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Doppler Effect in Light, Principle of Energy Conservation, Simultaneity: A Uniformly Moving Physical System

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The Doppler Effect in light describes the change in wavelength during the relative motion between a light (or in general electromagnetic radiation) source and its observer. For instance, when this source moves away from the observer, the wavelength of light increases or is redshifted. Conversely, if the source moves towards the observer, the wavelength of light decreases or is blueshifted.

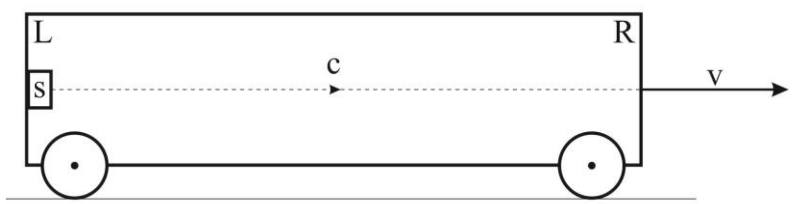

Fig. 1. A sketch of a train car moving at speed v with a light source on its left end.

We design two thought experiments. In the first one, a train car travels to the right at speed v relative to an outside observer, as shown in Fig. 1. This car represents a uniformly moving physical system (UMPS). Let us assume that there is one observer on each train car's ends and a source of (any electromagnetic radiation) S on the left end. Denote the left end observer with L and the right end observer with R. Allow now source S to emit a monochromatic light signal (or better to say a set of monoenergetic photons) towards observer R. Assign the energy and wavelength of the photons emitted by this source with E_S and their wavelength with λ_S and then assign their energy and wavelength measured by observer R with E_R and λ_R. According to the Doppler effect in light, observer R sees that these photons are redshifted or

$$\lambda_S < \lambda_R$$

We know that there is the following relation between the frequency of a photon ν and its wavelength λ

$$\nu = c/\lambda$$

where c (= 2.99792×10^5 km sec^{-1}) is the speed of light. According to this equation

$$\nu_S > \nu_R$$

We also know that $E_S = h\nu_S$ and $E_R = h\nu_R$, where h (= 6.63×10^{-34} J sec^{-1}) is Planck's constant. So the energy of the photons emitted by source E_S is higher than their energy E_R measured by observer R, or $E_S > E_R$. This, however, violates the Principle of energy conservation. The Special theory of relativity does allow that observers in different reference frames can measure different energies for the same event but observers L and R are in the same reference frame. One possible explanation would be that the photons lose their energy in transit. But the question now is: where does the lost energy go to?

Suppose everything is the same as in the first thought experiment except that the light source S is now on the right end of the train car, Fig. 2. According to the Doppler effect in light, if source S emits the photons towards observer L, he sees that they are blueshifted: $\lambda_S > \lambda_L$, or $\nu_S < \nu_L$. In other words, the energy of these photons $E_S = h\nu_S$ is lower than their energy $E_L= h\nu_L$ measured by observer L, or $E_S < E_L$. One possible explanation would be that the photons gain additional energy in transit. But the question now is where does that extra energy come from?

Applying the Principle of energy conservation, we find for the first thought experiment

$$h\nu_S = h\nu_R \quad \ldots (3).$$

And for the second one

$$h\nu_S = h\nu_L \quad \ldots (4).$$

Taking into account that $\lambda = c/\nu$ and dividing eqns. (3) and (4) with c and we find $\lambda_S = \lambda_R$ and $\lambda_S = \lambda_L$, but this is not what is measured by observers L and R.

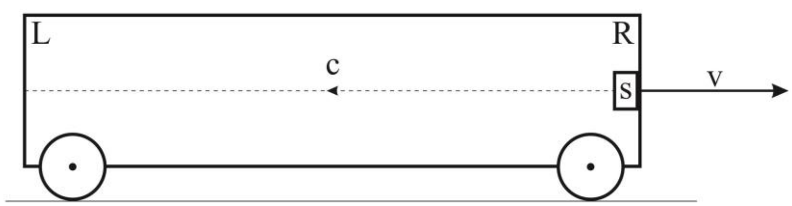

Fig. 2. A sketch of a train car moving at speed v with a light source on its right end.

How to explain the discrepancies, demonstrated by the above thought experiments[1], between the Doppler effect in light and the Principle of energy conservation?

One possible explanation is that the Doppler effect in light is irrelevant in the above cases. The second possible explanation is that the Principle of energy conservation is not valid.

Since conservation of energy is a well-established fact for any known physical process, the author of this communication prefers the Principle of energy conservation over the Doppler effect of light. In this case, the speed c, energy $E_S = h\nu_S$, and thus frequency ν_S or λ_S wavelength of light in

[1] Redshift (the first experiment) and a blueshift (the second experiment) would be observed by the outside observer regardless of the necessary relativistic corrections for the wavelengths of lights emitted by S.

UMPS is completely independent. In other words, light behaves like an absolute reference frame within this system.

The "relative speed" $\beta = v/c$ of UMPS is measured in units of the light speed c. This "speed" appears in several equations in Special relativity by which time, length, and mass changes are defined for an object while that object is moving. Thus, Einstein's theory of Special relativity explicitly supports the above contention that light is an absolute frame of reference as the relative speed of any massive object is defined in relation to the speed of light as the absolute frame of reference. Indeed, for each moving frame of reference with a speed v ($< c$) there is a reference frame whose speed is higher except for the "reference frame of light".

Accordingly, the photons emitted by S reaching observer R (the first thought experiment) or L (the second thought experiment) are not Doppler shifted or a result of the Doppler effect in light at all. These photons should have the same energy $E_S = h\nu_S$ and speed c, and as well as the frequency ν_S and wavelength λ_S, when they are detected by them.

So far so good. However, the time of flight of light from the source S on the left and the right of the train car to the observers R and L would be equal. This contradicts Einstein's concept of simultaneity. Indeed, this concept is based on the Doppler effect in light and if we exclude this effect we also exclude Einstein's concept of simultaneity. The question now is what is the correct answer for a uniformly moving physical system?

All of the nearby and distant galaxies[2] show redshift. This so-called cosmological redshift is due to the Universe expansion (in fact of stretching of space-time) during the flight of the light from these galaxies to the Earth. There are, however, about a hundred known galaxies having blueshifts and most of them in the Local Group. One of these "blueshifted" galaxies is Andromeda at a distance of about 2.5 Mly. It is heading toward the Earth and its blueshift (–0.001) is usually interpreted as a result of the Doppler effect in light. Based on the measured blueshift it is estimated that the Andromeda Galaxy approaching the Milky Way at speed of about 110 km sec^{-1}.

Because the energy of the photons is proportional to the inverse of their wavelength [see eqn. (2)] the energy of the photons emitted by the Andromeda galaxy is higher when they reach the Earth. We speculate that this increase in their energy is due to the enormous gravitational field of the Milky Way galaxy. In other words, Andromeda's blueshift could be gravitational.

Reference

[1] P. I. Premović, *Distant galaxies in the non-expanding (Euclidean) Universe: the light speed redshift.* The General Science Journal, May 2020.

[2] We define nearby galaxies as those whose redshift z is from 0.001 to 0.1 (or $0.001 \leq z \leq 0.1$) and distant galaxies with $z > 0.1$ [1]. Of course, there is no sharp line between nearby and distant galaxies.