in the belief that the only way to arrive at the truth in scientific matters is by free and open discussion. (Editor)

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**"ns" means "nanosecond", a unit of 10^{-9} second. (Editor)