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OVERCOMING THE WIDESPREAD MISSUNDERSTANDING IN THE SPECIAL THEORY OF RELATIVITY

Vladimir M. Ristić[1] and Tijana S. Kevkić[2]

[1]*Department of Physics, Faculty of Science, University of Kragujevac, Radoja Domanovića 12, 34000 Kragujevac, Republic of Serbia*
e-mail: ristic@kg.ac.rs
[2]*Faculty of Science, University of Kosovska Mitrovica, Lole Ribara 29, 38220 Kosovska Mitrovica, Republic of Serbia*

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ABSTRACT. Delivering lectures in special relativity one is introducing a lot of non-standard thinking to his audience. But, sometimes the reaction from his listeners could be very surprising. So much, indeed, that it can bring some confusion to the class and the teacher himself. One of the most surprising examples of such thinking is a non – standard "thought experiment" which was created by a high school student: as is well known; one of the basic principles of the special theory of relativity is constancy of the velocity of light in all inertial referent systems. But, if we attach the coordinate system to a ray of light itself we will get a contradiction. In that, obviously inertial referent system, the velocity of light will be obviously zero, and that will violate the principle of constancy of the velocity of light. Here we have shown that this kind of thinking is not a thought experiment at all, and that it can not violate anything.

INTRODUCTION

Teaching the special theory of relativity one have to introduce many non-standard thinking to his students. However, from time to time, he can meet with such reactions of his listeners that he have to understand it is a two way street. Here, we present a non – standard "thought experiment" which was created by a high school student; indicating immediately, with the help of working definition of thought experiment, that this thought experiment is not defined correctly, so it can deceive inexperienced students (in fact, even experienced scientists, sometimes – look at ref. 3 and 4). Thus going deeper into the unexplored field of thought experiments, one can lay foundation for more profound understanding of some physical concepts.

ONE NON-STANDARD THOUGHT EXPERIMENT

One such student's remark, which is not at all easy to answer, goes as follows [1]: As it is well-known, one of the basic principles of the special theory of relativity is constancy of the velocity of light in all inertial referent systems [2]. But, if we attach the coordinate system to a ray of light itself we will get a contradiction. In that, obviously inertial referent system, the velocity of light would be exactly zero, and that will violate the principle of constancy of the velocity of light.

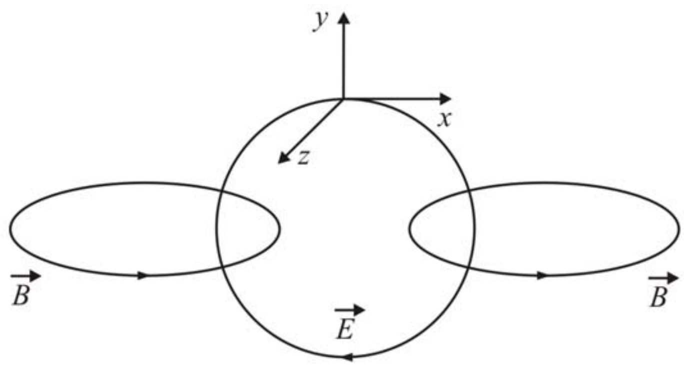

Figure 1

Of course, a glance at Figure 1 will show to an experienced physicist that "attaching" the coordinate system to a ray of light is not a well-defined operation. But, for an untrained student this can be just another way of using non-standard thinking. He can assert that "attaching" the coordinate system to a ray of light is a thought experiment. Unfortunately, that overlook isn't made only by students, since there are plenty of serious papers [3] and monographs [4] which use the coordinate system connected with a ray of light, so called system of rotating axes, which is in fact a coordinate system "attached" to rotating electromagnetic field, which is moving with the velocity of light.

Also, in the thought experiments which brought Einstein to discovering the special theory of relativity, that mistake was often made (young Einstein used to imagine himself as a traveler on the ray of light, literally sitting on the electromagnetic wave, but his deep penetrating thought showed later that it was not possible – no "material" object, i.e. object with nonzero rest-mass can move with the velocity of light, says his theory).

WORKING DEFINITION OF THOUGHT EXPERIMENT

Thus, we need now some, even working, definition of thought experiment so we could decide weather "attaching" of the coordinate system to a ray of light is in general a thought experiment, or just playing with imagination, without any consequences to our perception of the world. One working definition of thought experiment is proposed in paper [5]. As well as in that paper, we will start with the Einstein paper from 1907 [6] in which he wrote:

"...Let us consider two referent systems Σ_1 and Σ_2. Let Σ_1 be accelerated along the direction of it's $x-$axis with acceleration (constant in time) equal to γ. Let us suppose that Σ_2 is at rest, but is located in the homogenous gravitational field, which is giving the acceleration $-\gamma$ in the direction of $x-$axis.

As is well known, physical laws in system Σ_1 are not different of those in system Σ_2; this is connected to the fact that in the gravitational field all material bodies are accelerated in the same manner..."

We have here, stated in a rather rudimental manner, the *principle of equivalence*, which played the fundamental part in forming the general theory of relativity. Later on it was revealed that the equivalency of the referent system in the gravitational field and accelerated referent system is strictly local.

However, we will consider now the thought experiment which is suggested by Einstein, so that he could illustrate the equivalence principle (one of the thought experiments which can be found in all reviews of the theory of relativity).

Let us imagine an elevator in Space, far from any gravitational mass whatsoever, and let this elevator be accelerated. If acceleration were constant and equal to g, a man inside it would feel as if he were in the gravitational field of the Earth. And *vice versa*, in the elevator that is in the state of free fall inside the Earth's gravitational field, acceleration obtained in this manner completely neutralizes the effect of Earth's gravity, introducing thus weightlessness [see, for instance 7]

The conclusion is the same as the one which follows from Einstein's paper from 1907, namely, the equivalence principle is one of the basic principles of nature. But, in the case of the thought experiment with the elevator, the conditions under which it is possible to identify two coordinate systems mentioned above are defined (the dimensions of the elevator are small compared to the masses which produce gravitational field, so, therefore, equivalence principle is valid only locally).

The situation described in thought experiment with the elevator is now realized in the case of a spaceship which circles around the earth (radial component of its acceleration is g, so the gravitation inside is absent, i.e. we have weightlessness), but the thought experiment is much more illustrative.

Therefore, we can say:

Thought experiment is using real objects (objects that may be or will be realized), and putting them in relationships which cannot be realized at the present, or can be realized, but it is much clearer and simpler if they are described with the help of a thought experiment.

Finally, since we have now the working definition of the thought experiment, we can analyze the idea of "attaching" of the referent system to the ray of light. But in order to attach something to anything else objects have to be materialized, even in a thought experiment. Therefore, our referent system must become something more definite than three or four lines in the space-time (as we are used to draw it on the blackboard), i.e. it must be realized with one or few material bodies, whose relationships will give us the possibility of determination of the distance and time intervals. Nevertheless, the material bodies have the rest mass different from zero. According to the special theory of relativity objects having non-zero mass can not travel with the velocity of light. That generally means no referent system can be attached to the ray of light.

Therefore, the operation suggested by our student, and used by some physicists, is not at all a thought experiment, because it suggests the performance of something that is not possible, not only because of the deficiencies of our technologies or experimental skills, but it is impossible in principle, because its performance would be in contradiction with the basic laws of nature.

FINAL REMARKS

Thus we have come to the following conclusion: learning which kind of non standard thinking is productive in physics helps a young student to discover his own way in studying physics. Because we have shown that imaginative games have their limits, and not all of them can be pronounced thought experiments. And, of course, this line of thought shows to a trained physicist directly involved in research in this field that he should be careful in using "thought experiments" while resolving his problems, because not any playing with phantasy could be considered a thought experiment.

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