Fizeau Experiment Revisited

Rajeev Kumar*

Abstract

In this paper an alternative explanation of the result of the Fizeau experiment with moving water has been presented.

Keyword : Fizeau experiment.

1 SPEED OF LIGHT IN A MOVING BODY

Let c_2 be the speed of a light ray (or a photon) in a stationary body (medium 2) and let $c_{2,m}$ be the speed of the light ray (or a photon) in the body (medium 2) when it is moving with a velocity **v**. Then,

$$\left|\mathbf{c}_{2,m} - \mathbf{v}\right|^2 - \left|\frac{c_o}{c_1}\mathbf{c}_1 - \mathbf{v}\right|^2 = c_2^2 - c_o^2$$

where

c_o = speed of the light in vacuum

$\mathbf{c}_1$ = velocity of the light in medium 1

2 FIZEAU EXPERIMENT

Let's calculate $\Delta c_{2,f}$ for a forward moving ray of light (moving along the direction of water flow) and $\Delta c_{2,b}$ for a backward moving ray of light (moving against the direction of water flow).

$$\left|\mathbf{c}_{2,fm} - \mathbf{v}\right|^2 - \left|\frac{c_0}{c_1}\mathbf{c}_1 - \mathbf{v}\right|^2 = c_2^2 - c_o^2$$

$$\Rightarrow (c_{2,fm} - 7.059)^2 - (299792458 - 7.059)^2 = \left(\frac{3}{4}\times 299792458\right)^2 - (299792458)^2$$

$$\Rightarrow c_{2,fm} = 224844341 \quad ms^{-1}$$

$$\Rightarrow \Delta c_{2,f} = c_{2,fm} - c_2 = 224844341 - 224844343.5 = -2.5 \quad ms^{-1}$$

*rajeevkumar620692@gmail.com

$$\left|\mathbf{c}_{2,bm}-\mathbf{v}\right|^2-\left|\frac{c_0}{c_1}\mathbf{c}_1-\mathbf{v}\right|^2=c_2^2-c_o^2$$

$$\Rightarrow \left(c_{2,bm}+7.059\right)^2-\left(299792458+7.059\right)^2=\left(\frac{3}{4}\times 299792458\right)^2-\left(299792458\right)^2$$

$$\Rightarrow c_{2,bm}=224844346 \quad ms^{-1}$$

$$\Rightarrow \Delta c_{2,b}=c_{2,bm}-c_2=224844346-224844343.5=2.5 \quad ms^{-1}$$

Let

L = total distance traversed in water by a light ray (or a photon) in going from the source to an interference plane

t_{sw} = time spent in stationary water by a light ray (or a photon) in going from the source to the interference plane

c_{sw} = speed of the light ray (or a photon) in stationary water

λ_{sw} = wavelength of the light ray (or the stream of photons) in stationary water

Now, the time spent in air and glass (of the water tube) by a light ray (or a photon) in going from the source to the interference plane will be same for both a forward moving ray and a backward moving ray, so its effect gets cancelled out.

So, the fringe shift (additional optical path difference) for moving water as compared to stationary water in the Fizeau experiment

$$\delta=\frac{2\left|\Delta c_2\right|t_{sw}}{\lambda_{sw}}$$

$$\Rightarrow \delta=\frac{2}{\lambda_{sw}}\times\left|\Delta c_2\right|\times\frac{L}{c_{sw}}$$

$$\Rightarrow \delta=\frac{2}{\left(\dfrac{\lambda_o}{\mu_w}\right)}\times\left|\Delta c_2\right|\times\frac{L}{\left(\dfrac{c_o}{\mu_w}\right)}$$

$$\Rightarrow \delta=\frac{2L\mu_w^2\left|\Delta c_2\right|}{\lambda_o c_o}=\frac{2\times 2.974\times\left(\dfrac{4}{3}\right)^2\times 2.5}{\left(526\times 10^{-9}\right)\times 299792458}$$

$$\Rightarrow \delta=0.17$$

But the experimental fringe shift value, i.e., $\delta_e = 0.23$

The difference in the experimental value and the calculated value can be attributed to many factors such as :

- Lack of required precision in the measurement of the other parameters.
- Non-uniformity in the speed of the water flowing in the tube.
- Calculation limitation of the calculator.
- Lack of knowledge of the actual value of the speed ratio.

3 RESOLUTION BY SPEED RATIO

Let's define absolute speed ratio index as

$$\beta_i = \frac{c_i}{c_o}$$

$$\Rightarrow \frac{c_2}{c_1} = \left(\frac{\beta_2}{\beta_1}\right) = \beta_{21}$$

and $\beta_{vacuum} = 1$

Let's calculate $\Delta c_{2,f}$ for a forward moving ray of light and $\Delta c_{2,b}$ for a backward moving ray of light.

$$\left|\mathbf{c}_{2,fm} - \mathbf{v}\right|^2 - \left|\frac{c_0}{c_1}\mathbf{c_1} - \mathbf{v}\right|^2 = c_2^2 - c_o^2$$

$$\Rightarrow \left(c_{2,fm} - 7.059\right)^2 - \left(299792458 - 7.059\right)^2 = \left(\beta_w \times 299792458\right)^2 - \left(299792458\right)^2$$

$$\Rightarrow \Delta c_{2,f} = c_{2,fm} - c_2 = c_{2,fm} - \left(\beta_w \times 299792458\right)$$

$$\left|\mathbf{c}_{2,bm} - \mathbf{v}\right|^2 - \left|\frac{c_0}{c_1}\mathbf{c_1} - \mathbf{v}\right|^2 = c_2^2 - c_o^2$$

$$\Rightarrow \left(c_{2,bm} + 7.059\right)^2 - \left(299792458 + 7.059\right)^2 = \left(\beta_w \times 299792458\right)^2 - \left(299792458\right)^2$$

$$\Rightarrow \Delta c_{2,b} = c_{2,bm} - c_2 = c_{2,bm} - \left(\beta_w \times 299792458\right)$$

Now

$$\Delta c_{2,fm} \approx -\Delta c_{2,bm} \qquad [\because v << c]$$

$$\Rightarrow \left|\Delta c_{2,fm}\right| = \left|\Delta c_{2,bm}\right| = \left|\Delta c_2\right|$$

So

$$\delta = \frac{2}{\lambda_{sw}} \times \left|\Delta c_2\right| \times \frac{L}{c_{sw}} = \frac{2}{\beta_w \lambda_o} \times \left|\Delta c_2\right| \times \frac{L}{\beta_w c_o}$$

$$\Rightarrow \delta = \frac{2L\left|\Delta c_2\right|}{\beta_w^2 \lambda_o c_o} = \frac{2 \times 2.974 \times \left|\Delta c_2\right|}{\beta_w^2 \times \left(526 \times 10^{-9}\right) \times 299792458}$$

$$\Rightarrow \delta = 0.038 \times \frac{\left|\Delta c_2\right|}{\beta_w^2}$$

Letting

$$\delta \approx \delta_e$$

$$\Rightarrow 0.038 \times \frac{\left|\Delta c_2\right|}{\beta_w^2} \approx 0.23$$

$$\Rightarrow \frac{\left|\Delta c_2\right|}{\beta_w^2} \approx 6.05$$

Now

$$\left(c_{2,fm} - 7.059\right)^2 - \left(299792458 - 7.059\right)^2 = \left(\beta_w \times 299792458\right)^2 - \left(299792458\right)^2$$
$$\Rightarrow \left(\beta_w \times 299792458 - 6.05\beta_w^2 - 7.059\right)^2 - \left(299792458 - 7.059\right)^2 = \left(\beta_w \times 299792458\right)^2 - \left(299792458\right)^2$$
$$\Rightarrow \beta_w = 0.7$$

$$\left(c_{2,bm} + 7.059\right)^2 - \left(299792458 + 7.059\right)^2 = \left(\beta_w \times 299792458\right)^2 - \left(299792458\right)^2$$
$$\Rightarrow \left(\beta_w \times 299792458 + 6.05\beta_w^2 + 7.059\right)^2 - \left(299792458 + 7.059\right)^2 = \left(\beta_w \times 299792458\right)^2 - \left(299792458\right)^2$$
$$\Rightarrow \beta_w = 0.7$$

$$\Rightarrow \left|\Delta c_2\right| \approx 6.05 \times 0.7^2 = 3 \quad ms^{-1}$$

It should be noted that β_{21} need not be equal to μ_{12} because :

1. $\beta_{21} = \mu_{12}$, as derived by Christiaan huygens' wave theory, is valid for a mechanical wave, but light is not a mechanical wave.
2. $\beta_{21} = \mu_{12}$, as derived in Fermat's principle of least time, need not be applicable for the path of a light ray as the concept of the path of least time is meaningless unless the destination point is predefined.

References

1. Hugh D. Young, Roger A. Freedman, Albert Lewis Ford, *"Sears' and Zemansky's University Physics with Modern Physics 13th edition."*

2. M.H. Fizeau, *"On the Effect of the Motion of a Body upon the Velocity with which It is Traversed by Light", Philosophical Magazine and Journal of Science, Vol. 19, 1860.*