ATIVIDADE 6: Experimento de Michelson e Morley

- **James Clerck Maxwell** : Formulou à teoria moderna do eletromagnetismo (1862), que une a eletricidade, magnetismo e a óptica.
- **Maxwell** calculou que a radiação electromagnética é composta de ondas que se propagam com velocidade constante de $3x10^8$ m/s.
- Essa velocidade predita teoricamente, era em relação a qual referencial? Essa resposta não estava nas equações de Maxwell.
- A necessidade de imaginar um meio material – o éter – no qual a onda eletromagnética se propaga, e a multiplicidade de fenômenos de que ele precisava dar conta obrigou os cientistas da época a uma série de considerações sobre a natureza deste meio e sua relação com a matéria ordinária.

Hipóteses

1) O éter é livre e em repouso, não sendo afetado pelo movimento dos corpos;
2) uma parte do éter é livre e uma parte interage com os corpos. Os corpos arrastam o éter próximo deles.

O raciocínio de Michelson supõe que o éter estava em repouso (Hipótese 1)

- Se o éter existe e **as transformações de Galileu** pudessem ser aplicadas para a luz, teriamos que para um observador que se move num referencial com velocidade **V** em relação ao éter, medidas para a velocidade da luz com valores comprendidas entre **C-V** e **C+V**

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[THIRD SERIES.]

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

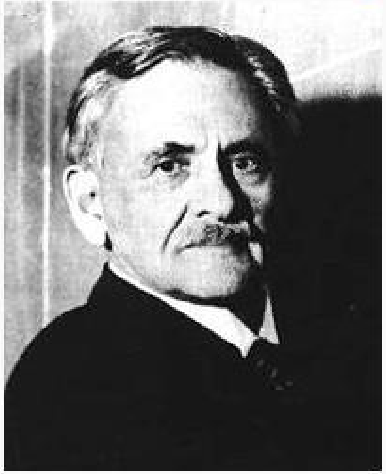
THE discovery of the aberration of light was soon followed by an explanation according to the emission theory. The effect was attributed to a simple composition of the velocity of light with the velocity of the earth in its orbit. The difficulties in this apparently sufficient explanation were overlooked 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!

Albert Abraham Michelson, foi o primeiro físico estadunidense a receber o Prêmio Nobel em Física

Albert Abraham Michelson



Nacionalidade	Estadunidense
Nascimento	19 de dezembro de 1852
Local	Strzelno, Reino da Prússia
Morte	9 de maio de 1931 (78 anos)
Local	Pasadena, Califórnia
Atividade	
Campo(s)	Física
Instituições	Case Western Reserve University, Universidade Clark, Universidade de Chicago
Alma mater	Academia Naval dos Estados Unidos, Universidade Humboldt de Berlim
Orientador(es)	Hermann von Helmholtz
Orientado(s)	Robert Andrews Millikan
Prêmio(s)	Medalha Matteucci (1903), Nobel de Física (1907)

displacement should be $2D\frac{v^2}{V^2}=2D\times10^{-8}$. The distance D was about eleven meters, or 2×10^7 wave-lengths of yellow light; hence the displacement to be expected was 0·4 fringe. The actual displacement was certainly less than the twentieth part of this, and probably less than the fortieth part. But since the displacement is proportional to the square of the velocity, the relative velocity of the earth and the ether is probably less than one sixth the earth's orbital velocity, and certainly less than one-fourth.

In what precedes, only the orbital motion of the earth is considered. If this is combined with the motion of the solar system, concerning which but little is known with certainty, the result would have to be modified; and it is just possible that the resultant velocity at the time of the observations was small though the chances are much against it. The experiment will therefore be repeated at intervals of three months, and thus all uncertainty will be avoided.

It appears, from all that precedes, reasonably certain that if there be any relative motion between the earth and the luminiferous ether, it must be small; quite small enough entirely to refute Fresnel's explanation of aberration. Stokes has given a theory of aberration which assumes the ether at the earth's surface to be at rest with regard to the latter, and only requires in addition that the relative velocity have a potential; but Lorentz shows that these conditions are incompatible. Lorentz then proposes a modification which combines some ideas of Stokes and Fresnel, and assumes the existence of a potential, together with Fresnel's coefficient. If now it were legitimate to conclude from the present work that the ether is at rest with regard to the earth's surface, according to Lorentz there could not be a velocity potential, and his own theory also fails.

Supplement.

It is obvious from what has gone before that it would be hopeless to attempt to solve the question of the motion of the solar system by observations of optical phenomena *at the surface of the earth*. But it is not impossible that at even moderate distances above the level of the sea, at the top of an isolated mountain peak, for instance, the relative motion might be perceptible in an apparatus like that used in these experiments. Perhaps if the experiment should ever be tried in these circumstances, the cover should be of glass, or should be removed.

It may be worth while to notice another method for multiplying the square of the aberration sufficiently to bring it within the range of observation, which has presented itself during the

OBS:

-Se o éter está em repouso. Então, um observador sobre a terra (terra com vel. orbital **V**) devería detetar um fluxo de vento (arrasto) de éter com sentido oposto a **V**

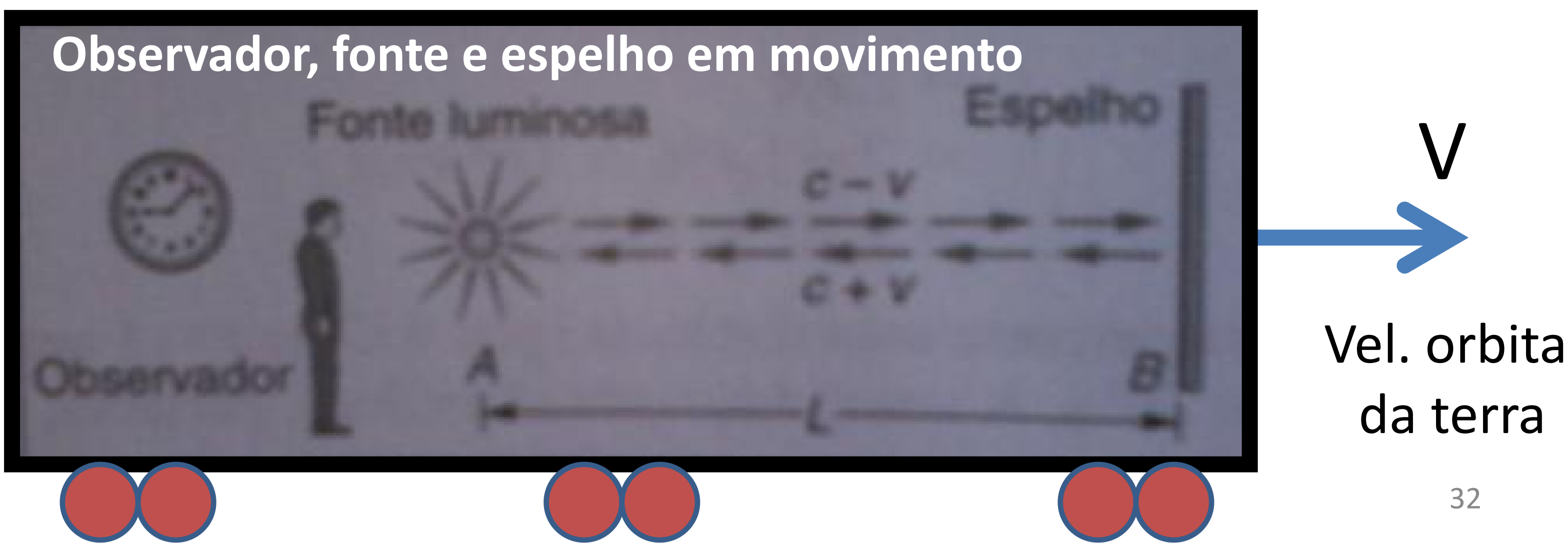
-Assim, se uma fonte luminosa, espelho e observador estão se movendo com velocidade V em relação ao éter

-De acordo com a teória clássica se a velocidade da luz em relação ao éter fosse **C**, a velocidade da luz em relação ao observador será **C-V** quando a luz viaja em contra do vento do éter (para direita). Porém, quando a luz viaja com o vento do éter a favor (para esquerda) sua velocidade será de **C+V**

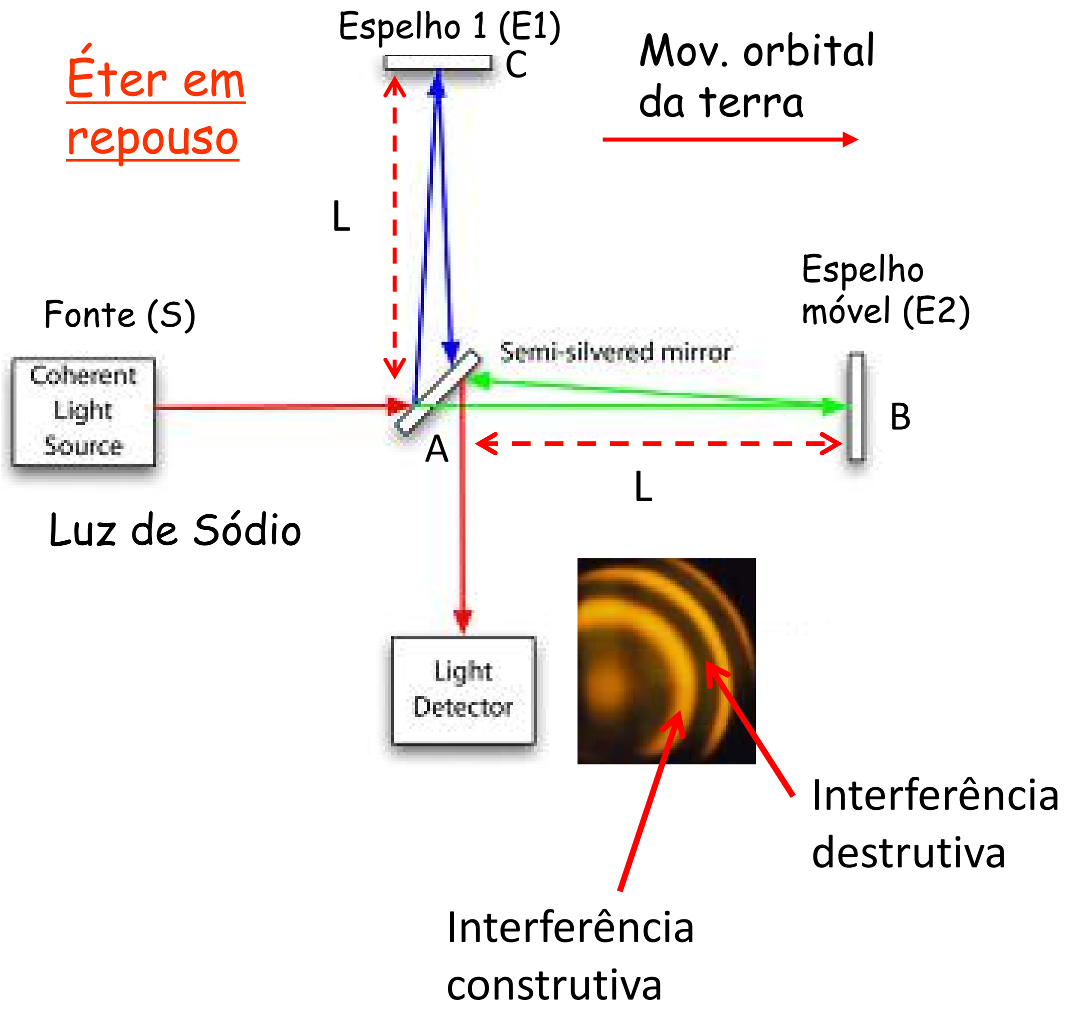
-Dessa maneira $\mathbf{t_{AB}}$ = L/C-V e $\mathbf{t_{BA}}$ = L/C+V , então $\mathbf{t_{AB} > t_{BA}}$

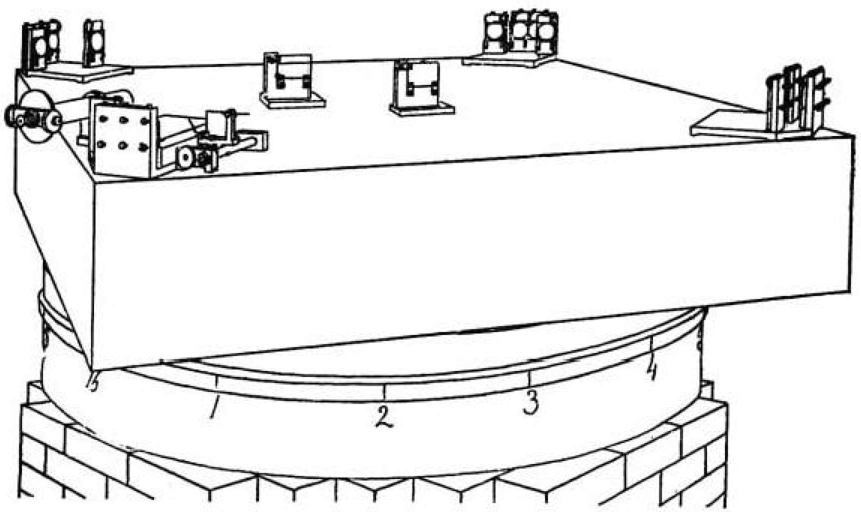
Éter em repouso / estacionário

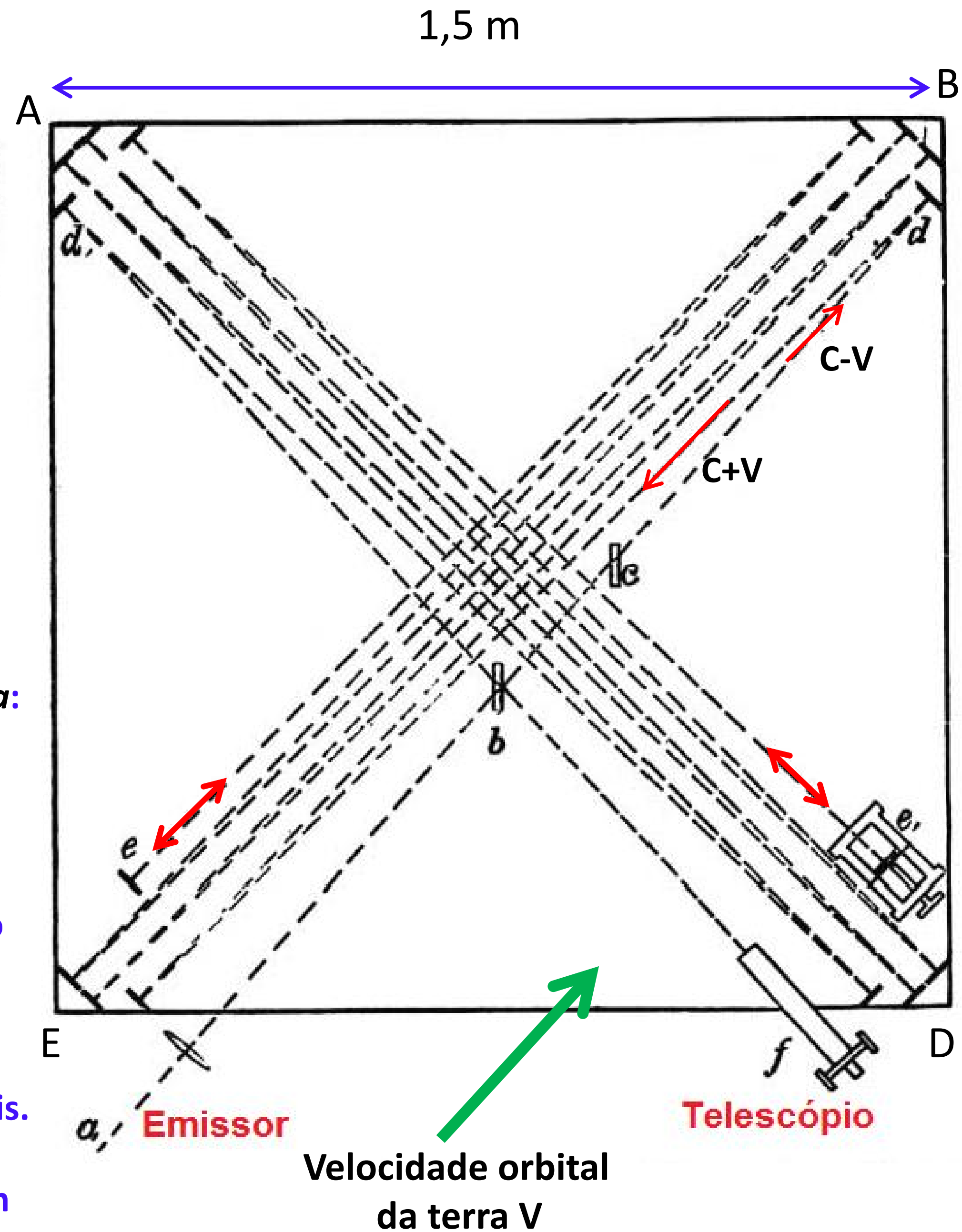
$\mathbf{t_{AB} > t_{BA}}$



O Experimento de Michelson e Morley (1881)







- Espelho semitransparente: ***b***
- Na direção E ↔ B a luz tem velocidade C+V e C-V

- **Caminhos ópticos percorridos pela luz emitida em *a*:**

  $bd_1e_1d_1bf$ **e** $bdedbf$

- **Comprimento da diagonal do quadrado = 2,1 m**

- **Comprimento percorrido pela luz em cada braço do interferômetro= 16*2,1 m = 33,6 m**

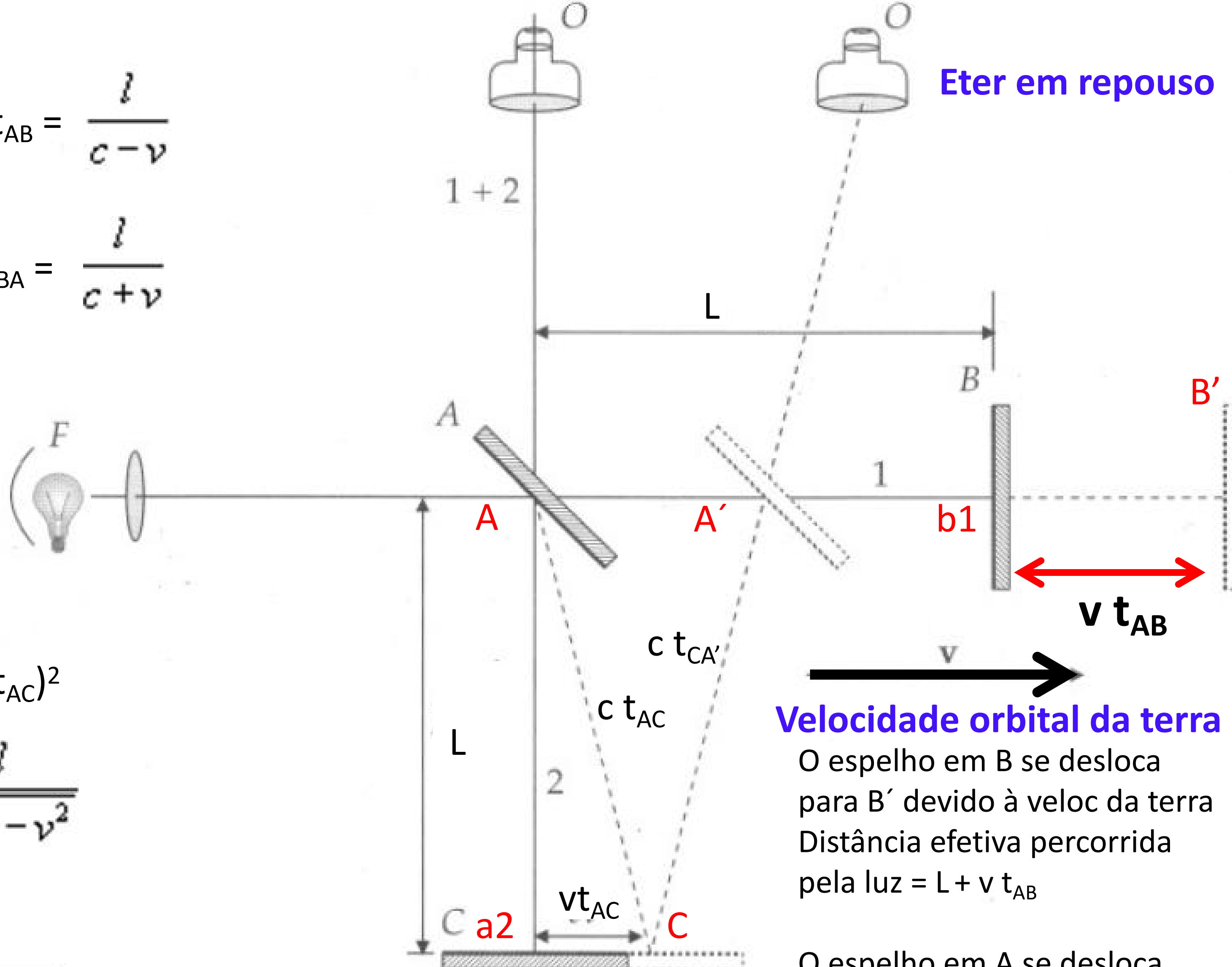
- **Os espelhos e_1 e e retornam a luz pelo mesmo caminho. Os dois caminhos têm comprimentos iguais.**

- **Inicialmente os caminhos ópticos são iguais porém um deles pode ser alterado deslocando o espelho e_1**

$$L + v\, t_{AB} = c\, t_{AB} \;;\quad t_{AB} = \frac{l}{c-v}$$

$$L - v\, t_{BA} = c\, t_{BA} \;;\quad t_{BA} = \frac{l}{c+v}$$

$$\mathbf{t_{AB} > t_{BA}}$$



Eter em repouso

$$L^2 + (v\, t_{AC})^2 = (c\, t_{AC})^2$$

$$t_{AC} = \frac{l}{\sqrt{c^2 - v^2}}$$

$$t_{CA'} = \frac{l}{\sqrt{c^2 - v^2}}$$

$$t_{AC} = t_{CA'}$$

Velocidade orbital da terra

O espelho em B se desloca para B´ devido à veloc da terra Distância efetiva percorrida pela luz = $L + v\, t_{AB}$

O espelho em A se desloca para A´ devido à veloc da terra Distância efetiva percorrida pela luz = $L - v\, t_{AB}$

$$\Delta t \approx (t_{AB} + t_{BA}) - (t_{AC} + t_{CA})$$

$$\Delta t = \left(\frac{l}{c-v} + \frac{l}{c+v}\right) - \left(\frac{l}{\sqrt{c^2 - v^2}} + \frac{l}{\sqrt{c^2 - v^2}}\right) \Rightarrow \boxed{\Delta t \approx \frac{lv^2}{c^3}} \quad \text{Eq 2}$$

Para demonstrar a Eq. 2 usar a aproximação : Se $x = (v/c)^m << 1$, $(1+x^m)^{-n} = 1-nx^m$

$L/(c-v) = (1+v/c)L/c$; $L/(c+v) = (1-v/c)L/c$; $L/(c^2-v^2)^{0.5} = [1+1/2(v/c)^2]L/c$;

$$\Delta d = c\Delta t$$ diferença de caminhos ópticos

Quantidade de comprimentos de ondas em $\Delta d = \frac{\Delta d}{\lambda} = \frac{lv^2}{\lambda c^2} = 0,22$

- **O Interferômetro que Michelson e Morley desenvolveram podia medir deslocamentos das linhas de interferência da ordem de 0,01 ! Porém nada foi observado.**
- **Qual o menor comprimento que podemos medir usando o nosso interferômetro?**

Formação de anéis de interferência

$$y = a_1 \sin(\omega t - \alpha_1) + a_2 \sin(\omega t - \alpha_2)$$

$$y = A \sin(\omega t - \delta)$$

$$A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\delta \quad .....(1)$$

$$\delta = \alpha_1 - \alpha_2$$

2π — λ

δ — $2d\cos\theta$

$$\Rightarrow \quad \delta = \frac{2\pi}{\lambda} 2d.\cos\theta$$

$$a_1 = a_2 = a \quad ....(2)$$

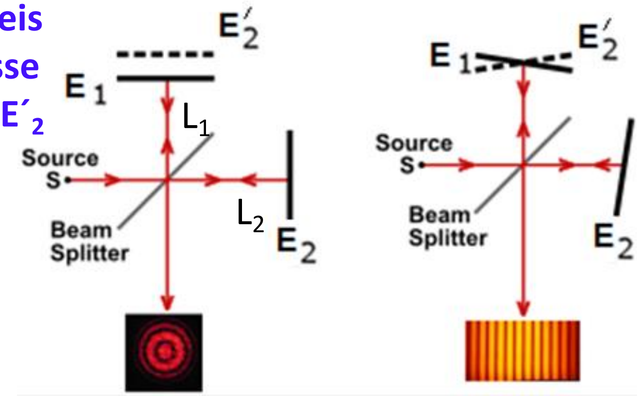
(2) em (1): $I \approx A^2 = 4.a^2.\cos^2\frac{\delta}{2}$

***I* será max quando :** $\delta = 2\pi m$

$$2.d.\cos\theta = m.\lambda \quad ; \quad m = 1, 2, \ldots$$

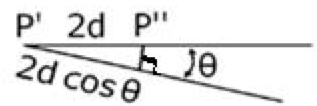
A formação dos aneis é como se as fontes de luz fossem virtuais em S'_1 e S'_2

A formação dos aneis é como se houvesse dois espelhos E_1 e E'_2

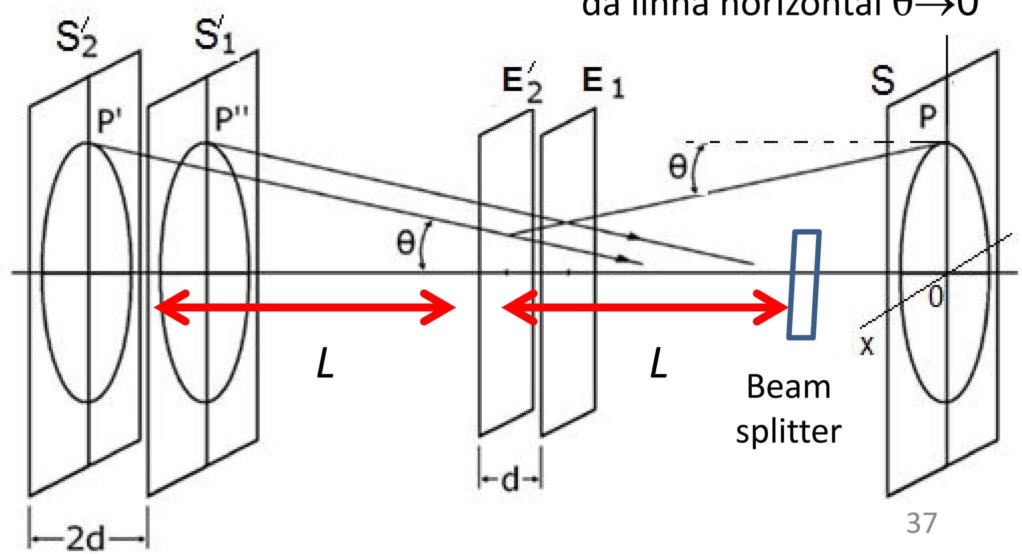


Se $L_2 > L_1$

$d = L_2 - L_1$

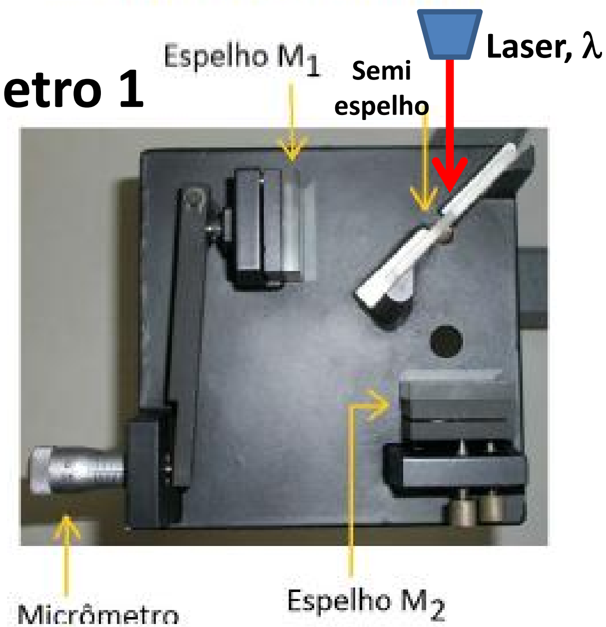


Quando P está perto da linha horizontal $\theta \to 0$



Fotografia da montagem experimental.

Interferômetro 1



esquema de espelho do interferômetro.

Sabemos que: $2d \cos\theta = m\lambda$

Quando $\theta \approx 0^o \rightarrow \cos\theta \approx 1$

$\rightarrow \quad 2d \approx m\lambda$

$\lambda \approx 2d/m$

m= número de anéis observados

OBS: No interferômetro 1 fazer:
d= leitura do micrômetro/10

-No interferômetro 2 fazer:
d= leitura do micrômetro/20

Contar a formação de m=200 anéis e determinar o valor da leitura do micrômetro, então determinar λ

Interferômetro 2