Specific Features of Time Dilation During Circular Movement

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Abstract
The paper considers observations of the transverse Doppler effect by an observer located in the center of a circle with a large diameter and observers, who are in motion at relativistic velocity around a circle.

Keywords: special relativity, transverse Doppler effect, aberration of light, blueshift, redshift

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Imagine that all the processes in your body, and the objects that you hold in your hands, have slowed. For those around you, you would become a dawdler, while a lamp in your hands, which you think is giving off a green light, during a certain degree of slowing would be perceived by the people around you as red due to a decrease in the light wave frequency. In turn, you would notice accelerated life and the rapid movement of each person in the world around you, while a lamp just like yours in the hands of one of these individuals would emit a blue light from your point of view. These disparate, diametrically opposed perceptions by you and the people around you can be called asymmetric. There is no similar asymmetric and what would appear to be such a natural result of mutual observation in Einstein's special theory of relativity. Therein, each observer in motion relative to another observer notices a slowing of the other observer's processes that is strange from the standpoint of "common" sense; i.e., the results prove to be symmetric. But can a disturbance of this symmetry be observed in the physics of moving bodies?

Yes, it can!

Let us consider a set of observers who are in motion at a high velocity, *V*, around a circle with a large diameter. Let's assume that an observer is also located in the center of the circle. We will further assume that each of the observers, including the one in the center, is in possession of a clock, a tube, and a lamp with a green light. (Fig.1)

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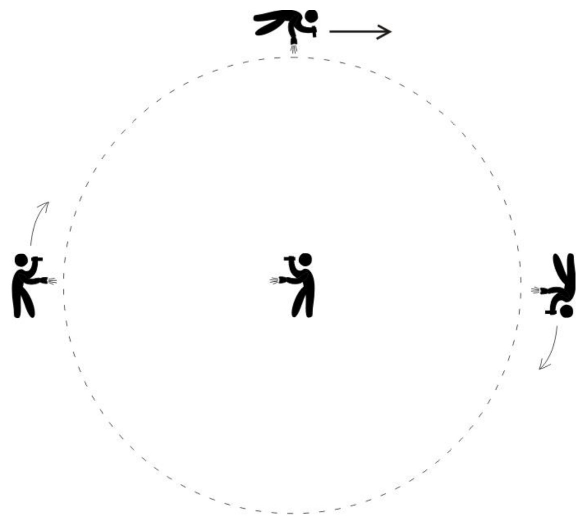

Fig. 1. A set of observers are in motion at a high velocity, V, around a circle with a large diameter and an observer is also located in the center of the circle.

Let’s imagine that the velocity of the observers at the circumference is such that the observer in the center sees a slowed rate for each of the clocks moving around the circle due to the transverse Doppler effect, and perceives the color of the lamps hurtling around the circle with the observers as red (Fig.2).

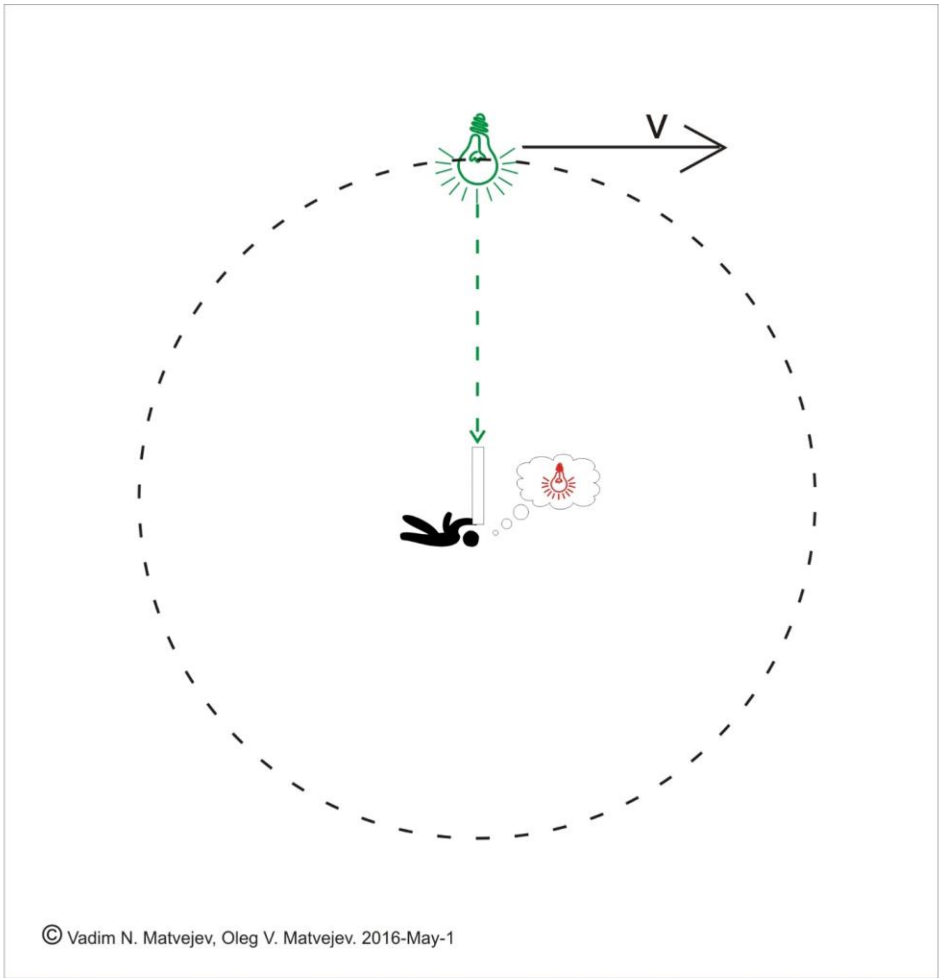

Fig. 2. An observer positioned in the centre of the circle observes redshift.

What do you think the observers positioned around the circle would see in the center of the circle?

In order to answer this question, let's recall what happens if an observer moves in a transverse direction with respect to a monochromatic emission. Due to aberration, the light flux falls on the observer not at a right angle relative to its direction of movement, but rather at an oblique angle to this direction (Fig.4) . An emission spectral line shift toward short waves simultaneously occurs.

The observers at the circumference will see an accelerated clock rate, while the lamp color will be perceived as blue (Fig. 3). The observers in motion at the circumference will never see a red lamp or clocks that have slowed rates, since the light beams from the central observer's lamp are propagated along the circle's radii. If the observers at the circumference direct their gaze into the circle perpendicular to the direction of their movement (strictly toward the center of rotation), they will then not see either the lamp or the observer in the center due to the light aberration – because of the aberration, the light in fact falls on the observers moving around the circle not perpendicular to their direction of movement, but rather at a certain angle in front. In the event that an observer in motion uses a tube that is kept perpendicular to the direction of its movement, the light emanating from the central observer's lamp will not enter the tube and will be absorbed by the tube's walls. In order to see the central observer, an observer at the circumference must look at an oblique angle to the direction of its movement (or orient the tube at this angle). Only then will it see the central observer, notice that the color of the lamp is blue, and that the clocks are running at an increased rate. The observer can find the oblique angle experimentally, or can calculate it, knowing the *V* velocity at which it is hurtling around the circle at right angles to the beams.

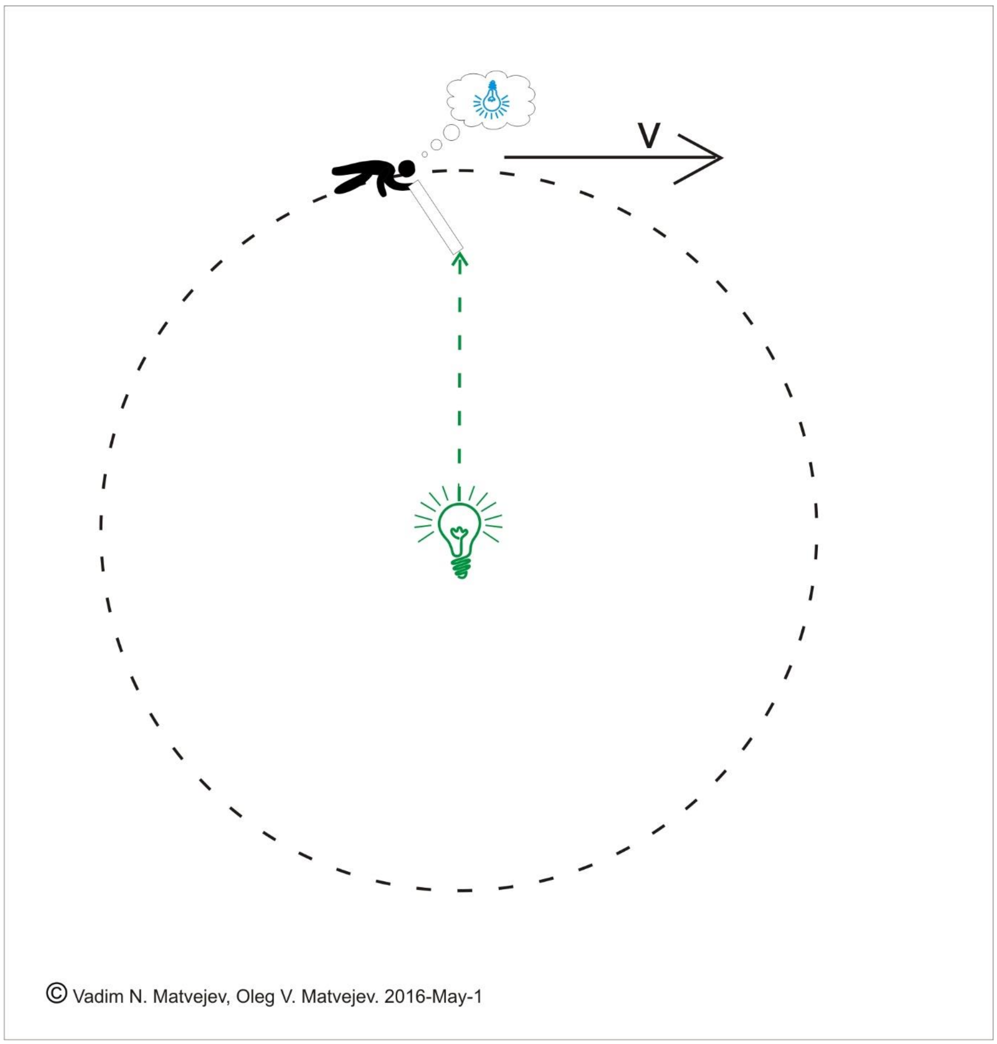

Fig. 3. An observer in motion at the circumference will detect blueshift.

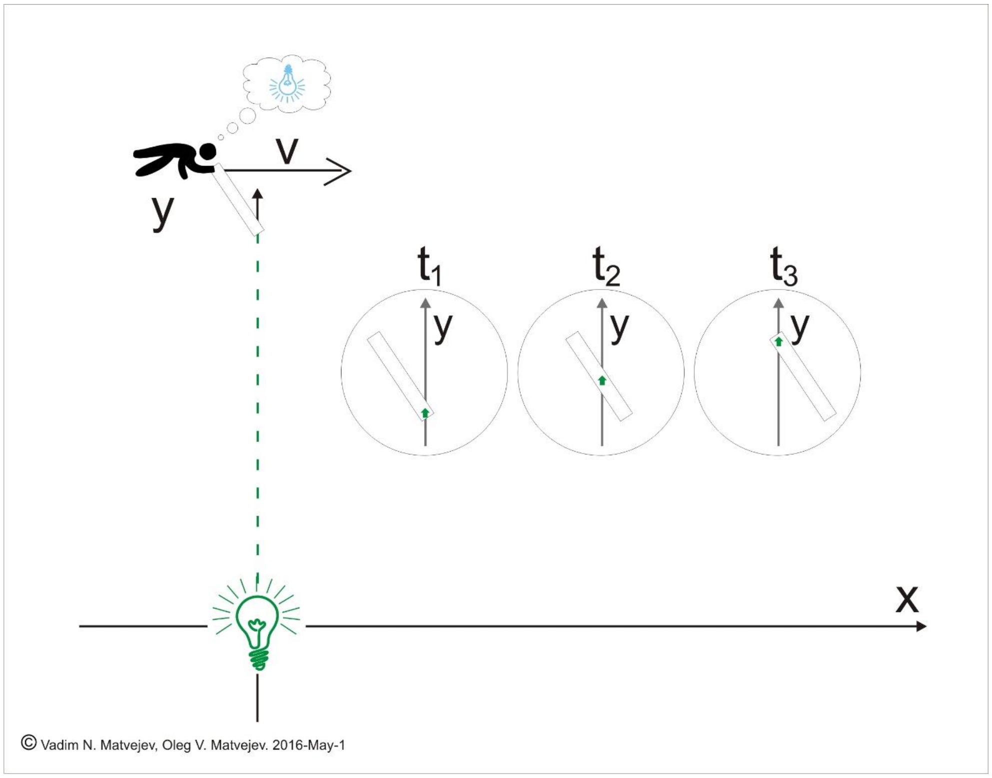

Fig. 4. If an observer is moving in the source's frame of reference, i.e, he ascribes to himself the condition of the relative motion, the obsever has to take aberration of light into account. The observer will detect a blueshift then.

The fact that the color of the lamp will be perceived as blue is not difficult to explain if one assumes that the central observer sent a green-colored light pulse to a mirror that one of the observers around the circle is holding in its hands in such a way that the pulse reflected from it is returned to the central observer. I.e., the mirror must be oriented along a normal line to the center of the circle. To the central observer, the returned pulse appears to be green in color, since the transverse movement of a mirror in the special theory of relativity does not change the color of a beam reflected from it. But if a pulse received from an observer in motion is green, that means the observer in motion perceived it as shifted into the short-wave (blue) region.

The observers moving around the circle are not justified in explaining the blue color of the lamp by way of the Doppler effect caused by the movement of the central observer (in fact, only they themselves, not the central observer, are in motion, during which they move at right angles to the beam). They can only explain the blue color by way of the fact that, in moving at right angles to the green beam, they experience time dilation and perceive the green beam as blue due to the slowing of all the processes in their rotating "laboratory".

And what will a comoving inertial observer (an observer of a comoving inertial frame of reference) see, who at some point in time ends up near one of the observers hurtling around the circle?

This will depend upon what velocity it ascribes to itself. Indeed, an observer of a comoving inertial frame of reference is entitled to assume both a state of proper rest and a state or proper motion. If it regards itself to be at rest, it will then direct its gaze perpendicular to the direction of movement of the central observer within its own frame of reference, and will see a red lamp and a slowed clock rate. If, however, like an observer at the circumference, it regards itself to be in motion at a velocity of V at a right angle to a beam, it will be looking in the same direction in which the observer at the circumference is looking, and like the latter, of course, will also see a blue lamp. And finally, if for some reason it ascribes a velocity equaling $½V$ to itself, then by calculating the necessary angle and directing the tube at this angle, it will see a green lamp and a normal central observer clock rate.

This direction of gaze (of a tube) and the rate variability of the observed moving clocks noticed in this direction corresponds to a comoving observer's recognition of its own motion relative to a certain frame of reference at the same velocity of $½V$ at which the central observer is moving within this system, but in the opposite direction. Since the comoving and central observers are in motion at identical velocities within this frame of reference (albeit in different directions), they will then experience an identical time dilation. The mutual compensation of identical slowing will result in the fact that the clock rate and lamp color of the central observer in motion within this frame of reference at a velocity of $½V$ is perceived as normal by a comoving observer in motion in the other direction at a velocity $½V$.

In the physical sense, the possibility of an inertial observer of a comoving frame of reference observing the dilatability of time in the center of a circle is explained by the fact that the observer can receive the emission given off by a central lamp not only at the circumference, but also outside its confines.

The following fact is interesting. If an observer in motion around a circle receives a light pulse given off by a moving source from a diametrically opposed point of a circle, it then would not notice a transverse Doppler effect, even though the source and the observer are in motion relative to one another in this instance (Fig.5). Let's assume, for example, that a light pulse proceeds from a green light source at the circumference, which, bypassing the center of the circle, reaches a diametrically opposed point of the circle. This might be a pulse that was sent either by an observer at the circumference or by a comoving observer. Another observer is in motion around the circle at the moment that the pulse intersects it. What pulse color will it see? It is not difficult to understand that it will see a green pulse.

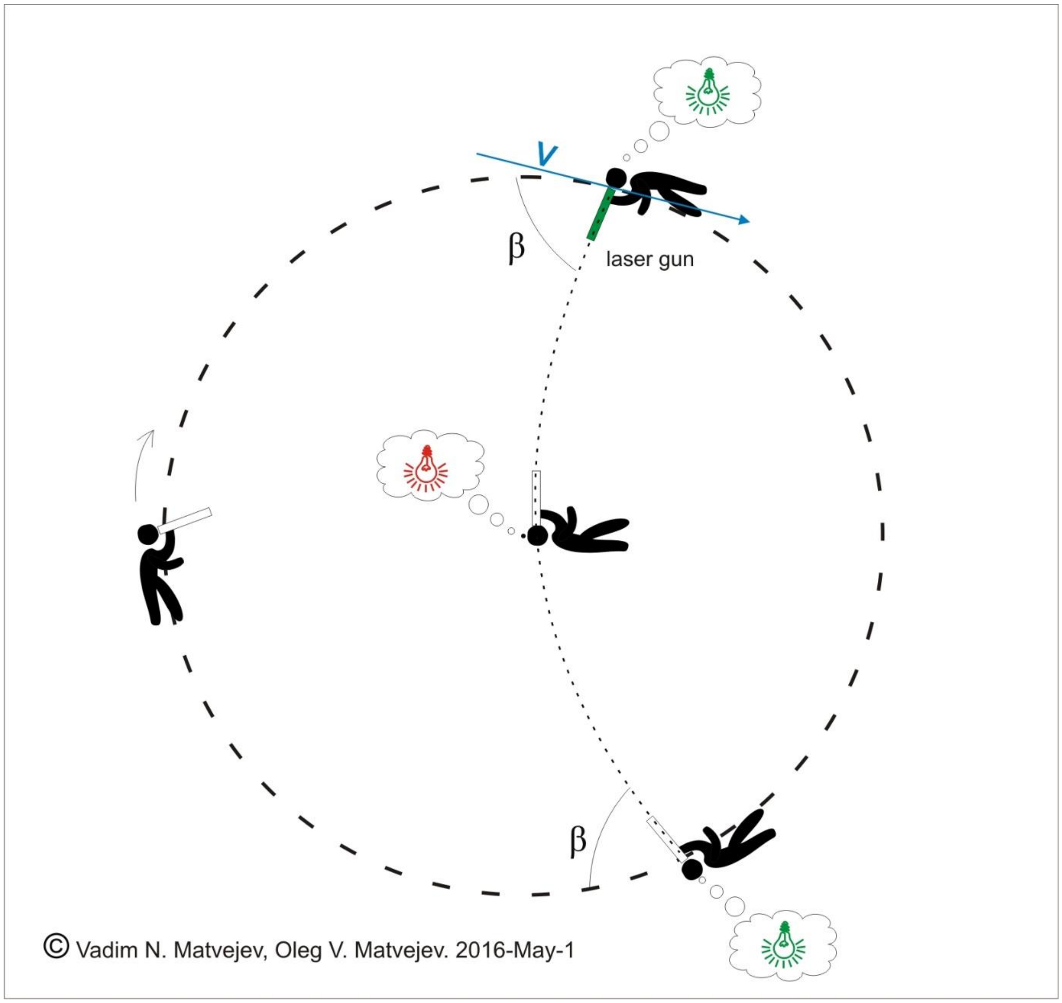

Fig. 5. If an observer in motion around a circle receives a light pulse given off by a moving source from a diametrically opposed point of a circle, it then would not notice a transverse Doppler effect.

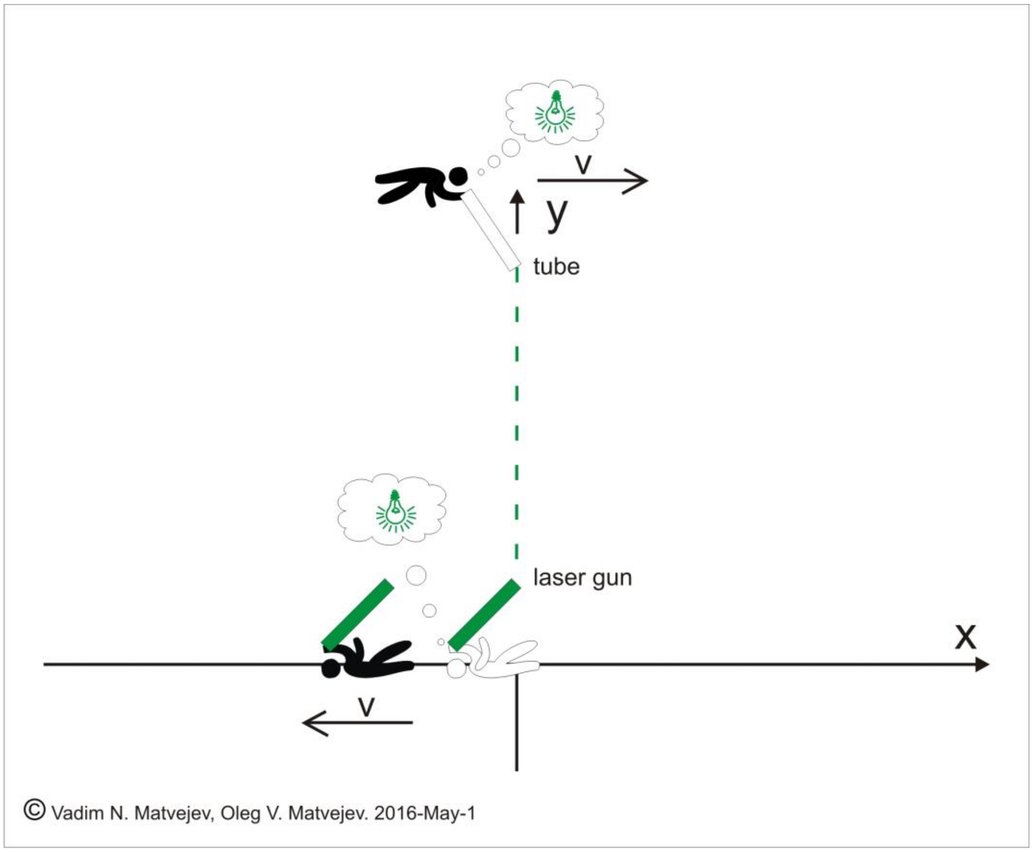

Fig. 6. Observers in relative motion may ascribe themselves about half of their relative speed each. Then the source and observer has to tilt tube while moving at equal angles, backward and forward correspondingly. In this case, the observer will see that the frequency of the radiation source is not changed and the color of light bulbs remained green.

But in fact, a green light pulse emitted from a point of a circle will appear red to a central observer past which this pulse proceeds due to the time dilation of the source moving around the circle that emitted this pulse. On the other hand, the light wave frequency of a red pulse emitted from the center of a circle and arriving at an observer in motion at the circumference will be perceived by the latter at shifted into the short-wave region due to time dilation itself, and the pulse will take on a green color for this observer.

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