teract to form the globular clusters associated with beads. The fifth histone, F1, is proposed to be associated with regions of DNA between the beads. This is consistent with the observation by Richards and Pardon that removal of F1 does not affect the x-ray diffraction pattern of chromatin, whereas removal of any of the other histones destroys this pattern.

Roger Kornberg of the Medical Research Council in Cambridge, England, and Jean Thomas of the University of Cambridge in England showed that histones form pairs in solution. Histone F2A1 associates with F3 and F2A2 associates with F2B. Kornberg and Thomas suggest that these same pairs exist when the histones are bound to DNA and that the beads of chromatin are composed of two each of these four histones together with 200 base pairs of DNA. The model of Kornberg and Thomas is the first attempt to coordinate the x-ray data, results from studies of histone stoichiometry and chemistry, and results from studies of the degradation of chromatin by nucleases. Irvin Isenberg of Oregon State University finds that not only do F2A1-F3 and F2A2-F2B pairs form in solution but also the pair F2A1-F2B forms. Thus, in principle, all four of the histones could be in contact with each other. The problem is to show that histone interactions in solution reflect their interactions when they are associated with DNA.

One test of whether histones interact in solution in the same way as when they are associated on DNA is to analyze the sensitivity of these various histone complexes to an enzyme—in this case, trypsin—that degrades histones into their constituent amino acids. Trypsin can only gain access to histones on the outside of beads. Thus trypsin degradation can be used to determine whether the same parts of histone molecules are on the outside of beads when the beads are on DNA as when they are removed from DNA.

Harold Weintraub and Frederick Van Lente of Princeton University showed that, when histones are associated with DNA in chromatin, trypsin degrades only 20 to 30 amino acids from one end—the amino terminus—of each histone molecule in a cluster. The remaining 70 to 100 amino acids that make up a histone molecule are very resistant to trypsin, presumably because they are interacting with each other in a compact globular conformation. The same pattern of histone degradation by trypsin is obtained when the enzyme acts on histones that have been gently removed from the DNA. The histones removed from DNA form clusters, each of which is made up of one each of the four histones.

Further evidence that histones may interact as beads on the chromatin fiber in a manner similar to the way in which they interact in solution was recently reported by Harold Martinson of the University of California at San Francisco together with McCarthy. These investigators used a reagent, tetranitromethane (TNM), to irreversibly join specific regions of interacting histones while they were on chromatin. Then they removed the histones from the chromatin and determined which of them were bound together. In this way, they found that F2A1 and F2B are paired on chromatin.

Martinson and McCarthy also report that histones F2A1 and F2B can be cross-linked by TNM on chromatin that is reconstituted from the individual histones and DNA. However, the F2A1-F2B pairs are only found if the histones are first mixed together and then added to the DNA (the pairs are not formed when the histones are added separately to the DNA) and if histone F2A2 is present during this initial mixing of the histones. These results are consistent with Isenberg's demonstration that, in solution, histones F2A1 and F2B and histones F2B and F2A2 associate.

The work of Martinson and McCarthy and the work of other groups of investigators who are probing the structure of beads by means of enzymes that degrade histones or that degrade DNA are leading many to believe that, if the globular clusters of histones in chromatin are not all alike, they are at least put together according to a set of rules. These rules are still unknown. However, there is evidence that a specification of these rules may be the next advance in understanding chromatin structure.

—GINA BARI KOLATA

Relativity: Experiments Increase Confidence in Einstein

Astronomers and astrophysicists are becoming more and more convinced that Einstein's general theory of relativity is the correct formulation from among a host of competitive theories of gravity. Although no single experimental result can thus far be regarded as definitive, scientists feel that the trend indicated by a succession of increasingly accurate experiments of various types is to rule out theories other than general relativity. One of the most recent and the apparently most accurate experiments is reported by Edward B. Fomalont and Richard A. Sramek of the National Radio Astronomy Observatory (NRAO), Green Bank, West Virginia, in which they measured the deflection of radio waves passing near the sun with an uncertainty of about 1 percent. Other experiments of comparable or greater accuracy are expected to be reported in the near future.

In the years since the publication of Einstein's general theory in 1916, a number of alternatives and modifications to general relativity have arisen. Many have been discarded, and those that remain as viable competitors are all metric theories, as is general relativity itself. Metric refers to a quantity called the metric tensor whose components are determined by the structure of the four-dimensional space-time continuum. Thus the components of the metric tensor are a measure of the curvature of space. In Einstein's theory the metric tensor plays a role akin to a potential in classical mechanics. The competing theories of gravity differ from general relativity in including additional potential-like terms. Depending on whether these additional terms are scalars, vectors, or tensors, the modified theories are called scalar-tensor, vector-tensor, or two-tensor theories.

The best known of these theories is the Brans-Dicke theory (also sometimes referred to as the Dicke-Brans-Jordan theory) which was put forth by Carl Brans and Robert H. Dicke of Princeton University in 1961. (Brans is now at Loyola University, New Orleans.) The Brans-Dicke scalar-tensor theory in particular has stimulated much theoretical and experimental work by researchers interested in astrophysics and cosmology. Moreover, because it makes specific predictions that are different from what general relativity would predict, the Brans-Dicke theory has been the theory most often compared with general relativity when experimental tests of relativity are made.

Until the last few years, the best experimental confirmation of general relativity was provided by the excess advance of the perihelion of Mercury. The apsis of Mercury, or the line connecting the parts of its elliptical planetary orbit that are nearest to and farthest from the sun, rotates slowly, as predicted by classical Newtonian gravitational theory. However, there is an additional rotation due to relativistic effects. Thus, the perihelion of Mercury (nearest point in the orbit of Mercury to the sun) advances 43 arc seconds per century faster than Newtonian theory would predict. This excess perihelion advance was well known even before Einstein's time and was most recently confirmed by radar ranging experiments. Einstein's general relativity nearly exactly accounts for this excess perihelion advance.

Then in 1967, Dicke and H. M. Goldenberg of Princeton (Goldenberg is now at the University of Massachusetts, Amherst) reported measuring a significant oblateness in the sun; that is, the sun's equatorial diameter was larger than its polar diameter. This oblateness, amounting to about 45 parts per million, was interpreted to mean that the sun had a quadrupole moment that could influence the orbits of the planets. Such an oblateness could account for 3 arc seconds of the advance of the perihelion of Mercury, thus causing the prediction of general relativity to be about 7 percent too large. Moreover, it has been shown that the scalar potential in the Brans-Dicke theory of relativity could retard the perihelion advance by this same 3 arc seconds, provided that an adjustable coupling parameter that measured the relative strengths of the scalar and tensor potentials was given an appropriate value.

The oblateness measurement and its consequences for general relativity have been controversial. A principal bone of contention concerns defining the edge of the sun, known as the limb of the sun. The solar limb is characterized by a rapid change in the observed brightness over a finite distance; that is, the edge is not perfectly sharp as the edge of a saucer or coin would be. The possibility thus arises that a difference between the limb darkening profiles at the equator and the poles could cause an apparent oblateness.

Last year, a group at the University of Arizona's Santa Catalina Laboratory for Experimental Relativity by Astrometry (SCLERA), headed by Henry A. Hill, measured the solar oblateness, using a different technique from that of the Princeton researchers. The oblateness as measured by the SCLERA group was more than five times smaller than the previous measurements indicated. Moreover, Hill and his colleagues say that the technique that they developed can detect differences in the solar limb darkening profile, and that they thus were able to show that an apparent excess brightness at the solar equator did occur at certain times during the year.

Experiments of the type that can be used to test gravitational theories are difficult to carry out, in part because the effect being measured is not the only one that can cause a signal and in part because systematic experimental errors are inevitably present but are difficult to detect. As a result, errors beyond the formal statistical errors are often subjectively estimated; and since only the experimenter himself knows exactly what he did, it is next to impossible for others to do more than take this word for the final uncertainty estimate.

Because of such considerations, scientists find it difficult to make a choice between the results of the Princeton and SCLERA oblateness measurements. If anything, the results of other experiments that test theories of gravity and that tend to confirm Einstein's general relativity would seem to lend credence to the results of Hill and his associates. Nonetheless, at the moment, the discrepancy between the two oblateness measurements means that the perihelion of Mercury is not regarded as a good test of relativity.

At present, more reliable tests deal with the effect of the curvature of space near massive bodies on the propagation of electromagnetic radiation. Since space near a large mass, such as the sun, has a greater curvature than elsewhere, as reflected in the large gravitational field, at least two phenomena can be observed: (i) Light from a distant star (or a radio wave from a far off radio source) that passes near the sun on the way to the earth will be deflected in such a way that the star or radio source will appear to be at a greater angular distance from the sun that it would if the sun's gravitational field were not present. (ii) A radar signal traveling to and from a planet on the far side of the sun will suffer a time delay because of changes in the velocity of light when it passes through the sun's gravitational field.

Actually, all the viable theories of gravity predict these effects. Within the solar system, where the effect of gravity is relatively weak, the differences between the theories are reduced to differences in the values of certain coefficients or parameters. In effect, there is one weak field theory of gravity that applies in the solar system, the so-called parameterized post-Newtonian theory, and general relativity, the scalar-tensor theories, and the other theories each correspond to different values of the parameters. The parameters in turn are a measure of different physical effects. Light bending and time delay experiments, for example, measure the value of a parameter that tells how much curvature of space is produced by a unit mass.

On the other hand, when environments where the effect of gravity is very strong are being dealt with, the differences between the theories can become quite crucial. Whether a black hole is or is not possible under a given set of circumstances might depend on which theory of gravity is being considered. However, some scientists think it is arguable whether tests of gravity via the rather weak effects found in the solar system would be reliable guides to the correct theory of gravity for such extreme situations as black holes.

Bending of Radio Waves by the Sun

The most conclusive evidence for the validity of general relativity has been given by the radio waves deflection experiment at NRAO by Fomalont and Sramek, although two other slightly less conclusive measurements of a similar type have also been reported in the last few months. The deflection of radio wave is measured with two radio telescopes located some distance apart to form an interferometer. Radio waves from a distant source can be considered to be plane waves by the time they reach the earth. Because of the separation of the two radio telescopes, the wave front will arrive at each site at a different time. The time difference is equivalent to a difference in the phase of the sinusoidally varying radio wave when it is simultaneously detected at each site. The phase difference can then be used to locate the angular position of the radio source in the sky.

Because differential measurements can be made to a higher accuracy than absolute measurements (to within a few thousands of an arc second in the best experiments), the usual procedure is to locate one radio source with respect to a second source. To carry out the deflection experiment, it is further required to find pairs of sources located in the sky such that over a period of a few weeks, one of the sources will be occulted by the sun. The experiment then consists of measuring the relative position of the two sources at regular intervals during the period of the occultation.

The accuracy of the deflection measurement increases with the distance between the radio telescopes until the separation becomes great enough to give rise to technical problems that counteract the advantages of a very long baseline. One difference between shorter and longer baselines is that in the use of the shorter baseline, the signals received by the two antennae can be electronically compared immediately via electrical cables or microwave links. In the latter case, the signals must be recorded on magnetic tape for later processing. This also requires that accurate clocks be maintained separately at each site so that phase differences can be computed.

At NRAO, Fomalont and Sramek had access to four radio telescopes. Three antennae, 26 meters in diameter, were located within about 3 kilometers of each other at one site, and a fourth, 14 meters in diameter, was about 35 kilometers distant, so that three interferometers with baselines of 35 kilometers could be used. The NRAO scientists also used three radio sources located very nearly on a straight line in the sky. (The nature of the three sources has not been identified and they are labeled simply 0116+03, 0119+11, and 0111+02 according to their positions in the sky.) Use of three collinear sources meant that two could serve as references when the center source was occulted by the sun. Among the primary sources of error in this type of experiment are changes in the earth's atmosphere that cause the positions of the sources to appear to move, as reflected by a change in the phase of the radio wave. By interpolating between the positions of the two references, a pseudoreference can be created at the position of the occulted source, and the accuracy of the measurement considerably enhanced.

A cause of spurious apparent deflection is the solar corona, a thin plasma which acts like a lens and refracts the radio waves as they pass near the sun. Fortunately, unlike the gravitational deflection, deflection due to the corona depends on the frequency of the radio waves. By using two frequencies (corresponding to wavelengths of 3.7 and 11.1 centimeters), the frequency-dependent portion of the measured deflection could be corrected for, and the deflection due to gravity retained.

The final result reported by Fomalont and Sramek indicates a deflection equal to 1.015 ± 0.011 of that predicted by Einstein's general relativity. By way of contrast, the Brans-Dicke scalar-tensor theory with a coupling constant Dicke considers to be reasonable would have predicted a deflection of about 0.95. In order to make the Brans-Dicke theory agree with the results of this experiment, the value of the coupling constant would have to be increased to the point where this scalar-tensor theory would not be appreciably different from general relativity. Similar statements apparently could be made about the other gravitational theories. Many scientists prefer, however, not to regard this result as definitive. Instead, it is seen as one piece of evidence among many that will be required to settle the issue of the correct formulation of a theory of gravity.

A group composed of researchers from the Massachusetts Institute of Technology (MIT), the Haystack Observatory, Westford, Massachusetts, and NASA's Goddard Space Flight Center, Greenbelt, Maryland, used a very long baseline interferometer to obtain a similar, but less accurate result. Two interferometers were constructed from four radio telescopes, two of which were located at the Haystack Observatory and two at NRAO in Green Bank, thus creating a baseline of about 845 kilometers. The result reported by this group was a deflection equal to 0.99 ± 0.03 that predicted by Einstein.

According to Irwin I. Shapiro of MIT and Thomas A. Clark at Goddard, atmospheric turbulence was again a major source of error. However, because of a lower sensitivity inherent in the equipment available, brighter radio sources than those used by the NRAO team were required. The only available sources were the two well-known bright quasars 3C279 and 3C273; consequently, the interpolation technique requiring two references to reduce the uncertainty could not be used.

A third group at the Westerbork Radio Observatory of the Netherlands Foundation for Radio Astronomy in the Netherlands obtained a deflection of 1.038 ± 0.034 times that predicted by general relativity. The Dutch group used the shortest baseline of all, 1.5 kilometers. Except for the shorter baseline and use of the two quasars 3C279 and 3C273, the experiment was quite similar to that of the NRAO group.

Time Delay Measurements

Prior to the recent observation of the deflection of radio waves, the most accurate experiments verifying general relativity were the time delay measurements by John D. Anderson and his associates of the Jet Propulsion Laboratory (JPL), Pasadena, California, of the time delay of radio signals sent to and from the Mariner 6 and Mariner 7 satellites while in an interplanetary orbit on the far side of the sun during 1970. The satellites served the same function as the planets in the time delay of radar waves referred to earlier. The time delay obtained by the JPL scientists was 1.00 ± 0.03 that predicted by general relativity. Principal sources of error were associated with uncertainties in the exact location of the satellites, because nongravitational forces, such as the impingement of the solar wind on the spacecraft, could move it at random by distances of a few hundred meters from its presumed orbit.

More recent measurements on Mariner 9 while in orbit around Mars during 1971 and 1972 are currently under analysis by scientists at JPL and at MIT. Because the satellite is in effect locked into orbit around Mars, nongravitational forces are less important than before, and an uncertainty of only 1 percent, the same as in the NRAO deflection experiment, may be achieved.

But the most accurate of all tests of gravity theories to date may be laser lunar ranging experiments. One of the basic assumptions of general relativity is the equivalence of inertial and gravitational mass. This equivalence has been demonstrated to within one part in 10^{12} in laboratory experiments in which objects made of different materials are affected by a gravitational field in the same way. But when the objects become much more massive, as the moons and planets in the solar system, the objects need not fall in the same way, according to some theories, including the scalar-tensor theories, because of a so-called gravitational self-energy. General relativity does not predict the existence of such an effect.

A group known as the U.S. Lunar Ranging Team (or LURE team), composed of scientists from nine different institutions, has been looking for an anomolous motion of the moon relative to the earth caused by the gravitational self energy. The amplitude of such a motion would be of the order of 1 meter if the Brans-Dicke theory, for example, were correct. By aiming laser beams at reflectors that were left on the moon by the Apollo astronauts, the moon's position can be determined to within a few centimeters. As a result, the potential accuracy of the experiment is perhaps ten times better than that of other experiments.

According to the current chairman of the LURE team, Eric Silverberg of the University of Texas McDonald Observatory, Fort Davis, results obtained so far are apparently in agreement with general relativity, but further analytical work is needed before the accuracy of the original data can be fully used.

Among scientists interested in relativity, there seems to be an undercurrent of emotional attachment to Einstein's theory, a hope that the old master will turn out to be right in the end. One researcher noted that the alternative formulations of relativity seemed to him to be contrived and unesthetic. The bulk of the experimental observations taken as a group appear to be vindicating the intuitive feeling held by many, but the issue is not completely settled. For example, Thomas C. Van Flandern of the U.S. Naval Observatory, Washington, D.C., has been reporting that he has measured a time variation in the value of the universal gravitational constant. A value of the gravitational constant that decreased with time would be incompatible with general relativity but could be compatible with other theories. Van Flandern's report is currently controversial, but if his observations survive the scrutiny they are sure to receive, the last word on theories of gravity will remain to be said.

—ARTHUR L. ROBINSON