The extraordinary penetration and boldness which Einstein showed in 1905 in accepting a new group of experimental facts and following them to what seemed to him to be their inevitable consequences, whether they were reasonable or not as gauged by the conceptions prevalent at the time, has never been more strikingly demonstrated.

Any small contributions that I myself may have made to the progress of physics have been largely in the nature of experimental verification of predictions contained in three theoretical equations first set up by Einstein and but one of these has had anything to do with relativity.

The first of these was the Brownian movement equation (1905) whose verification by a number of observers removed the last doubts as to the atomic theory of matter; the second was the aforementioned photo-electric equation (1905) which changed radically our conception as to the nature of radiation; the third was the equation expressing the interconvertibility of mass and energy. This grew out of special relativity (also 1905) and it has recently predicted for me verifiable relations in the radio-active field, and it also constitutes the most important basis for the cosmic ray conclusions that I am now wishing to draw. All these three are of equal significance, I think, with the predictions from general theory of relativity, the experimental verification of which Dr. Campbell has just described.

You can throw (*Turn to page* 61)

PHYSICS

Relativity Passes Three Tests Declared Crucial by Einstein

Motion of Mercury, Bending of Light and Red Shift of Spectrum Described by One of Theory's Judges

By DR. W. W. CAMPBELL

WHEN Professor Einstein published his immortal theory of relativity, a theory evolved within the four walls of his study room, he in effect advised his colleagues in the physical sciences not to accept it until it had been subjected to certain observational tests of an astronomical nature. He described three such tests by which his theory must stand or fall.

Test No. 1.—The theory of relativity, he said, must explain and remove the discrepancy between the predicted and the observed motions of the planet Mercury. This little brother of the earth, revolving around the sun at an average distance about one-third as great as the earth's distance from the sun, refused to follow the path assigned to it by Sir Isaac Newton's law of gravitation. For more than half a century before Einstein, astronomers had sought diligently but in vain for the explanation. Promptly following the publication of Einstein's work, astronomer De Sitter of Holland applied the test to Mercury, and the theory of relativity accounted in full for the discrepancies referred to.

Test No. 2.—The theory of relativity, he said, required that a ray of light, say from a distant star, when passing close to the surface of our sun, should be bent slightly from its straight-line course by the gravitation pull of the sun upon it as an addition as an effect of the curvature of the space in which the sun is immersed. That a ray or pulse of light should be subject to gravitational attractions and that space should be curved were results or hypotheses new to the world. Einstein urged that astronomers endeavor to observe the phenomenon at times of total solar eclipse, the only times when the test can be applied by photographing the eclipsed sun's surroundings in order to record on the photographic plates the images of the stars in the neighborhood of the sun,—though of course these stars would be millions of times as far away as the sun. The star images should be slightly displaced from their normal positions, he said, and those nearest the sun displaced the most. In 1919, there occurred a total eclipse extremely favorable as to the astronomical elements, and the British Eclipse Committee, represented by Eddington and Davidson, sought to observe the Einstein phenomenon. Unfortunately, the programs of observations were sorely afflicted with clouds, and the images of only a few stars, seven as a maximum, were recorded, faintly and otherwise, on only a part of the plates exposed. Nevertheless, the measurements of the plates showed that the rays were bent from their straight-line courses in passing the sun and through angles approximately of the minute dimensions predicted by Einstein.

The William H. Crocker expedition from the Lick Observatory, University of California, represented by astronomers Campbell and Trumpler, observed the total solar eclipse of 1922 on the northwest coast of Australia, using four photo- (*Turn to page* 60)

EINSTEIN COLLABORATORS

In order of seniority, the scientists working with Einstein at Pasadena are:

Albert A. Michelson, Emeritus Director of the Ryerson Physical Laboratory of the Univerity of Chicago, now a permanent resident of Pasadena and an Associate of both the California Institute and the Mount Wilson Observatory;

Charles E. St. John, astrophysicist of the Mount Wilson Observatory.

William Wallace Campbell, President Emeritus of the University of California and formerly Director of the Lick Observatory.

Robert A. Millikan, Director of the Norman Bridge Laboratory of Physics of the California Institute.

Walter A. Adams, Director of the Mount Wilson Observatory.

Richard C. Tolman, Professor of Physical Chemistry and Theoretical Physics of the California Institute.

Edwin P. Hubble, astrophysicist of the Mount Wilson Observatory.

ber 31, 1900 since it seemed questionable whether we can assign the deviations with the necessary exactness for calculation of a definite disturbance.

In A. N. 3678 Mr. Millosevich published further improvements of the elements which harmonize better with the observations of the second opposition and finally he published the result in N. A. 3741 of a repeated calculation with reference to four normal positions which are distributed during the span of time from October 31, 1900, to March 20, 1901. The calculation of the disturbances up to this later date I could not take into account for the reason already mentioned above; on the other hand the two extreme normal positions, which by the way are not yet entirely definitive, were accepted unchanged.

For the period from March 20, 1901 to June 8, 1903 the disturbances of 433 by five planets, namely Venus, Earth, Mars, Jupiter and Saturn, were calculated by Mr. Wedemeyer on behalf of the Royal Recheninstitute in Berlin according to the method of the variation of the constant with 20 day intervals; a resumé of the end results is to be found on page 534 of the Berlin Astronomical Yearbook for the year 1905. Since the bases of this calculation were the elements deduced by Mr. Millosevich which were undoubtedly of sufficient exactness, a repetition appeared unnecessary, in spite of the fact that the calculation of the Ephemeride for the opposition of 1903 did not agree as closely with the already quoted observations at Rome as might be expected.

Now we have only to make a few general remarks concerning the photographic position of the planet Eros in the years 1893-4 and 1896. Twenty-one plates, twelve photographed in Cambridge and nine in Arequipa (Peru), were measured. Since we could not use the original plates, from each photograph two enlargements were prepared on which one millimeter represented about ten " gr. Kr. The position of the planet resulting from the measurement of these enlargements, the more or less close agreement of which permits an approximate estimate of exactness of the measurements, were published by Mr. Edward C. Pickering et al. A. N. No. 3652. . . .

The distribution of the observations from the years 1893 and 1894 permits the assumption of five normal positions; two isolated positions made November 26, 1893 and May 19, 1894 may be overlooked for at least the present. Of the six observations in the year 1896 five may be concentrated into two normal positions; a single solitary position on April 6, 1896 can not be utilized at the present time.

It appeared uncertain to carry out the definite calculation of the disturbance to the oldest date of observation at a single operation. The planet came into the closest proximity of the earth with 0.125 a.E. January 20.5, 1894. The elements must be very exact if one can not expect to find the disturbances by the Earth faulty around this date in appreciable quantities. For this reason I decided to carry out an improvement of the elements with the exclusion of the observations of 1893-4.

Here follow the tables of Witt's calculations.

From this I conclude that the numerical results at this time indicate that observation of the planet at a favorable opposition similar to that of 1893-94 would yield valuable material for an independent determination of the mass of the earth with greater precision, and that from this point of view it is worth while keeping (433) Eros under observation.

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Relativity Passes Three Crucial Tests

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graphic telescopes, designed and constructed anew to apply with great efficiency upon the Einstein test. The weather and sky conditions were essentially perfect. Hundreds of star images were recorded on the plates, all in excellent focus. The images of about a hundred stars whose light had passed the sun at varying distances were selected for measurement. The ten results from the ten plates were each in good and satisfactory accord with Einstein's prediction, and the mean of all the results was essentially in precise accord with the prediction.

Test No. 3.—If the positions of the thousands of dark lines in the spectrum of the sun, representing the gases and vapors of the chemical elements composing the surface strata of the sun be measured very accurately, it should be found, Einstein said, that the lines are displaced by an exceedingly small but definite amount toward the red end of the spectrum, because the strong gravitational pull of the sun upon the radiating materials in the sun's surface would affect the outgoing waves of light in such manner as to lengthen them slightly; and we know that a lengthening of the wave lengths shifts a spectrum toward the red end of it.

Several astronomers endeavored to observe this phenomenon but by far the most comprehensive and successful program was that conducted by Dr. St. John, a member of the staff of the Mount Wilson Observatory, based upon photographs secured with the powerful tower telescopes on Mount Wilson. Although several influences are known to be capable of displacing the lines of the solar spectrum very slightly toward the red, yet St. John's results after eliminating the other influences as well as possible, reached conclusions in substantial agreement with the Einstein prediction.

A few years ago, through the work of Eddington and others, it became evident that the fainter star in the well-known double star Sirius, though about as massive as our sun, is a surprisingly small and exceedingly dense body. A cubic inch of it, on the average, it is confidently believed, would weigh as much as 50,000 cubic inches of water. That is, on the earth a cubic inch of the star would weigh almost a ton. It was pointed out that the Einstein displacement of the lines in this star's spectrum should therefore be about twenty-seven times as great as for the lines in the sun's spectrum. Director Adams of the Mount Wilson Observatory, using the 100-inch reflecting telescope, and demanding the full power of that great instrument, succeeded in observing this displacement and he found it to be of the dimensions required by the Einstein theory.

And thus has the theory of relativity met and passed the three astronomical tests set for it by its distinguished author.

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Einstein Discusses Revolution in Thought

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general relativity into the waste basket if you will, and Professor Einstein's position as the leading mind in the development of our modern physics would still remain unchallenged.

By DR. A. A. MICHELSON

I CONSIDER it particularly fortunate for myself to be able to express to Dr. Einstein my appreciation of the honor and distinction he has conferred upon me for the result which he so generously attributes to the experiments made half a century ago in connection with Professor Morley, and which he is so generous as to acknowledge as being a contribution on the experimental side which led to his famous theory of relativity. I may recall the fact that in making this experiment there was no conception of the tremendous consequences brought about by the great revolution which Dr. Einstein's theory of relativity has caused—a revolution in scientific thought unprecedented in the history of science.

Science News Letter, January 24, 1931