Highlight of the Issue: Einstein's Visit in Asia

How I Constructed the Theory of Relativity

Albert Einstein

Translated by Masahiro Morikawa[1] from the text recorded in Japanese by Jun Ishiwara

Preface by Jun Ishiwara
This is my dictation note of a lecture given by Prof. Albert Einstein open for general students on the 14th December last year (1922) in the Kyoto Imperial University. All misunderstanding or missing logic, if any, are my responsibility, but not Einstein's. I would like to make this note open for public since I believe it contains unique record of the grand creation which cannot be found in any other publication.

It is not an easy task to tell the whole story how I got to the theory of relativity. This is because there are diverse complexities which indirectly motivate the human thought. I do not want to describe the full detail of the development of my thought referring to my papers, but would simply like to tell you the essence of the development of my thought.

The first time I got an idea to construct the principle of relativity was about seventeen years ago. I cannot exactly tell from where such an idea came out, but it is sure that the idea was in an optical problem on moving bodies. Light propagates in the sea of ether, and the earth moves in the same ether. Therefore the motion of the ether should be observed from the earth, as a flow relative to the observer on the earth. However I couldn't find any evidence on the experimental detection of such ether flow in the literature of physics. So I eagerly desired to prove the ether flow relative to the earth, in other words, the motion of the earth in the ether. At this time, I had no doubt about the existence of the ether and the relative motion of the earth to the ether. Actually I expected a possible detection of the difference in speed between the two kinds of light rays, one traveling in the same direction to the earth motion and the other, reflected by a mirror, traveling backwards. My idea was to use a pair of thermocouples and measure the difference in the heat generated by the two light rays, and to calculate the energy difference between them. This idea was similar to the one of Albert Michelson's interference experiment, but at that time, I was not familiar with the detail of his experiment. I came to know the strange null result of this Michelson's experiment when I was a student and cherishing my idea. I intuitively felt that if one adopts this null result, it would lead to the statement that our conception of the earth moving in the ether is false. This was the first step which drew me toward the principle of special relativity. Since then I have come to believe that even if the earth rotates around the sun, its motion can never be detected by the light ray experiments.

I had a chance, at this time, to read a paper by Hendrik Lorentz dated 1895. He claimed that he could completely solve the electrodynamics within the first approximation, that is, the second power or higher in the ratio of the body velocity to the light velocity is neglected. Then I tried to develop a similar argument on the experiment by Armand Fizeau, assuming that the equation of motion for the electron as Lorentz demonstrated holds also in the coordinate system fixed to the moving body as well as in that fixed to the vacuum. I believed the validity of the electrodynamics by James Maxwell and Lorentz and that they correctly describe the actual world. Especially the fact that the same equation holds in the moving coordinate system as well as in the vacuum clearly teaches us the invariance of the light velocity. However this conclusion apparently conflicts with the familiar law of the composition of velocities. Why these two basic properties contradict with each other? This great antinomy made me stuck. I had to spend a whole year in vain exploring the chance to modify the Lorentz theory. The problem really seemed to be too hard for me.


Professor Masahiro Morikawa

One day, a conversation with one of my friends in Bern happened to help me to solve

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Albert Einstein at his studio in 1919. (Photo courtesy by Tsutomu Kaneko.)

this big problem. I visited him on a sunny day, and asked, "I recently have a tough problem which I could never solve. Now I bring it with me to share it with you." I tried to have various discussions with him, and suddenly I got a crucial idea. On the next day, I told him, "Thank you very much. I've completely solved our problem."

My central idea for the solution was about the concept of time. Namely the time should not be defined *a priori* as the absolute reality, but instead, it is firmly dependent on the finite signal velocity. My abnormally difficult problem could be fully resolved by this new concept of time.

It took only five weeks for me to complete the principle of special relativity after this breakthrough. I had no doubt of its validity also from the philosophical point of view. Especially the principle was in accord with the Mach principle, at least partially as compared to the perfect accordance in the case of general relativity.

The special theory of relativity has been constructed in this way.

The first step toward the general theory of relativity came out two years later, in 1907, in a distinct manner.

I was not fully satisfied with the special theory of relativity, since the relativity principle is limited to the motions with constant relative velocities and cannot be applied to general motions. Therefore I always kept in mind this problem to remove the constraint somehow. In 1907, I was asked by Johannes Stark to write a review article on the various results of the theory of special relativity in his annual report *Jahrbuch der Radioaktivität und Elektronik*. When I was ready to write the article, I recognized that the theory of special relativity can be successfully applied to all phenomena but gravity, and therefore deeply desired to find a way to apply the theory also to gravity. However, I couldn't complete this program so easily. The most unsatisfactory point was the fact that, while the special theory of relativity gives a perfect relation between the inertia and energy, the relation between the inertia and weight, *i.e.* the energy of the gravitating system, is kept unmentioned at all. I suspected this problem was far beyond the special theory of relativity.

I was sitting on a chair in the Swiss Patent Office in Bern. That was when a wonderful idea flashed into my mind. "A freely falling man would never recognize his weight." This simplest idea gave me really a deep impression. The wild emotion at this moment forced me to proceed toward the theory of gravity. I continued to think, "A falling man has acceleration. The observations by this man are indeed those in the accelerated system." I've decided to extend the principle of relativity to general systems with finite acceleration. I also expected this generalization would simultaneously solve the problem of gravity. This is because the fact that the falling man does not recognize his weight implies another gravitational field which exactly cancels the gravitational field of earth. That is, any accelerating body necessitates a new field of gravity.

However, I could not yet resolve the problem completely. Further eight years were necessary for me to derive the real relations. Before that, I could only obtain some general foundations which included them.

Ernst Mach also claimed the equivalence between the relatively accelerated systems. Apparently this is not compatible with our ordinary geometry. This is because if such systems were allowed, then the Euclidean geometry does not hold in each of them. Describing the physical law without geometry is like describing a thought without words. We must prepare the words before describing our thought. What should I put as the foundation of my theory?

This problem remained unsolved until 1912. In this year, I realized that the surface theory of Karl Friedrich Gauss could have a deep reason to solve the above mystery. Gauss' surface coordinate came upon me as really an important tool. However, I didn't know that Georg Riemann had already developed the deep foundation of geometry. I got to my idea simply because I happened to remember the Gauss theory given in a lecture by a math teacher Carl Friedrich Geiser when I was a student. Thus I came to believe that the fundamental property of geometry should have physical meaning.

When I came back to Zürich from Prague, I met my close friend and a mathematician Marcel Grossmann. He helped me with various mathematical references I was inexperienced when I was in the Swiss Patent Office in Bern. This time, I first learned from him the work by Curbastro Ricci and then the work by Riemann. I asked him whether my problem could be solved by Riemann's theory, *i.e.* whether the invariance of the line element was sufficient to determine the whole coefficients of my interest. Then in collaboration with him, I wrote a paper in 1913, though the correct equation of gravity could not yet be derived in it. Further investigation on Riemann's theory only exposed, unfortunately, a plenty of conclusions against my expectations.

Further two years had passed while I was cudgeling my brains trying to solve the problem. At long last, I found an error in my previous calculations. Then I tried again to derive the correct equation for gravity based on the invariant theory. After two weeks the final complete answer appeared in front of me.

As for my works after 1915, I would only pick up my work on cosmology. This is a research on the geometry and time of the Universe. It is based on the treatment of the boundary condition in general theory of relativity and on Mach's argument on inertia. Though I didn't know how definite an idea Mach had had for the general relativistic substance of inertia, I am sure that his great thought was indeed my philosophical ground.

I first tried to make the boundary condition for the equations of gravity invariant, and finally I could even remove the boundary under the assumption that the universe is closed. Thus I could successfully solve the problem on cosmology. As a result, it was deduced that the inertia appears as a relative property among material bodies and it should disappear if there were no other bodies to interact with. I believe that this decisive property makes the theory of general relativity satisfactory even in the point of view of epistemology.

Here I would like to end my brief story of constructing the basics of the theory of relativity. Thank you very much.