Department of Physics
Stanford University
Stanford, California

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Office of Space Flight Programs
1520 H Street, N.W.
Washington 25, D. C.

Attention Dr. Abe Silverstein

Proposed Experimental Test of General Relativity

One of us (LIS) has proposed an experiment to check the equations of motion in Einstein's general theory of relativity by means of a gyroscope which is forced to go around the earth either in a stationary laboratory fixed to the earth, or in a satellite. We believe that this experiment is important, in that it will provide unique information that bears on the theory of gravitation. The gravitational red shift can be understood quantitatively in terms of the equivalence principle, without using general relativity theory. Thus the gyroscope experiment would be the first terrestrial experiment to supplement the astronomical observations on the deflection of starlight by the sun, and on the precession of the perihelion of the orbit of the planet Mercury. It would also provide new information on the difference between the gravitational field of a rotating and a non-rotating body. This last effect, predicted by general relativity, has never been observed.

The arguments and predictions are discussed in the attached reprint. According to the Einstein theory, the axis of a gyroscope forced to go around the earth once a day at the latitude of Palo Alto, California, will precess 0.4 second per year if the axis is at right angles to the axis of the earth. This precession will take place in the absence of all external torques. In a satellite which circles the earth 15 times per day, the corresponding precession is about 7 seconds per year. Although such an experiment seems beyond the possibility of existing experimental techniques in an earthbound laboratory, our calculations indicate that it is feasible in a satellite equipped with an astronomical observatory and a superconducting gyroscope.

The most important single factor which makes possible this experiment in a satellite and not in an earthbound laboratory is the very large reduction in the effective value of g in the satellite which reduces the torques caused by the necessity of supporting the gyroscope against gravity.

We propose to perform such an experiment using a superconducting gyroscope in one of the Orbiting-Astronomical-Observatory satellites. We have discussed this experiment with William Triplett and Robert T. Jones of Ames Research Center, NASA, at Moffett Field. They indicated to us that a satellite is being designed with a 36-inch telescope, capable of locking on a fixed star to 0.1 second of arc. We propose to use a superconducting sphere supported in an appropriate magnetic field for a gyroscope. We have worked out a system for detecting the orientation of such a sphere to within 0.1 second of arc without distorting the nearly perfect spherical shape of the sphere. It is proposed that several times during the course of a year the direction of the axis of the sphere be ocmpared with the direction of a fixed star. It is anticipated that, at the instant of time the telescope is locked on a fixed star and the sensing equipment of the gyroscope is exactly lined up with the axis of the gyroscope, the direction of the telescope will be compared with the direction of the sensing equipment of the gyroscope. The relative directions should change by about seven seconds per year according to the relativity theory. Thus in a year we anticipate that it may be passible to measure the predicted effect to within a few percent.

The experiment is greatly aided by the great reduction in the effective gravitational force on a sphere in the satellite. However, we realize that this will not be exactly zero, since the satellite is slowed down by residual atmospheric gas, the gradient of the earth's field has an effect if the gyroscope is not at the center of mass of the satellite, and the satellite may be rotating. We have calculated the effects of such small effective accelerations on the ball assuming that the ball is a few feet from the center of the satellite and assuming that the ball can never be made into a perfect sphere. We have also calculated the effects of the distortion of the sphere due to rotation. We have considered the effect on the rotating ball of the eddy currents produced by the presence of the supporting magnetic field, assuming that the ball is in the superconducting state at a temperature of about half the transition temperature. We have considered the torques due to flux frozen in the superconducting ball. When all of these effects are considered, we calculate that it is possible to make a gyroscope whose axis will precess, owing to applied torques by roughly 0.1 second per year. This will make possible the observation of the predicted general relativity effect with an accuracy of about ten percent in two months, and about two percent in a year.

We have designed, in principle, such a gyroscope including cryogenic cooling and a detection system. If the satellite is rotated during the course of the experiment to allow experimental observation of several stars, it will probably be necessary to keep the supporting apparatus of the gyroscope approximately fixed in space. A simple system for accomplishing this inside the dewar system has been designed. With this complication, it is anticipated that the relativity experiment could be carried out simultaneously with experiments which requirea satellite to be reorientated in space. While it is desirable that thegyroscope be very close to the center of mass of the satellite, it is not necessary that it be just at the center of mass, and we have assumed it is not to be more than a few feet away. We estimate the total weight of the experimental apparatus including cryogenic coolants to be about 100 pounds for an experiment designed to last one year. The main weight is in the cryogenic collants and surrounding dewars and therefore a function of the duration of the experiment.

In some preliminary experiments we have supported a superconducting ball and set it in rotation by a means suitable for remote control in a satellite. We have devised a means for observing the axis of the ball and are in the process of checking this experimentally. This method allows for very easy telemetering of the data from the satellite. It is anticipated that the ball will be clamped in position during take-off and hence unaffected by the large acceleration.

In conclusion, we believe the relativity experiment would be important. We believe it is possible to perform this experiment in an OAO satellite to an accuracy of a few percent. We have thought through the design of such an experiment and calculated, we believe, the effect of the known disturbing torques. We are performing preliminary experiments to check these speculations, and have built a preliminary gyroscope. We hereby make a tentative proposal to perform such an experiment in cooperation with NASA in an OAO or similar satellite. We have not included details in this tentative proposal but are prepared to do so if the experiment receives favorable preliminary consideration.

Submitted by:

W. M. Fairbank
Professor of Physics

L. I. Schiff
Professor of Physics and Executive Head

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Stanford University
Stanford, California

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