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TWO MASER EXPERIMENTS TO TEST GENERAL RELATIVITY

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The area of thought expressed in the assay bearing the same title is mainly the general theory of relativity of Einstein and its experimental tests. One of the basic principles of this theory, namely, the principle of equivalence can be tested by optical means with the help of modern MASER techniques. Also a basic assumptions of the theory, the impossibility of detecting locally the changes of lengths and time intervals can be put to test with the same techniques. The accuracy needed is already within the reach of present techniques.

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Despite the fact that special relativity is firmly established on experimental grounds, the same cannot be claimed for the general theory. First of all there are only three experimental tests of general relativity and not all of them are sufficiently conclusive in favor of the theory. i) The bending of light rays, though correct as an order of magnitude, is just outside the experimental error. ii) The observed shift of spectral lines twoards red is qualitatively in agreement with the theory but a quantitative agreement is still a much discussed and investigated question. iii) In the case of the advance of the perihelion of Mercury the situation is different. Here we have a satisfactory quantitative confirmation. Until recently it was thought that the advance of the perihelion of Mars was not correctly predicted by the theory.[1] In the last few years more elaborate calculations have shown that the theory predicts the effect within the observational error.[2] The calculations for the Earth's perihelion are at present in progress, but preliminary calculations are in agreement with the theory. It must be remembered that the perihelion motion is a second order effect and its quantitative agreement lends great support to the theory. Nevertheless one cannot say that these facts provide sufficient tests for such a fundamental physical theory as general relativity. There is definite need for further practicable experiments in the field of gravitation. This need is being felt all the more strongly as time goes on because of man's increasing interest in space and gravitation.

In this assay two closely related but essentially different experimental tests of the theory are proposed. Only a year ago it would be impossible to carry them out. Thanks to the recent advances in MASER techniques that these experiments can now be done without much difficulty and with great accuracy.[3]

Experiment 1. The first experiment provides a direct test for the principle of equivalence. As is well known, according to the principle of equivalence, the effects of an external gravitational field in a local coordinate system (say a small material box) can be eliminated completely by letting the coordinate system free in that gravitational field (freely falling box). In such a coordinate system the external gravitational field does not have any influence either on the motions of particles or any other physical process whatever. Thus according to the principle of equivalence such a system must locally be equivalent to a Lorentz frame and in it light rays must travel with the same velocity in all directions. Now in the gravitational field of the Sun, our Earth may be considered as a small box and the above statement concerning the propagation of light may be tested by comparing the velocity of light in the direction of the line joining the Earth and the Sun and in any direction perpendicular to it (Figure 1). Nowadays the MASER techniques can compare the two velocities to the accuracy $\delta c/c \simeq 10^{-12}$ where c is the velocity of light. On the other hand if the principle of equivalence is wrong a first order effect of the order of dimensionless quantity $GM/c^2R \simeq 1.5 \times 10^{-9}$ would be expected. Here M is the Mass of the Sun, G gravitational constant and R is the distance of the Earth from the Sun. We see that if there is any first order effect of the gravitational field on the propogation of light it can be detected with MASER techniques with sufficient accuracy.

Experiment 2. The second experiment is similar in appearance but essentially different in nature. To see its function clearly let us assume that the first experiment gave a negative result so that the principle of equivalence is confirmed. We can then ask the following question: Is the propagation of light the same in all directions in a coordinate system fixed in a gravitational field? A laboratory room on our Earth is such a fixed coordinate system in the gravitational field of the Earth. This question can be answered by comparing the velocity of light in the vertical and horizontal directions on the earth (Fig. 2). If there is a first order influence due to the Earth's gravitational field it must be of the order $Gm/c^2r \simeq 7\times10^{-10}$, where m is the mass of the earth and r its radius. This experiment does not test the principle of equivalence. It tests an implicit assumption, namely, the local isotropy of space-time continuum. This assumption may conveniently be expressed as follows: The gravitational field influences all lengths and length-measuring rods in the same way.

Also all periodic phenomena and time measuring devices are influenced in the same proportion. As a result one never is able to detect locally the effects of a gravitational field by kinematical means.

The second experiment is slightly more difficult than the first one because when one rotates the MASER into the vertical directions stresses and strains are introduced due to the Earth's gravitational field. In the first experiment such complications can be avoided by doing the experiment during the sun-rise or sun-set. In this case rotations are only around the vertical axis.

In conclusion we would like to emphasize that the experiments suggested here are essentially independent of any theory although it would have been difficult to present or even to think of them without the aid of the general theory of relativity of Einstein.

*At the suggestion of the author such experiments are being tried by Professor C. H. Townes at Watson Laboratories, Columbia University.

1) J. Chazy, La Theorie de la Relativite et la Mechanique Celeste, Chapter IV (1928).
2) G. M. Clemence, Rev. Mod. Phys. 19, 361 (1947). Also, private communication with the Naval Observatory, Washington, D. C.
3) C. H. Townes and A. L. Schawlow, Phys. Rev. 112, 1940 (1959). See also C. H. Townes et al., Phys. Rev. Lett. 1, 342 (1958).

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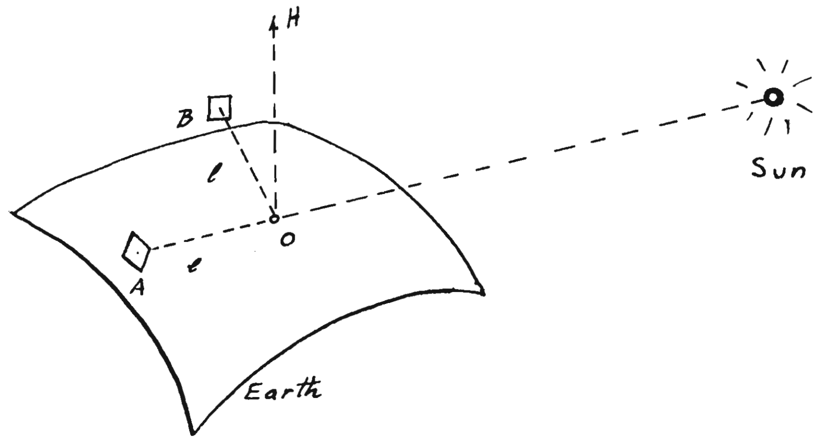

Fig 1. Test of equivalence principle
OA and OB are paths of light rays. OH is the vertical axis.

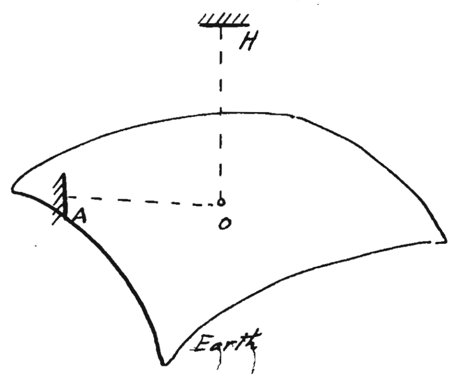

Fig 2. Test of local isotropy of space
OA and OH are paths of light rays. OH is the vertical direction.