Einstein's Ether: E. Annual Motion of the Earth

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In my paper "Einstein's ether part A" I mainly re-examined the bucket experiment and earth's daily rotation (the problems that had been occupying Mach and Poincaré) from Einstein's General Relativistic point of view. In this paper I further discuss Einstein's General Relativistic solution to the problems that had been occupying Mach and Poincaré.

The disc experiment

Instead of Newton's bucket, let us imagine a rotating disc. In his 1916 review article, "The Foundation of the General Theory of Relativity", Einstein proposed the disc experiment (1916, pp. 774-775; Einstein and Infeld, 1938, pp. 226-228). Imagine a large disc with two circles, one very small the other very large, with a common centre drawn with it. The disc rotates relative to an outside observer K' (his reference frame is an inertial one), and there is an inside observer K on the disc.

Euclidean geometry is valid in the outside observer's reference frame, since it is inertial. Therefore K' may draw, in his frame, the same two circles, both a small and a large circle that are at rest in his frame but coinciding with the circles on the rotating disc. He will then discover that the ratio of the circumferences equals that of the radii. K then attempts to find, by measurement, the circumference and radii on the rotating disc. He uses the small measuring stick used by K' (a stick having the same length as the stick of K' when both sticks are at rest in a reference frame).

K begins measuring the radius and circumference of the small circle on the disc. His result must be the same as that of K'. The axis on which the disc rotates passes through the centre. Those parts of the disc near the centre have very small velocities. If the circle is small enough, we can safely apply classical mechanics and ignore the special relativity theory. This means that the stick has the same length for K and K', and the result of these two measurements will be the same for them both. Now K measures the radius of the large circle. Placed on the radius, the stick moves for K'. Such a stick, however, does not contract and will have the same length for both observers since the direction of the motion is perpendicular to the stick. Thus the three measurements are the same for both observers: two radii and the small circumference.

However, this is not true with respect to the fourth measurement. The length of the large circumference will be different for the two observers. The stick placed on the circumference in the direction of the motion will now appear contracted to K', compared to his resting stick. The velocity is much greater than that of the inner circle and this contraction should be taken into account. If we apply the results of special relativity theory, then we should arrive at the following conclusion: the length of the larger circumference must be different as measured by the two observers. The ratio of the two radii cannot be equal to the ratio of the two circumferences for K, as it is for K'. This means that K on the disc cannot confirm the validity of Euclidean geometry in his reference frame.

According to Einstein, the breakdown of Euclidean geometry is due to absolute rotation. In a non-inertial reference frame the laws of mechanics do not hold (and thus Euclidean geometry breaks down). If we wish to reject absolute motion, then we must build a new physics on the basis of non-Euclidean geometry. According to the principle of equivalence, we can also eliminate absolute motion from the example of the rotating disc by a gravitational field. In this new gravitational physics, a gravitational field, being directed toward the outside of the disc, deforms the rigid measuring rods. Non-inertial motion will no longer mean absolute motion. Therefore (Einstein and Infeld, 1938, p. 225):

> *To save the Euclidean geometry, we should accuse the objects of not being rigid, of not exactly corresponding to those of Euclidean geometry. We should try to find a better representation of bodies behaving in the way expected by Euclidean geometry. If, however, we should not succeed in combining Euclidean geometry and physics into a simple and consistent picture, we should have to give up the idea of our space being Euclidean and seek a more convincing picture of reality under more general assumptions about the geometrical character of our space.*

Einstein concluded that since non-Euclidean measurements were performed on the rotating disc, then these measurements are done in a curved space. He later identified this curved space-time with ether. He also presented an alternative interpretation to the same measurements: The observer on the disc could seek some physical reasons, say temperature differences, deforming his measuring instruments and causing deviation from Euclidean geometry. Therefore, we could equally assume that space is Euclidean and that our measuring rods shrink or dilate as a result of a gradient of temperature.

Poincaré made this last choice when he suggested just the same experiment using a disc heated at its centre, and thus having a temperature gradient (see Granek, 1998, pp. 340-344). Poincaré concluded that Euclidean geometry would always be confirmed by and compatible with experience. He explained this point with the aid of a well-known thought experiment. Suppose that we find that certain results of astronomical experiments are not in accord with one of the predictions of Euclidean geometry. We discover that light does not travel on a straight trajectory, as expected by Euclidean geometry. "A straight line in astronomy is simply the trajectory of a light ray" (1902, pp. 95-96):

> *We should have a choice between two conclusions: we could renounce the Euclidean geometry or, better, modify the laws of optics and admit that light is not rigorously propagated in a straight line. It is needless to add that everybody would regard this solution as more advantageous. Euclidean geometry has therefore nothing to fear from new experiments.*

Therefore, measurements cannot say whether space is Euclidean or not, and they cannot determine what is the geometry of the world. On choosing, with Einstein, that the measuring devices remain rigid, we conclude that the measurements show that space *itself* is non-Euclidean. However, on assuming with Poincaré that geometry is Euclidean, then the very same measurement shows that measuring devices are non-rigid. The geometry of space depends on the choice of convention: either space is non-Euclidean or, the measuring devices become non-rigid. However, once we choose one convention out of the above two conventions, it follows that experiments verify what is the geometry of the word.

Einstein chose the convention according to which the measurements point to a non-Euclidean space, and from the measurements he thus deduced the existence of space-time itself. What is this curved space-time? In light of Einstein's bucket experiment we can further ask: what is the eventual difference between Newton's space R_1, which is at rest with respect to absolute space, and Einstein's solution, which involves a cavity in which the bodies are situated? Einstein's cavity is part of the curved space-time, which Einstein later identified with a new kind of ether. Einstein explained in 1920 that this ether is certainly not a space at rest with respect to absolute space.

Therefore, if one adopts Einstein's attitude of a cavity in which the fluid body is situated and chooses the convention according to which space-time is non-Euclidean, then Einstein's version to the bucket experiment and his disc experiment each exemplify the inevitable need for an ether. The path leading from Einstein's choice above to adopting a new kind of ether emerges right away.

Free falling elevators experiment

If Einstein's space-time (or ether) were endowed with the property of being at absolute rest, then the principles of Special Relativity would have been excluded. Einstein therefore formulated the strong principle of equivalence, according to which all the results that we have already obtained in the special theory would also be locally applicable in the general theory:

> *In a system, which is in free fall, only the gravitational force is acting. We can* locally *neutralize all the effects of gravitation inside it. It can be used as an inertial system*

> *K_0 in which all the laws of the special theory of relativity hold. The laws of gravitation can only be neutralized locally, because a uniformly accelerating frame is not equivalent to a frame in a non-homogenous gravitational field. Thus, we gain locally an inertial system, in a region over which the variation of the gravitational field is extremely small. In such inertial systems, masses remain at rest or move in straight lines with uniform velocity. The above conclusion finds its expression in the strong principle of equivalence: for each point in some gravitational field (*i.e.*, a field changing with time, place and in each point) we can choose a local inertial frame, so that for the extremely small environment of the given point, all the physical laws take the same form as they would in a non-accelerating frame with no gravitational field.*
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> *The principle of relativity is thus extended to all reference frames, non-inertial (*i.e.*, accelerated) as well as inertial. The principle of equivalence makes it impossible for us to speak of the absolute acceleration (and uniform rotation) of a reference frame, in the same manner that the special theory of relativity forbids us to talk of the absolute velocity of a reference frame (1911, p. 899).*

Einstein explained the strong principle of equivalence again using the elevator thought experiment. Imagine the large elevator K' situated at the top of a skyscraper much higher than any real one (Einstein and Infeld, 1938, pp. 214-217).

> *Suddenly the cable supporting the elevator breaks and the elevator falls freely toward the ground. Observers in the*

> *elevator are performing experiments during the fall. In describing them we need not bother about air resistance or friction, as we may disregard their existence under our idealized conditions. One of the observers takes a handkerchief and a watch from his pocket and drops them. What happens to these two bodies?*

For an outside observer K, who is looking through the window of the elevator, both the handkerchief and the watch fall toward the ground in exactly the same way and at the same acceleration (the acceleration of the falling bodies is quite independent of their mass and this fact reveals the equality of gravitational and inertial mass). But so is the elevator falling, as are its walls, ceiling, and floor. Therefore, the distance between the two bodies and the floor will not change. For the inside observer, the two bodies remain exactly where they were when the observer let them go.

The inside observer may ignore the gravitational field, since its source lies outside his reference frame. He finds that no forces inside the elevator act upon the bodies, and so they are at rest, just as if they had been in an inertial reference frame. If the observer pushes a body in any direction, up or down for instance, it would always move uniformly, so long as it does not collide with the ceiling or the floor of the elevator. Our new inertial frame, which is rigidly connected with the freely falling elevator, differs from the inertial reference frame in only one respect. In an inertial reference frame, a moving body, on which no forces are acting, will move uniformly forever. Therefore the inertial reference frame is neither limited in space nor in time. However, the inertial character of the inertial frame of the observer in the elevator is limited in space and time. Sooner or later the uniformly moving body will collide with the wall of the elevator, destroying the uniform motion. Sooner or later the whole elevator will collide with the earth destroying the observers' experiments. The reference frame is only *locally* (limited in time and space) inertial for the inside observer.

Imagine another (non-rotating) reference frame K_0, another elevator moving uniformly in the gravitational field of the earth, relative to the one falling freely (on the earth). The outside observer K finds that the motion of this elevator is not uniform, but accelerated because of the action of the gravitational field of the earth. However, an observer, born and brought up in the elevator, would reason quite differently. He would refer all laws of nature to his elevator, and therefore it would be natural for him to assume his elevator is at rest and that his reference frame is the inertial one. Therefore, both these reference frames, K' and K_0, will be *locally* inertial. All laws are exactly the same in both and the transition from one to the other is given by the Lorentz transformation.

Annual rotation of the earth

Let us explain the rotation of the earth round the sun according to Einstein's strong equivalence principle. Consider again the bucket experiment. In "Einstein's ether part A" I mentioned that according to Mach's explanation to the bucket experiment 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.

Suppose case (or reference frame) number 1 is the Ptolemaic system of the world and case number 2, the Copernican system. The water is to be replaced by the earth and the sky is the sun and the fixed stars. It makes no sense, accordingly, to speak of a difference in truth between

Copernicus and Ptolemy. The equivalence of the two views does not maintain that Ptolemy's system is correct; but rather contests the absolute meaning of either view. The equivalence of the geocentric and the heliocentric views involves the gravitational field. Although, from the kinematical point of view, no difference exists between the Copernican and the Ptolemaic systems, Newton, taking the standpoint of dynamics, decided in favour of Copernicus because his gravitational law provided an explanation to the latter view, whereas the complicated planetary orbits of Ptolemy did not fit into any explanation. The general theory of relativity provides both systems of the world with an equal justification in terms of dynamics. It explains the Ptolemaic as well as the Copernican planetary motion as a phenomenon of gravitation.

According to the strong principle of equivalence, we have a double explanation for the planetary motion as well: the Copernican frame of the earth (neglecting the earth's own rotation) revolving about the sun is a frame in which, relative to a hypothetical observer on the sun, a large spherical object, the earth, freely falls toward the centre of a strong gravitational field created by a massive object, the sun. We on the earth do not feel the gravitational attraction because we are also falling. The earth is thus found to remain at rest, by an observer situated on earth. An observer on earth may ignore the sun's gravitational field, since its source lies outside his frame. He can regard his frame, locally in each instant of time, as a Ptolemaic one. Einstein expressed his thoughts in the following way (Einstein and Infeld, 1938, p. 212):

> *Can we formulate physical laws so that they are valid for all CS [coordinate systems], not only those moving uniformly, but also those moving quite arbitrarily, relative to each other? [...] The struggle, so violent in the*

early days of science, between the views of Ptolemy and Copernicus would then be quite meaningless. Either CS could be used with equal justification. The two sentences: "the sun is at rest and the earth moves" or "the sun moves and the earth is at rest" would simply mean two different conventions concerning two different CS.

Poincaré and Mach had probably inspired Einstein who turned their ideas and arguments into a realization of the two different conventions, as being applicable to two different coordinate systems (see my paper "Poincaré's ether part C" for Mach and Poincaré's ideas).

Einstein concluded that the strong principle of equivalence eliminated absolute motion from physics. According to the general theory of relativity, there are two equivalent physical explanations, the one using inertia and the other using gravity (gravity is equivalent to inertia). The status of non-inertial reference frames is, accordingly, like that of inertial frames. Therefore, the laws of physics are valid for all reference frames, inertial and non-inertial (Einstein and Infeld, 1938, pp. 221-222):

Non-uniform motion may, or may not, be assumed. We can eliminate "absolute" motion from our examples by a gravitational field. But then there is nothing absolute in the non-uniform motion. The gravitational field is able to wipe it out completely.

The ghosts of absolute motion and inertial CS can be expelled from physics and a new relativistic physics built. Our idealized experiments show how the problem of the general relativity theory is closely connected with that of

> *gravitation and why the equivalence of gravitational and inertial mass is so essential for this connection.*

The key to Einstein's above success is the suggestion that we can eliminate absolute motion from physics by a gravitational field. Locally, should we wish to neutralize gravitational effects and gain free fall, we can say that the motion is due to the curvature of space-time: the system is in free fall because space is curved. In a free fall, bodies travel on geodesics in a gravitational field. Euclidean geometry is violated and we find ourselves in need of non-Euclidean geometry, which is the geometry of curved space-time. One may also ask: what conveys the gravitational and Machian inertial interactions? If Special Relativity rejects absolute simultaneity, then according to the strong principle of equivalence, General Relativity must reject instantaneous action-at-a-distance of gravitational interactions. We are thus in the need for a conveying medium for gravitational interactions.

According to Einstein's conception presented in the thought experiments above, the gravitational field is identified with curved space-time. Space-time is then identified with a new kind of medium named "ether". This medium conveys the gravitational and inertial interactions. Thus the ghosts of absolute motion are expelled from physics, but the ghosts of the ether are still there.

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