How Einstein Discovered the Special Theory of Relativity

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Contrary to what we learn in textbooks on the Special Theory of Relativity, Michelson–Morley experiment had no direct influence on Einstein's discovery although he undoubtedly knew about it. At the age of only 16, Einstein imagined himself standing in front of a plane mirror while he himself together with the mirror was being carried forward with the velocity of light. He asked himself the question whether he would be able to see his image in the mirror in such a situation. In trying to solve this problem he thought over the whole foundation of physics with no assistance from any physicist. He, however, profited from some discussions with a few of his colleagues (the main person being Besso) who were unknown to the world of physics. Here we try to reconstruct in our own way the arguments that perhaps led Einstein to his goal. In our effort, we are guided by some of his utterances and interviews given to different people in his later life.

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Introduction

The international physics community had set aside the year 2005 as the 'World Year of Physics' to commemorate the miraculous year 1905 [1] when the special theory of relativity was discovered by Einstein together with the photon concept of light and the theory of Brownian motion. I assume that the readers are familiar with the basic concepts of the special theory of relativity. Both philosophers and historians of science are interested in the origins of the theory. The special theory of relativity represents a break from the usual scientific tradition

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in the sense that most other scientists questioned certain scientific theories but Einstein questioned the very axioms which formed the foundations of physics. According to Whitehead, Einstein's work provided "a principle, a procedure and an explanation."

Many people are curious to know the exact steps that led Einstein to the discovery. Two weeks before his death Einstein told Bernard Cohen that he thought that the worst person to document any ideas about how discoveries are made is the discoverer. He believed that the historian is likely to have a better insight into the thought processes of a scientist than the scientist himself [1].

My aim here is to try to reconstruct the processes that led Einstein to the final result as an inference from various historical facts. Einstein wrote in his autobiographical notes [2]: "The exposition of that which is worthy of communication does nonetheless not come easy: today's person of 67 is by no means the same as the one of ...20, ...it is well possible that such an individual in retrospect sees a uniformly systematic development, whereas the actual experience takes place in kaleidoscopic particular situations"

Einstein's original papers and books do not show us the path which he originally followed to derive the postulates. Normally in textbooks on relativity the authors start from the result of Michelson–Morley experiment, state the two postulates of relativity and derive the equations of Lorentz transformation from them. Einstein's original paper [3] starts from the two postulates but does not mention the experiment. Shankland, therefore, asked Einstein in 1950 as to how he was influenced by the Michelson–Morley experiment [4]. Einstein replied that he had learnt about it by reading Lorentz's book published in 1895 but had not known the details. He added that the experimental results which influenced him more were Bradley's observations on aberration and

Fizeau's measurements on the speed of light in flowing water. We must remember that Einstein was then a mere clerk in the patent office at Berne, where no research journal was available. A book by Lorentz published in 1895 was available in the library and was read by Einstein. In the 1905 paper [3] referred to above Einstein wrote about "unsuccessful attempts to discover any motion of the Earth relative to the light medium" In the next sentence he stated "...as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid in all frames of reference, for which the equations of mechanics hold good" But the Michelson–Morley experiment deals with the second order in the small quantity v/c. This shows that Einstein did not include this experiment among "unsuccessful attempts"

The experimental results which influenced Einstein more were Bradley's observations on aberration and Fizeau's measurements on the speed of light in flowing water.

Shankland also asked Einstein in 1950 [4] as to how long the latter had worked on the special theory of relativity before 1905. Einstein told him that he had started at the age of 16 and worked for ten years; first as a student when, of course, he could only spend part time on it, but the problem was always with him. Einstein imagined himself standing in front of a plane mirror. He further imagined that he was carried in the forward direction together with the mirror at the speed of light. He asked himself the question if he would be able to see his face in the mirror in such a situation. Rays of light starting from different points of his face would proceed towards the mirror, get reflected and reach his eye which would see his face. According to Galileo and Newton these light rays would have zero velocity relative to Einstein if he moved forward with the same speed as light. Einstein argued that since light waves follow Maxwell's equations, if we transform to the frame of reference moving with the speed of light c, light waves would appear to be stationary and non-advancing.

The Absence of a Stationary Non-Advancing Electromagnetic Wave

Maxwell's equations in matter-free space are:

$$\text{div} \ \mathbf{E} = 0 \tag{1a}$$

$$\text{div} \ \mathbf{H} = 0 \tag{1b}$$

$$\text{curl} \ \mathbf{E} = -\frac{1}{c} \ \frac{\partial \mathbf{H}}{\partial t} \tag{1c}$$

$$\text{curl} \ \mathbf{H} = \frac{1}{c} \ \frac{\partial \mathbf{E}}{\partial t} \tag{1d}$$

Taking the curl of both sides of (1c) we obtain

$$\text{curl curl} \ \mathbf{E} = -\frac{1}{c} \ \frac{\partial}{\partial t} \ (\text{curl} \ \mathbf{H}).$$

Using (1d) we then get

$$\text{grad div } \mathbf{E} - \nabla^2 \mathbf{E} = -\frac{1}{c^2} \ \frac{\partial^2 \mathbf{E}}{\partial t^2}.$$

On account of (1a) we get

$$\nabla^2 \mathbf{E} = \frac{1}{c^2} \ \frac{\partial^2 \mathbf{E}}{\partial t^2}. \tag{2}$$

Similarly taking the curl of (1d) and using (1c) and (1a) we get

$$\nabla^2 \mathbf{H} = \frac{1}{c^2} \ \frac{\partial^2 \mathbf{H}}{\partial t^2}. \tag{3}$$

The two wave equations (2) and (3) can be written in the combined form:

$$\nabla^2 \mathbf{\Psi} = \frac{1}{c^2} \ \frac{\partial^2 \mathbf{\Psi}}{\partial t^2}, \tag{4}$$

where $\mathbf{\Psi}$ is either $\mathbf{E}$ or $\mathbf{H}$.

A solution of (4) is of the form:

$$\mathbf{\Psi} = f(\mathbf{k}.\mathbf{r} - ct) = f(lx + my + nz - ct), \tag{5}$$

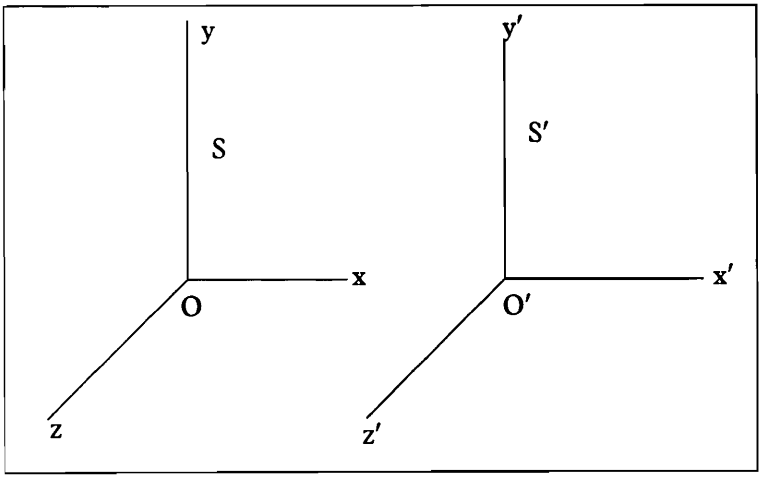

Figure 1.

where **k** is the propagation vector with the components (l, m, n), which are the direction cosines of the light ray with respect to the axes (x, y, z) of the inertial frame S (*Figure* 1).

The equations of Galilean transformation are:

$$\mathbf{r}' = \mathbf{r} - \mathbf{v}t \quad (6a)$$

$$t' = t \quad (6b)$$

where **v** is the relative velocity between two inertial frames S and S'.

Hence the solution of the wave equation in S' in place of (5) is:

$$\Psi' = f\{\mathbf{k}.(\mathbf{r}' + \mathbf{v}t') - ct'\} = f\{\mathbf{k}.\mathbf{r}' - (c - \mathbf{k}.\mathbf{v})t'\}. \quad (7)$$

Thus we see that in the frame S' the velocity of light is $(c - \mathbf{k}.\mathbf{v})$ which is different in different directions. It follows logically that (7) will be a solution of the transformed form of the differential equation (4) in the S' frame. For simplicity we take the two frames S and S' with their axes parallel and the relative velocity v along the x and x' axes. We further assume that the origins O and O' coincide at $t = t' = 0$. In this case the equations of Galilean transformation will be

$$x' = x - vt, \quad y\,' = y, \quad z\,' = z, \quad t' = t. \tag{8}$$

The differential equation (4) becomes in terms of Cartesian coordinates:

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} = \frac{1}{c^2}\frac{\partial^2 \Psi}{\partial t^2}. \tag{9}$$

Now from (8)

$$\frac{\partial x'}{\partial x} = 1, \quad \frac{\partial x'}{\partial t} = -v, \quad \frac{\partial y'}{\partial y} = 1, \quad \frac{\partial z'}{\partial z} = 1, \quad \frac{\partial t'}{\partial t} = 1.$$

Hence,

$$\begin{aligned} \frac{\partial}{\partial x} &= \left(\frac{\partial x'}{\partial x}\right)\frac{\partial}{\partial x'} + \left(\frac{\partial y'}{\partial x}\right)\frac{\partial}{\partial y'} + \left(\frac{\partial z'}{\partial x}\right)\frac{\partial}{\partial z'} + \\ &\quad \left(\frac{\partial t'}{\partial x}\right)\frac{\partial}{\partial t'} \\ &= \frac{\partial}{\partial x'}. \end{aligned}$$

Similarly

$$\begin{aligned} \frac{\partial}{\partial y} &= \frac{\partial}{\partial y'}, \quad \frac{\partial}{\partial z} = \frac{\partial}{\partial z'}, \\ \frac{\partial}{\partial t} &= \left(\frac{\partial x'}{\partial t}\right)\frac{\partial}{\partial x'} + \left(\frac{\partial y'}{\partial t}\right)\frac{\partial}{\partial y'} + \\ &\quad \left(\frac{\partial z'}{\partial t}\right)\frac{\partial}{\partial z'} + \left(\frac{\partial t'}{\partial t}\right)\frac{\partial}{\partial t'} \\ &= -v\frac{\partial}{\partial x'} + \frac{\partial}{\partial t'}. \end{aligned}$$

Hence the double derivatives will be

$$\frac{\partial^2}{\partial x^2} = \frac{\partial^2}{\partial x'^2}, \quad \frac{\partial^2}{\partial y^2} = \frac{\partial^2}{\partial y'^2}, \quad \frac{\partial^2}{\partial z^2} = \frac{\partial^2}{\partial z'^2},$$

$$\frac{\partial^2}{\partial t^2} = \left(\frac{\partial}{\partial t'} - v\frac{\partial}{\partial x'}\right)\left(\frac{\partial}{\partial t'} - v\frac{\partial}{\partial x'}\right) = \frac{\partial^2}{\partial t'^2} + v^2\frac{\partial^2}{\partial x'^2} - 2v\frac{\partial^2}{\partial x'\partial t'}.$$

The wave equation is not invariant under Galilean transformation.

Hence the transformed form of (4) will be

$$\frac{\partial^2\mathbf{\Psi}}{\partial x'^2} + \frac{\partial^2\mathbf{\Psi}}{\partial y'^2} + \frac{\partial^2\mathbf{\Psi}}{\partial z'^2} = \frac{v^2}{c^2}\frac{\partial^2\mathbf{\Psi}}{\partial x'^2} + \frac{1}{c^2}\frac{\partial^2\mathbf{\Psi}}{\partial t'^2} - \frac{2v}{c^2}\frac{\partial^2\mathbf{\Psi}}{\partial x'\partial t'}$$

or

$$\left(1 - \frac{v^2}{c^2}\right)\frac{\partial^2\mathbf{\Psi}}{\partial x'^2} + \frac{\partial^2\mathbf{\Psi}}{\partial y'^2} + \frac{\partial^2\mathbf{\Psi}}{\partial z'^2} = \frac{1}{c^2}\frac{\partial^2\mathbf{\Psi}}{\partial t'^2} - \frac{2v}{c^2}\frac{\partial^2\mathbf{\Psi}}{\partial x'\partial t'}. \tag{10}$$

This is no longer a wave equation in the S′ frame. The wave equation is, therefore, not invariant under Galilean transformation. Newton's laws of mechanics are known to be invariant when we go from one inertial frame S to another S′. Further, we found earlier that light waves would be stationary according to Galilean transformation if $v = c$. The electric and magnetic fields in such a stationary wave would be given by

$$\frac{\partial \mathbf{E}}{\partial t} = \frac{\partial \mathbf{H}}{\partial t} = 0.$$

Hence equations (1a-1d) show:

$$\text{div } \mathbf{E} = \text{curl } \mathbf{E} = 0,$$

$$\text{div } \mathbf{H} = \text{curl } \mathbf{H} = 0.$$

If both the divergence and curl of a vector vanish, it is either a constant or a zero vector. So it does not have the character of a wave. This was a puzzling situation.

Einstein's Solution to the Puzzle

The following possibilities arise:

(i) A relativity principle exists for mechanics but not for electrodynamics; in electrodynamics a preferred frame, The following possibilities arise: A relativity principle exists for mechanics but not for electrodynamics. The relativity principle is true for both mechanics and electrodynamics but the equations of Galilean transformation are not correct.

i.e., ether frame exists. Galileo talked about the impossibility of detecting which of two frames in uniform relative motion is 'really' moving. He cited various mechanical experiments performed on a uniformly moving ship to illustrate his point. If the ether frame exists it could be detected with the help of experiments performed with light or other electromagnetic phenomena. But Einstein knew of some experiments that failed.

(ii) A relativity principle holds for both mechanics and electrodynamics but the velocity of light depends on the velocity of the source rather than the nature of the medium alone. Such theories are called 'emission theories' Einstein realized that Maxwell's equations must be modified in order to accommodate 'emission theories'. Einstein commented [4] that he could think of no form of differential equation which could have solutions representing waves with velocity depending on the motion of the source.

(iii) The relativity principle is true for both mechanics and electrodynamics but the equations of Galilean transformation are not correct. We have to modify them in such a way that the wave equation (9) retains the same form in both frames S and S′. It may not be possible for the observer to move together with the mirror with the speed of light. Scientists before Einstein regarded the equations of Galilean transformation as axioms. Einstein questioned the validity of these axioms.

It may not be out of place to mention here that Michelson did not like Einstein's theory of relativity and commented that he was sorry that his own work had started this "monster"

On the other hand, Einstein tried various forms of equations of transformation which failed to fulfil his objective. He told Shankland that he had to abandon many fruitless attempts "until it came to me that time was suspect" This means that he gave up the concept of absolute time, i.e., $t = t'$. Einstein also commented that mental processes did not proceed step by step to a solution and emphasized how devious a route our minds take through a problem. "It is only at the last that order seems at all possible in a problem"

"It is only at the last that order seems at all possible in a problem."
– Einstein

Let us now try to guess the final arguments that Einstein used to get an alternative to Galilean transformation.

Let an event be specified in S frame (*Figure* 1) by x, y, z, t. Let the same event be specified in S′ by x', y', z', t'. We must have functional relationships between them:

$$x' = x'(x, y, z, t), \quad y' = y'(x, y, z, t),$$

$$z' = z'(x, y, z, t), \quad t' = t'(x, y, z, t).$$

Then Einstein writes in his paper [3]: ". . it is clear that the equations must be linear on account of the properties of homogeneity which we attribute to space and time" He did not explain what he meant by 'homogeneity'. Homogeneity means that all points of space-time have the same property. For example, let us assume that $x' \propto x^2$, i.e., $x' = a_{11}x^2$. Then the distance between two points on the x' axis in the S′ frame, $x'_2 - x'_1 = a_{11}(x_2^2 - x_1^2)$ Let us take a rod of unit length placed on the x axis of the S frame with its end points at $x_1 = 2$ and $x_2 = 3$. Then $x'_2 - x'_1 = 5a_{11}$ is the length in the S′ frame. If, however, we now place the same rod with end points at $x_1 = 3$ and $x_2 = 4$, then $x'_2 - x'_1 = 7a_{11}$. Hence in the S′ frame the length of the rod would depend on its position. This goes against the principle of homogeneity of space-time. Similarly t' should be proportional to the first power of t. Otherwise, the unit time intervals recorded in the S frame between $t_1 = 7, t_2 = 8$ and $t_1 = 9, t_2 = 10$ would have different values in the S′ frame. This was probably at the back of Einstein's mind when he took linear transformation equations. A rigorous group theoretic definition of homogeneity and the proof of the linearity was given by Berzi and Gorini [5] (see also Gorini and Zecca [6] and Lugiato and Gorini [7]). Now we write the linear equations in the form:

$$x' = a_{11}x + a_{12}y + a_{13}z + a_{14}t \quad (11a)$$

$$y' = a_{21}x + a_{22}y + a_{23}z + a_{24}t \quad (11b)$$

$$z' = a_{31}x + a_{32}y + a_{33}z + a_{34}t \quad (11c)$$

$$t' = a_{41}x + a_{42}y + a_{43}z + a_{44}t \quad (11d)$$

where the coefficients $a_{11}, a_{12}, \ldots$ are constants. Now in our special frame of reference (*Figure* 1) x' axis coincides continuously with the x axis. This implies that for $y = 0, z = 0$ we have always $y' = 0, z' = 0$. So the transformation equations for y' and z' are:

$$y' = a_{22}y + a_{23}z \quad (12)$$

$$z' = a_{32}y + a_{33}z. \quad (13)$$

The coefficients $a_{21}, a_{31}, a_{24}, a_{34}$ vanish. Also the $x - y$ plane ($z = 0$) should transform to the $x' - y'$ plane ($z' = 0$). Similarly the $x - z$ plane ($y = 0$) transforms always to the $x' - z'$ plane ($y' = 0$). So again $a_{23} = a_{32} = 0$. Hence

$$y' = a_{22}y \quad (14)$$

$$z' = a_{33}z. \quad (15)$$

Now we look at the t' equation (11d). For reasons of symmetry we assume that t' does not depend on y and z. Otherwise clocks placed symmetrically in the $y - z$ plane ($x = 0$) about the x axis (e.g. $y = a, z = b$ and $y = -a, z = -b$) would appear to disagree in time as observed from S$'$. But this would violate the isotropy of space. So $a_{42} = a_{43} = 0$. Hence

$$t' = a_{41}x + a_{44}t. \quad (16)$$

Now the point O$'$ with $x' = 0$ appears to move in the positive direction of x-axis with speed v, so that we may write

$$x' = a_{11}(x - vt), (i.e., a_{14} = -va_{11}, a_{12} = a_{13} = 0). \tag{17a}$$

Also from (14), (15), and (16):

$$y' = a_{22}y \tag{17b}$$

$$z' = a_{33}z \tag{17c}$$

$$t' = a_{41}x + a_{44}t. \tag{17d}$$

Hence

$$\frac{\partial x'}{\partial x} = a_{11}, \quad \frac{\partial x'}{\partial t} = -a_{11}v, \quad \frac{\partial y'}{\partial y} = a_{22}, \quad \frac{\partial z'}{\partial z} = a_{33}, \tag{18a}$$

$$\frac{\partial t'}{\partial x} = a_{41}, \quad \frac{\partial t'}{\partial t} = a_{44}. \tag{18b}$$

Using (18a,18b) we have

$$\frac{\partial}{\partial x} = a_{11}\frac{\partial}{\partial x'} + a_{41}\frac{\partial}{\partial t'} \tag{19a}$$

$$\frac{\partial}{\partial y} = a_{22}\frac{\partial}{\partial y'} \tag{19b}$$

$$\frac{\partial}{\partial z} = a_{33}\frac{\partial}{\partial z'} \tag{19c}$$

$$\frac{\partial}{\partial t} = -va_{11}\frac{\partial}{\partial x'} + a_{44}\frac{\partial}{\partial t'}. \tag{19d}$$

Substituting these values in (9), i.e.,

$$\frac{\partial^2 \boldsymbol{\Psi}}{\partial x^2} + \frac{\partial^2 \boldsymbol{\Psi}}{\partial y^2} + \frac{\partial^2 \boldsymbol{\Psi}}{\partial z^2} = \frac{1}{c^2}\frac{\partial^2 \boldsymbol{\Psi}}{\partial t^2}$$

we obtain

$$\left(a_{11}\frac{\partial}{\partial x'} + a_{41}\frac{\partial}{\partial t'}\right)^2 \boldsymbol{\Psi} + a_{22}^2\frac{\partial^2 \boldsymbol{\Psi}}{\partial y'^2} + a_{33}^2\frac{\partial^2 \boldsymbol{\Psi}}{\partial z'^2} =$$

$$\frac{1}{c^2}\left(-va_{11}\frac{\partial}{\partial x'}+a_{44}\frac{\partial}{\partial t'}\right)^2\mathbf{\Psi}$$

or

$$a_{11}^2\left(1-\frac{v^2}{c^2}\right)\frac{\partial^2\mathbf{\Psi}}{\partial x'^2}+a_{22}^2\frac{\partial^2\mathbf{\Psi}}{\partial y'^2}+a_{33}^2\frac{\partial^2\mathbf{\Psi}}{\partial z'^2}=$$

$$\frac{1}{c^2}\left(a_{44}^2-c^2a_{41}^2\right)\frac{\partial^2\mathbf{\Psi}}{\partial t'^2}-\left(\frac{2a_{11}}{c^2}\right)\left(va_{44}+a_{41}c^2\right)\frac{\partial^2\mathbf{\Psi}}{\partial x'\partial t'}. \tag{20}$$

We demand that in a new frame S′ the electromagnetic field satisfy a wave equation like (9) perhaps with a different velocity c' so that (20) will reduce to

$$\frac{\partial^2\mathbf{\Psi}}{\partial x'^2}+\frac{\partial^2\mathbf{\Psi}}{\partial y'^2}+\frac{\partial^2\mathbf{\Psi}}{\partial z'^2}=\frac{1}{c'^2}\frac{\partial^2\mathbf{\Psi}}{\partial t'^2}. \tag{21}$$

Comparing (20) and (21) we obtain

$$a_{11}=\left(1-\frac{v^2}{c^2}\right)^{-1/2},\ a_{22}=1,\ a_{33}=1,$$

$$a_{41}=-\frac{va_{44}}{c^2},\quad a_{44}=\frac{c}{c'}\left(1-\frac{v^2}{c^2}\right)^{-1/2} \tag{22}$$

Hence the equations of transformation between S and S′ frames become:

$$x'=g(x-vt),y'=y,z'=z,t'=g\left(\frac{c}{c'}\right)\left(t-\frac{vx}{c^2}\right)$$

$$\text{where}\quad g=\left(1-\frac{v^2}{c^2}\right)^{-1/2} \tag{23}$$

These will reduce to the following when $v/c\to 0$:

$$x'=x-vt,\quad y'=y,\quad z'=z,\quad t'=\left(\frac{c}{c'}\right)t. \tag{24}$$

These equations agree with the equations of Galilean transformation (8) except for the last one unless $c=c'$ It is obvious from the equations (23) that g is real only if $v/c \leq 1$. Hence c, the velocity of light in empty space in the S frame is the maximum possible velocity as all measurable quantities in physics must be real. If c' is the velocity of light in empty space in the S′ frame it will also be the maximum possible velocity for the S′ frame. However, it is obvious that we cannot have two maximum values of the velocity. So logical consistency demands that $c = c'$. Hence the correct form of equation (23) must be

$$x' = g(x - vt), y' = y, z' = z, t' = g\left(t - \frac{vx}{c^2}\right) \qquad (25)$$

So the velocity of light is independent of the coordinate system, which was a strange result in those days. Einstein made some consistency checks and was convinced that it was true. Then he raised these two 'conjectures' of the Principle of Relativity and the invariance of the velocity of light to the status of 'postulates' while presenting his paper [3]. Galileo was the father of the first postulate but the second postulate was entirely Einstein's own. In addition, Einstein used the hypothesis of the homogeneity and isotropy of space-time to prove the equations of transformation.

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The Contributions of Einstein's Predecessors to the Theory of Relativity

Lorentz had arrived at the equations (25) in 1904, one year before Einstein and in 1905 Poincaré first called these equations "Lorentz transformations" in his paper. Einstein, who had no access to scientific journals had no idea of the papers by Lorentz and Poincaré. He once said that he had never met a theoretical physicist before he was 30 years old. Einstein's student Infeld added a rider to Einstein's statement "except in a mirror" Einstein could carry out his research work practically without help from anybody else. The only person whom he thanked for discussions in the historic paper was his friend and colleague M Besso who is otherwise unknown

Einstein wrote in his 1905 paper "The introduction of a 'luminiferous ether' will prove to be superfluous in as much as the view here to be developed will not require an 'absolutely stationary space' provided with special properties, nor assign a velocity vector to a point of the empty space in which electromagnetic processes take place"

to physicists. Einstein once said that he would love to become a lighthouse keeper implying thereby that he could continue his work there undisturbed by the world around him.

Now that we have indicated the logical steps that led Einstein to his equations of space-time transformation, the reader may be wondering as to how Lorentz arrived at them. Lorentz wanted only to find a mathematical transformation of space-time coordinates such that Maxwell's equations in matter-free space retain the same mathematical form in two inertial frames of reference. Lorentz's paper [3] contained as many as eleven hypotheses [8]. Lorentz called t' the "local time" but he had no idea if it had anything to do with the real time. If we read Lorentz's paper, we find that he was still sticking to the concept of the ether. But Einstein wrote in his 1905 paper [3] "The introduction of a 'luminiferous ether' will prove to be superfluous in as much as the view here to be developed will not require an 'absolutely stationary space' provided with special properties, nor assign a velocity vector to a point of the empty space in which electromagnetic processes take place"

Lorentz wrote in 1915 [9] in the book *Theory of Electrons*: "If I were to write the last chapter of my book, I would have surely given a special place to Einstein's theory of relativity. In this theory electromagnetic events assume a very simple form which I could not realize earlier. The reason for my inability was that I stuck to the idea that the variable t alone could be taken as the real time and my 'local time' was nothing but a mathematical quantity. On the other hand in Einstein's theory t and t' have the same role, if we want to write everything in terms of x', y', z', t' we shall have to use these variables in the same way as x, y, z, t." What Lorentz considered a mathematical trick appeared to have a physical reality to Einstein.

Fifteen years later, Lorentz wrote: "A transformation of time was necessary, so I introduced the conception of local time which is different for different systems of reference which are in motion relative to each other. But I never thought that this had anything to do with real time...so the theory of relativity is really solely Einstein's work. And there can be no doubt that he would have conceived it even if the work of all his predecessors in the theory had not been done at all"

"...the theory of relativity is really solely Einstein's work. And there can be no doubt that he would have conceived it even if the work of all his predecessors in the theory had not been done at all"
– Lorentz

Møller wrote about the theory of relativity: "It is one of the most beautiful chapters in the history of science which has been written by a single individual"

Poincaré was the only scientist other than Lorentz who came very close to the ideas of special relativity. He rectified some errors in Lorentz's paper in 1905. But Poincaré wrote in the introductory notes to his paper, "therefore, I have not hesitated to publish my incomplete results" This shows that Poincaré considered his theory to be incomplete while Einstein presented a complete theory.

In 1902 Poincaré was the first person to refer to the theory of relativity. He wrote: "The relative velocities of bodies can be determined" He had earlier said in 1900: "Our ether, does it really have any existence? I do not believe that some accurate experiments will be able to detect anything other than the relative displacement"

Poincaré also gave a method of synchronization of clocks using light rays. He said that in the case of a moving frame of reference we cannot determine the 'real time'; what we determine is the 'local time'. This shows that he still believed in the existence of 'real time', i.e., 'absolute time'. He never rejected the Newtonian conception of time nor did he say how we could determine the two types of time. He, however, came to the conclusion "the observer can never know if he is at rest or in absolute motion" In 1906 he talked about the spheroidal shape of a moving electron resulting from Fitzgerald contraction. Poincaré's mind had doubts regarding the validity of the theory of relativity. But Einstein's mind was free from such doubts. In his paper of 1904 Poincaré talked about the variation of mass with velocity.

In 1911 Poincaré wrote while recommending Einstein for the post of Professor at Zurich Polytechnic [9] "Einstein is one of those acquaintances who are most gifted with creative ability. In spite of his young age, he has already found an honourable place among the most learned people of the present age. His most praiseworthy quality is his ability of coming to grips with new ideas and to derive from them new results. He does not cling to old theories and can realize all the possibilities when physics faces problems... ."

Thus we find that both Lorentz and Poincaré realized the importance of Einstein's contributions. It was only some of their disciples who refused to give Einstein the credit which was justly his due.

The Last Question

We may ask ourselves as to the reason why a young and inexperienced person like Einstein succeeded in solving a problem where established scientists like Lorentz and Poincaré had failed. The reason probably was that the experienced people were so much influenced by the ideas of their predecessors that it became impossible for them to get rid of these. On the other hand, Einstein was only 26 and had no access to research papers. He had developed no bias towards the theories of other scientists. Einstein said: "One should have a knowledge of mathematics in order to become a physicist, but not too much, one must be critical of earlier theories, but not too much, one must have the capacity for original thinking, but not too much."

Suggested Reading

[1] Special Issue : 'Beyond Einstein', *Scientific American*, September 2004.

[2] P A Schilpp, *Albert Einstein: Philosopher Scientist*, Vol. 1, Harper 1951.

[3] A Einstein, H A Lorentz, H Weyl and H Minkowski, *The Principle of Relativity*, Dover, 1923.

[4] R S Shankland, *Am. J. Phys.*, Vol. 31, pp. 47-57, 1963.

[5] V Berzi and V Gorini, *J. Math. Phys.*, Vol.10, pp.1518-24, 1969.

[6] V Gorini and A Zecca, *J. Math. Phys.*, Vol.11, pp. 2226-30, 1970.

[7] L A Lugiato and V Gorini, *J. Math. Phys.*, Vol. 13, pp. 668-71, 1972.

[8] G Holton, *Am. J. Phys.*, Vol. 28, pp.627-36, 1960.

[9] J Bernstein, *Einstein*, Fontana/ Collins 1974.

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