# GRAVITATION PROBLEMS IN A LITTLE-KNOWN N. ROSEN'S PAPER OF HIS KYIV PERIOD (1936–1938): TO THE ORIGINS OF FORMATION OF THE GRAVITATIONAL WAVE THEORY

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A little-known paper of N. Rosen, a co-author of A. Einstein, entitled "Plane Polarized Waves in General Relativity Theory" and published within the two-year period of the work of N. Rosen at the Institute of Physics of the Academy of Sciences of the UkrSSR has been analyzed in the context of the formulation and development of the theory of gravitational waves. The unknown earlier correspondence of V.M. Molotov and N. Rosen with A. Einstein was used to reveal the causes of Rosen's staying in Kyiv, as well as to illustrate the debatable moments of the plane-polarized wave model in the framework of the general theory of relativity. Attention has been focused upon the fact that N. Rosen, during his residence period in the UkrSSR, had published – as a single author and in co-authorship with A. Einstein and G.P. Ilkovych – a number of papers devoted to the problems of gravitational waves and particles in the general theory of relativity.

The process of physics development comprises, first of all, the development of such ideas and concepts which brought about the modern scientific picture of the world. In the history of the development of theoretical physics in Ukraine during the XX-th century, there had been – till now – many blank spots connected with the activity of scientists. In particular, some pioneer works of outstanding scientists remained sometimes unknown; therefore, a disclosing of their historical background, the analysis of their basic statements, and the elucidation of their role in the course of formulation and development of the corresponding theory are actual at present. In particular, the life and activity of Nathan Rosen – one of the co-authors of A. Einstein and one of the researchers of the effect that was named the Einstein–Podolsky–Rosen effect – can be cited as an example. But only a few know that Rosen's life had been, for some time, connected with Ukraine. His activity in Ukraine is so little-known that even in a thorough work [5] it had not been covered absolutely accurately. Therefore, let us pay attention to some moments of N. Rosen's life and to circumstances of his finding himself in Ukraine.

N. Rosen was born in a family of emigrants in Brooklyn, New York, in 1909. In 1929, he received a bachelor's degree in electrochemical engineering from the Massachusetts Institute of Technology, a master's degree in physics in 1931, and a doctorate in physics in the next year. When N. Rosen was writing his M.Sc. dissertation, he, having arrived to Princeton to deal with molecular physics, addressed to A. Einstein. N. Rosen was interested in the opinion of the outstanding scientist about his dissertation work. This meeting of two scientists had started their fruitful cooperation. N. Rosen was Albert Einstein's Assistant at the Institute for Advanced Studies of Princeton University in 1934–1936. Then, owing to a personal A. Einstein's request to V.M. Molotov, Nathan Rosen started to work in Ukraine, which was a part of the Soviet Union at that time. The motive of his solution to move to the USSR becomes clear from the following fragment of his biography: "In 1936, Rosen moved to the Soviet Union, as many other young physicists – hurt and disillusioned by the economic depression in the West – did at that time" [3]. It should be noted that it was not a single case at that time when a foreign expert worked in the USSR.

The correspondence between N. Rosen and A. Einstein has remained preserved and can be used both to trace the initial period and the development of modern physical theories and to feel the breath of that epoch. In his first – since coming to Ukraine – letter to A. Einstein (dated by February 26, 1937), after having discussed some issues of theoretical physics, N. Rosen writes: "I am working at the Physical Institute of the Ukrainian Academy of Sciences, doing research, and I also lecture at the University of Kiev [in Russian, of course; but it was not surprising, because Rosen was born in the emigrant family – the authors' remark]. I am always very busy – there is so much to be done! But, although I haven't the leisure that I had in Princeton, I have other, more important, thing. I have the feeling that I am useful and needed (and without such a feeling life is not worth very much). And – at any rate, up to the present – in order to get my bread I have not had

to win the favor of little men in high positions. So, all in all, I am still grateful to you for your help in arranging for me to come here." One may guess that N. Rosen planned to work in Ukraine as long as possible.

In the next letters, he describes – in the same enthusiastic tone – the Soviet system. He even discusses an opportunity for a chemist from Princeton to find a job at the Dnipropetrivsk University. But he could not find a person in the USSR who would answer for that scientist, since "the authorities are cautions because of their experiences with foreign spies and wreckers". But no later than in a year, in his letter dated by 24 March 1938, we can read the following: "As you see, we are still in Kiev. And we still feel very enthusiastic about the Soviet Union ... Perhaps I shall have occasion to speak with you in person next summer."

But, gradually, his plans change. The scientist's family has already left for America. The last letter from Ukraine dated by 31 July 1938 differs very much by its mood: "When I last wrote to you, I was expecting to come to America this summer for a visit. Since then my plans have changed. In a few weeks I am coming back to U.S. to remain there. This I am doing in spite of the fact that I am very pleased with what I have seen of the Soviet Union and very much enjoy living in it. The reason for this step is mainly that I am dissatisfied with my own work and my ability. I feel that I am not accomplishing as much as I ought to. *My conscience does not permit me to remain here* [emphasized by us – the authors]. Hence I am returning to the States and shall look for some kind of job not requiring research work. If I find it then I shall work on research in my spare time without feeling any responsibility." An impression arises that N. Rosen knew about the perusal of his correspondence and tried to make A. Einstein know the true reasons of his departure from the USSR. One may suppose that A. Einstein, who knew N. Rosen well, could guess why "conscience" did not allow him to stay more in the USSR. Taking into account that it was just a period when the "cleaning" of the Soviet science was running and a plenty of scientists had already been condemned or even shot dead, Rosen's case can belong to those few when a scientist – moreover, a foreign scientist – succeeded in avoiding the NKVS (later KGB) jails. After moving to the USA, the scientist had been working at the Institute of Northern Carolina, and, since 1952, as Professor in Haifa. He had not returned to Kyiv any more.

Let us focus our attention upon his works, which were published within his two-year job in Kyiv in the staff of the Institute of Physics of the Academy of Sciences of the UkrSSR from 1936 to 1938. The papers were devoted to the problems of gravitational waves and particles in the general theory of relativity. They were written both independently and in co-authorship with A. Einstein and G.P. Ilkevych. Simultaneously, N. Rosen lectured at the Kyiv University.

One of these papers was devoted to the consideration of plane-polarized waves in the general theory of relativity. Judging from the note at the end of the article, this work was a continuation of researches, the results of which had been published in the Journal of the Franklin Institute in 1937. The correspondence of this period between N. Rosen and A. Einstein contains a letter from 6 May 1937, where the problem concerned is characterized as follows: "About the work I sent you – I thought over carefully your remarks in connection with it and I read the improved version in the Journal of Franklin Institute but I am not yet satisfied. Our original problem was the question of plane waves (where plane is in the sense of a Euclidean space into which the space considered goes over in the absence of the waves). True there was an error in our reasoning. In the published paper the error is avoided – but at the cost of avoiding the problem. The question is raised: are there plane waves? And the answer is given: yes, there are cylindrical waves. For this reason it seems to me that the original problem needs further investigation. It seems to me that from the point of view of the original problem what I wrote in the paper I sent you is not incorrect but is perhaps incomplete. I think one can show that for all plane waves of the type under discussion there are no solutions which are free from singularities everywhere and for all time" [6].

In his work [2], devoted to the considerations of plane-polarized waves, N. Rosen studied how the system of equations (the Maxwell equations and the gravitational ones), which are nonlinear with respect to the variables corresponding to the electromagnetic field (the components of the electromagnetic tensor $F_{\mu\nu}$), describes the propagation of waves through a space free of matter:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 2F_{\alpha\nu}F^{\nu}_{\alpha} - \frac{1}{2} g_{\mu\nu} F_{\alpha\beta} F^{\alpha\beta}, \tag{1}$$

$$F_{\mu\nu};\sigma + F_{\nu\sigma};\mu + F_{\sigma\mu};\nu = 0, \tag{2}$$

$$F^{\mu\alpha};\alpha = 0. \tag{3}$$

The coordinate system $(x, y, z, t) = (x_1, x_2, x_3, x_4)$ was selected by the author in such a manner that, in the

absence of fields, there would be a Minkowski space. The polarization was determined by the following conditions: the $y \to -y$ transformation must keep only the metric tensor to be invariable, while the $z \to -z$ one the both. As the author wrote, "Those positions can be imagined physically in the case of two particles with equal masses and equal but opposite charges, which oscillate along a line connecting them ... If the distance from the oscillating system increases infinitely, while the charges and the masses grow to keep the field finite, the example considered here is attained."

In this case, the nonvanishing tensor components are $(g_{11}, g_{22}, g_{33}, g_{44}, g_{14}) = (-A, -B, -C, D, E)$, $F_{12}$, and $F_{24}$.

By introducing the vector potential $\Phi_\mu$ and supposing that $F_{\mu\nu} = \frac{\partial \Phi_\mu}{\partial x_\nu} - \frac{\partial \Phi_\nu}{\partial x_\mu}$ is the general solution of Eq. (2), the author found that the electromagnetic field is described by a single component $\Phi_2$ (he referred to it as $\Phi$). If one introduces, as N. Rosen did, a general transformation $\bar{x} = f(x,t)$ and $\bar{t} = g(x,t)$, which does not violate the conditions specified above, the following restrictions can be imposed on the metric tensor: $g_{14} = 0$ and $g_{11} = -g_{44}$, i.e. the speed of light $c$ is assumed constant, $c = 1$.

Equation (3) can be written down in the form

$$\left(\sqrt{\frac{C}{B}}\Phi_1\right)_1 - \left(\sqrt{\frac{C}{B}}\Phi_4\right)_4 = 0. \tag{4}$$

Expressing the field equations in terms of tensor components, introducing new independent variables $\lambda = x + t$ and $\mu = x - t$ (in what follows, subscripts 2 and 3 will be used to designate the differentiation with respect to $\lambda$ and $\mu$, respectively), and replacing the independent variables $A$, $B$, and $C$ by such new functions that $\alpha = \ln A$, $\beta = \ln\sqrt{B/C}$, and $\sigma = \sqrt{BC} = \sqrt{g_{22}g_{33}}$, the author obtained the following system of field equations:

$$\sigma_{23} = 0 \tag{5a}$$

$$\frac{\sigma_{22}}{\sigma} - \frac{1}{2}\frac{\sigma_2^2}{\sigma^2} + \frac{1}{2}\beta_2^2 - \frac{\alpha_2\sigma_2}{\sigma} + \frac{2}{B}?_2^2 = 0, \tag{5b}$$

$$\frac{\sigma_{33}}{\sigma} - \frac{1}{2}\frac{\sigma_3^2}{\sigma^2} + \frac{1}{2}\beta_3^2 - \frac{\alpha_3\sigma_3}{\sigma} + \frac{2}{B}\Phi_3^2 = 0, \tag{5c}$$

$$\alpha_{23} - \frac{1}{2}\frac{\sigma_2\sigma_3}{\sigma^2} + \frac{1}{2}\beta_2\beta_3 = 0, \tag{5d}$$

$$\beta_{23} + \frac{1}{2}\frac{\beta_2\sigma_3}{\sigma} + \frac{1}{2}\frac{\beta_3\sigma_2}{\sigma} + \frac{2}{B}\Phi_2\Phi_3 = 0. \tag{5e}$$

The solution of Eq. (5a) can be written down easily, while to find the solution of the whole system is more difficult. N. Rosen used the fact that the conditions $g_{14} = 0$ and $g_{11} = -g_{44}$ do not fix the coordinate system, so that a transformation of the type $\bar{\lambda} = \bar{x} + \bar{t}$ and $\bar{\mu} = \bar{x} - \bar{t}$ can be used.

In the case of propagating waves, for which every introduced function depends only on $\lambda$ (or on $\mu$), Eqs. (4) and (5) are satisfied automatically, except Eq. (5b),

$$\frac{\sigma''}{\sigma} - \frac{1}{2}\frac{\sigma'^2}{\sigma^2} + \frac{1}{2}\beta'^2 - \frac{\alpha'\sigma'}{\sigma} + \frac{2}{B}\Phi'^2 = 0.$$

While analyzing this equation, the author considered the following two cases. If $\sigma' = 0$, the fields disappear. If $\alpha = 0$, the equation reads

$$(\sqrt{\sigma})'' + \sqrt{\sigma}\left(\frac{1}{4}\beta'^2 + \frac{1}{B}\Phi'^2\right) = 0,$$

so that the quantity

$$(\sqrt{\sigma})' = -\int_{t_0}^{t_1}\left(\frac{1}{4}\beta'^2 + \frac{1}{B}\Phi'^2\right)\sqrt{\sigma}\,dt$$

can be only negative, and the function $\sigma$ starts to diminish, "as it happens when electromagnetic or gravitational waves propagates in space, until it equals zero"; since the relation $\sigma = \sqrt{g_{22}g_{33}}$ means the metrics violation. The author pointed out that "after the wave has arrived and left and the space has become free of fields, a true catastrophe takes place. Since the function $\sigma$ is invariant with respect to the transformations of $x$ and $t$, one can see that this result does not depend on the fact that certain conditions were imposed on the coordinate system" [2, p. 57].

L. Landau and E. Lifshits pointed out that such generalizations, i.e. generalizations on the case of a weak plane-polarized wave, were obtained for the first time by I. Robinson and G. Bondi in 1957. At the same time, the analysis of the space, where the wave packet propagates, brought the authors to somewhat different results. Namely, the metrics singularity has no physical origin; "it stems from the defects of the reference coordinate system 'damaged' by a propagating gravitational wave, which can be removed by an appropriate transformation; after the wave propagation, the space, in fact, proves to be flat again" [4, p. 449].

N. Rosen's paper was devoted to the consideration of plane-polarized waves. It demonstrated that the nonlinearities of such a kind, whatever small they were, in the equations of gravitational perturbation would inevitably lead to the change of the tensor sign, which, it its turn, would make the solution proposed out of sense. That is, N. Rosen made a conclusion that "the limit, mentioned above, of plane waves with finite amplitudes does not obviously exist in the general theory of relativity". I. Robinson and G. Bondi, applying the same approach, obtained a similar result and pointed out this singularity too; but they emphasized that this singularity can be eliminated by a coordinate transformation.

Since the paper concerned was published in the *Ukrainski Fizychni Zapysky* (Ukrainian Physical Transactions) journal, which is not always accessible to foreign physicists, and, moreover, in Ukrainian, it remained practically unknown to the world community. Nevertheless, a conclusion can be drawn that N. Rosen's work was among the first which concerned the creation of the model of gravitational waves, the latter having been developed till now.

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ПРОБЛЕМИ ГРАВІТАЦІЇ В МАЛОВІДОМІЙ РОБОТІ Н. РОЗЕНА КИЇВСЬКОГО ПЕРІОДУ (1936–1938): ДО ВИТОКІВ СТВОРЕННЯ ТЕОРІЇ ГРАВІТАЦІЙНИХ ХВИЛЬ

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Р е з ю м е

У контексті розвитку і становлення теорії гравітаційних хвиль проведено аналіз маловідомої статті Н. Розена "Plane Polarized Waves in General Relativity Theory", співавтора А. Ейнштейна, написаної під час дворічної роботи Н. Розена в Інституті фізики Академії наук УРСР. З невідомого раніше листування В.М. Молотова та Н. Розена з А. Ейнштейном з'ясовано мотиви перебування Н. Розена у Києві та дискусійні моменти моделі плоскополяризованих хвиль у загальній теорії відносності. Звернуто увагу на те, що під час свого життя в УРСР Н. Розеном була опублікована низка статей, присвячених проблемам гравітаційних хвиль та частинок у загальній теорії відносності як самостійно, так й у співавторстві з А. Ейнштейном, Г.П. Ількевичем.