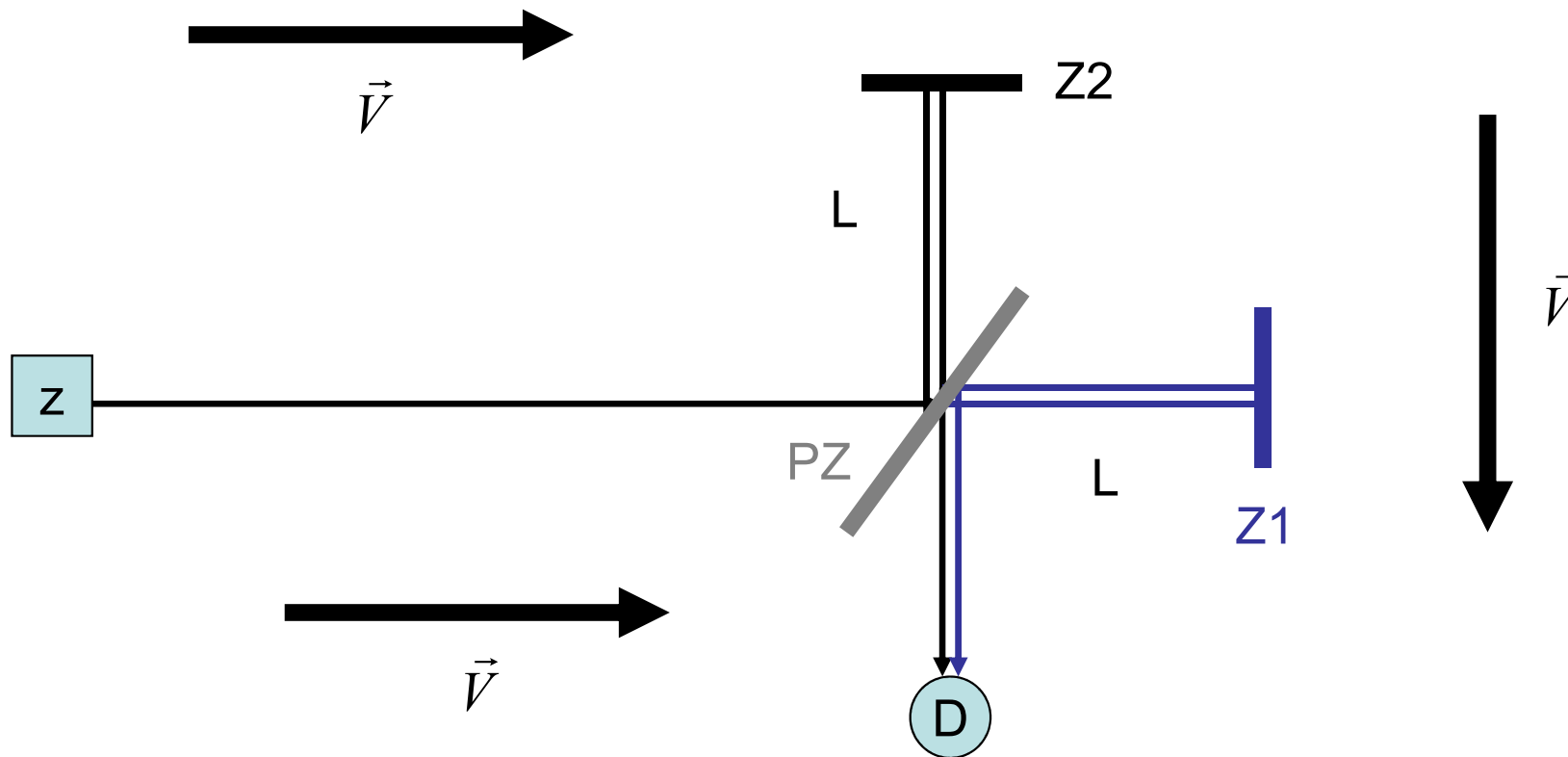


# Michelsonův interferometr

Detaily experimentu

# Michelsonův interferometr

- Soustava v klidu vůči éteru



# Michelsonův článek

No. 203. Vol. XXXIV.

NOVEMBER, 1887.

Established by BENJAMIN SILLIMAN in 1818.

THE  
AMERICAN  
JOURNAL OF SCIENCE.

EDITORS

JAMES D. AND EDWARD S. DANA.

ASSOCIATE EDITORS

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THIRD SERIES.

VOL. XXXIV.—[WHOLE NUMBER, CXXXIV.]

WITH PLATES II TO IX.

No. 203—NOVEMBER, 1887.

NEW HAVEN, CONN.: J. D. & E. S. DANA.  
1887.

TUTTLE, MOREHOUSE & TAYLOR, PRINTERS, 571 STATE STREET.

Six dollars per year (postage prepaid). \$6.40 to foreign subscribers of countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks.

THE

AMERICAN JOURNAL OF SCIENCE.

[THIRD SERIES.]

ART. XXXVI.—*On the Relative Motion of the Earth and the Luminiferous Ether*; by ALBERT A. MICHELSON and EDWARD W. MORLEY.\*

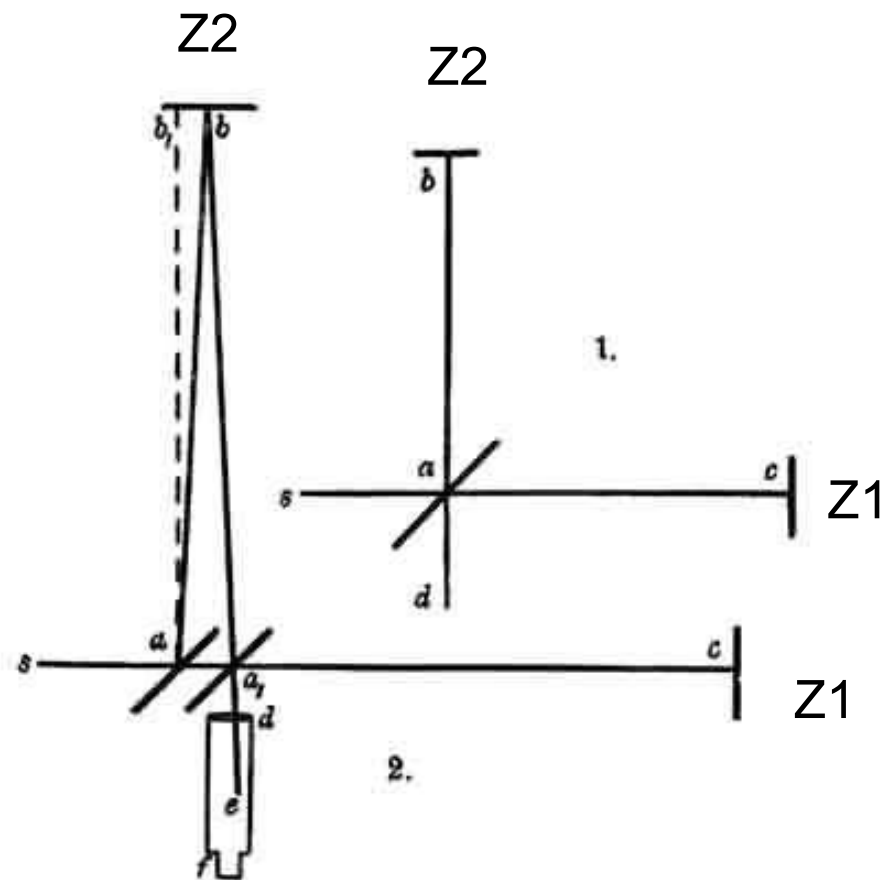
THE discovery of the aberration of light was soon followed by an explanation according to the emission theory. The effect was attributed to a simple composition of the velocity of light with the velocity of the earth in its orbit. The difficulties in this apparently sufficient explanation were overlooked until after an explanation on the undulatory theory of light was proposed. This new explanation was at first almost as simple as the former. But it failed to account for the fact proved by experiment that the aberration was unchanged when observations were made with a telescope filled with water. For if the tangent of the angle of aberration is the ratio of the velocity of the earth to the velocity of light, then, since the latter velocity in water is three-fourths its velocity in a vacuum, the aberration observed with a water telescope should be four-thirds of its true value.†

\* This research was carried out with the aid of the Bache Fund.

† It may be noticed that most writers admit the sufficiency of the explanation according to the emission theory of light; while in fact the difficulty is even greater than according to the undulatory theory. For on the emission theory the velocity of light must be greater in the water telescope, and therefore the angle of aberration should be less; hence, in order to reduce it to its true value, we must make the absurd hypothesis that the motion of the water in the telescope carries the ray of light in the opposite direction!

AM. JOUR. SCI.—THIRD SERIES, Vol. XXXIV, No. 203.—Nov., 1887.

# Pohyb interferometru vůči éteru



# Odhad velikosti časového rozdílu

Let  $V$  = velocity of light.

$v$  = velocity of the earth in its orbit.

$D$  = distance  $ab$  or  $ac$ , fig. 1.

$T$  = time light occupies to pass from  $a$  to  $c$ .

$T$  = time light occupies to return from  $c$  to  $a$ , (fig. 2.)

Then  $T = \frac{D}{V-v}$ ,  $T' = \frac{D}{V+v}$ . The whole time of going and coming is  $T+T' = 2D \frac{V}{V^2-v^2}$ , and the distance traveled in this time

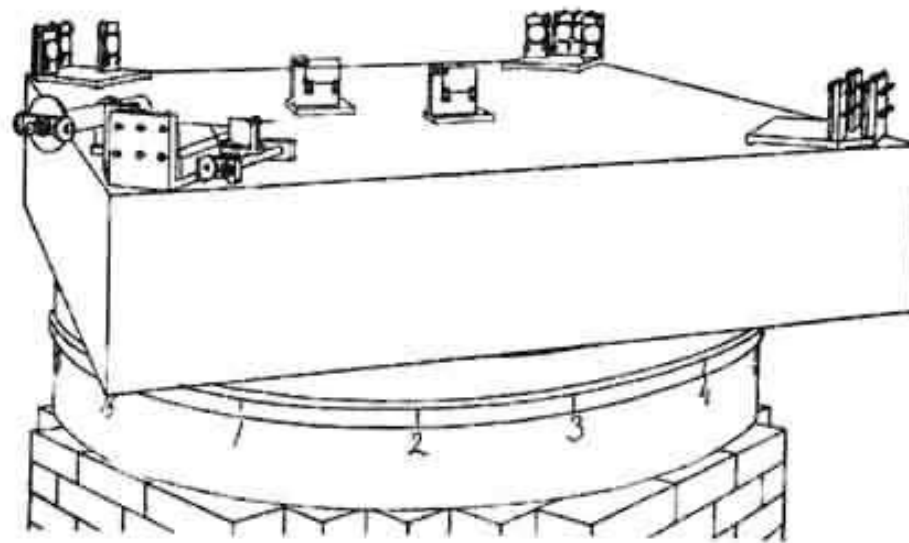
is  $2D \frac{V^2}{V^2-v^2} = 2D \left(1 + \frac{v^2}{V^2}\right)$ , neglecting terms of the fourth order.

The length of the other path is evidently  $2D \sqrt{1 + \frac{v^2}{V^2}}$ , or to the same degree of accuracy,  $2D \left(1 + \frac{v^2}{2V^2}\right)$ . The difference is therefore  $D \frac{v^2}{V^2}$ .

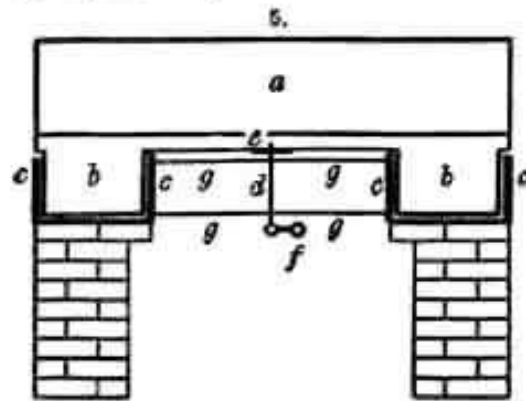
If now the whole apparatus be turned through  $90^\circ$ , the difference will be in the opposite direction, hence the displacement of the interference fringes should be  $2D \frac{v^2}{V^2}$ . Considering only the velocity of the earth in its orbit, this would be  $2D \times 10^{-8}$ . If, as was the case in the first experiment,  $D = 2 \times 10^8$  waves of yellow light, the displacement to be expected would be 0.04 of the distance between the interference fringes.

# Vlastní provedení interferometru

- Celkový pohled na interferometr



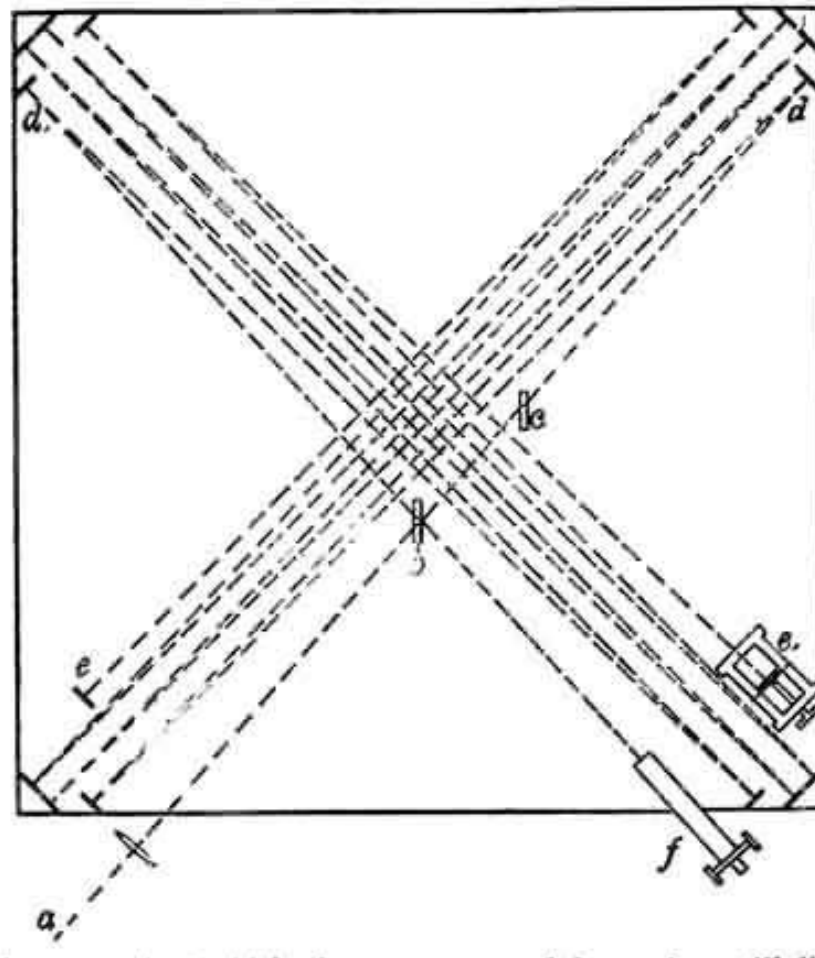
# Svislý řez



Možnost otáčet interferometrem kolem svislé osy.

# Získání dostatečného dráhového rozdílu

- Mnohočetné odrazy paprsků, kompenzace dráhového rozdílu na nulu pro východo-západní orientaci interferometru

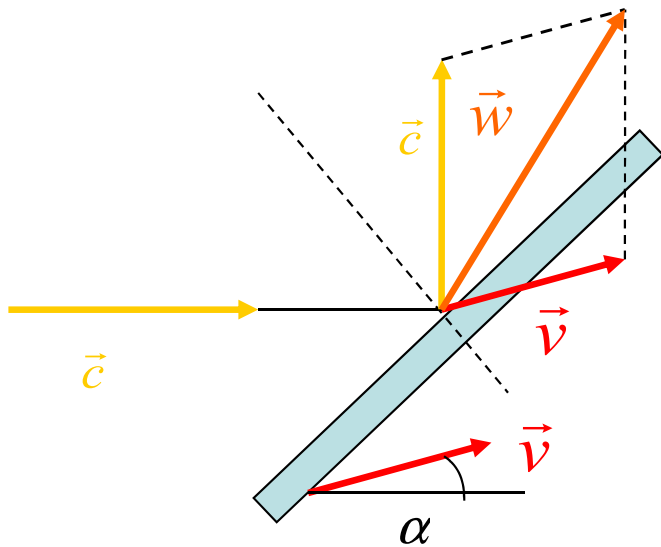




# Získání teoretické křivky

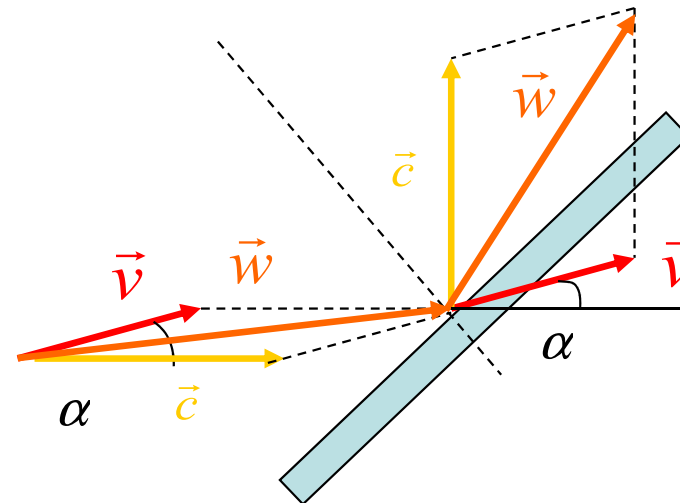
- ?soustava spojená s éterem anebo s interferometrem?

S éterem – pohyb zrcadla



Neplatí zákon odrazu!

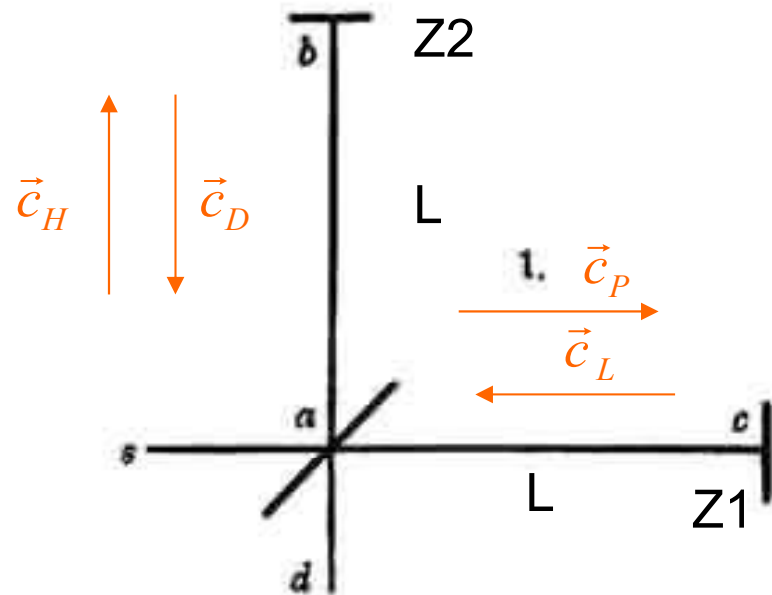
S interferometrem – pohyb prostředí



Zákon odrazu platí.

# Výpočet – soustava spojená s interferometrem

- Soustava 1. podle Michelsonova nákresu ( $\alpha = 0^\circ$ )
- V ní se světlo pohybuje podél ramen (nečárkované rychlosti)



$$\vec{c}_P = (c^\otimes, 0)$$

$$\vec{c}_L = (-c^\oplus, 0)$$

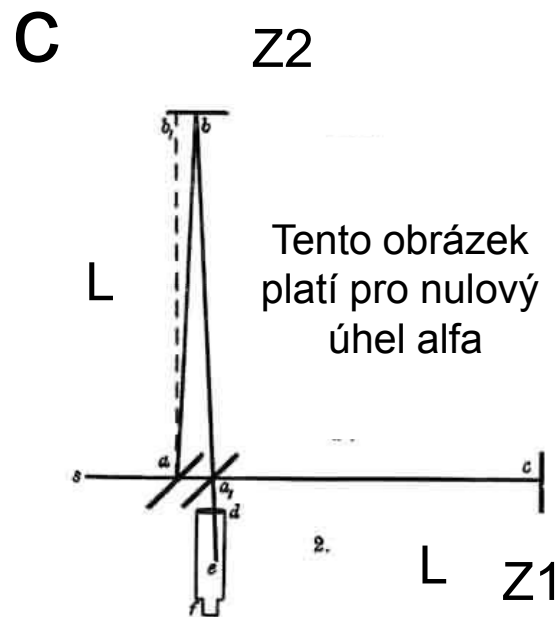
$$\vec{c}_H = (0, c^\times)$$

$$\vec{c}_D = (0, -c^*)$$

- Pro soustavu spojenou s éterem je třeba udělat transformaci  $\vec{c}' = \vec{c} - \vec{V}$ , přičemž éter se pohybuje rychlostí  $\vec{V} = (V \cos \alpha, V \sin \alpha)$

# Výpočet – soustava spojená s étérem

- Se soustavou spojenou s interferometrem je spojena Galileiho transformací  $\vec{c}' = \vec{c} - \vec{V}$
- Velikost rychlostí v této soustavě musí být



$$\vec{c}_P = (c^\otimes - V \cos \alpha, -V \sin \alpha)$$

$$\vec{c}_L = (-c^\oplus - V \cos \alpha, -V \sin \alpha)$$

$$\vec{c}_H = (-V \cos \alpha, c^\times - V \sin \alpha)$$

$$\vec{c}_D = (-V \cos \alpha, -c^* - V \sin \alpha)$$

$$c^2 = |\vec{c}_P|^2 = c^{\otimes 2} - 2Vc^\otimes \cos \alpha + V^2$$

odkud ...  $c^\otimes = \dots$  atd.

# Další postup

- Vypočítat hodnoty jednotlivých rychlostí  $c^{\otimes} \dots$

$$c^{\otimes} = V \cos \alpha + \sqrt{c^2 - V^2 \sin^2 \alpha}$$

$$c^{\oplus} = -V \cos \alpha + \sqrt{c^2 - V^2 \sin^2 \alpha}$$

$$c^{\times} = V \sin \alpha + \sqrt{c^2 - V^2 \cos^2 \alpha}$$

$$c^* = -V \sin \alpha + \sqrt{c^2 - V^2 \cos^2 \alpha}$$

- Použít je pro vyjádření dráhového rozdílu v soustavě spojené s interferometrem

$$t_{DZ1D} = \frac{L}{|c_P|} + \frac{L}{|c_L|} = \frac{L}{V \cos \alpha + \sqrt{c^2 - V^2 \sin^2 \alpha}} + \frac{L}{-V \cos \alpha + \sqrt{c^2 - V^2 \sin^2 \alpha}} = \frac{2L\sqrt{c^2 - V^2 \sin^2 \alpha}}{c^2 - V^2}$$
$$t_{DZ2D} = \frac{L}{|c_H|} + \frac{L}{|c_D|} = \frac{L}{V \sin \alpha + \sqrt{c^2 - V^2 \cos^2 \alpha}} + \frac{L}{-V \sin \alpha + \sqrt{c^2 - V^2 \cos^2 \alpha}} = \frac{2L\sqrt{c^2 - V^2 \cos^2 \alpha}}{c^2 - V^2}$$

# Výsledný dráhový rozdíl – soustava spojená s interferometrem

- Výsledek je tvaru

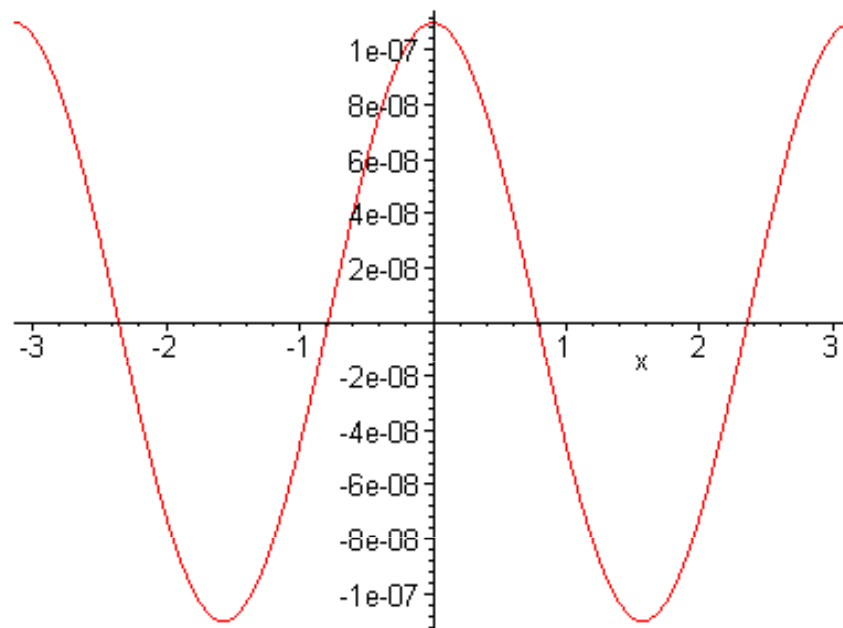
$$\Delta t = t_{DZ1D} - t_{DZ2D} = \frac{2L}{c^2 - V^2} \left[ \sqrt{c^2 - V^2 \sin^2 \alpha} - \sqrt{c^2 - V^2 \cos^2 \alpha} \right]$$

- Po použití Taylorova rozvoje dostaneme

$$\Delta t = t_{DZ1D} - t_{DZ2D} = \frac{L}{c} \frac{V^2}{c^2} \cos 2\alpha$$

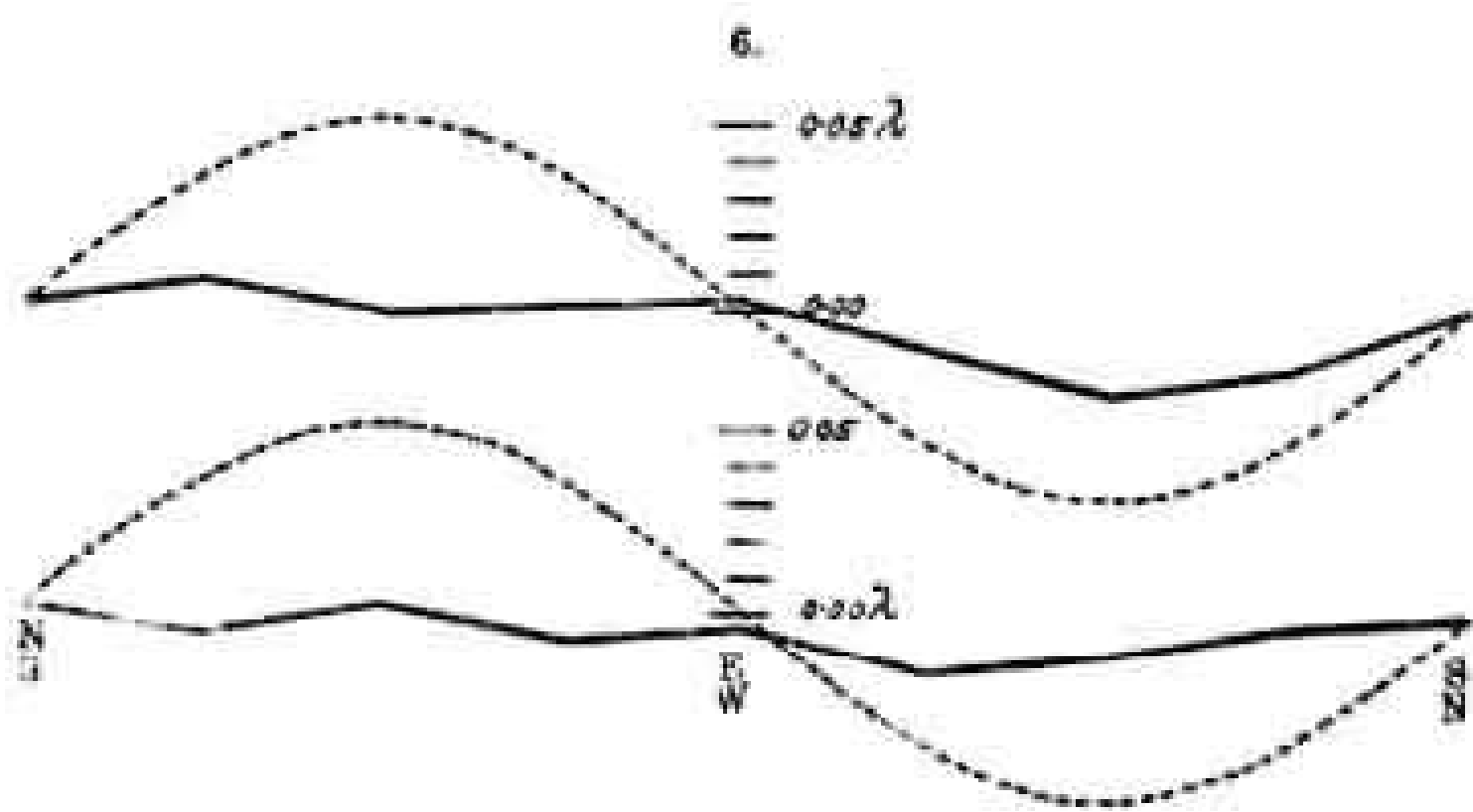
# Výsledky výpočtů – konkrétní úhly

- Pro úhly 0, 180, 360 stejné časové rozdíly  $\Delta t = \frac{2Lc}{\sqrt{c^2 - V^2}} \left[ 1 - \sqrt{1 - \frac{V^2}{c^2}} \right]$  (ve „vodorovném“ rameni DZ1 je paprsek rychlejší než ve „svislém“ DZ2).
- Pro úhly 90, 270 stejně velké časové rozdíly, ale s opačným znaménkem (ve „svislém“ rameni DZ2 proběhne paprsek rychleji než ve „vodorovném“ DZ1).
- Pro úhly 45, 135, ... je rozdíl časů nulový.



+případná kompenzace:  
vytvoří posuv podél osy x

# Michelsonovy výsledky



# Michelsonovy výsledky -tabulky

NOON OBSERVATIONS.

|                | 16.  | 1.   | 2.   | 3.   | 4.   | 5.   | 6.   | 7.   | 8.   | 9.   | 10.  | 11.  | 12.  | 13.  | 14.  | 15.  | 16.  |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| July 8 . . .   | 44.7 | 44.0 | 43.5 | 39.7 | 35.2 | 34.7 | 34.3 | 32.5 | 28.2 | 26.2 | 23.8 | 23.2 | 20.5 | 18.7 | 17.5 | 16.8 | 13.7 |
| July 9 . . .   | 57.4 | 57.3 | 58.2 | 59.2 | 58.7 | 60.2 | 60.8 | 62.0 | 61.5 | 63.3 | 65.8 | 67.3 | 69.7 | 70.7 | 73.0 | 70.2 | 72.2 |
| July 11 . . .  | 37.3 | 33.5 | 32.0 | 19.3 | 19.2 | 19.3 | 18.7 | 18.8 | 16.2 | 14.3 | 13.3 | 12.8 | 13.3 | 12.3 | 10.2 | 7.3  | 6.5  |
| Mean . . . . . | 43.1 | 41.6 | 41.2 | 36.4 | 31.7 | 38.1 | 37.9 | 37.8 | 35.2 | 34.6 | 34.3 | 34.4 | 34.4 | 33.9 | 33.6 | 31.4 | 30.8 |
| Mean in w. l.  | 782  | 782  | 824  | 738  | 754  | 782  | 758  | 756  | 708  | 682  | 688  | 688  | 688  | 678  | 672  | 628  | 616  |
| Final mean.    | 784  | 782  | 756  | 738  | 721  | 739  | 715  | 692  | 661  |      |      |      |      |      |      |      |      |

P. M. OBSERVATIONS.

|                   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| July 8 . . . . .  | 61.2  | 63.3  | 63.3  | 68.2  | 67.7  | 69.3  | 70.3  | 69.8  | 69.0  | 71.3  | 71.3  | 70.8  | 71.2  | 71.2  | 70.5  | 72.5  | 75.7  |
| July 9 . . . . .  | 26.0  | 26.0  | 28.2  | 29.2  | 31.3  | 32.0  | 31.3  | 31.7  | 33.0  | 35.8  | 36.5  | 37.3  | 38.8  | 41.0  | 42.7  | 43.7  | 44.0  |
| July 12 . . . . . | 66.8  | 66.5  | 66.0  | 64.3  | 62.2  | 61.0  | 61.3  | 59.7  | 58.2  | 55.7  | 53.7  | 54.7  | 55.0  | 58.2  | 58.5  | 57.0  | 56.0  |
| Mean . . . . .    | 51.3  | 51.9  | 52.5  | 53.9  | 53.8  | 54.1  | 54.3  | 53.7  | 53.4  | 54.3  | 53.8  | 54.2  | 55.0  | 56.8  | 57.2  | 57.7  | 58.6  |
| Mean in w. l.     | 1.028 | 1.028 | 1.050 | 1.078 | 1.076 | 1.082 | 1.086 | 1.074 | 1.068 | 1.086 | 1.076 | 1.084 | 1.100 | 1.136 | 1.144 | 1.154 | 1.172 |
| Final mean.       | 1.047 | 1.032 | 1.063 | 1.081 | 1.088 | 1.109 | 1.115 | 1.114 | 1.120 |       |       |       |       |       |       |       |       |

„hypotéza stacionárního éteru je mylná“





„Vy, ctěný doktore Michelson, jste začal tuto práci v době, kdy jsem byl ještě mladíček sotva tři stopy vysoký. Byl jste to vy, kdo vedl fyziky na nové cesty a vaše podivuhodná experimentální práce uvolnila cestu pro vývoj teorie relativity. Odhalil jste zrádný efekt v éterové teorii světla, který v ní tehdy byl, a stimuloval jste myšlenky H. A. Lorentze a FitzGerala, z nichž se vyvinula speciální teorie relativity. Bez vaší pomoci by tato teorie byla dnes sotva něčím víc než zajímavou spekulací; to vaše ověření poprvé postavilo teorii na reálný základ.“

A. Einstein

# Výpočet – v interferometru vítr

