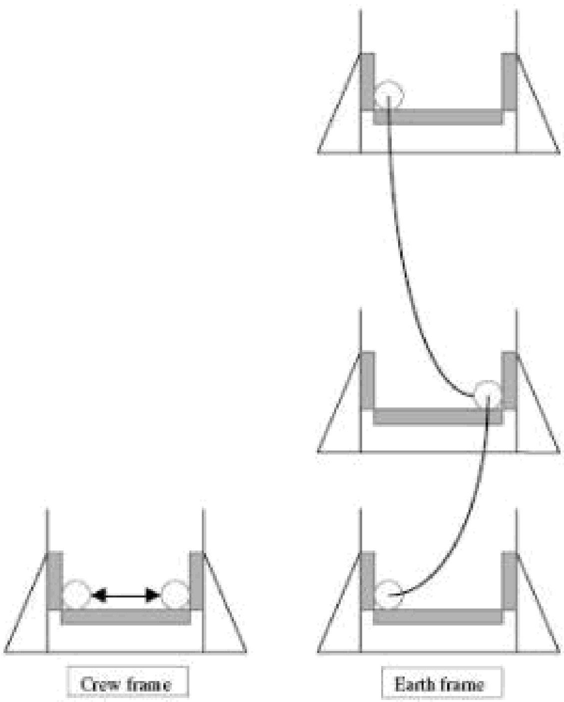
New light clock concept explains time dilation in special relativity

July 5 2007, By Lisa Zyga



The FMEL: In the crew frame, the floor mirror keeps the photon from falling out the back of the rocket as it bounces between the two parallel mirrors. In the Earth frame, the photon appears to be pushed along with the rocket, following a curve which appears to make the clock slower. Credit: Joseph West.

Joseph West, a physicist at Indiana State University, has recently proposed a method for intuitively visualizing and calculating the time dilation effects in special relativity—one of the stranger concepts in modern physics.

In a recent issue of the *European Journal of Physics*, West has introduced a modified type of light clock based on the classic “Einstein-Langevin light clock” (ELC) gedanken experiment. West’s version, which he calls a “floor-mirrored Einstein-Langevin light clock” (FMEL), enables the light clock to work under acceleration by introducing a secondary mirror.

“The classic ELC is so intuitive, and pretty much every instructor uses it to introduce time dilation to students,” West told *PhysOrg.com*. “I wanted to be able to visualize a light clock that had the same macroscopic feel to it. I feel that the FMEL has a significant advantage over the classic ELC in that it can be used by accelerating observers. I looked at the case of constant acceleration in the paper, but it could be used in the case of changing acceleration as well, as long as the direction of the acceleration stays the same.”

In special relativity, light clocks are used to explain such ideas as high-speed trains and the twin paradox. In the latter, one twin travels in a rocket at speeds close to c, while the second twin stays at home. When the first twin returns, she has aged less compared with her twin brother due to the fact of relativity theory that time slows down as a rocket travels at near-light speeds compared with time in an inertial reference frame.

The classic ELC—which describes a high-speed train passing an observer—consists of a photon bouncing between two mirrors, where the photon moves perpendicular to the direction of the train’s motion.

The ELC can also be applied, with some limitations, to the twin paradox. For the twin on the rocket, the photon’s motion is straightforward. For the Earth twin, however, the photon moves with the rocket diagonally away from Earth as the rocket moves away from Earth. This path makes the photon appear to be covering a longer distance, and so taking more time to bounce, making the clocks on the rocket appear to be ticking slower. By knowing the distance between the two mirrors and counting the number of times the photon bounces back and forth, the twins can calculate the elapsed time on the rocket—as long as the rocket travels at a constant velocity.

However, when accelerating the rocket, this light clock runs into a problem: as soon as the rocket picks up speed, the photon falls out the back end.

Realizing that angled mirrors don't provide a consistent time (when the distance between mirrors differs), West decided to try keeping the photons in by adding a second mirror to the floor of the rocket. The floor mirror "pushes" photons along with the accelerating crew in the two-dimensional rocket floor. Further, no matter the distance between mirrors, the light clock gives the same results, and will stay synchronized with any other such clocks in that plane.

"I wanted to think about an accelerating 'frame,' with mirrors that were separated enough for students to imagine them being used on a train, or a rocket ship," West explained.

For the accelerated rocket twin, the elapsed time measurement is again straightforward. But for the Earth twin, the photon does not appear to follow a straight line path of least time, but instead makes a curve in order to stay within the plane of the mirrors of the FMEL. As in the ELC, this greater distance makes the light clock appear to slow down in the Earth twin's observation.

"The path of the light in the FMEL is *not* a least-time path between the mirrors, but it *is* the least-time path for motion of objects restricted to motion in that plane," West explained in the paper.

Nevertheless, using the FMEL and standard meter sticks, the crew will measure the value c for the speed of the photons stuck in their clock.

"Photons that are allowed to move in a straight line, as viewed by the Earth, can get back and forth between the mirrors in less time, apparently traveling from mirror to mirror at a speed greater than c, according to the crew," West explained. "This would apparently allow superluminal communication among the crew members. In order to do so, however, the photons do have to leave the plane of the crew and the clock. The crew could even observe the slice of a solid object that intersects the plane of the crew appear to travel with speeds greater than c."

However, West explained that causality is not violated in such a situation. The crew cannot establish the Lorentz transformations that would convert the different measurements of an Earth observer and the rocket itself, which are required to imply causality violations.

Citation: West, Joseph. "A light clock satisfying the clock hypothesis of special relativity." *Eur. J. Phys.* 28 (2007) 693-703.