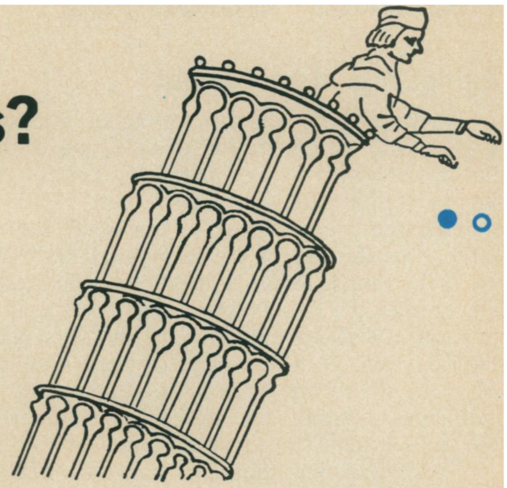
Which theory of gravity fits?



Physics Today

Tests of gravity theories started at the Leaning Tower. Now they are going into orbit.

by Dietrick E. Thomsen

In the July 8 Science News (p. 30), physics editor Dietrick Thomsen reported on experiments being established to try to confirm the detection of gravitational radiation. In this article, he reports on experiments in another frontier area of gravity research—attempts to determine which of two competing theories of gravitation (Einstein or Brans-Dicke) is correct.

Traditional theories of gravitation (Newton's and Einstein's) are based on the assumption that there is one characteristic, called mass, that determines both the size of the gravitational forces a body exerts and its inertial response to any forces exerted on it. This is called the principle of equivalence because it equates what might be called gravitational charge with mass.

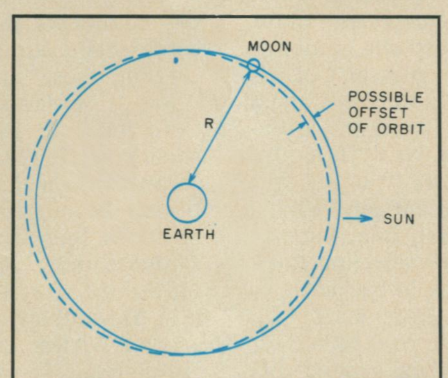
Galileo is supposed to have proved the principle of equivalence by dropping balls from the campanile at Pisa, though modern science historians say that if he did a proof, he probably used balls rolling down inclined planes. Since his time, many tests of the principle have been made, none of which have shown significant deviance.

Nevertheless it is possible to disbelieve in the principle of equivalence. Mentally, the concepts of gravitational charge or gravitational mass (responsible for gravitational forces) and inertial mass (responsible for all inertial responses) can be separated. Indeed experience with other natural forces makes this easy to do. In electricity, for example, electric charge is quite a separate characteristic from mass. It is charge that determines the size of electric forces, and inertial mass that governs the bodies' response to them.

The equivalence principle sets gravity apart from the other natural forces and appears to give it a special connection with the very being of material objects, the mass that measures the quantity of matter they contain. Some physicists dislike the uniqueness, and theories that deny the principle of equivalence have been put forward. Of these the most widely quoted is one by Carl H. Brans of Loyola University and Robert H. Dicke of Princeton University.

Although the Brans-Dicke theory would make only minute changes in current measurements, it makes important philosophical and mathematical alterations. One of the most striking changes is that the relative strength of the forces in Brans-Dicke gravitation depends on the distribution of matter in the universe and declines as the universe expands. Some cosmologists would prefer to have this kind of link between cosmology and gravitation rather than the Newtonian and Einsteinian gravitation in which the forces retain a constant strength unto ages of ages regardless of what happens to the universe. There is thus a continuing series of experiments attempting to decide between the rival theories.

This can be done by testing the principle of equivalence directly or by measuring other consequences of Brans-Dicke and similar theories: The motions of the planets, the gravitational redshift of light, and the gravitational delay or deflection of a light beam should all differ from the Einsteinian prediction. Experiments aimed at all these points were described at the Fourth Cambridge Conference on Relativity held at the Massachusetts Institute of Technology in June.



LURE

Nortvedt effect offsets lunar orbit.

One way to test the equivalence principle directly is to compare accelerations induced by gravitational and nongravitational forces on the same bodies. This is called an Eötvös experiment after the Hungarian physicist who first did it with modern precision. The National Aeronautics and Space Administration's Manned Spacecraft Center has plans for doing it in orbit. Philip Chapman described the scheme at the meeting.

It will take a hollow aluminum sphere with a gold "proof mass" inside it. The apparatus will be put into orbit at a distance from the earth where the earth's gravitational attraction and the centrifugal force are equal and oppositely directed. If the principle of equivalence is not exact there is likely to be a difference between the ratios of gravitational to inertial mass for aluminum and for gold. That inequality would produce a small acceleration of one substance with respect to the other. The experiment hopes to measure the acceleration if there is one.

Another orbital experiment will put a pair of gyroscopes into orbit. A characteristic of a rotating gyroscope is that if an outside force like gravity or centrifugal force due to the orbital motion of the spacecraft is imposed on it, its rotation axis will change orientation in a cyclic way. The experiment will have two gyroscopes. One will be oriented so that it suffers precession from the earth's gravity; the other so that it suffers motional precession only.

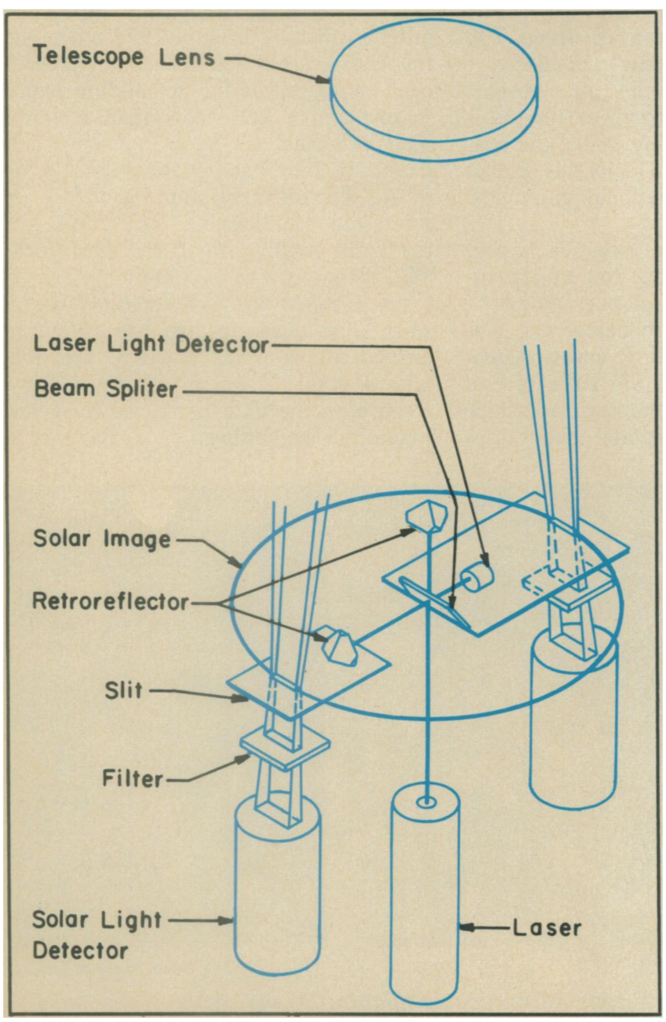
The difference in the two precessions may help tell which of the rival theories is correct.

This experiment has been talked of for a long time. Development of the rotors has now progressed so far that laboratory spin-up tests are expected soon, both at the NASA Marshall Space Flight Center and at Stanford University. Marshall has been working on glass balls coated with superconducting niobium; Stanford on quartz balls coated with niobium. The superconducting metal makes possible suspension of the balls without wires or bearings by levitation in an electric field. They would be made to spin by jets of hydrogen gas. After the tests the better rotor will be chosen, and then, before the experiment itself, a test flight will be necessary to determine how the gyros perform in zero gravity.

A sounding-rocket experiment by the Smithsonian Astrophysical Observatory intends to determine how the gravitational redshift varies as the strength of the earth's gravitational field changes with increasing altitude above the surface. As Robert Vessot described it, a very accurate atomic clock will be launched by rocket into a ballistic trajectory that will go as high as 800 nautical miles. Changes in the clock rate will be recorded. The rate depends on the same kind of atomic transitions that give rise to radio and light waves. As the redshift alters the frequencies of these transitions, the clock rate should change.

Astronomers first gathered evidence that Newton might not be entirely accurate from the orbits of the planets. The planets remain a primary place to look for evidence to decide between Einstein and his rivals. The motions of the planets in their orbits will be different according to which theory applies. This is most noticeably true of the precession of the orbits, which is called precession of perihelion. Nineteenth-century astronomers found that Mercury's perihelion precessed perceptibly faster than Newton had predicted, and accounting for this excess perihelion advance was one of the early triumphs of Einstein's theory.

Mercury's orbital motion has been checked and rechecked by radar, notably in a collaborative effort between the Lincoln Laboratory's Haystack telescope at Tyngsboro, Mass., and the Cornell-Sydney University Radio Astronomy Center at Arecibo, Puerto Rico. With a "rather exquisite accuracy" the results so far confirm Einstein, says Irwin I. Shapiro of Lincoln Laboratory and MIT. Further tests, on both Mercury and Venus, are being contemplated.



A laser interferometer measures the distance between the sun's edges in H. A. Hill's solar oblateness observations.

H. A. Hill

The moon is also a possible testing ground. The differences between the gravitational theories would result in some extremely small differences in the motion of the moon. One of these is a general relativistic correction to the Newtonian prediction which would alter the moon's position by about one meter. Between Einstein and a particular form of Brans-Dicke there is a difference of about five centimeters in the size of this correction.

A second change is an offset of the moon's orbit resulting directly from a failure of the equivalence principle. As Kenneth Nordtvedt of the University of Montana has suggested, failure of the equivalence principle would cause the gravitational self energy of the moon to contribute to its gravitational and inertial mass in different ways, and this could result in the offset. Self energy is the energy latent in the forces that prevent the moon from collapsing gravitationally into a black hole. Such a self energy makes a contribution to mass as a consequence of $E = mc^2$.

The third possibility is a long-term decrease of lunar motion due to a gradual decrease of the universal gravitational constant. This decrease is predicted by Brans-Dicke but not by Einstein. The predicted decrease is between one part in 300 billion to one part in 30,000 billion per year. This would result in a proportionate increase in the moon's distance from the earth.

The Lunar Ranging Experiment (LURE) that involves sending laser beams from a number of terrestrial stations to reflectors left on the moon by astronauts is trying to find evidence of any or all these effects. But as Peter L. Bender of the Joint Institute for Laboratory Astrophysics at the University of Colorado points out, the moon's motion is very complicated. More accurate theoretical calculations will be required before such minute effects as these can be determined by comparing observation with theory.

The calculations of the planetary orbits are all based on the assumption that the sun is a perfect sphere. If the sun is only slightly oblate, Dicke has repeatedly pointed out, part of the excess perihelion precession of Mercury (and the other planets) would be due to solar oblateness, and the agreement with Einstein would no longer hold.

Determining oblateness involves finding a difference between the polar and equatorial radii of the sun. This is not easy to do because the sun does not show up with a sharp edge: The brightness declines gradually from a maximum at a point definitely within the disk to zero at a point definitely outside it. The technique used by Henry A. Hill of the University of Arizona and Wesleyan University is to measure the curve of this decline over a certain distance at both ends of equatorial and polar diameters. An on-line computer analyzes the curves to find the edge, and a laser interferometer measures the diameter within a fraction of a wavelength of the laser light. The experiment, at Kitt Peak National Observatory, should be able to determine if there is any difference in the two diameters. If there is it should be only a few milliseconds of arc. First Hill must calibrate his equipment so that he can subtract out about 100 milliseconds of instrumental error. To do this he needs observations of the sun at all times of day. The telescope is used for other things so Hill can use it only a short time each day. The rains set in in Tucson six weeks early (at the end of May), so he has not been able to complete the calibration.

A related problem, as Dicke puts it, is that brightness differences between points on the edge of the sun may masquerade as oblateness. His technique is to use a revolving slit that exposes a portion of the whole edge of the sun and integrate the flux in the hope of removing anomalies due to brightness differences.

The radio and radar ranging of the planets can also be used to determine the amount of relativistic time delay produced by the sun's gravity as the signal passes close to the sun. To obtain such data, passage times are compared for signals taken when the planet is far from the sun and when it is nearly behind the sun. This has been done several times with Mercury and Venus, and has generally supported Einstein. In this case, though, the difference between Einstein and Brans-Dicke is only a few percent, and greater accuracies are sought in the measurement. Another way to do the same experiment, with possibly greater accuracy, was to observe the quasar 3C 279 as the sun passed in front of it. The gravitational slowing of the radio waves produces a bending of the beam; as the sun passed in front of it, 3C 279 should have appeared to move out of its true position. The result, says Richard Sramek of the National Radio Astronomy Observatory, is 94 percent of what Einstein predicted. But the uncertainty is 6 percent, and the result is not conclusive.

Cosmologists hope for a conclusive result. Modern cosmology is based on Einstein's theory. Lately quite a number of anomalies have shown up: galactic redshifts that appear to defy theory, the mystery of where the quasars are, sources of electromagnetic and gravitational radiation that appear fantastically large. If Einstein is not correct, some of these things may be explicable by proper alterations in gravity theory. If he is correct, other explanations will have to be found. □

'This is the forest primeval'

Biome researchers want a model of the total deciduous forest

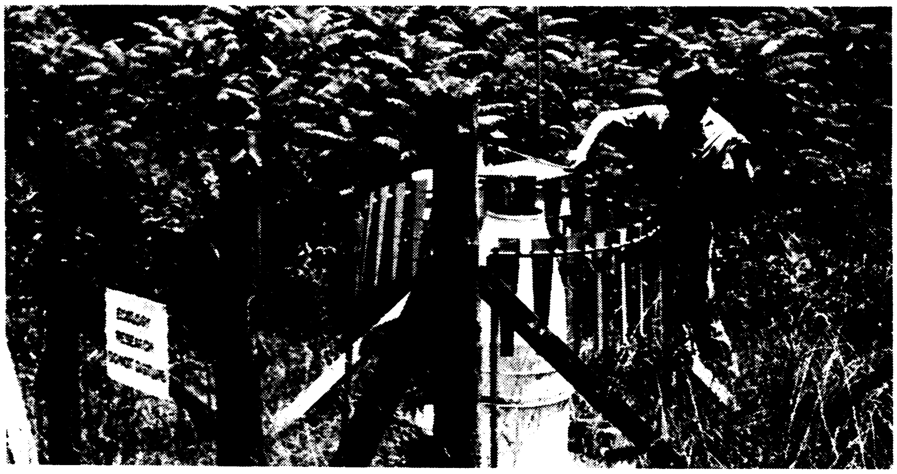
by Joan Arehart-Treichel

Although land east of the Mississippi contains two-thirds of all Americans, it still boasts rich and productive forests. Which of these forests should be retained? Which should be turned into farmland, cities, suburbs, highways or industrial complexes? When pesticides are sprayed on a deciduous forest, what happens to photosynthesis of forest leaves? What effects does forestry have on animals in a forest? How does dumping of heavy minerals affect plants in forest lakes or watersheds? These and related questions are pressing for answers based on scientific facts.

In the past few years ecologists have attempted to examine isolated aspects of the eastern deciduous forest, or of the lakes, streams, birds, insects, mammals, weather and other ecosystems that comprise the larger environment, or "biome." However no scientist or group of scientists dared to take an intensive look at the total forest. During the past year and a half, however, some 200 ecologists from different specialties and universities throughout the eastern United States have risen to the challenge. They are working under the auspices of the Eastern Deciduous Forest Biome of the International Biological Program.

The work they are doing is important, not only to science but to humanity, and a great deal of peer judgment went into the program before the National Science Foundation and Congress supported it. "I think we have several interrelated goals," Stanley Auerbach of the Oak Ridge National Laboratory in Tennessee and director of the program, says. "One goal is to develop a group of interdisciplinary environmental researchers who can work effectively on environmental problems covering a broad area of the United States and considering them in regional context. A second goal of the program has been to develop a base of knowledge that will enable us to deal more effectively with environmental problems that are crowding in on us in the eastern United States. These problems are increasingly calling for a synthesis of ecological knowledge in a fashion that society, and particularly people concerned with development and technology, can understand. A third goal of our studies is the development of data banks and information that can be drawn upon to answer pressing environmental questions."

When asked how the goals of the studies are being met—they are to terminate officially in July 1974 when the IBP ends—Auerbach replies, "We have been more successful in building teams in one and a half years than I would have expected, taking 200 investigators from different backgrounds and sitting in different universities and getting them interested, enthusiastic, and most importantly, willing to share their ideas and data. As far as obtaining knowledge, I think we have made a useful start. The questions we are trying to answer are complex and will probably take a good 10 years to answer fully. Regarding the data bank, we have just made the beginnings of a start. It is



Joan Arehart-Treichel

Frank Harris checks out rainfall accumulation at one of the forest sites.