Professor Dr. Pascual Jordan

Theoretical Physicist

Born 1902 at Hannover

Study of physics, mathematics, zoology at Hannover and Goettingen. Founded in common work with Max Born and Werner Heisenberg quantum mechanics, later with other authors (W. Pauli, E. Wigner, O. Klein) quantum theory of wave fields. Later research also in pure mathematics ("Jordan algebras"), biophysics, cosmology, general relativity, geophysics. - Since 1928 Professor University at Rostock, later Berlin, since 1947 Hamburg. Max Planck medal 1942. Gauss medal 1953.

Summary

The attached manuscript discusses the present status of empirical test of the gravity hypothesis put forward 1937 by the famous physicist Dirac. At first I state shortly, that in a book of mine (published several months ago) the result came out that in geophysics and geology no really proven fact seems to exist which would be in disagreement with the hypothesis. Then two possibilities of testing by modern astronomical precision measurements are discussed.

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Empirical tests of Dirac's hypothesis about gravitation

In the year 1937 Dirac put forward an hypothesis, motivated by considerations regarding cosmology, and the physics of elementary particles at the other hand, expressing the idea that the gravitational constant G might be in reality not a constant, but a physical value slowly decreasing in the course of cosmological evolution. Having been fascinated by this idea, linking the universe with the electron, I devoted several years to a study of the question, how Einstein's theory of gravitation had to be revised or generalised if Dirac's hypothesis might be correct.

A series of physicists, astronomers and mathematicians joined me in this endeavour. R. Dicke from other considerations came to a similar theory. But though mathematically beautiful relations were revealed by these studies - summarized in a book of mine [1] - it remained unsatisfactory, that the extreme slowness of the surmised decrease seemed to leave scarcely any hope to connect these mathematical speculations with empirical facts.

Therefore I was again fascinated as my late friend J.E. Fisher at New York made the remark, that Dirac's decrease of G , if existent, must have caused a marked expansion of the earth in the course of its history. I believed to see here a possible answer [2] to one of the great problems of earth research: Why this division of the surface of the earth into two different parts, continental areas and deep sea?

I began to read ~~a little~~ about the beautiful sciences concerning Earth and Moon, and saw that there are many theories which cannot be reconciled with Dirac's hypothesis (as for instance

the interpretation of the great craters of the Moon as volcanoes). But I did not find proven facts which could be used to discard the hypothesis. Selecting a set of ideas, every one of which has been put forward to discussion already by at least one specialist (though remaining controversial), I got a theoretical picture which seems to be in agreement with what we really know, and with what we should have to infer if Dirac's hypothesis would be correct [2].

But though this manner to compare Dirac's hypothesis and its consequences with empirical facts, gives surely good support to the hypothesis, and encouragement for further investigation, this comparision is complicated, and needs decisions with regard to very controversial questions in geophysics and geology.

Therefore the question becomes urgent whether it would be possible to test the hypothesis - separated from the discussion of the great bulk of its connections with problems of Earth and Moon - by purely astronomical measurements, including the use of modern instruments as atomic clocks, lasers and Moon rockets.

Now from Dirac's hypothesis it can be inferred by a very simple mathematical calculation [2], that ephemeris time T - definable also in the case of correctness of this hypothesis - cannot be identical with the exact time t of any inertial system of space-time-coordinates. We have theoretically the relation

$$T = t(1 - \varepsilon t) \tag{1}$$

with

$$\varepsilon = -\dot{G}/G; \quad \varepsilon^2 \approx 0 . \tag{2}$$

Since nearly ten years Nicholson and Sadler 3 measured and registered the relation between T and t, using sharply defined values of T, given by occultations of

stars by the Moon, and measuring the corresponding inertial times by an atomic clock. Becker and Fisher [4] rediscussed their registrations with the help of a computer, comparing them with the theoretical formula (1). Ten years of registration were not yet enough to put their results beyond every doubt. But it seems that the most probable empirical value of ε fulfils

(3) $$\boxed{10^{-10}/y < \varepsilon < 10^{-9}/y .}$$

From this basis further registration probably may lead soon to considerable diminution of the probable error, and to a real decision about Dirac's hypothesis.

Going a little more into details, the result from which (1) is a consequence, may be formulated ~~in the following manner~~ thus:

If in the n body problem

(4) $$\ddot{\mathfrak{r}}_k = G \sum_l M_l \frac{\mathfrak{r}_l - \mathfrak{r}_k}{|\mathfrak{r}_l - \mathfrak{r}_k|^3}$$

with $l \neq k$ we have according to Dirac then the consequences of (2) may be expressed in the following manner: At first we define new coordinates for space and time by

(5) $$\begin{cases} \mathfrak{R} = (1 - \varepsilon t)\mathfrak{r} , \\ T = (1 - \varepsilon t)t. \end{cases}$$

In these new coordinates we have then exactly a Newtonian n body problem:

(6) $$\ddot{\mathfrak{R}}_0 = G_0 \sum_l M_l \frac{\mathfrak{R}_l - \mathfrak{R}_k}{|\mathfrak{R}_l - \mathfrak{R}_k|^3}$$

with $G_0 = \text{const.}$

Though the proof of this mathematical theorem is quite trivial, the fact that it holds is quite meaningful. Without knowing it we could doubt whether Dirac's hypothesis could be accepted without bringing disorder into the old successes of the Newtonian theory of the planetary system. An instructive example of finer details of the Newtonian theory is given by the well known fact that in the ring of Saturn there are the two empty rings of Cassini and Encke, explainable by resonance between particles which would have their orbits in these empty rings, with the

(2') $G = G_0(1 - \varepsilon t)$,

moon Mimas of Saturn. Now one can scarcely doubt that long time has been needed in order to clear out the empty rings of Cassini and Encke. Therefore Dirac's hypothesis would be false if it would not lead to the consequence that this resonance would have remained intact in spite of the slow change of G . But our theorem guarantees maintenance of the resonance in spite of changing G .

In the same manner every result concerning a Newtonian n body problem is maintained also after acknowledgement of Dirac's hypothesis - only it is now concerning the new coordinates $\mathcal{R}, T$ instead of r , t.

Therefore also the definition of ephemeris time can remain as before - but this time, defined by using the planetary system as a clock (better than the rotating earth with its measurable irregularities), is now T , and not t .

The older astronomy - before the introduction of radio echos - could measure the angular coordinates with errors of about 10^{-7} ; but the distances of the planets from the earth only with relative errors of about 10^{-4} . Using radio echos this can be improved to about 10^{-6}; but the first line of (5) remains unmeasurable in the planetary motion. Therefore concerning the planets, (1) is all what we can measure and test now.

But in the case of the Moon the situation is more favourable, because in this case we can use lasers instead of radar. It is now possible to transport optical orthogonal-reflectors to the Moon, and measure the distance from any point on the earth with an error of about only one meter. In this manner also the motion of the Moon can be measured with sufficient precision in order to see the influence of Dirac's decrease of G (giving an increase of the orbital radius of the Moon in the order of magnitude of 10 cm per year), though the action of tidal friction makes the situation a little more complex.

So we see two possibilities to measure $\varepsilon = -\dot{G}/G$ astronomically - one of these possibilities is already in performance, and the other one a possibility of the near future.

The laser experiment with orthogonal-reflectors has been proposed by Franken, and its relation to the Dirac hypothesis discussed in my book. In the meantime also a group of American investigators emphasized this relation.

Literature

[1] P. Jordan, Schwerkraft und Weltall, Braunschweig 1952. - 2nd ed. 1955

[2] P. Jordan, Die Expansion der Erde. Braunschweig 1966.

[3] W. Nicholson and D.H. Sadler, Nature 210, 187 (1966).

[4] G. Becker and Fischer, PTB-Mitteil. 77, 15(1967).