General Theory of Relativity or a Theory of Gravitation?

M. F. SHIROKOV

(Submitted to JETP editor, September 14, 1954)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 180-184 (January, 1956)

IN a series of articles, V. A. Fock[1-5] gives a new interpretation of the general theory of relativity, according to which its physical content consists entirely of the familiar law of universal gravitation of A. Einstein

$$R^{\mu\nu} - {}^1\!/_2 g^{\mu\nu} R = -kT^{\mu\nu}, \qquad (1)$$

which determines the deviation of the metric of space-time from the Galilean metric. In contradiction to the general principle of relativity, it is assumed that a preferred reference system exists with coordinates which satisfy the "harmonic" condition:

$$\partial(\sqrt{g}\, g^{\mu\nu})/\partial x^\nu = 0. \qquad (2)$$

Hence in the articles of Fock cited above it is proposed to replace the designation "general theory of relativity" by another: "theory of gravitation".* This proposal involves not merely a change of terminology, as has been assumed by some physicists, but a fundamentally different interpretation of the general theory of relativity, as is seen from the following quotations:

"From what has been said it is clear that the use of the terms "general relativity", "general theory of relativity" or "the general principle of relativity" is inadmissible. It not only leads to misunderstandings, but reflects an incorrect understanding of the theory itself. Paradoxically, such a lack of understanding has been shown by the very author of the Einstein theory..." (p. 135 in reference 5.)

"As for accelerated motion, the principle of relativity is inapplicable to it, to say nothing of the fact that the very concept of the "accelerated reference system" is not clearly defined" (p. 25 in reference 4). "The principle of equivalence has a strictly local character (in space and time) and is applicable only to weak and homogeneous fields and slow motions: only under these conditions can one replace, in an approximate manner, a field of acceleration by a gravitational field, and vice versa. As a general principle, it is, in general, incorrect" (p. 25 in reference 4) "Thus, in itself, the covariance of equations is by no means the expression of any physical law" (p. 133 in reference 5).

What has been said above prompts us to make certain observations concerning the problem formulated in the title of the present article.

1. DOES THE GENERAL PRINCIPLE OF RELATIVITY HOLD IN NATURE?

Mathematically this principle is expressed in the covariance of the fundamental equations of physics with respect to a rather extensive class of coordinate transformations, including also changes of all kinds from one inertial or non-inertial reference system to another. The physical essence of the general principle of relativity reduces to the fact that the curvilinear nature of space-time coordinates is manifested in the existence of two fields: gravitational and inertial, which underlie various physical effects existing in nature and possessing objective reality.

In the absence of gravitational fields the Riemann-Christoffel curvature tensor vanishes:

$$R^{\varepsilon}_{\mu\nu\sigma} = 0. \qquad (3)$$

This equality is the necessary and sufficient condition for space-time to be Galilean. In such a space, a coordinate system can always be constructed, which satisfies, upon introduction of the imaginary time coordinate $x_4 = ict$, the requirement:

$$g_{\mu\nu} \begin{cases} = 1, & \mu = \nu; \\ = 0 & \mu \neq \nu. \end{cases} \qquad (4)$$

In the presence of gravitational fields, on the other hand, Eq. (3) is no longer satisfied, space-time is no longer Galilean, and its metric is determined by the equation of gravitation (1).

The opinion is expressed[4] that the difference

*Unfortunately, this point of view of Fock, at best controversial, has been reflected in the new edition of the "Great Soviet Encyclopedia", in which, in the article "Relativity, Theory of" only the special theory of relativity is treated, and instead of an article on the general theory of relativity an article "Gravitation, Theory of" is planned.

[1] V. A. Fock, J. Exptl. Theoret. Phys.(U.S.S.R.) 9, 375 (1939).

[2] V. A. Fock, *Nicholas Copernicus*, Acad. Sci. USSR (1947).

[3] *Some Applications of the Ideas of N. I. Lobachevsky in Mechanics and Physics*, GTTI, 1950.

[4] V. A. Fock, *Modern Theory of Space and Time*, Priroda, 12, 1953.

[5] V. A. Fock, Voposy filosofii (Problems of Philosophy) 4, 1955.

between the "special" and "general" theories of relativity reduces only to whether Eq. (3) is satisfied or not; it is also asserted that in the "special" theory, while Eq. (3) is valid for the coordinates, the general covariance of the equations is trivial and has no physical content. If this were so, the general theory of relativity would in fact reduce fully and completely to the theory of gravitation formulated in the form of Eq. (1), which determines the properties of spaces which do not satisfy Eq. (3). Actually, however, the situation is different. The region of application of the special theory of relativity is considerably narrower than the region defined by Eq. (3), and is limited to the reference systems which satisfy Eq. (4).

There is an essential difference between requirements (3) and (4). Eq. (4) is satisfied by all inertial reference systems, without gravitational field, and with coordinate meshes (nets) which are connected with each other by linear Lorentz transformations. But Eq. (3) is satisfied also by all non-inertial reference systems which do not contain gravitational fields. In these latter, however, there appear the effects of the fields of inertial forces on the course of mechanical, electromagnetic (optical) and other processes which can in no way be explained on the basis of Lorentz transformations, i.e., within the framework of the special theory of relativity.

It is also very essential that in non-inertial systems, when Eq. (3) for space to be Galilean is satisfied, the metric of space-time does not satisfy the conditions (4). In particular, Einstein himself has pointed out the possibility of deviations from the Euclidean properties of space in non-inertial reference systems (e.g., rotating systems). It is well-known, however, that in the special theory of relativity the axioms of Euclidean geometry are valid for space.

Thus, the extension of the principle of special relativity to phenomena satisfying Eq. (3), combined with a denial of physical content to the generally covariant formulation of the laws of nature, reduces, in fact, to a denial of the objective reality of the fields of inertial forces and of specific effects produced by them in non-inertial reference systems, many of which have been experimentally demonstrated a long time ago. This makes it necessary to generalize the principle of relativity to inertial* reference systems also, i.e., to formulate the general principle of relativity as a physical assertion, which reflects the objective reality of nature.

*Translator's note: It would appear that this word should be "non-inertial."

2. DO PREFERRED REFERENCE SYSTEMS EXIST?

In the references 1-5 the existence of privileged, or, in our terminology, preferred, coordinate systems, defined by these solutions, is inferred from the fact of uniqueness of the solutions of the equation of gravitation (1) with the harmonic condition (2) for coordinates and boundary conditions (4) at infinity for isolated aggregates of matter. The existence of such solutions is therefore regarded as a weighty argument against the general principle of relativity. They are, indeed, determined by equations (1) and (2), the second of which is obviously not covariant with respect to general coordinate transformations.

Without doubt the solution quoted, whose discovery was to a considerable degree facilitated by a fortunate choice of condition (2), has considerable value and scientific interest. However, its uniqueness would be an argument against the general theory of relativity only if Eq. (2) were the expression of some physical law. Then the law of universal gravitation would be formulated by Eqs. (1) and (2). However, Eq. (2) is simply an arbitrary condition which defines the system of coordinates in which it is most advantageous to seek the solution of the proposed problem. The choice of the harmonic coordinates (2) is, in a sense, equivalent to the choice of cylindrical, spherical, and other coordinates convenient for the solution of the given problem.

It is, however, necessary to make completely clear the concept of a preferred reference system. Actually, in Newtonian mechanics, such a system was taken to be one in which the center of inertia of a given collection of matter is at rest or moves uniformly and rectilinearly. The existence of the center of inertia was guaranteed by the laws of conservation of mass, energy, momentum and angular momentum. Such a concept of a preferred reference system for an isolated collection of matter can be formulated also in the general theory of relativity, since in this theory also it has been shown that the theorem concerning the center of inertia holds in generally covariant form, i.e., for arbitrary coordinate systems, but with the Galilean conditions (4) at infinity.[6]

In accordance with this theorem, and without any contradiction with the general theory of relativity, the heliocentric system of coordinates of Copernicus will be a preferred system for our planetary system even in the general theory of relativity.

[6] Iu. M. Shirokov, J. Exptl. Theoret. Phys. (U.S.S.R.) 21, 748 (1951). M. F. Shirokov, J. Exptl. Theoret.Phys. (U.S.S.R.) 27, 251 (1954).

For this reason, a negative solution is given to the problem of equivalence of the Copernican and Ptolemaic systems, which is thought to follow from the general theory of relativity by some physicists and philosophers abroad. To this it must be added thata rotating reference system can exist in reality only in limited regions of space[7], as a result of which the geocentric system of Ptolemy for the world as a whole does not exist in nature.

3. IS THE PRINCIPLE OF EQUIVALENCE OF INERTIAL FORCES AND GRAVITATION CORRECT?

The general principle of relativity contains inherently the principle of equivalence of gravitational and inertial forces, without which the generally covariant formulation of the equations of physics is altogether impossible. This is the reason why Einstein's efforts to create a general theory of relativity have led him to formulate a new law of universal gravitation. The physical essence of the principle of equivalence consists in the identity of the physical actions of fields of inertial and gravitational forces in spite of their different origin.. For instance, the equation of a geodesic is a differential equation of the trajectory of a small test body in gravitational as well as inertial fields, and it is impossible to separate them at a given point of space. The equations of electrodynamics, mechanics of continuous media, etc., also have the same form in the fields of both inertial and gravitational forces.

The principle of equivalence holds exactly only locally, i.e., only at a given point of space-time. This is quite sufficient for the formulation of physical laws in a generally covariant form. The fact that the principle of equivalence does not hold for the entire gravitational field as a whole means that it is impossible to interpret gravitational fields purely kinematically, and cannot be regarded as an objection against the principle of equivalence in its present form.

4. REMARKS CONCERNING PROSPECTS OF APPLICATION OF THE GENERAL THEORY OF RELATIVITY TO PHENOMENA OF THE MICROWORLD

The general theory of relativity is usually regarded to be applicable only to macroscopic phenomena, for instance the motion of celestial bodies in astronomy. Does it have any prospects of application to processes taking place in the microworld? We should like to point out here certain circumstances which are of significance for a correct answer to this question.

It is well known that in recent years a consistent covariant formulation of quantum electrodynamics (Schwinger, Feynman, Tomonaga and others), with respect to Lorentz transformations has led to marked successes in achieving a clearer formulation of the theory and in interpreting certain new experimental data. This makes it possible to hope that a still more complete generally covariant formulation of the quantum theory of fields and particles may turn out to be fruitful in view of its undoubtedly greater physical content (due to account being taken of gravitational and inertial fields). Even if it should turn out that these fields do not play an essential role in the processes of the microworld, the very proof of the correctness of this supposition could be regarded as an important result, since at present it is usually assumed without any serious attempt at justification. It should be pointed out, however, that certain calculations of a methodological character in the classical theory of fields and particles suggest doubts as to its correctness. It turns out that even in the well-known linear and non-linear generalizations of electrodynamics due to Born-Infeld and Bopp-Podolsky, in which point charges do not lead to divergences and possess a finite electromagnetic mass, the hypothesis of weak (Newtonian) gravitational field, assumed in these theories, is not fulfilled, and this results in a substantial contribution to the mass of particles[8,9].

CONCLUSIONS

The general theory of relativity is a physical theory concerning the dependence of the properties of space and time on matter and its motion. This theory is based on the assumptions of identity (covariance) of the laws of nature in all inertial and non-inertial reference systems which exist or can objectively exist in nature (general principle of relativity), and on the law of universal gravitation (1). The theory contains two universal constants: c-the velocity of light in inertial reference systems without gravitational fields, and k-the constant of gravitation, which occurs in Eq. (1) of the law of universal gravitation. The first expresses the mutual connection between space and time, and the second the dependence of

[7] L. Landau and E. Lifshitz, *Classical Theory of Fields*.

[8] M. F. Shirokov, Vestnik Moscow State Univ. 4, 67, (1947).

[9] Ia. Pugachev and M. Shirokov, J. Exptl. Theoret. Phys.(U.S.S.R.) 24, 375, 1953.

the properties of space-time on matter and its motion.

The interpretation of the general theory of relativity as only a theory of gravitation, while rejecting the general principle of relativity as a law of nature, is unacceptable because it leads to a denial of the objective reality of the fields of inertial forces and all physical effects (mechanical, electrodynamic, etc.) caused by them.

The division of the theory of relativity into special and general has no fundamental significance, and results from practical considerations in using the theory in various degrees of approximation.

Translated by A. V. Bushkovitch
22

SOVIET PHYSICS JETP VOLUME 3, NUMBER 2 SEPTEMBER, 1956

The Electron Spectrum of U^{237}

S. A. BARANOV AND K. N. SHLIAGIN

(Submitted to JETP editor, April 19, 1955)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 225-230 (February, 1956)

The electron spectrum of U^{237} was investigated on a $\pi\sqrt{2}$ focussing angle magnetic β spectrometer, beginning with electron energies of 1 kev. Two components of the spectrum were determined, with energy limits E_{0A}=84 kev (26%) and E_{0B}=249 kev (74%). The following γ transitions for Np^{237} were computed from the conversion electron lines; 26; 33; 43; 60; 69(?); 101(?) 124(?); 165; 193(?); 208; 267; 331; 370 and 436 kev. A tentative decay scheme of U^{237} is given.

The study of the decay of U^{237} has been clarified by several researches.[1-4] However, these investigations, with the exception of the last,[4] were not carried out with sufficient accuracy, and do not give the complete picture of the decay of U^{237}. We have undertaken to carry out more carefully the study of the electron spectrum of U^{237}, including the low energy region, on a spectrometer with increased resolving power and light sum.

APPARATUS

A magnetic β spectrometer with double focussing of the electrons at an angle of $\pi\sqrt{2}$ was employed for the study of the electron spectrum of U^{237}.[5] The radius of the central trajectory of the electrons was r_0=22.5 cm. The resolving power of the spectrometer, determined by the relative half width of the conversion line of Ba^{137} (Cs^{137}, $h\nu$= 661.6 kev) for a source width of 1.5 mm, coincided with the calculated value and equaled 0.3%.

The U^{237} source has the dimensions 1.5 x 25 mm^2; for it, the relative halfwidth of the conversion lines had a value > 0.3%. The deviation from the computed value (0.3%) is explained by the effect of the thickness of the source. The relative solid angle of the spectrometer amounted to about 0.43 % of 4π.

A vacuum of $\sim 10^{-5}$ mm was maintained in the spectrometer chamber. The intensity of the magnetic field at the central orbit was measured by the ballistic galvanometer method. The magnetic field of the spectrometer was calibrated by the conversion line of Ba^{137}.

The electrons were recorded by a single cylindrical Geiger-Muller counter. A window (dimensions 1.5 x 25 mm^2) was located on the lateral wall of the counter to admit electrons. The window was covered by a celluloid film of thickness $\sim 10^{-5}$ cm. The film was supported by a tungsten wire grid (φ= 0.04 mm, spacing $\sim$ 0.3 mm). The counter was filled with a gas mixture of argon and ethyl alcohol (10% alcohol, 90% argon). The pressure of the mixture was $\sim$ 50 mm mercury. The voltage level of the counter was 100-150 v. Pulses from the counter were recorded by the usual counting apparatus of the type PS-64.

PREPARATION OF THE RADIOACTIVE SOURCE

For the investigations, the preparation of U^{237},

---

[1] Y. Nishina, T. Yasaki, H. Ezoe, K. Kimura and M. Ikawa, Phys. Rev. 57, 1182 (1940).

[2] E. McMillan, Phys. Rev. 58, 178 (1940).

[3] L. Melander and H. Slatis, Arkiv. Mat. Astr. Fys. A36, No. 15 (1948).

[4] F. Wagner, Jr., M. S. Freedman, D. W. Engelkemeir and J. R. Huizenga, Phys. Rev. 89, 502 (1953).

[5] S. A. Baranov, A. F. Malov and K. N. Shliagin, *Apparatus and Techniques of Experiment* 1, 1, 1956).