the general science journal

The Fizeau Experiment with Moving Water.

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In all papers on the Fizeau experiment with moving water, an analysis contains the statement: "The beams travel relative to the interferometer with different speeds $C/n+V$, $C/n-V$, cover the distance L for different times $t_1=L/(C/n+V)$, $t_2=L/(C/n-V)$ and the estimated fringe shift is $\delta_V=\frac{C(t_2-t_1)}{\lambda_0}$." Already there is a principal error in calculation because the estimated value δ_V is greater than the experimental value. In the ether hypothesis, this discrepancy is explained by a partial entrainment of light by moving water and the Fresnel drag coefficient $\left(1-\frac{1}{n^2}\right)$. The relativistic velocity addtion law can only approximately explain this discrepancy. The estimated value δ_V has never been questioned.

As shown below, the calculation made by Fizeau in the interferometer with moving water experiment using only the time difference Δt is wrong because the change of the frequencies of the interfering beams was not taken into account. The estimated fringe shift calculated with the change of the frequencies corresponds exactly to the experimental value.

1. The conventional calculation of the interferometer.

Instead of the real experiment, we consider a simpler scheme in Fig.1 in which coherent beams enter two identical pipes containing water with counter motion. Beams travel in the air with frequency ν_0 and wavelength $\lambda_0=\frac{C}{\nu_0}$ which decreases to $\frac{\lambda_0}{n}$ in water .

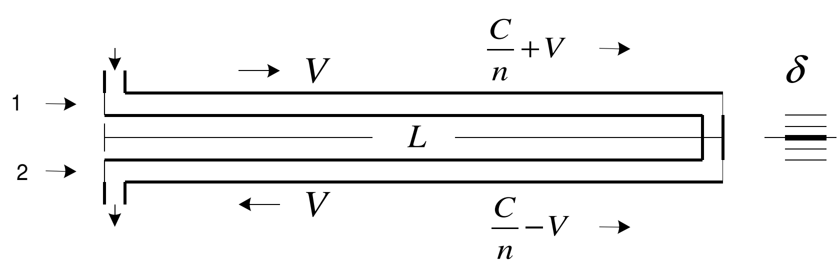

Fig.1.

Relative to the water beams travel with speed $\frac{C}{n}$ but because of the entrainment by moving with speed V water their speeds relative to interferometer are different:

Beam 1 travels with speed $\frac{C}{n}+V$ and covers distance L in the time $t_1=\frac{L}{\frac{C}{n}+V}$,

Beam 2 travels with speed $\frac{C}{n}-V$ and covers distance L in the time $t_2=\frac{L}{\frac{C}{n}-V}$.

Because beams travel relative to the water with identical speed $\frac{C}{n}$, for different time intervals t_1 and t_2 they cover different distances relative to the water:

Beam 1 during t_1 covers the distance $L_1=\frac{C}{n}t_1=\frac{LC}{n\left(\frac{C}{n}+V\right)}<L$,

Beam 2 during t_2 covers the distance $L_2=\frac{C}{n}t_2=\frac{LC}{n\left(\frac{C}{n}-V\right)}>L$.

This allows us to consider a simpler scheme in Fig.2 where coherent beams simultaneously enter two different pipes with still water, covering different distances L_1

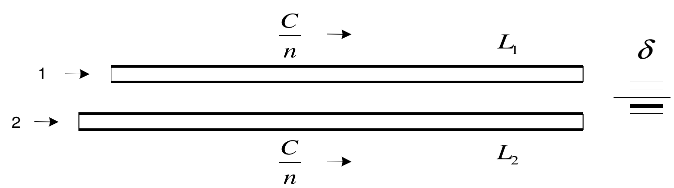

Fig.2.

and L_2 with an identical speed $\frac{C}{n}$ and exit from the water at identical distances from the screen. If we suppose, as Fizeau did, that beams travel with identical frequency ν_0 , the fringe shift in the interferometer has to be equal to

$$\delta_V=\frac{C(t_2-t_1)}{\lambda_0}=\frac{2LVC}{\lambda_0\left(\frac{C}{n}+V\right)\left(\frac{C}{n}-V\right)}$$.

2. Influence of the frequency of interfering beams on the fringe shift.

We consider a monochromatic beam as a sequence of wavefronts consisting of photons of identical frequency ν_0 and moving in a vacuum with speed C . The distances between wavefronts consisting of identical-phase photons are equal to a wavelength of $\lambda_0=\frac{C}{\nu_0}=CT_0$ (Fig.3).

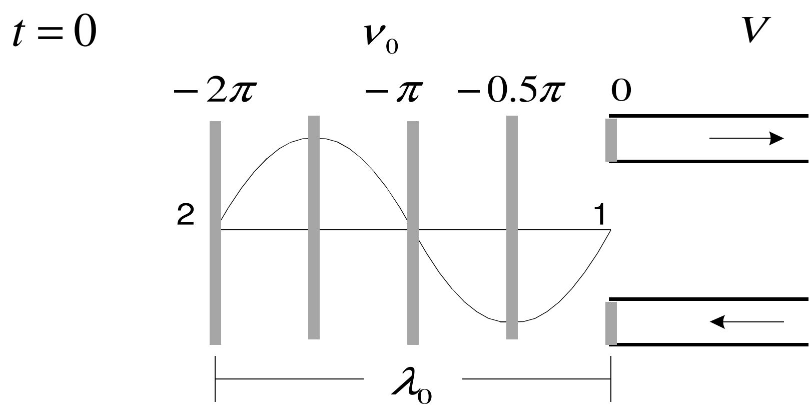

Fig.3.

At the moment $t=0$ let wavefront 1 of photons with zero phase enter two pipes with moving water. By entering, the photons change the frequency and travel in water with frequencies $\nu_1=\nu_0(1-\frac{V}{C})<\nu_0$ and $\nu_2=\nu_0(1+\frac{V}{C})>\nu_0$.

Relative to the interferometer, photons move with different speeds $\frac{C}{n}+V$ and $\frac{C}{n}-V$ but relative to the water, their speeds are identical and equal $\frac{C}{n}$.

Relative to water and during time T_0 , photons of the frequencies ν_1 and ν_2 cover the same distance $\frac{C}{n}T_0=\frac{\lambda_0}{n}$ as photons ν_0 and at the moment $t=T_0$ when wavefront 2 enters water, are in position 1 (Fig.4).

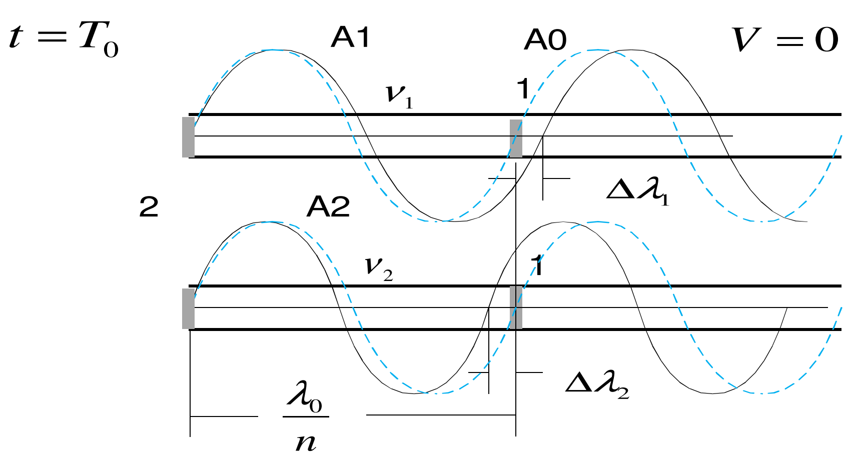

Fig.4

During time T_0 photons ν_0 arrive at position 1 and their phase changes by 2π .
During time T_0 photons $\nu_1<\nu_0$ cover the same distance $\frac{\lambda_0}{n}$ but their phase changes

less than 2π . Their phase changes by 2π only up to moment T_1 when they cover the distance λ_1 which is greater than $\frac{\lambda_0}{n}$ by $\Delta\lambda_1=\lambda_1-\frac{\lambda_0}{n}$ (curve A1). That is every oscillation of the frequency $\nu_1<\nu_0$ is behind the oscillation ν_0 by the distance $\Delta\lambda_1$.

The phase of photons $\nu_2>\nu_0$ become equal to 2π at the moment T_2 , when they cover the distance λ_2 , which is less than $\frac{\lambda_0}{n}$ by $\Delta\lambda_2=\frac{\lambda_0}{n}-\lambda_2$ (curve A2). That is, every oscillation of the frequency $\nu_2>\nu_0$ is ahead the oscillation ν_0 by the distance $\Delta\lambda_2$.

It should be noted that shifted by $\Delta\lambda_1$, the oscillations ν_0 in the pipe 1 are synchronous with these shifted by $\Delta\lambda_2$ oscillations ν_0 in pipe 2.

Let us next compare the situations in the two pipes with still water.

a) At the moment $t=0$ the same wavefront of frequency ν_0 simultaneously enters two identical pipes of still water. That is, photons with identical phases enter simultaneously in the pipes. It is obvious that photons cover the distance L in the identical time $t_L=\frac{Ln}{C}$ and at the moment t_L simultaneously exit from water (Fig.5).

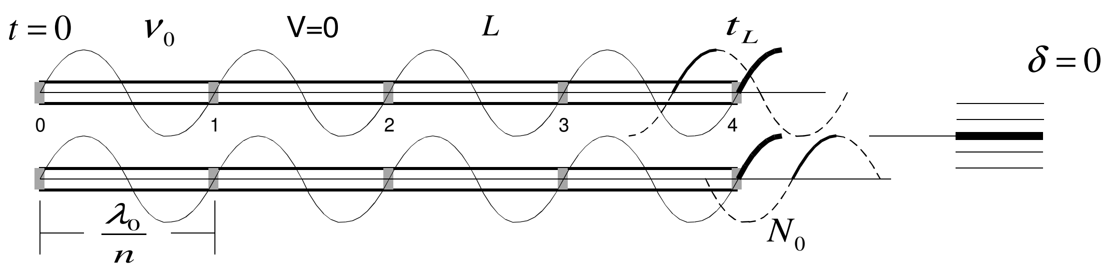

Fig.5.

During t_L , $N_0=\frac{t_L}{T_0}=\frac{Ln}{\lambda_0}$ identical numbers of photon oscillations and N_0 of the wavelengths $\frac{\lambda_0}{n}$ are contained in both pipes. That is, at moment t_L **synchronous** photons exit from water at identical distances from the screen. The fringe shift δ in the interferometer is determined by these synchronous photons and is equal to zero. The photons of the next wavefront cover the distance L in the same time t_L . They remain synchronous when they exit the water and create fringes in the same part of the screen.

b) **Now let us suppose** that photons entering the pipes with still water change frequencies and cover the distance L with different frequencies $\nu_1<\nu_0$ and $\nu_2>\nu_0$. The photons move in water with the same speed $\frac{C}{n}$ and cover the distance L in the same time $t_L=\frac{Ln}{C}$ (here and below we suppose that ν_1 and ν_2 differ an insignificant amount and therefore neglect the dispersion). When exiting from the water, the photons change frequencies again and interfere on the screen with an identical frequency ν_0 (Fig.6).

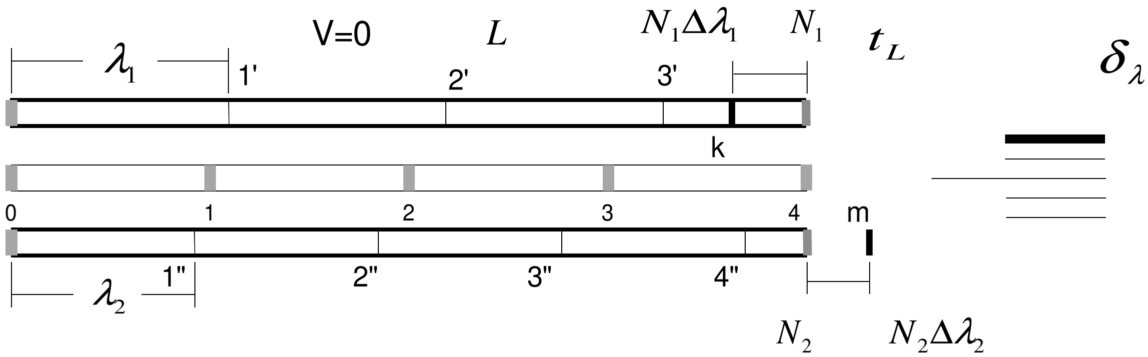

Fig.6.

Simultaneously entering the water, the photons of frequencies ν_1 and ν_2 exit the water at the moment t_L t. That is, at the same time as the photons of frequency ν_0 in Fig.5. However photons travel in water with different frequencies and their phases change by 2π not in the points 1, 2, 3, 4 as in the beam of frequency ν_0 but in the points 1', 2', 3' in beam 1 and in the points 1", 2", 3", 4" in beam 2 and at the moment when photons exit from water their phases are diferent ($N_1 \neq N_2$).

$N_1 = \frac{L}{\lambda_1}$ of wavelengths λ_1 are contained in the distance L in water. Because every oscillation of the frequency $\nu_1 < \nu_0$ lags behind the oscillation ν_0 by $\Delta\lambda_1$, oscillation N_1 of frequency ν_1 is shifted relative to oscillation N_1 of frequency ν_0 by the distance $N_1 \Delta\lambda_1 = N_1 \lambda_1 - N_1 \frac{\lambda_0}{n} = L - N_1 \frac{\lambda_0}{n} = N_0 \frac{\lambda_0}{n} - N_1 \frac{\lambda_0}{n}$.

$N_2 = \frac{L}{\lambda_2}$ of wavelengths λ_2 are contained in the distance L in water. Because every oscillation of the frequency $\nu_2 > \nu_0$ is ahead the oscillation ν_0 by $\Delta\lambda_2$, oscillation N_2 of frequency ν_2 is shifted relative to oscillation N_2 of frequency ν_0 by distance $N_2 \Delta\lambda_2 = N_2 \frac{\lambda_0}{n} - N_2 \lambda_2 = N_2 \frac{\lambda_0}{n} - L = N_2 \frac{\lambda_0}{n} - N_0 \frac{\lambda_0}{n}$.

So, simultaneously entering the water, photons of frequency ν_0 cover identical distances L in both pipes, and at the moment t_L simultaneously exit from the water with identical phases and at identical distances from the screen with, fringe shift $\delta = 0$ (curve A0 in Fig.7).

Photons ν_1 and ν_2 also enter water simultaneously, cover the same distance L in water and at the same moment t_L exit the water but they reach the exit with different phases (curve B1 that passes through the point "k" is shifted relative to the curve A0 by $N_1 \Delta\lambda_1$ and curve B2 that passes through the point "m" is shifted relative to the curve A0 by $N_2 \Delta\lambda_2$). When exiting the water, the photons change frequencies and reach the screen with identical frequency ν_0 and with different phases.

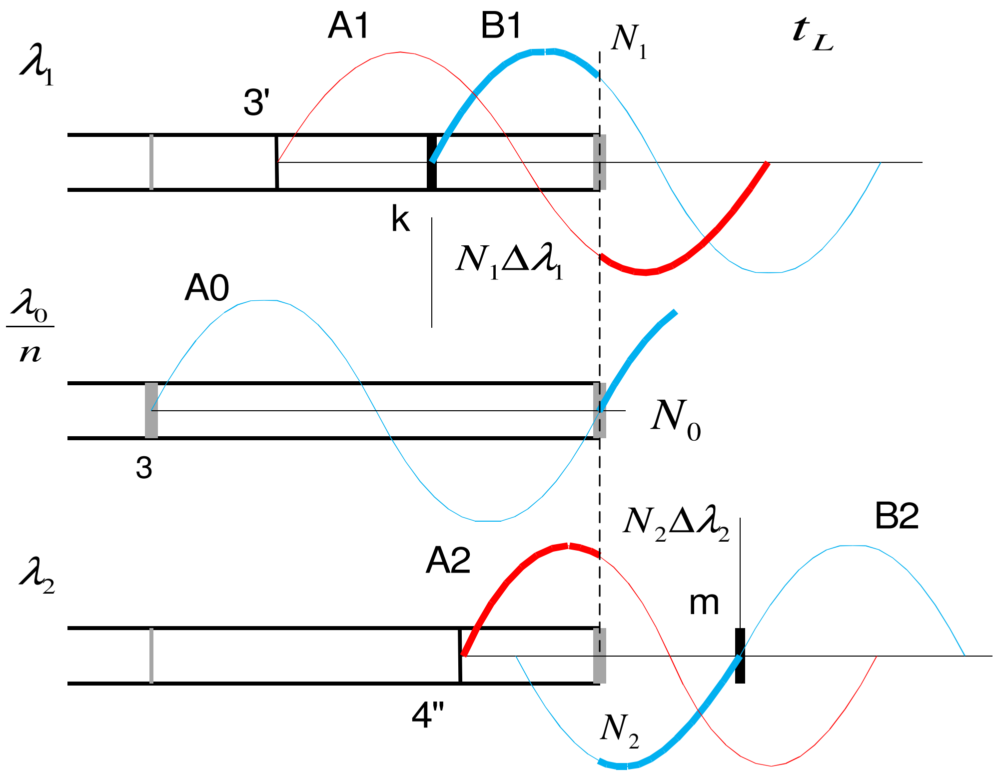

Fig.7.

The interferometer "sees" that at the moment t_L instead of synchronous wavefronts N_0, wavefront N_1 which is shifted back relative to the interferometer by $N_1 \Delta\lambda_1$, exits from pipe 1 (curve A1) and **at the same moment** t_L the synchronous wave front N_2 which is shifted forward relative to the interferometer by $N_2 \Delta\lambda_2$ exits from the pipe 2 (curve A2).

The fringe shift in the interferometer turns out as in the case where synchronous wavefronts which are shifted relative to the pipes by $N_1 \Delta\lambda_1$ back and $N_2 \Delta\lambda_2$ forward (or relative to each other by $\Delta\lambda_1 N_1 + \Delta\lambda_2 N_2$) simultaneously exit the water.

So, if interfering beams change frequencies and cover identical distance L with different frequencies $\nu_1 < \nu_0$ and $\nu_2 > \nu_0$, the fringe shift $\delta_\lambda = \dfrac{N_1 \Delta\lambda_1 + N_2 \Delta\lambda_2}{\lambda_0}$ arises as in the case where beams travel with different speeds and cover different distances $L_1^{'} = L - \Delta\lambda_1 N_1$ and $L_2^{''} = L + \Delta\lambda_2 N_2$ for an identical time $t_L = \dfrac{Ln}{C}$.

3. The fringe shift in the Fizeau interferometr.

In the Fizeau interferometer, beams cover different distances L_1 and L_2 in different times t_1 and t_2 in water (Fig.2) and, if we suppose that beams do not change frequencies, the fringe shift has to be equal to $\delta_V = \frac{2LVC}{\lambda_0\left(\frac{C}{n}+V\right)\left(\frac{C}{n}-V\right)}$. But the fringe shift δ is less than δ_V because beams travel with different frequencies.

In accordance with the Doppler effect, beams entering moving water change frequency:

in beam 1 the frequency of photons decreases to $\nu_1=\nu_0(1-\frac{V}{C})$,

in beam 2 the frequency of photons increases to $\nu_2=\nu_0(1+\frac{V}{C})$,

Photons cover the distances L_1 and L_2 in water with different frequencies ν_1 and ν_2 , When beams exit from moving water, frequency of photons in beam 1 changes by $(1+\frac{V}{C})$ and becomes equal to $\nu=\nu_0(1-\frac{V^2}{C^2})$. Frequency of photons in beam 2 changes by $(1-\frac{V}{C})$ and becomes equal to $\nu=\nu_0(1-\frac{V^2}{C^2})$ too. Beams interfere with identical frequency $\nu=\nu_0(1-\frac{V^2}{C^2})\approx\nu_0$ and create a stationary interference pattern.

When water is at rest, photons of frequency ν_0 have wavelength $\frac{C}{n\nu_0}=\frac{\lambda_0}{n}$.

Beam 1 covers the distance L_1 in water with frequency $\nu_1=\nu_0(1-\frac{V}{C})$ and wavelength $\lambda_1=\frac{C}{n\nu_1}=\frac{CC}{n\nu_0(C-V)}=\frac{\lambda_0}{n}\frac{C}{(C-V)}=\frac{\lambda_0}{n}+\frac{\lambda_0 V}{n(C-V)}=\frac{\lambda_0}{n}+\Delta\lambda_1$. That is, the wavelength is greater than $\frac{\lambda_0}{n}$ by $\Delta\lambda_1=\frac{\lambda_0 V}{n(C-V)}$. During time t_1 while beam 1 covers the distance L_1 , there are $N_1=\frac{L_1}{\lambda_1}=\frac{L(C-V)}{\lambda_0\left(\frac{C}{n}+V\right)}$ oscillations and the wavefront shifts by $\Delta\lambda_1 N_1=\frac{LV}{n\left(\frac{C}{n}+V\right)}$.

Beam 2 covers the distance L_2 in water with frequency $\nu_2=\nu_0(1+\frac{V}{C})$ and wavelength $\lambda_2=\frac{C}{n\nu_2}=\frac{CC}{n\nu_0(C+V)}=\frac{\lambda_0}{n}\frac{C}{(C+V)}=\frac{\lambda_0}{n}-\frac{\lambda_0 V}{n(C+V)}=\frac{\lambda_0}{n}-\Delta\lambda_2$. That is the wavelength is less than $\frac{\lambda_0}{n}$ by $\Delta\lambda_2=\frac{\lambda_0 V}{n(C+V)}$. During the time t_2 while beam 2 cover the distance L_2 , there are $N_2=\frac{L_2}{\lambda_2}=\frac{L(C+V)}{\lambda_0\left(\frac{C}{n}-V\right)}$ oscillations and the wavefront shifts by

$$\Delta\lambda_2 N_2 = \frac{LV}{n\left(\frac{C}{n} - V\right)} \quad .$$

Because of change of the frequencies, the total the shift of wave fronts

$$\Delta\lambda_1 N_1 + \Delta\lambda_2 N_2 = \frac{LV}{n\left(\frac{C}{n} + V\right)} + \frac{LV}{n\left(\frac{C}{n} - V\right)} = \frac{LV}{n} \frac{\frac{C}{n} + V + \frac{C}{n} - V}{\left(\frac{C}{n} + V\right)\left(\frac{C}{n} - V\right)} = \frac{2\,LVC}{n^2\left(\frac{C}{n} + V\right)\left(\frac{C}{n} - V\right)}$$

decreases the fringe shift by $\delta_\lambda = \frac{\Delta\lambda_1 N_1 + \Delta\lambda_2 N_2}{\lambda_0}$ and the resultant fringe shift in the interferometer is

$$\delta = \delta_V - \delta_V = \frac{2\,LVC}{\lambda_0\left(\frac{C}{n} + V\right)\left(\frac{C}{n} - V\right)} - \frac{2\,LVC}{n^2\lambda_0\left(\frac{C}{n} + V\right)\left(\frac{C}{n} - V\right)} = \delta_V\left(1 - \frac{1}{n^2}\right)$$

which exactly coincides with the experimental fringe shift in Fizeau interferometer.

Conclusion

Fizeau made a mistake in the calculation of his interferometer experiment and therefore the result was explained improperly. By taking into account the change of the frequencies of interfering beams, the calculation gives a value that exactly corresponds to the experimental value of the fringe shift. Therefore Fizeau's experiment cannot be considered as confirmation of special relativity or an ether hypothesis and all attempts to explain this experiment with a partial entrainment of light by moving water or relativistic addition of velocities are wrong.