Measuring the speed of light by spinning mirror

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Ⅰ. Background

Ole Christensen Romer (1644~1710) used an astronomical measurement to make the first quantitative estimation of the speed of light was 2.2*10^8(m/s). *Michelson* in 1920 used octahedral mirror and measured the speed of light which was 2.997*10^8(m/s).

Ⅱ. Theory

When the spinning mirror is static, light will pass through the red path (Fig.1), and we can find a beam of light on the screen. Now the spinning mirror is rotating, light will pass through the red path at A part and pass through the blue path at B part (Fig.1). Why will light pass through the blue path at B part? First, light only enter the red path at A part at the initial angle of the spinning mirror. Besides, the speed of light is not infinity, so light pass through the red path at A part in little times, and the spinning mirror rotates a small angle in this times. It results the beam of light would not pass through the red path at B part but the blue path after the beam of light reaches the spinning mirror again. At this time, we can still find a beam of light on the screen, but it is not the same position with the static condition of the spinning mirror. By this process, we can calculate the speed of light.

However, why beam of light on the screen is not a line but a point when the spinning mirror is rotating? We let the path at A part is very long. If the spinning mirror is not at the initial angle, light can not enter the red path at A part and back to the spinning mirror, and then light can not arrive the screen.

Ⅲ. Method

How to find the speed of light? First, when the spinning mirror is rotating, the beam of light pass through the path at A part in a time Δt, the spinning mirror rotates $\Delta\theta$ in this time, and $\Delta t = \Delta\theta / \omega$ (ω is the angular velocity of the spinning mirror). From Fig.1, the angle between the red and the blue path at B part is $2\Delta\theta$. Because speed of light is fast, so $\Delta\theta$ is very small, and $2\Delta\theta \approx \tan(2\Delta\theta) = \Delta X / B$, we insert this equation into $\Delta t = \Delta\theta / \omega$. Finally, light pass through the path at A part in Δt, the speed of light $v = A/\Delta t$. so we can find:

$$v = \frac{2\omega AB}{\Delta X}$$

Equations

$$\Delta\theta \to 0$$

$$2\Delta\theta \approx \tan 2\Delta\theta = \frac{\Delta X}{B}$$

$$\Delta t = \frac{\Delta\theta}{\omega} = \frac{\Delta X}{2\omega B}$$

$$v = \frac{A}{\Delta t} = \frac{2\omega AB}{\Delta X}$$

Schematic diagram

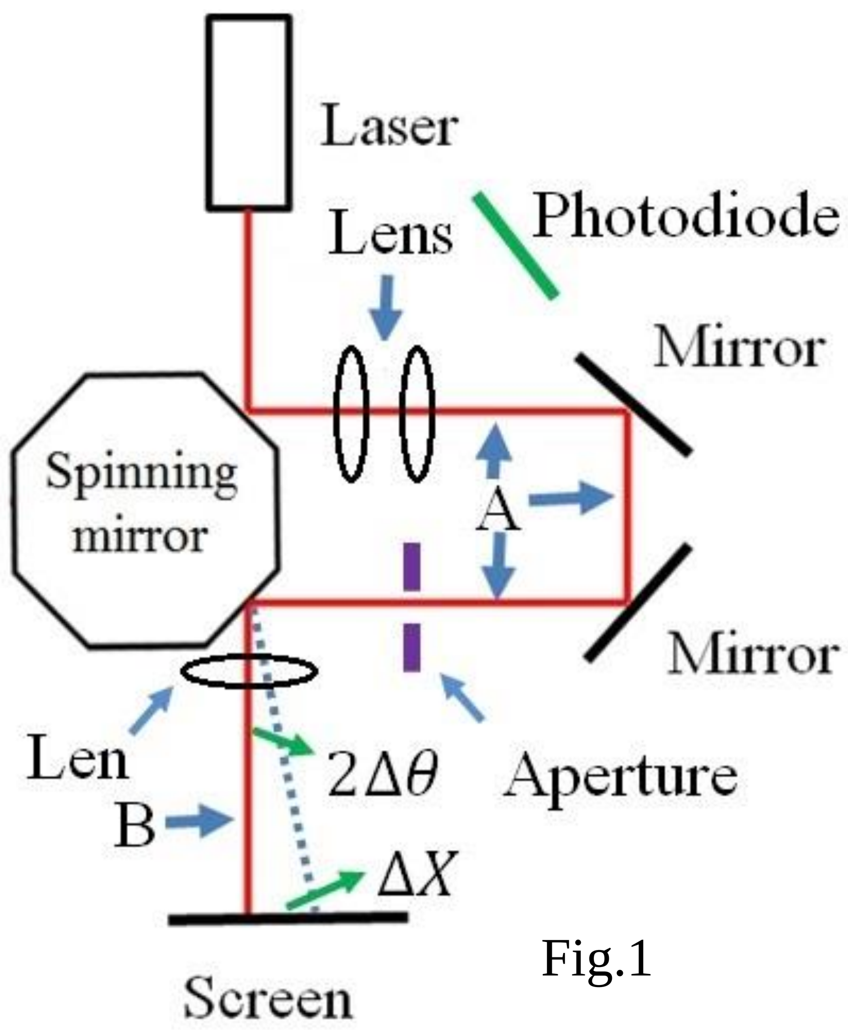


Fig.1

Two convex lens

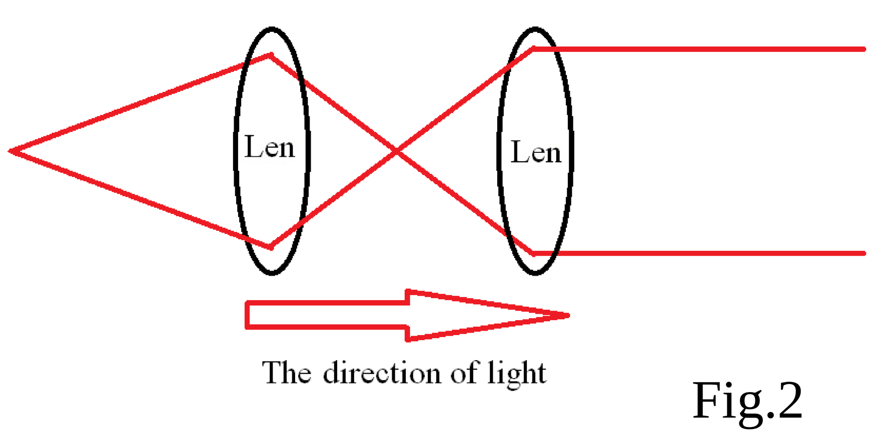


Fig.2

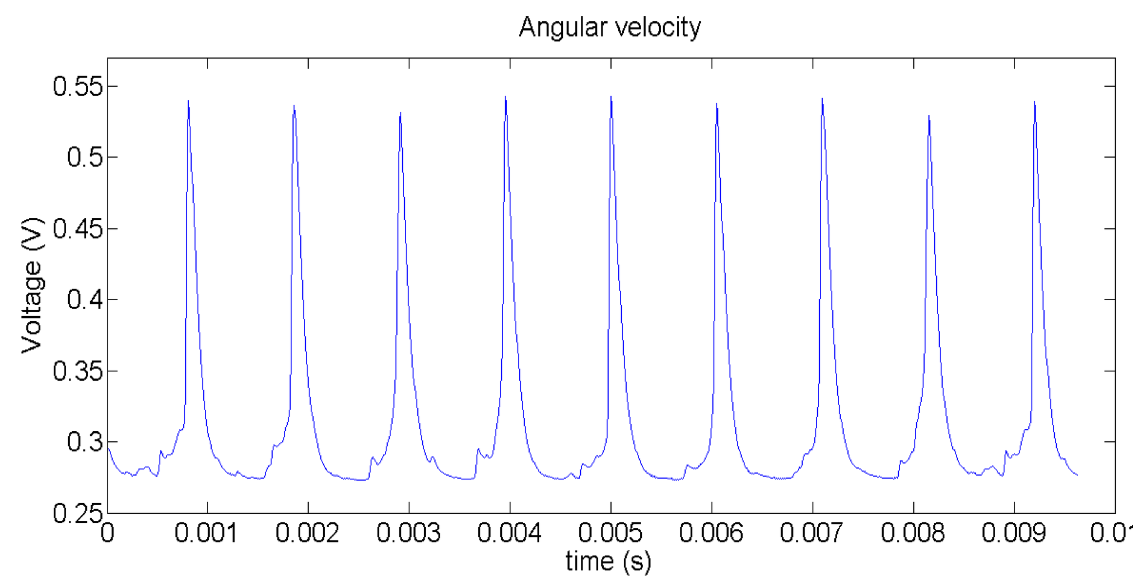
Ⅳ. Problems we solved

Because the path at A part is very long, we need the laser which is parallel light, or the laser will be divergence when passing a long distance, so we use two convex lens (fig.2) to make light parallel. Besides, theoretically, light only enter the path at A part at the initial angle of the spinning mirror. However, within the certain range, light can arrive the screen at other angle which is close to initial angle in actually, so we add an aperture to make experiment be close to theorem.

Ⅴ. Result

Angular velocity (ω)

We set a photodiode near the spinning mirror. When the spinning mirror is rotating, the photodiode will receive light and change light into electric signal. We measure the electric signal by ADDA card and Lab-VIEW, the result is following:



$$\omega = \frac{2\pi}{8t}$$

By this plot, we can find the period t of the electric signal, and the period of spinning mirror is 8t. We can calculate angular velocity from above equation. The result is following:

Average ω (rad./s)	Standard deviation (rad./s)
754.87	6.50

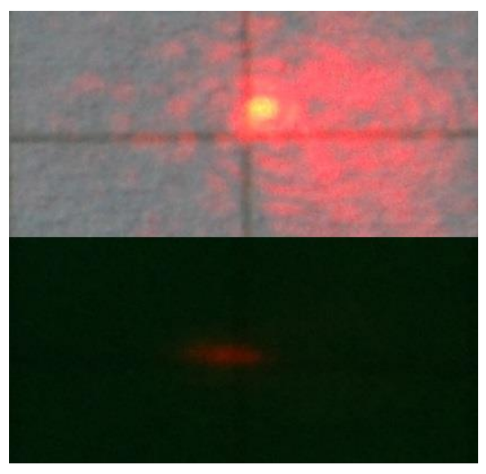
ΔX

We take pictures with a high-resolution camera and insert the pictures to Image-J and find 2-D plot of relation of intensity of light and position. Then, we integral intensity of light along vertical axis to find 1-D plot of relation of intensity of light and horizontal position, and we can see the intensity of light have a peak in a position. Finally, we find positions of peaks as positions of beams of light.

By this way, we respectively find the position of beam of light X_1 and X_2, and compare their position to get ΔX.

X_1

X_2



We made twenty experimental data and got average:

Average ΔX (mm)	Standard deviation (mm)
1.333	0.119

The speed of light

$$v = \frac{2\omega AB}{\Delta X}$$

A = 40.122 (m)
B = 6.502 (m)
ω = 754.87 (rad./s)
ΔX = 1.333 (mm)

Speed of light c is 299,792,458(m/s)

The speed of light we got (m/s)	Deviation with c
2.954E+08	-1.46%

Ⅵ. Conclusion

We measured the distance ΔX, the angular velocity ω, and the distance A and B. Finally, we use the average ΔX and other data to got the speed of light.

Ⅶ. Reference

1.Wikipedia，speed of light (http://en.wikipedia.org/wiki/Speed_of_light)
2.David J. Griffiths. *Introduction to Electrodynamics*. Fourth Edition, Addison-Wesley • Cloth, 2012, CH.9