The gyroscope experiment

The article by Barbara Levi (May, page 20) on the "Orbiting test of general relativity" is misleading in several respects. A subsequent letter by C. W. F. Everitt (August, page 84) partially clarified the situation in one respect but then confused it in other ways.

Referring to the work of B. M. Barker (University of Alabama) and myself, Everitt quoted a 1974 paper of mine, completely ignoring many relevant subsequent contributions. In addition, Everitt said: "R. F. O'Connell (and) B. M. Barker applied the analogy of spin–orbit and spin–spin coupling to investigate higher-order terms affecting the gyroscope experiment as well as a variety of astrophysical phenomena." I would like to point out that

- most of the so-called "higher-order terms" are larger than the accuracy sought by the experimentalists
- the theoretical results transcend one-body situations (as in the case of a gyroscope orbiting the earth) and are applicable to two-body problems (such as the binary pulsar PSR 1913 + 16)
- the orbiting gyro experiment is *not* the only way to test the so-called motional precession
- there is no viable reason for expecting that a future quantum theory of gravitation will have an effect on the predicted result for the motional precession.

Schiff's original proposal in 1960 considered two contributions to the precession of a gyroscope, namely, the spin–orbit (geodetic) and spin–spin (motional) precessions. The main interest is in the latter effect, which experimentalists desire to measure with an accuracy of 1 milliarcsec per year, an even lower figure of 0.3 milliarcsec/yr being quoted in a more recent description of the experiment.[1] For the most part, the discussions of the theory[1] are no different from what has been presented by Schiff and completely ignore the host of other contributions that serve to make the goal of isolating the motional precession more difficult to attain.

We now turn to a brief discussion of the other effects that contribute more than 1 milliarcsec/yr. An altitude of 500 (the figure most often quoted) miles is assumed, but the numbers will, of course, be even larger if one uses the recently quoted[1] altitude of 550 km.

- The earth's quadrupole moment contributes[2] 4 milliarcsec/yr for a gyro in the desired polar orbit, but it also makes an indirect contribution[3] of 1.33 milliarsec/yr, due to the resulting distortion of the satellite orbit from a pure elliptic orbit.
- The Sun makes a relatively large contribution[4] of 19.2 milliarcsec/yr; it also deflects the light from the reference star, thereby causing an apparent drift of the gyroscope.[5] In the case of Rigel (the present choice of the experimentalists), we calculated that the effect can be as large as 14.4 milliarcsec.
- Even if a gyroscope could be made perfectly spherical, it would distort due to the rotation and acquire a quadrupole moment[6]—which, in turn, will make a contribution to the drift rate that is greater than the experimental accuracy desired (0.3 msec)—if the alignment of the gyro is off as much as just 20 minutes of arc from being either in the orbit plane or perpendicular to the orbit plane.
- There are contributions[7] due to the aberration of the starlight (20.5″ due to the earth's orbital motion and 5″ due to the satellite's motion).
- Finally, we note that the accuracy with which the proper motion and parallax of the reference star itself can be measured could be another weak link in a long chain since 3 milliarcsec appears to be the present limit of attainable accuracy[8] and the use of the space-telescope observatory[9] will probably not reduce this number below 1 milliarcsec.

We conclude that there are a plethora of contributions to the gyro precession that are larger than the desired accuracy. As a consequence, the desired goal of measuring the motional precession is more difficult than originally envisaged.

Turning now to the general problem of the gravitational interaction of two rotating bodies of arbitrary mass to post-Newtonian accuracy, which was derived[10] for the first time by Barker and me: We pointed out that each term in the Lagrangian (spin–spin, spin–orbit, and so on) was analogous to corresponding terms appearing in the quantum electromagnetic Lagrangian for the interaction of two charged, spinning particles. Corresponding to what is regarded as the most rigorous derivation of the latter result (using one-photon exchange), our derivation is based on one-graviton exchange.[11] One of the most interesting applications of these results has been the demonstration that large precessions (compared to the earth-gyro precession) may be obtained for astrophysical bodies. In particular, we calculate that the pulsar spin axis of PSR 1913 + 16 may be precessing by about 1°23/yr.[10]

Finally, while agreeing that a measurement of the spin–spin precession would be very interesting, it should be emphasized that—contrary to the implication given in the recent PHYSICS TODAY article—while most theorists agree that "Einstein's general theory of relativity . . . may need to be amended . . .", such amendment is not expected to change the predicted results for the earth-gyro precession. The spin–spin interaction in gravitation should be viewed as no more mysterious than the corresponding term in quantum electrodynamics that gives rise to hyperfine structure. In addition, assuming only the conservation of total angular momentum, it follows[10] that any contribution to spin precession is accompanied by a corresponding contribution to the periastron precession, which might provide another possible test of the spin–spin interaction. Still another possibility for such a test, one which we feel has potential, is the proposal to use[12] a ring-laser interferometer to measure the frequency difference of the counterpropagating beams in a Sagnac-type experiment, with the possibility of testing both the geodetic and motional precessions.

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ROBERT F. O'CONNELL
Louisiana State University
9/84 *Baton Rouge, Louisiana*

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