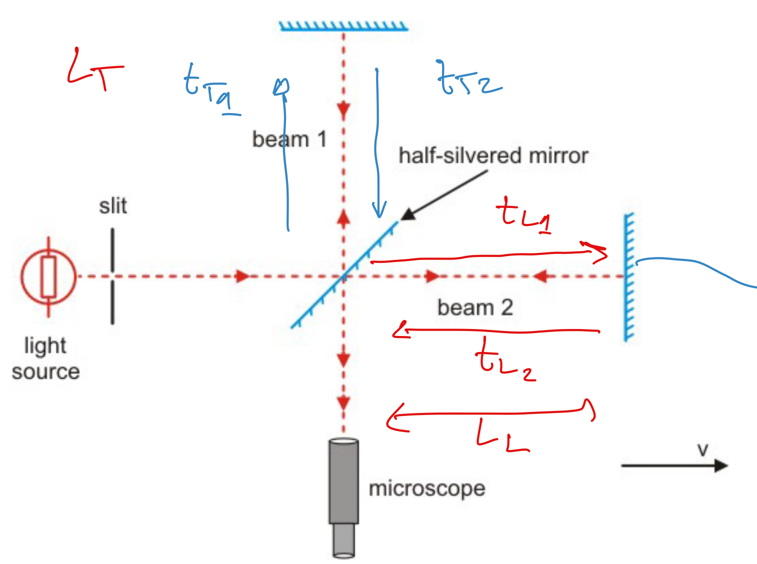
TOKEN 393683

$E^2 = p^2 + m^2$

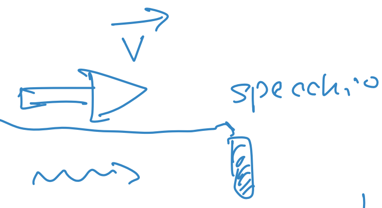
Michelson-Morley 1887

Galileo $\vec{v} = \vec{v}' + \vec{V}_0$



$t_T = t_{T1} + t_{T2}$

tempo trasversale



$t_{L1} = \dfrac{L}{c-V}$

$t_{L2} = \dfrac{L}{c+V}$

$t_{L,tot} = \dfrac{2L}{c}\dfrac{1}{1-V^2/c^2}$

Note: the actual interference pattern will most probably be more irregular and show less fringes.

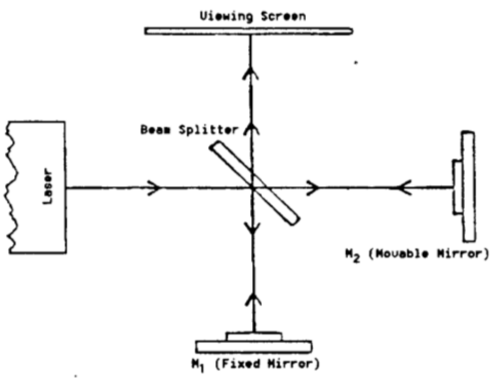
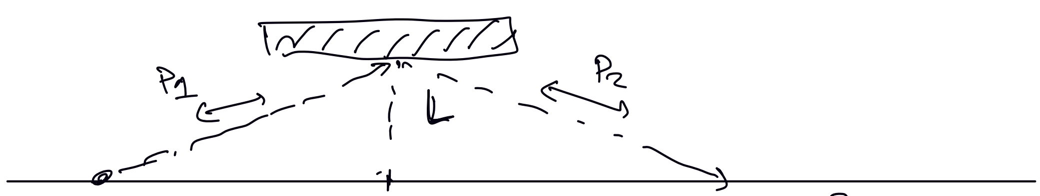


Figure 1: Michelson Interferometer

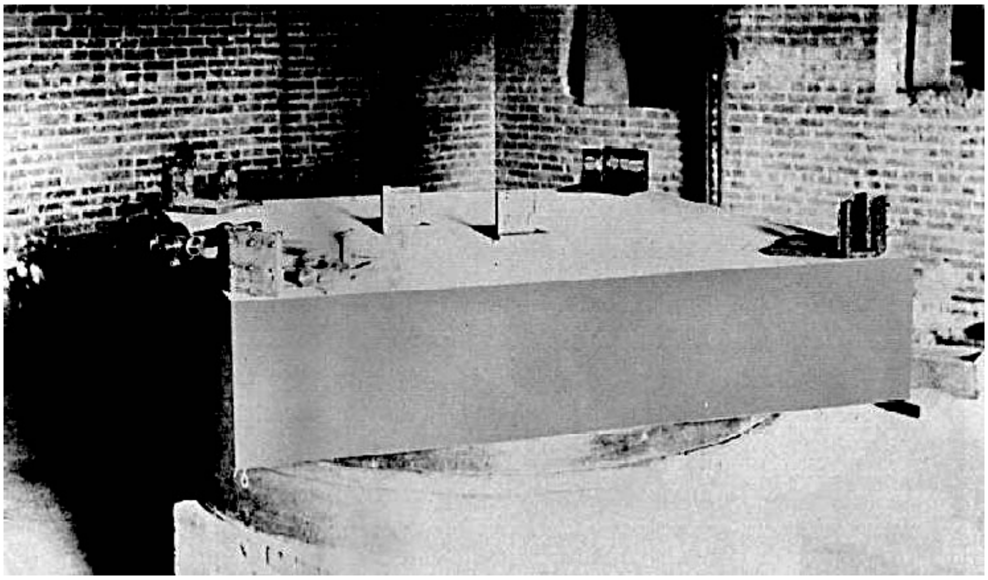
Figure 2: Interference Pattern
Note: the actual interference pattern will most probably be more irregular and show less fringes.



$P_1^2 = (V t_{T1})^2 + L^2$ $\quad$ $P_2^2 = (V t_{T2})^2 + L^2$

$$t_T = t_{T_1} + t_{T_2} = \frac{2L}{c} \frac{1}{\sqrt{1-v^2/c^2}}$$

$$t_T = \frac{2L}{c} \frac{1}{\sqrt{1-v^2/c^2}} \overset{?}{\underset{X}{=}} \frac{2L}{c} \frac{1}{1-v^2/c^2} = t_{L_1}.$$



Aspettativo: spostamento fino a 0.4 riga

osservato: spost medio 0.01

dev. max 0.02

$$\frac{2L_L}{c} \frac{1}{\underline{1-v^2/c^2}} = \frac{2L_T}{c} \frac{1}{\sqrt{1-v^2/c^2}}$$
$$(\sqrt{1-v^2/c^2})^2$$

$$2 \quad \frac{L_L}{\sqrt{1-v^2/c^2}} = L_T$$

$$(1+\varepsilon)^n = 1 + n\varepsilon$$

$$\underline{x} = (t, \vec{x})$$

$E = ?$ $\quad \vec{p} = ?$

tutti sistemi inerziali: $\quad S \equiv \int_{t_1}^{t_2} L\, dt$

$$L = L(\vec{x}, \vec{v}, t) \qquad L(q, \dot{q}, t)$$

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}} = \frac{\partial L}{\partial q}$$

$$\underline{dx} = (dt, d\vec{x})$$
$$dx' = (d\tau, \vec{0})$$

inv. rispetto al tempo
$$L = L(\vec{x}, \vec{v})$$

inv. trasl. spaziale $\Rightarrow$ $L = L(\vec{v})$

inv. per isotropia $\Rightarrow$ $L = L(|\vec{v}|)$

$$S = \int_{\tau_1}^{\tau_2} A\, d\tau = \int_{t_1}^{t_2} L\, dt$$

(inv. nei sist inerziale)

$$dt = \gamma\, d\tau$$

$$= \int \frac{A}{\gamma} dt = \int L\, dt$$

L part. libera non relat. $\quad L = \frac{1}{2} m v^2$

$$\lim_{v \to 0} \frac{A}{\gamma} = \lim_{v \to 0} A\sqrt{1 - v^2/c^2} \simeq A\left(1 - \frac{1}{2}\frac{v^2}{c^2}\right)$$

$$\Rightarrow \frac{1}{2} m v^2 = A - \frac{A}{2}\frac{v^2}{c^2}$$

$$\frac{1}{\cancel{2}} m \cancel{v^2} = -\frac{A}{\cancel{2}}\frac{\cancel{v^2}}{c^2} \Rightarrow A = -mc^2$$

$$L = -mc^2\sqrt{1-v^2/c^2} \qquad \dot{x}_i = v_i$$

$$\vec{p}_i = \frac{\partial L}{\partial \dot{x}_i} = \cancel{-}m\cancel{c^2}\frac{1}{\cancel{2}\sqrt{1-v^2/c^2}}(\cancel{-}\cancel{2}v_i/\cancel{c^2})$$

$$= \gamma m v_i$$

$$\vec{p} = \gamma m \vec{v}$$

$$E = \sum_i p_i \dot{x}_i - L = \gamma m v^2 - \left(-\frac{mc^2}{\gamma}\right)$$

$$= \gamma m c^2\left(\frac{v^2}{c^2} + \frac{1}{\gamma^2}\right)$$

$$= \gamma m c^2\left(\cancel{\frac{v^2}{c^2}} + 1 - \cancel{\frac{v^2}{c^2}}\right) = \gamma m c^2$$

$$\underline{P} = \left(\frac{E}{c}, \vec{p}\right) = (\gamma m c, \gamma m \vec{v})$$

$$\underline{P}\cdot\underline{P} = |\underline{P}|^2 = \left(\frac{E}{c}\right)^2 - p^2 = m^2c^2$$

$$E^2 = p^2c^2 + m^2c^4$$

$c = 1$ $\qquad E^2 = p^2 + m^2$

$$\underline{P}\cdot\underline{P} = m^2$$

massa a riposo
massa particella libera
massa invariante.

limite non relativ.

$\lim_{v\to 0}$

$p \to 0$

$$E = \sqrt{p^2+m^2} = m\sqrt{1+\frac{p^2}{m^2}} \simeq \left(1+\frac{1}{2}\frac{p^2}{m^2}\right)m$$

$$= m + \frac{1}{2}\frac{p^2}{m}$$

massa a riposo

Definizione en. cinetica: $K = E - m$

$$K = E - m = \gamma m - m = (\gamma - 1) m$$

$$\gamma = \frac{E}{m}$$

$$\vec{p} = \gamma m \vec{v} = \gamma m \underbrace{\frac{\vec{v}}{c}}_{\beta} c = \gamma \beta m c = p$$

$$\frac{p}{E} = \beta$$

Quadrivelocità

$$u_\mu = \left(\frac{dt}{d\tau}, \frac{d\vec{x}}{d\tau} \right) = (\gamma c, \gamma \vec{v}) \qquad \underline{u} = \frac{dx}{d\tau}$$

$$\underline{p} = m \underline{u} \qquad \frac{E}{mc} \qquad \frac{\vec{p}}{m}$$

perché $\underline{p} = \left(\frac{E}{c}, \vec{p} \right)$ è un quadrivettore?

$$E^2 = p^2 + m^2 \implies E = \pm \sqrt{p^2 + m^2}$$

$$\vec{p} \longrightarrow -i \vec{\nabla}$$

$$E \longrightarrow i \frac{\partial}{\partial t}$$

$$-\frac{\partial^2}{\partial t^2} \psi = (-\nabla^2 + m^2) \psi \qquad \psi(\vec{x}, t)$$

$$\left(\frac{\partial^2}{\partial t^2} - \nabla^2 + m^2 \right) \psi = 0 \qquad \partial_\mu = (\partial_t, \vec{\nabla})$$

$$(\Box^2 + m^2) \psi = 0$$

Eq. Klein-Gordon
part. scal. pseudoscal.

$(i\gamma^\mu\partial_\mu - m)\psi = 0$ $\qquad (i\not{\partial} - m)\psi = 0.$

Eq. di Dirac per fermioni

γ^μ: 4 matrici di Dirac 4×4

soluzione negative per $E \Rightarrow$ esistenza anti-particelle.

$e^- \longrightarrow e^+$ positrone

$p \longrightarrow \bar{p}$ antiprotone.

mecc. classica

$E = \frac{1}{2} m v^2 \qquad m \to 0, \; E \to 0$

$\underline{P} = (\gamma m c, \gamma m \vec{v})$

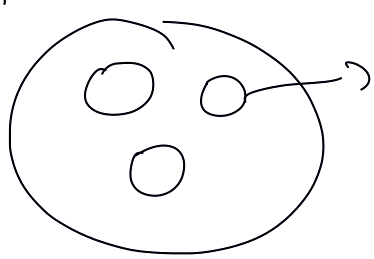
$$\frac{m}{\sqrt{1 - v^2/c^2}} \qquad \begin{matrix} m \to 0 \\ v \to c \end{matrix} \qquad \frac{0}{0}$$

$E^2 = p^2 + m^2$

$m \to 0 \Rightarrow E = p$

mecc. relativ. $M = 0$ $\quad \underline{P} = (\underset{E}{\underset{\shortparallel}{p}}, \vec{p})$

protone



quark. $\Delta x \simeq 10^{-18}$ m

$\begin{pmatrix} up \\ down \end{pmatrix} \begin{pmatrix} charm \\ strange \end{pmatrix} \begin{pmatrix} top \\ bottom \end{pmatrix}$ 6 quark.

sapori diversi

$\times$ 3 colori diversi

barioni: $q_1 q_2 q_3$ protone, neutrone.

mesoni: $q_1 \bar{q}_2$

numero quantico.

u colore rosso
verde
blu

$q = +\frac{2}{3}$ $\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$

$q = -\frac{1}{3}$

quark: masse
carica elettrica.
spin.
colore
sapore

$q = +\frac{1}{3}$ $\begin{pmatrix} \bar{d} \\ \bar{u} \end{pmatrix} \begin{pmatrix} \bar{s} \\ \bar{c} \end{pmatrix} \begin{pmatrix} \bar{b} \\ \bar{t} \end{pmatrix}$

$q = -\frac{2}{3}$

pione, mesone di quark u, d

π^+ $(u\bar{d})$ $q = +1$.

π^- $(\bar{u}d)$

protone $q = 1$
(uud)

neutrone $q = 0$
(udd)

particelle composte da quark: adroni

Interazioni: EM, forte, debole

Leptoni: $\begin{pmatrix} e^- \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau^- \\ \nu_\tau \end{pmatrix}$ $q = -1$
$q = \emptyset$

EM
debole
non forte.

leptoni: fermioni $s = \frac{1}{2}$

$m_e \simeq 0.5$ MeV

$m_\mu \simeq 106$ MeV

$m_\tau \simeq 1.8$ GeV