

Oblate Sun Supports Scalar-Tensor Theory

One of the three classical tests of Einstein's gravitational theory has been its prediction of Mercury's orbit; the Einstein value agreed with observations to within 1%. Now measurements by Robert H. Dicke and Mark Goldenberg of Princeton University show that the sun is slightly elliptical in shape. The quadrupole moment indicated by such a solar oblateness would perturb Mercury's motion and could account for 8% of the classical excess in the precession of Mercury's perihelion; this would imply an 8% discrepancy in the Einstein value. The other two tests of Einstein's theory are the gravitational red shift, which is also predicted by other theories, and the gravitational deflection of light, which is poorly known.

Dicke reported the results at the Texas Symposium on Relativistic Astrophysics in New York on 27 Jan. (and also in the 27 Feb. issue of *Phys. Rev. Letters*).

Observations show that Mercury's perihelion rotates approximately 5600 seconds of arc per century. If one uses classical mechanics to compute the rotation and includes the perturbations induced by Venus, Jupiter, Earth and Saturn, the result is about 5556 sec/century. The difference between observation and classical theory, actually 43.1 sec/century, seemed to agree almost perfectly with Einstein's gravitational theory, which predicts 43 sec/century.

Which theory? In recent years Dicke has considered the possibility that in addition to the tensor field required by Einsteinian gravitation, there is also a scalar field, which is determined by the distribution of matter throughout the universe (*PHYSICS TODAY*, January, page 55). Dicke and Carl Brans described such a scalar-tensor theory in 1961. Then came the problem of finding an experiment that could distinguish between a pure tensor and a scalar-tensor theory.

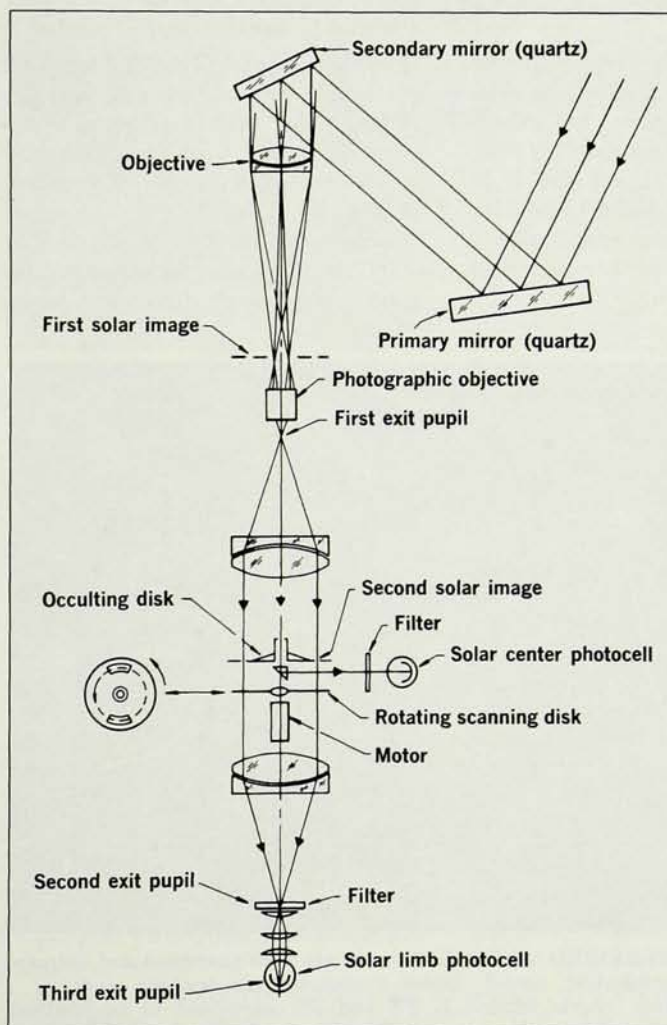
Brans-Dicke theory, interpreted in the light of available observations,

predicts that the perihelion rotation should be less than the Einstein value by roughly 10%. On the other hand, if there were a solar quadrupole moment that nobody had taken into account, the scalar-tensor theory might be in good agreement with observations after all. (Other experiments capable of distinguishing between the two kinds of theories are being prepared by Henry Hill of Wesleyan University and the University of Arizona and by William Fairbank and his collaborators at Stanford.)

Why should one expect the sun to have a quadrupole moment? Dicke believes that the sun may have an inner core that rotates every one or two days. Magnetic torque induced

by solar wind on the sun's surface could be strong enough to keep the outer layer turning slowly to balance the viscous torque set up in the core.

Solar telescope. After the Mariner II flight in 1963 cleared up the last reasonable doubt about planetary perturbations in Mercury's orbit, Dicke decided to look for a solar quadrupole moment by measuring the shape of the sun. In the Princeton experiment, performed last summer, light from the sun enters a telescope (see figure) and is projected on an occulting disk. Light from the outer edge of the sun's image that is not blocked off by the disk falls on a scanning disk, turning at 123 rev/sec, which is notched at opposite sides with two slots of slightly



TELESCOPE used by Robert Dicke and Mark Goldenberg to measure solar oblateness. Their results imply an 8% discrepancy between the observed excess in precession of Mercury's perihelion and that predicted by Einstein gravitational theory.

different size. Then a photocell picks up the light, flickering at twice the speed of the spinning wheel. After phase-sensitive detection the 123 cycle/sec components of the photocurrent send two signal voltages to a servo system that automatically orients the main mirror and centers the solar image on the occulting disk.

To find the vertical and diagonal components of the solar image, the sine and cosine terms of the second harmonic signal are analyzed by phase-sensitive detection equipment and then the amplitude is determined.

Voltages are averaged over one-minute intervals; then the whole system below the secondary mirror is turned 90 deg about a vertical axis to cancel errors connected with these components. The primary and secondary mirrors are also periodically turned 90 deg to eliminate astigmatism errors.

Since a systematic brightening of the sun could cause a systematic error in measuring oblateness, the experimenters made measurements for three different amounts of exposed limb. The sun was found to be remarkably uniform in brightness—there was a temperature variation between pole and equator of at most 3°.

An elliptical sun. Dicke and Goldenberg find that the fractional difference between equatorial and polar radii is $(5.0 \pm 0.7) \times 10^{-5}$, which indicates that 8% of the Mercury perihelion precession may be due to a solar quadrupole moment. They note that this implies an 8% discrepancy in the Einstein value and lends support to a scalar-tensor theory.

Dicke, at the Texas Symposium, remarked, "It wouldn't surprise me if general relativity is just plain wrong." Many relativists in the crowded Statler Hilton ballroom did seem surprised; in the heated question period that followed, Dicke was barraged with objections. He appeared to have thought of all of them, however. Dicke remains convinced that if oblateness and perihelion measurements are accurate, general relativity is in trouble. —GBL

Superconductor Acts as Phonon Generator and Detector

If you excite quasi-particles in a superconductor, you can generate and detect phonons. Aly Dayem and Wolfgang Eisenmenger, who reported their work in the 23 Jan. issue of *Phys. Rev. Letters*, have built such a quantum generator and detector of phonons at 300 GHz. The same technique can be used over a large frequency range

where conventional generators and detectors become prohibitively difficult. Until now phonons have been generated only piezoelectrically and at much lower frequencies.

In the experiment, done at Bell Telephone Laboratories, Dayem and Eisenmenger put two identical superconducting tunnel diodes at opposite ends of a sapphire rod. In the first diode, quasi-particles are injected by tunneling; they then relax, recombine and generate phonons, which are detected by the second diode.

The tin-tin-oxide-tin tunnel diodes are built as crossed stripes of tin; the first stripe, 100 nanometers thick, is evaporated onto the oxide layer that forms on the first stripe. The diode-crystal combination is immersed directly in a liquid helium bath.

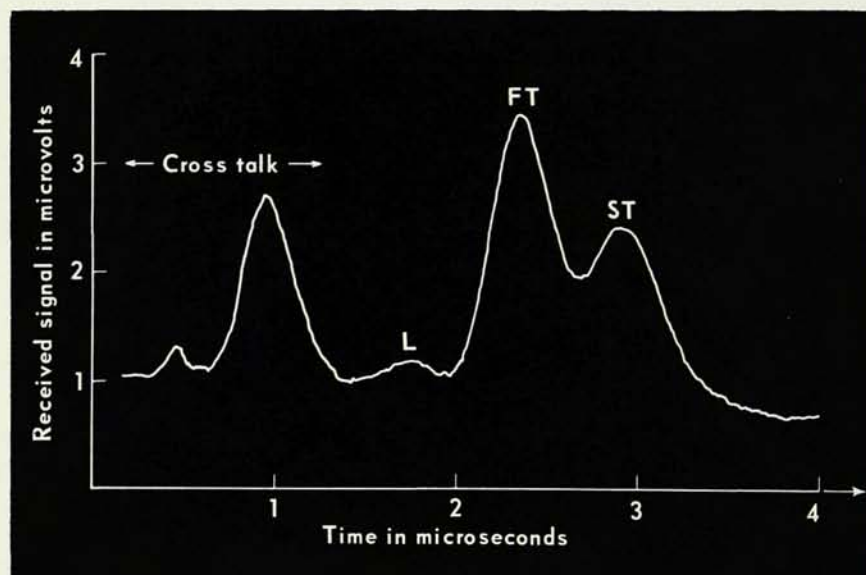
Eisenmenger and Dayem bias the generating diode at a voltage at least as big as the energy gap, 2Δ ; they keep the receiver biased at less than 2Δ .

In their paper, Eisenmenger and Dayem draw the following conclusions: (a) An excited quasi-particle of energy E (measured from the Fermi level) relaxes first to the top of the energy gap, emitting a phonon of energy $E - \Delta$. Then pairs of quasi-particles of opposite spin and momentum recombine, emitting phonons of energy 2Δ . (b) Phonons incident on the receiving diode produce a change in the tunneling current, which depends on both the frequency and number of the phonons. The detector is sensitive only to phonons with energy greater than or equal to 2Δ . Thus, as Dayem told *PHYSICS TODAY*, the tunnel junction can be used as a quantum counter.

To excite the quasi-particles, the experimenters apply dc pulses 2.5 microsec long, at a rate of 10kHz. At the receiving diode they keep a constant dc bias of 0.8 mV.

The figure shows receiver signal as a function of time. At the left, one can see the electrical signal. Then there are three peaks due to acoustical signals; these correspond to longitudinal, fast and slow transverse modes of propagation in the sapphire.

For tin the experimenters find a phonon frequency of about 300 GHz. Dayem notes that if they use lead instead, they can generate 633 GHz; for



SIGNAL RECEIVED VS TIME. Phonons are both generated and detected by superconducting tunnel diodes evaporated on opposite ends of a sapphire rod. Peaks labeled L, FT and ST correspond to longitudinal, fast transverse and slow transverse modes of propagation in sapphire.