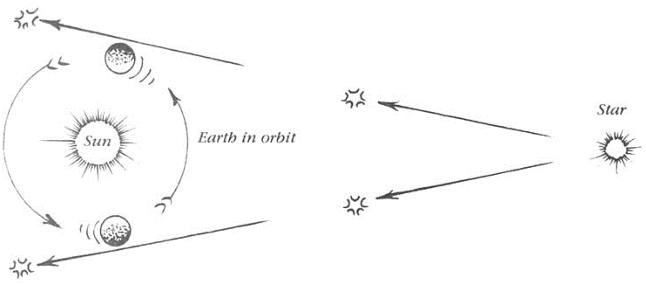
UNL2206, Nature's Threads: Tutorial 8

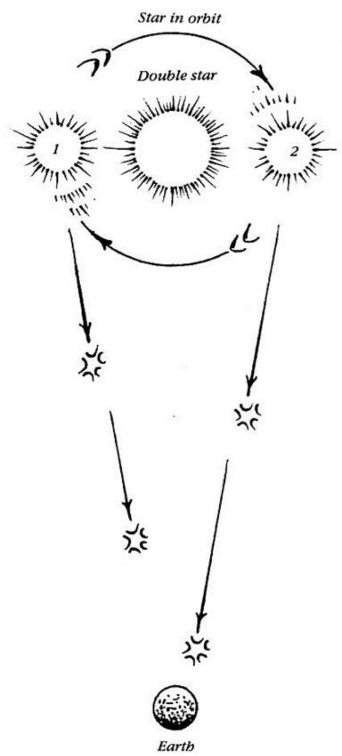
1) Can the speed of light be increased or decreased a little by moving towards or away from the source? The fastest thing at our disposal is the planet on which we ride; as the Earth moves around the Sun at about 30 km/s, we could imagine measuring the speed of starlight reaching us from a distant star. This speed of starlight is first measured when we are hurtling towards the star, then again when we are moving away from it as illustrated in the figure below. The two speeds differ:



(a) by twice the Earth's orbital velocity

(b) they don't differ at all

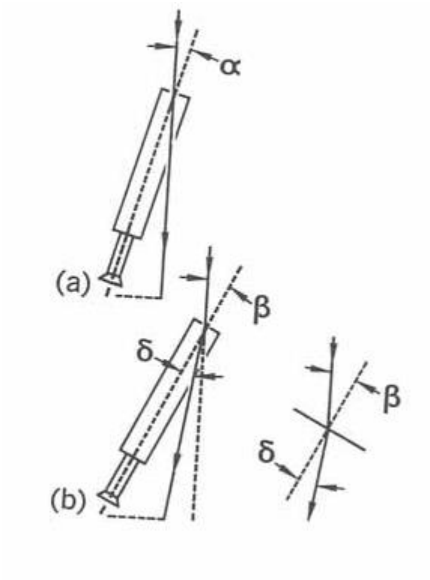
2) Does the speed of light depend on the speed of the source? Perhaps the speed of starlight coming from a star that is moving towards the Earth is faster than the speed of light from one moving away. The figure shows the orbiting companion star of a binary or double star system moving, alternately, towards and away from the Earth.



In fact, if the speed of light depended on the speed of the source, starlight leaving the orbiting companion star when it is at position 2, might get to us BEFORE the light leaving the star when it is at position 1 tells us that the star is there! But in reality this never happens.

3) Discuss the observations described in questions 1) and 2) above in the light of your understanding of the Principle of Relativity.

4) A telescope is aimed at a star whose 'true' direction is perpendicular to the plane of the earth's orbit around the Sun. Let the unknown angle of stellar aberration be α and let the unknown speed of the earth through the hypothetical *ether* be v. Suppose that the telescope is now filled with water, of refractive index *n*. Since light travels more slowly in water than in either air or vacuum, the time it takes for light to travel down the length of the telescope will be lengthened by a factor *n*. One might therefore expect that, to keep the star's image at the centre of the field of view through the telescope's eyepiece, one would have to tilt the telescope further to some new aberration angle β and that the amount of this adjustment could be used to determine v.



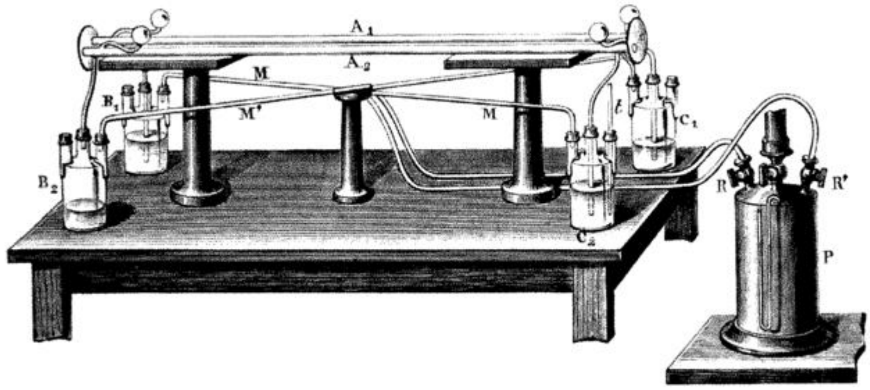
Show that the condition for centering the star's image in the telescope is:

$$\delta = nv/c$$

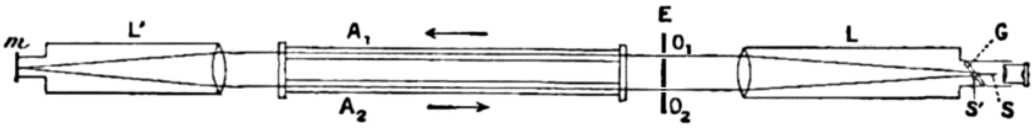
and obtain that $\beta - \alpha \approx (n^2 - 1)\, v/c$.

Since α, β and n are each directly measurable, we can imagine solving this equation for v, the speed of the earth through the *ether*. However this experiment (performed by George Bidell Airy in 1871) gives $\alpha = \beta$ *i.e.* there is absolutely no change in the apparent position of the star! How can we explain this *null* result?

5) The following experiment was performed in 1851 (more than 50 years before Einstein published his 1905 paper) by Fizeau to measure the speed of light in water moving within a tube.



The speed of light in *stationary* water is known to be *less* than its speed in empty space and is conventionally written as *c/n* where c is the speed of light in vacuum and *n* is the *refractive index*



of water. From the *"non-relativistic"* or Galilean velocity addition law, one would expect that if water flowed through a pipe with velocity *v*, then the speed of light in the moving water would be its speed in stationary water increased by the speed of the water flowing in the pipe: $w = c/n + v.$ However, what Fizeau observed instead was:

$$w = c/n + v\,(1 - 1/n^2)$$

At the time, Fizeau's experimental result was viewed as confirmation of a rather elaborate contemporary calculation based on the idea that the water was partially successful in dragging the ether along with it.

Show that this result can instead easily be understood as an elementary consequence of a *"relativistic"* velocity addition law.

OPTIONAL QUESTIONS:

6) **Michelson–Morley Experiment -** Suppose one wanted to use a Michelson type of interferometer to measure with sound waves to measure the speed of an airplane.

What would be measured, air speed or ground speed?

For an airplane moving at one half the speed of sound, what would be the difference of transit times if
$\ell_{parallel} = \ell_{perpendicular}$ = 150 cm. (Assume the speed of sound is 30,000 cm/s.)

To how many wavelengths does this correspond?

7) Let us assume that material bodies contract in the direction of motion when they are moving according to the formula proposed by FitzGerald (and later Lorentz).

Show that if this is so, the Michelson-Morley experiment cannot detect any effect of the relative motion of the Earth with respect to an *ether*.

8) How can the results of the Michelson-Morley experiment be explained by assuming that the *ether* is dragged along with the Earth as is the Earth's atmosphere?

Explain how the above assumption of the *ether* being dragged with the Earth can be tested by performing the Michelson-Morley experiment at two different altitudes above the surface of the Earth?