Einstein's Ether: D. Rotational Motion of the Earth

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Ludwik Kostro is the most influential historian and philosopher of science who has written about Einstein's post 1916 return to the ether concept (1988, 1992). He has endeavored to show that (Kostro, 1988, p. 239): "the notion of the ether was not destroyed by Einstein, as the general public believe." In addition, Kostro showed (1988, p.238): "Lorentz wrote a letter to Einstein in which he maintained that the general theory of relativity admits of a stationary ether hypothesis. In reply, Einstein introduced his new non-stationary ether hypothesis."

In parts A, B and C I suggest a new view of the problem tackled by Kostro. I ask the following question: Did Einstein respond to Poincaré too when returning to the ether concept? In parts A and B I first introduce the problem by re-examining the problems that had been occupying Poincaré from Einstein's point of view.

Introduction

Einstein asserted in his first memoir on relativity from 1905 "On the electrodynamics of Moving Bodies" (1905, p. 892; my italics; compare to Poincaré's 1902 words quoted in my paper "Poincaré's ether part B, section 1.2):

> *The introduction of a "light ether" will prove to be superfluous, because the view here to be developed will introduce neither a "space at absolute rest" provided with special properties, nor* assign *a velocity vector* to a point *of empty space in which electromagnetic processes take place.*

This was a most daring step taken by Einstein, because the ether was so rooted in the scientific thought of the time. Later, after the 1905 and 1907 versions of his theory had captured the hearts of many scientists, Einstein was stricter and more daring, and asserted, in 1910, for instance that (1910, pp. 18-19): "The first step to be made [...] *is to renounce the ether*." Einstein thus rejected absolute rest and absolute (empty) space.

As opposed to Poincaré, in (1905) Einstein renounced the ether because it was a body to which we could apply the idea of a body at absolute rest. He reasoned that the motion of a ponderable body with respect to the ether in absolute rest is absolute motion. Einstein held that not only absolute space but also absolute rest should not have been introduced into physics. Einstein reasoned, "the concept of absolute space, comprised that of absolute rest" (1934, p. 181). Einstein was influenced by Mach to speak only of observable quantities. The ether was not an observable fact of experience.

In my papers "Poincaré's ether" I suggested that Poincaré did not renounce the ether because he could not find a solution to four major problems:

1. Stellar aberration necessitated ether for the explanation and attainment of the aberration constant.
2. Action-at-a-distance: a signal is not noticed at once in a far removed place, but after some delay. It is therefore conveyed by a medium.
3. Rotation motions violate the principle of relativity, which is applicable to rectilinear and uniform motions. A body can thus rotate in absolute motion with respect to absolute space. In order to prevent this possibility, we say that the body rotates with respect to the ether and not with respect to absolute space. We define motion with respect to the ether in terms of relative motion by considering the ether as a ponderable body.
4. Poincaré's philosophical solution to the problem of absolute rotation was the following: the two conventions "the earth rotates and the sky is at rest" and "the earth is at rest and the sky rotates" are logically and experimentally equivalent for inhabitants of a planet (earth), the sky of which is forever covered with clouds, so that the inhabitants can never see the other stars. This solution does not solve the above problem, because we can imagine a being standing outside Poincaré's cloudy planet and deciding on the basis of experience whether the planet rotates or not. For that hypothetical being, the earth can rotate with respect to absolute space. We therefore again need a medium with respect to which the earth rotates (as explained in point 3 above).

In 1905 Einstein managed to give up the ether only when dealing with stellar aberration and when remaining in the domain of the special theory of relativity. He could not treat action-at-a-distance and uniform rotations without retaining some kind of ether.

Einstein therefore changed his mind after 1916, and it appeared in his lecture, "Ether and Relativity Theory" (1920), after the advent of the general theory of relativity. Absolute space still remained for him an unobservable entity, but he did not any more regard the ether as an unobservable fact of experience, because he managed to suggest an ether that was no longer in a state of absolute rest, or else, a non-ponderable entity to which we cannot apply the idea of motion and it cannot consist of parts that may be tracked through time (1920, p. 15). If we ascribe arbitrary motion in space to the ether and to the whole universe embedded in it, since we should no longer be dealing with observable quantities, this possibility is, in fact, quite devoid of meaning (Schlick, 1919, pp. 6-14).

Einstein's new kind of ether was the metrical tensor field. He thus started to adhere to this new ether. He named it "Mach's ether" or simply "ether," and supplied the same reasons that Poincaré had provided in his writings as to why we should adhere to the ether (we need the ether in order to remove absolute rotation and action-at-a-distance: see my papers "Poincaré's ether"). Einstein thus returned to the 19th century concept of the ether, but stripped of it its most important characteristic: a medium being in absolute rest. One could still pose the perplexing question: Was Einstein's ether endowed with any properties independent of the masses in it? For if it did possess such properties then there was actually no difference between Einstein and Poincaré's ether. Einstein did not give a definitive answer to the above question in his (1920) lecture.

In this paper I focus on the above state of affairs, starting with Einstein's physical struggles with absolute rotation.

The elevator experiment and the daily rotation of the earth

In his 1911 short paper, "On the Influence of Gravitation on the Propagation of Light," Einstein suggested a new principle "which, if it is really true, has great heuristic importance" (1911, p. 900). The principle (usually referred to as the weak equivalence principle) can be formulated in the following way: a uniformly accelerated reference frame K', far away from any matter and thus from gravitational fields, is exactly equivalent to a reference frame at rest (or with uniform motion) K, in the presence of a homogeneous gravitational field. Frames K and K' are equivalent with respect to all physical processes (1911, p. 899). By assessing the processes, which take place relatively to a reference frame with uniform acceleration, we obtain information as to the processes in a homogeneous gravitational field (1911, p. 900). The equivalence of the systems K and K' is embodied in the empirical observation that the gravitational mass with respect to K is exactly equal to the inertial mass with respect to K' (1911, p. 903).

Einstein suggested two kinds of experiments to demonstrate the above equivalence: the disc experiment (1916) and the elevator experiment in 1917 (1920). I shall start with the elevator experiment.

The elevator experiment deals with a problem quite similar to the one embodied in Newton's bucket experiment. Consider a great elevator K' at rest at the bottom of a skyscraper much higher than any real one (Einstein and Infeld, 1938, pp. 218-221). Someone outside has fastened a rope to the elevator and is pulling, with a constant force **F**, in an upward direction toward the top of the building. The whole elevator moves with a constant acceleration in the direction of the motion. An outside observer K, standing on the surface of the earth (in the earth's gravitational field), claims that the elevator moves with constant acceleration, because a constant force **F** is acting. He reasons that an observer inside is in absolute motion. Since the laws of mechanics are valid only in inertial reference frames, the outside observer concludes that for the inside observer, the laws of mechanics are invalid. He does not realize that bodies, on which no forces are acting, are at rest. If a body is released, it soon collides with the floor of the elevator, since the floor moves upward toward the body. The inside observer K' does not see any reason for believing that his elevator is in absolute motion. He knows that his system is not really inertial, but he reasons that all bodies are falling because the whole elevator is in a gravitational field. He notices exactly the same motions as an observer K on the earth, and explains them, as does the observer K, very simply by the action of a gravitational field.

We can assume that either one of the two above descriptions (of K and K') applies in respect to the description of phenomena in the elevator: either non-uniform motion and an absence of a gravitational field with the outside observer, or at rest, and the presence of a gravitational field with the inside observer. However, should we decide in favor of the outside observer in contrast to the inside observer, we can assume the former, i.e. that the elevator is in absolute non-uniform motion.

Einstein solved this problem in his (1911) paper. Imagine that a light ray enters the elevator horizontally through a side window and reaches the opposite wall after a very short time. Again let us see how the two observers would predict the path of the light.

The outside observer, believing in accelerated motion of the elevator, would argue that the light ray enters the window and moves horizontally along a straight line, at a constant velocity toward the opposite wall. But the elevator moves upwards and during the time in which the light travels toward the wall, the elevator changes its position. Therefore, the ray will meet a point not exactly opposite its point of entrance, but a little below. The difference will be very slight, but it exists nevertheless. The light ray travels, relative to the elevator, not along a straight line but along a slightly curved line. The difference is due to the distance covered by the elevator during the time the ray crosses the interior. The inside observer, who believes that the gravitational field is acting on all the objects in his elevator, would say that there is no accelerated motion of the elevator, but only the action of the gravitational field. A beam of light is weightless and, therefore, will not be affected by the gravitational field. If the beam of light is sent in a horizontal direction, it will meet the wall at a point exactly opposite to that at which it entered.

We thus have two observers K and K' and two opposite points of view: the phenomenon is different for the two. There would be no equivalence of K and K' and from the behavior of the light ray we could say that K' is in absolute motion: whenever an observer finds a bent light ray he knows that the reference frame under consideration is in absolute motion.

According to Newton's bucket experiment (see my paper "Poincaré's ether part C"), we have two opposite points of view: the surface of the water is flat and the surface of the water is curved. We could thus say that whenever the surface of the water is curved, we are dealing with absolute rotation and whenever the surface is flat, we describe an inertial motion. We have a way of knowing whether a reference frame is inertial: whenever the surface of the water is flat and, at the same time, the light rays are straight.

Einstein solved the problem concerning the light rays in (1911, pp. 900-903). According to the inside observer a beam of light is weightless and therefore, the gravitational field will not affect it. Einstein demonstrated the following: according to the ideas of the special theory of relativity, a beam of light carries energy and energy has mass. But every inertial mass is attracted by the gravitational field, as inertial and gravitational masses are equivalent (1911, p.

903): the increase in gravitational mass is equal to E/c^2, and therefore equal to the increase in inertial mass as given by the special theory of relativity. A beam of light will bend in a gravitational field exactly as a body would if thrown horizontally with a velocity equal to that of light. Thus the reasoning of the inside observer is incorrect, because he did not take into account the bending of light rays in a gravitational field. Therefore, by taking into account this reasoning the inside observer's results would be exactly the same as those of an outside observer. The essential assumption needed for this conclusion is the equivalence of gravitational and inertial mass incorporated in the principle of equivalence.

This also solves the problem of the daily rotation of the earth. According to Einstein, the argument over whether the earth turns around or the heavens revolve around it, is seen to be no more than an argument over the choice of reference frames. There is no frame of reference from which an observer would not see the effects of the flattening of the poles. Thus in frame number 1 (the earth turns round while the sky is at rest), the centrifugal force is a consequence of the earth's motion (uniform acceleration) relative to the heavens. This causes the flattening. In the latter frame, number 2 (the sky rotate and the earth stands still), the centrifugal force should be understood as being an effect of "the rotating heavens," which is generating a gravitational field that causes the flattening of the poles. The two explanations are equivalent as there is equivalence between inertial and gravitational mass.

Einstein's bucket experiment

The above equivalence is already found in a philosophical way in Mach's explanation to the bucket experiment (see my paper "Poincaré's ether part C"): the two following cases are equivalent:

1. The water is fixed and the whole sky (of the fixed stars) is rotating.
2. The water is rotating and the whole sky (of the fixed stars) is fixed.

All inertial forces have the mass as a constant of proportionality in them. Thus all inertial forces are proportional to the mass of the body experiencing them. The force of gravitation behaves in the same way. In addition, there is the equivalence of gravitational and inertial mass. Therefore the two forces $m\mathbf{a}$ and $m\mathbf{g}$ should be considered as arising from the same origin. Einstein treated gravitation as an inertial force and in doing so, followed the principle of equivalence (1916, pp. 771-772). As a result, he explained the bucket experiment in the following way.

Einstein combined the bucket experiment with Newton's following experiment (1729, p.12): consider two globes kept at a given distance one from the other, by means of a cord that connects them, and revolved about their common center of gravity. We might, from the tension of the cord, discover the endeavor of the globes to recede from their axis of motion, and from that we might compute the centrifugal force and therefore their absolute motion; this is even in an immense vacuum, where there was nothing external or sensible with which the globes could be compared.

Consider two fluid bodies of the same size and nature that revolve freely in space at a very great distance from each other and from all other masses so that only the gravitational forces are taken into account (1916, pp. 771-772; Born, 1962, pp. 309-312). These forces arise from the interaction of different parts of the same body (gravitational effects of one body on the other are thus extremely small). The distance between the two bodies is invariable, and in neither of the bodies are there any relative motions of the parts with respect to one another. The two bodies are in relative uniform motion of rotation around the line joining them. With each body, there is a co-moving observer who judges how the other body to rotate with constant angular velocity (uniform rotation) around the line joining the masses.

Each observer surveys his own body by means of measuring instruments. The surface of body S_1 is measured to be a sphere and that of S_2 a flattened ellipsoid of revolution. What is the reason for the difference between the two bodies? Newtonian mechanics does not give a satisfactory answer to this question. According to this mechanics, the laws of mechanics apply to the "Galilean" or inertial space R_1, with respect to which the body S_1 is at rest, but not to the space R_2, with respect to which the body S_2 is at rest. According to Newtonian mechanics, S_1 is at rest in absolute space but S_2 executes an absolute rotation. The flattening of S_2 is then explicable by centrifugal forces. S_1 cannot be responsible for the flattening of S_2, since the two bodies are in exactly the same condition relative to each other and therefore cannot deform each other differently. The laws of Newtonian mechanics apply to inertial systems and not to systems in absolute rotation. The cause R_1 (the space at rest relative to absolute space) is responsible for the observable differences in the two bodies.

Mach thought that absolute space which is responsible for observable effects, is a fiction of our imagination (1893, p. 284; English translation):

> *The one [bucket] experiment only lies before us, and our business is, to bring it into accord with the other facts known to us, and not with the arbitrary fictions of our imagination.*

The cause of the behaviour of the water in the bucket experiment "must be accepted as a fact of experience" (1893, p. 288).

Einstein was inspired by Mach to express the following reasoning: Newtonian mechanics introduces the inertial space R_1 (at rest or in uniform motion relative to absolute space) as a fictitious cause. To take space as a cause does not satisfy the requirements of causality. For as we have no other indication of its existence than centrifugal forces, we are supporting the hypothesis of absolute space only by the fact it was introduced for the purpose of explaining it. Such a hypothesis (which is not an observable fact of experience) is at odds with the aim of scientific research.

The law of causality can be applied to the world of experience only when observable facts ultimately appear as causes and effects. The privileged space R_1 is not a thing that can be observed. Space thus must not be accepted as the cause of the different shapes of the two bodies. What then is the reason for the difference in the shapes of the surfaces of the two bodies? No answer can be considered as epistemologically satisfactory because the difference in shapes is not an observable fact of experience, as we cannot observe two bodies in an otherwise empty universe. We therefore cannot marshal observable facts to support the assumption that the two bodies would behave differently under these circumstances. A valid mechanics should rather exclude this assumption. The only satisfactory answer to the above question would then be, that the physical system consisting of the two bodies does not evince within itself any imaginable cause to which the differing behavior of the bodies can be attributed.

The cause must therefore lie outside the system of the bodies. First, the general laws of motion, which, in particular, determine the shapes of the two bodies, must be such that the mechanical behavior of the two bodies is partly conditioned by distant masses, which have not been included in the system under consideration. The systems should rather be: 1) S_1 and R_1 (distant masses). 2) S_2 and R_2 (distant masses). Distant masses can be observable facts of experience because they are present in the form of the fixed stars. Regardless of the stellar body we select, it would be surrounded by innumerable others which are at an enormous distance from it and which move very slowly relative to one another, so that, as a whole, they exert the effect of a solid mass containing a cavity in which the body under consideration is situated (they curve space-time and this conditions the bodies' behavior).

Mach's inertial interaction—distant masses are the cause of the centrifugal forces—is combined with the gravitational interaction and later with the conception of curved space-time. These distant masses, and their motions relative to S_1 and S_2, are the causes of the different behavior of the two bodies. The laws of mechanics apply to both systems, 1 and 2, but not to the Newtonian systems S_1R_1 and S_2R_2, where R_1 and R_2 are considered to be only the space near the two bodies. Systems 1 and 2 only involve relative positions and motions of bodies, whereas the laws of mechanics apply to both, with no reference frame that is favored a priori as an inertial system (the Newtonian system S_1R_1). Therefore, the laws of physics apply to the two bodies in question.

Acknowledgements:

This paper is based on my dissertation that was carried out under the supervision of Prof. Mara Beller. I would like to thank Prof. Beller for many fruitful historical discussions and for invaluable help. I would also like to thank Prof. Michele Barone for letting me know about Ludwik Kostro's works.

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