40. Warren Nyer
42. Anthony Turkevich
43. Aaron Sayvetz
44. Bernard Smaller
45. —Hanna
46. Theodore Novey
47. Arthur G. Barkow
48. Leonard Lieberman
50. Lloyd Lewis
51. J. M. Bradford
62. Leslie Coad
63. Gerhard Groetzinger
64. *not* Francis Shonka
65. James B. Coon
66. Fitzhugh Marshall
67. *not* Serge Golian
69. Serge Golian
71. —Newman
73. George R. Carlson
74. Donald A. Edwards
75. Ted Wahlschlagel
78. Lester Skaggs
81. L. W. Phillips
85. Warren Henry
87. E. Newman Pettitt
88. —Sawyer
89. Joe Novak
91. Harry M. Allred
92. Henry E. Duckworth
93. William Frye
96. Joseph Getzholz
98. Jack (?) Moulton
99. Duilio N. DiConstanzo

Besides identifying himself as 91, Harry M. Allred insists that the picture was taken at the University of Chicago in 1940. The winners were Mark Fred (80) and Stanley Siegel (29) of Argonne National Laboratory who supplied 26 new names.

The Editor

More clock paradox

Enough would seem to have been said on Mendel Sachs's article itself (September 1971, page 23 and January 1972, page 9). But I would like to call attention to a related matter. James Terrell states: "Acceleration with respect to Lorentz reference frames is an absolute matter, readily detected, as any one who has been a passenger in an automobile or airplane knows." In a similar vein, Victor Korenman asserts "... the *felt* acceleration of the travelling twin is sufficient asymmetry to remove the paradox ..." Such statements are found in many treatments of relativity, but they are incorrect. If for example the "travelling twin" undergoes his accelerations under the influence of gravitational fields, rather than rocket motors, he need "feel" no acceleration whatever; and if the earthbound twin is spun in a circle, he will "feel" an acceleration. So you see the problem is not so simple as merely deciding who feels an acceleration. Determination of field derivatives will similarly not solve the problem, since arbitrarily large ones may be introduced without any net acceleration by using large and small masses suitably positioned. The fact is that there is no simple experiment that the twins can do inside their respective cubicles to reveal the asymmetry. They must either look at the fixed stars, which are the source of the asymmetry in Mach's sense, or they must wait until they are together again, in order to see which one it was that took the trip.

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There is no need to add to the numerous excellent replies to Mendel Sachs that appeared in your January issue. I wish only to call attention to some earlier discussions that deserve to be read and to emphasize a point that has not been made.

The superb expository paper[1] in which P. Langevin replaced Einstein's bare clock[2] by a space traveler sending and receiving electromagnetic time signals contains a lucid derivation of the result.

In calculating what is observed in the frame of the traveling twin it is necessary to allow for the effect of the longitudinal acceleration. Max Born[3] has pointed out that the principle of equivalence and the formula (derived[4] from it and special relativity) for the effect of a gravitational field on clocks suffice for this calculation. C. Moller[5] has given the corresponding exact general-relativity calculation, as have Born and Walter Biem[6].

The twin who stayed at rest in one inertial frame, using special relativity, and his accelerated brother, using the principle of equivalence as well, come to the same conclusion. The twin problem is not a paradox. It is a thought-experiment demonstrating the logical consistency of special relativity and the principle of equivalence[7].

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3. M. Born, *Die Relativitätstheorie Einsteins* (3. aufl.) J. Springer, Berlin, 256 ff. (1922), now available in a revised English translation: M. Born, *Einstein's Theory of Relativity*, revised edition with G. Leibfried and W. Biem, Dover, New York (1962) pages 354–356.
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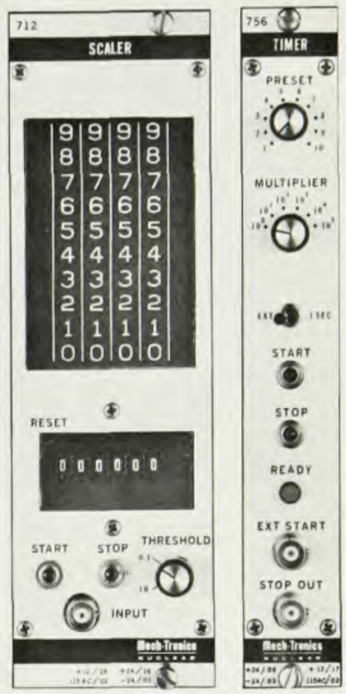

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5. C. Moller, *The Theory of Relativity*, Oxford U. P., London (1952), pages 258–262.
6. M. Born, W. Biem, Proceedings Amsterdam Series **B 61**, 110 (1958).
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In my view most of the debate and most of the profusion of erroneous statements on this subject arise from a failure to ask the proper questions. Except for a few competitors of greatly similar character the theory of general relativity is presently accepted as the proper description of space–time and its interaction with matter (for problems in which quantum effects may be ignored). Thus the theoretical prediction for the result of round-trip clock experiments should be done with general relativity as Sachs asserts. The questions that should be asked are then: What is the correct result, and is it the same as predicted by a naive application of special relativity? In contrast, much of the debate seems to concern itself with the question of whether special relativity is or is not a logically complete theory for dealing with such problems.

As several of the letters in reply to Sachs assert, experimental evidence seems to provide the answer to the first question; that is, for experiments carried out in small regions, naive special relativity gives the answer. The second question is where erroneous answers abound. The fundamental idea of relativity theory is that physical laws have the same mathematical expression for all observers regardless of their position or state of motion. Special relativity consists of those results obtainable from restricting that principle to observers moving uniformly with respect to each other. (That is, they have to be "far away" from large masses or only compare measurements over small intervals of space and time!) Thus, in this view the answer to the second question is an emphatic no. Statements that the felt acceleration of the "travelling" twin creates an asymetry that resolves the "paradox" (Korenman) or that acceleration is an absolute (Terrell) appear as *ad hoc additions* to the special theory, which can only derive their justification from a larger theory describing effects due to acceleration in terms of motion with respect to matter. General relativity is believed to be that theory.

In his article Sachs presents a formulation of space–time theory that is supposed to remove an ambiguity in general-relativistic computations of proper time intervals, namely the sign of the square root of a quadratic form. The requirements for such a formulation are that the interval computed be always equal to that computed according to the original method and that it always successfully remove the ambiguity. Sachs's formulation, as several of the letters pointed out (Richard Price and Vern Sandberg, John Fletcher), falls on the first count and is thus a theory different from general relativity. Meeting the second criterion is not really so helpful, since the supposed ambiguity is easily resolved. In principle one may refer, say, to measurements of the Hubble parameter at the beginning and end of an interval to determine whether the appropriate sign of ds be positive or negative for the interval.

In the present view then the question may be stated as follows: The comparison of ages between a "stationary" and a "travelling" twin is made by comparing

$$\int ds = \int (g_{ij}dx^i dy^j)^{1/2}$$

computed for each in a coordinate system obtained by solving the general-relativity equations. Provided the "travelling" twin doesn't travel very far (as in laboratory experiments), or on long trips he remains "away from large masses" (black holes for example) and is accelerated by mechanical rather than gravitational forces, the answer will be essentially the same as given by special relativity. To demonstrate the nonexistence of a paradox, an adequate general-relativistic description of an accelerated coordinate system is required; to my knowledge this does not exist yet.

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Metric time?

At present most of the countries of the world are either metric or going metric, including traditionally minded countries like Great Britain. The advantages of the metric system are obvious, and so there is no reason why one should not extend this system to include the measurement of time. We cannot change the number of days in a year since Nature does not permit this, but it should be possible to divide one full day into twenty hours so that night and day will consist of ten hours each. This would be more convenient than dividing a full day into ten hours, because this would make an hour much longer as compared with the present