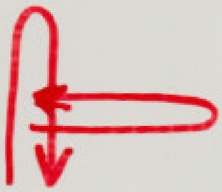


ABA: "$\perp$"

ACA: "$\parallel$"

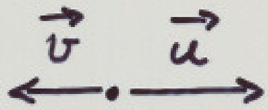
· STILL WATER ·

Time ABA: $T_{\perp}(\text{still}) = \frac{2L}{u}$

Time ACA: $T_{\parallel}(\text{still}) = \frac{2L}{u}$

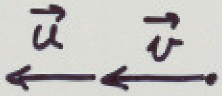
$T_{\parallel}$:

AC...



$$V^{R}_{Ground} = u - v$$

CA...



$$V^{L}_{Ground} = u + v$$

ROUND TRIP

$$T_{\parallel} = \frac{L}{V_G^R} + \frac{L}{V_G^L} = \frac{L}{u-v} + \frac{L}{u+v}$$

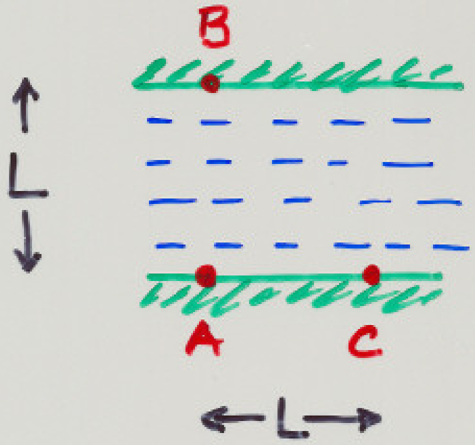
$$T_{\parallel} = \frac{2L}{u} \frac{1}{1 - v^2/u^2}$$

and

$$T_{\perp} = \frac{2L}{u} \frac{1}{\sqrt{1 - v^2/u^2}}$$

show D2

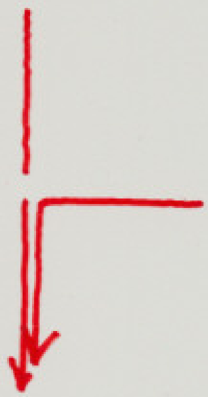
THE (CLEVER) IDEA...



SWIMMERS EACH CAPABLE OF

u

RELATIVE TO WATER

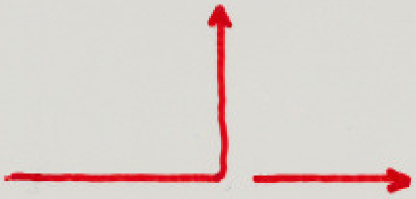


← allow them to interfere

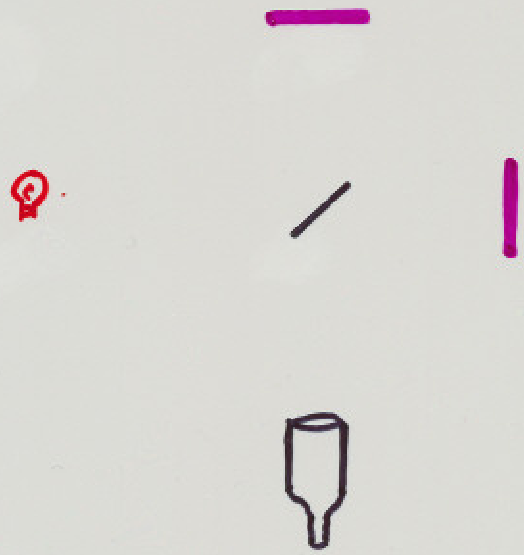
EXPECT A FRINGE PATTERN

w/ ~ 0.37 FRINGE SHIFT

... could detect ~ $\frac{1}{100}$ of FRINGE



MICHELSON MORLEY IDEA:



$u \sim c$

$v \sim$ velocity of ether wind

$$T_{\parallel} - T_{\perp} = \frac{2L}{c} \frac{1}{1 - v^2/c^2} - \frac{2L}{c} \frac{1}{\sqrt{1 - v^2/c^2}}$$

$v_e \sim 3 \times 10^4$ m/s $\qquad c = 3 \times 10^8$ m/s

$v_e/c \sim 10^{-4}$

$$\frac{1}{1 - v^2/c^2} \simeq 1 + v^2/c^2 - \cdots$$

$$\frac{1}{\sqrt{\quad}} \simeq 1 + \tfrac{1}{2} v^2/c^2 + \cdots$$

$T_{\parallel} - T_{\perp} \sim \frac{L}{c}\left(\frac{v^2}{c^2}\right)$ TINY for reasonable L

$\Delta t \sim 10^{-16}$ s for their apparatus

... letting 2 beams ($\perp$ & $\parallel$) interfere ..

that 10^{-16} s is fair fraction of wavelength

→ fringes

THE ANSWER:

ϕ

zero

zip

nada

earth drags ether? ... like still water ... ?

stellar aberration undisputed...

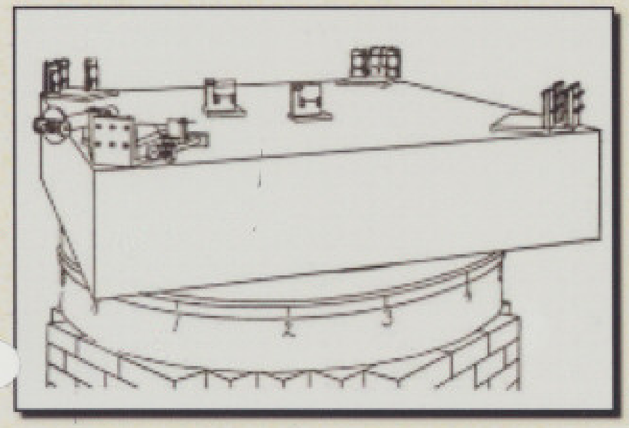
• A BIG PROBLEM •

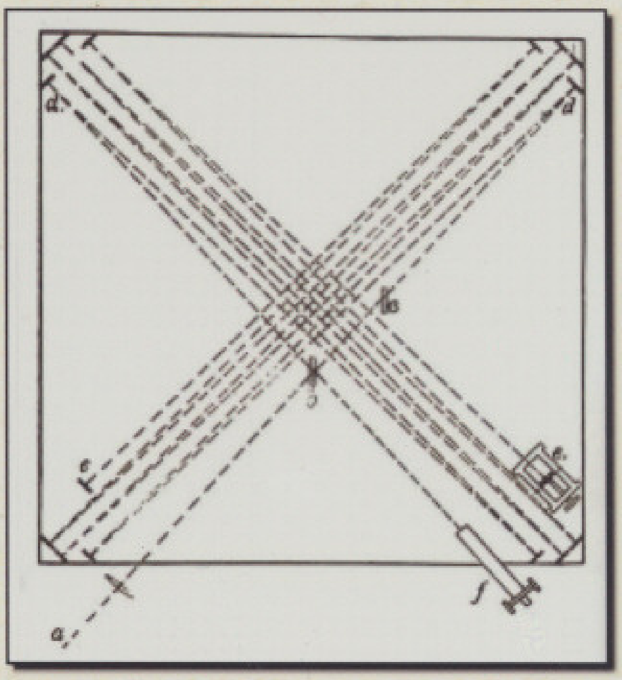
Michelson and Morley's experiment

AIP http://www.aip.org/history/einstein/ae20.htm

michels

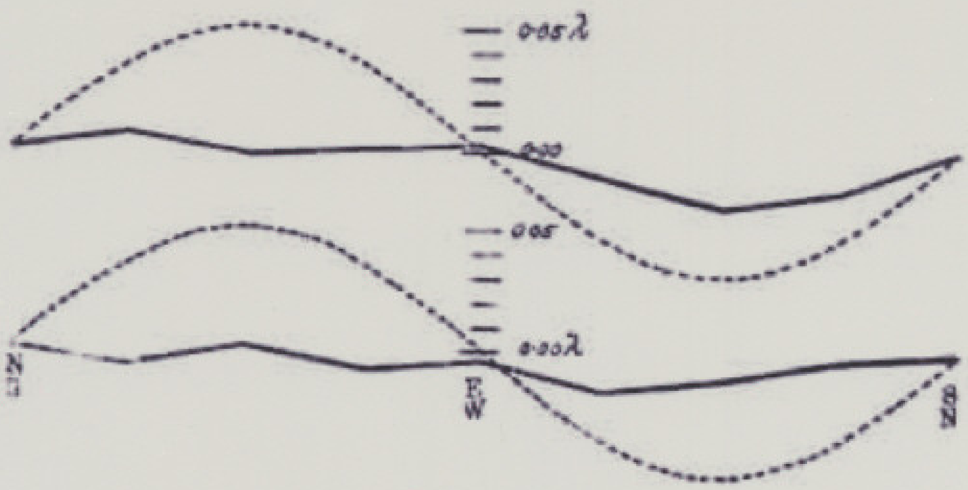
el.icio.us DOE/NSF Lebanese basecamp SAM Grid capTwiki Pretty Planet Po





The results of the observations are expressed graphically in fig. 6. The upper is the curve for the observations at noon, and the lower that for the evening observations. The dotted curves represent *one-eighth* of the theoretical displacements. It seems fair to conclude from the figure that if there is any dis-

6.



placement due to the relative motion of the earth and the luminiferous ether, this cannot be much greater than 0·01 of the distance between the fringes.

Considering the motion of the earth in its orbit only, this

A WAY OUT?

George Fitzgerald & Lorentz independently came to the same DESPERATE suggestion:

SUPPOSE THE ∥ ARM SHRUNK ALONG THE ETHER WIND DIRECTION BY:

$$L(\text{along } v) = L(\perp)\sqrt{1 - v^2/c^2}$$

THEN:

$$T_{\parallel} - T_{\perp} = \frac{2L_{\parallel}}{c}\frac{1}{(1 - v^2/c^2)} - \frac{2L_{\perp}}{c}\frac{1}{\sqrt{1 - v^2/c^2}}$$

$$\rightarrow \frac{2L_{\perp}\sqrt{1 - v^2/c^2}}{(1 - v^2/c^2)} - \frac{2L_{\perp}}{c}\frac{1}{\sqrt{1 - v^2/c^2}}$$

$$= 0$$

THEY MEANT... really, physically SHRUNK...

"Lorentz-Fitzgerald Contraction" 1899

nope.

40

da' Man

The Great Works I

"A storm broke loose in my mind."

March 1905

Light quanta.

Einstein *in the patent office*.

Einstein discovered light quanta by pondering experiments on particles discovered only a few years earlier. See our Web exhibit, The Discovery of the Electron.

Einstein sent to the *Annalen der Physik*, the leading German physics journal, a paper with a new understanding of the structure of light. He argued that light can act as though it consists of discrete, independent particles of energy, in some ways like the particles of a gas. A few years before, Max Planck's work had contained the first suggestion of a discreteness in energy, but Einstein went far beyond this. His revolutionary proposal seemed to contradict the universally accepted theory that light consists of smoothly oscillating electromagnetic waves. But Einstein showed that light quanta, as he called the particles of energy, could help to explain phenomena being studied by experimental physicists. For example, he made clear how light ejects electrons from metals.

May 1905

Brownian Motion

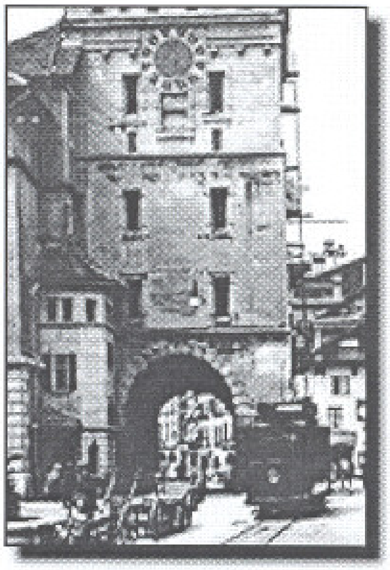
The *Annalen der Physik* received another paper from Einstein. The well-known kinetic energy theory explained heat as an effect of the ceaseless agitated motion of atoms; Einstein proposed a way to put the theory to a new and crucial experimental test. If tiny but visible particles were suspended in a liquid, he said, the irregular bombardment by the liquid's invisible atoms should cause the suspended particles to carry out a random jittering dance. Just such a random dance of microscopic particles had long since been observed by biologists (It was called "Brownian motion," an unsolved mystery). Now Einstein had explained the motion in detail. He had reinforced the kinetic theory, and he had created a powerful new tool for studying the movement of atoms.

"When the Special Theory of Relativity began to germinate in me, I was visited by all sorts of nervous conflicts... I used to go away for weeks in a state of confusion."

June 1905

Relativity

Einstein sent the *Annalen der Physik* a paper on electromagnetism and motion. Since the time of Galileo and Newton, physicists had known that laboratory measurements of mechanical processes could never show any difference between an apparatus at rest and an apparatus moving at constant speed in a straight line. Objects behave the same way on a uniformly moving ship as on a ship at the dock; this is called the Principle of Relativity. But according to the electromagnetic theory, developed by Maxwell and refined by Lorentz, light should not obey this principle. Their electromagnetic theory predicted that measurements on the velocity of light would show the effects of motion. Yet no such effect had been detected in any of the ingenious and delicate experiments that physicists had devised: the velocity of light did not vary.



Time and motion: the old clock tower and an electrified trolley in Bern.

Einstein had long been convinced that the Principle of Relativity must apply to all phenomena, mechanical or not. Now he found a way to show that this principle was compatible with electromagnetic theory after all. As Einstein later remarked, reconciling these seemingly incompatible ideas required "only" a new and more careful consideration of the concept of time. His new theory, later called the special theory of relativity, was based on a novel analysis of space and time -- an analysis so clear and revealing that it can be understood by beginning science students.

September 1905

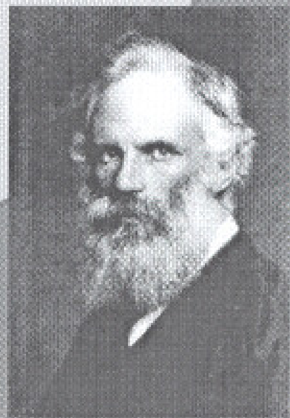
mc^2

Einstein reported a remarkable consequence of his special theory of relativity: if a body emits a certain amount of energy, then the mass of that body must decrease by a proportionate amount. Meanwhile he wrote a friend, "The relativity principle in connection with the Maxwell equations demands that the mass is a direct measure for the energy contained in bodies; light transfers mass... This thought is amusing and infectious, but I cannot possibly know whether the good Lord does not laugh at it and has led me up the garden path." Einstein and many others were soon convinced of its truth. The relationship is expressed as an equation: $E=mc^2$.

George Francis FitzGerald in correspondence with Lorentz who had just learned of his length-contraction idea, 1894

"

[my paper was submitted to Science]…but I do not know if they ever published it…I am pretty sure that your publication is prior to any of my printed publications…[he was delighted to hear of Lorentz's agreement'…for I have been rather laughed at for my view over here.



THE RELATIVITY PAPER IS AN INTERESTING APPROACH

POSTULATES

⇒ purely deductive

1. The laws of physics retain their form for all inertial rest frames – all laws of physics, mechanics and electromagnetism

→ same equations, same "laws"

• the physics is the same •

2. The speed of light is always propagated in empty space with the same velocity, c, which is independent of any rest frame if inertial

whoa.

$$= v T_e/2$$

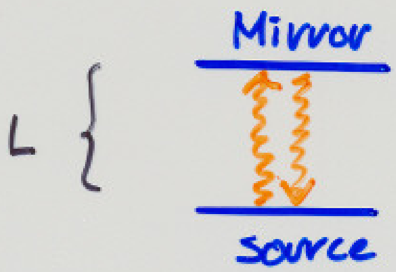
$$T_e = \frac{2l}{c_e}$$

$$l^2 = L^2 + d^2$$

$$T_e = \frac{2L}{c_e} \frac{1}{\sqrt{1 - v^2/c_e^2}}$$

GO BACK TO MM SETUP... the ⊥ path:

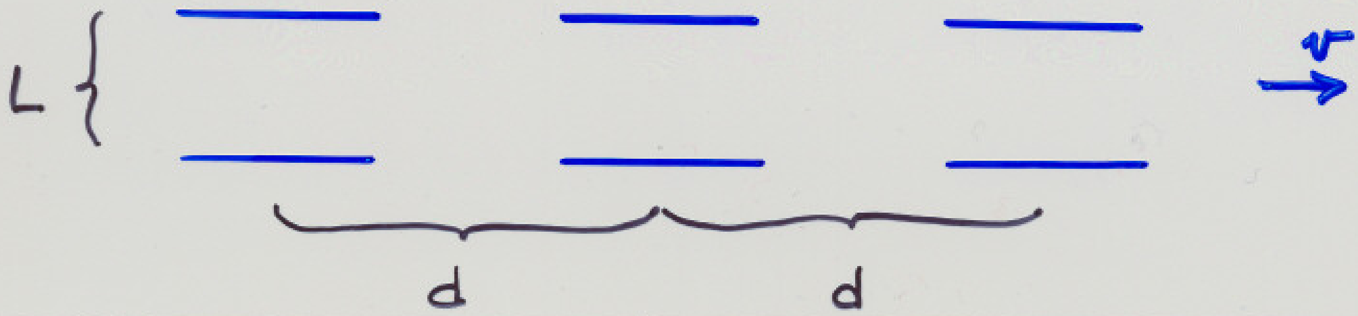
IN THE MM REST FRAME:



RT: $T_{MM} = \frac{2L}{c_{MM}}$

speed of light in MM frame

IN THE ETHER REST FRAME:



Pre-Einstein...

$$T_e = T_{MM}$$

$$\frac{2L}{c_e}\frac{1}{\sqrt{1-v^2/c_e^2}} = \frac{2L}{c_{MM}}$$

$$c_{MM} = c_e\sqrt{1-v^2/c_e^2}$$

Post-Einstein...

$$c_{MM} = c_e \equiv c$$

then:

$$T_{MM} = \frac{2L}{c}$$

$$T_e = \frac{2L}{c}\frac{1}{\sqrt{1-v^2/c^2}}$$

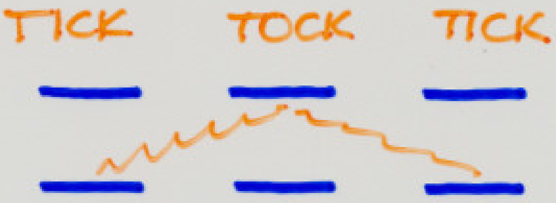
same c (P#2)

so:

$$T_{MM} \neq T_e$$

$$T_e = T_{MM}\frac{1}{\sqrt{1-v^2/c^2}} = T_{MM}\,\gamma$$

THIS THING... *is a clock*



T_e

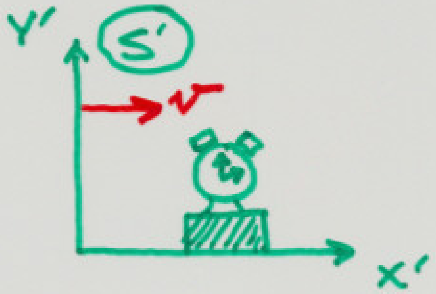
T_{MM}

$T_e > T_{MM}$

TIME INSIDE OF THE "CLOCK'S" REST FRAME

TIME AS VIEWED FROM A FRAME... watching the clock go by

THE CLOCK GOING BY RUNS S L O W E R

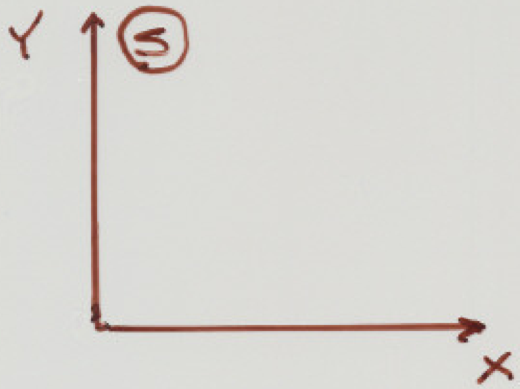


clock at rest in (S')

Δt for a clock in its own rest frame called

PROPER TIME → Δt_0

CALLED "TIME DILATATION"



$$T = \gamma T'$$

HE THOUGHT DEEPLY ABOUT THINGS..

→ WHAT DOES IT MEAN TO SAY

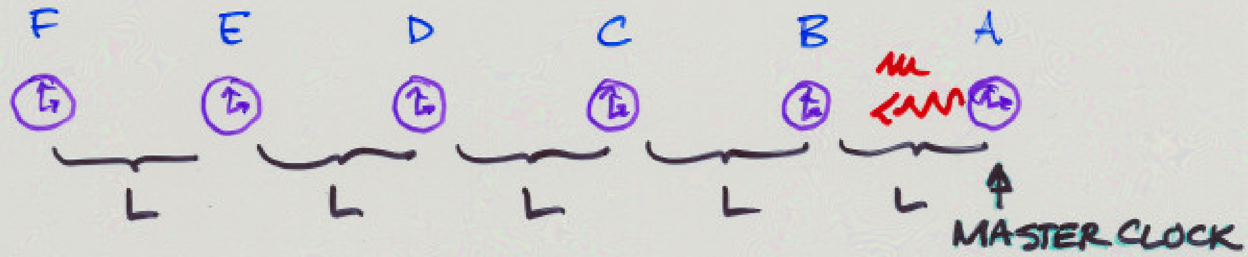
THAT A PARTICULAR EVENT

HAPPENS

AT A PARTICULAR TIME?

→ SIMULTANEOUS THINGS

HOW TO SYNCHRONIZE CLOCKS?



Master clock sends a signal, m, to B...

who knows that after it's received

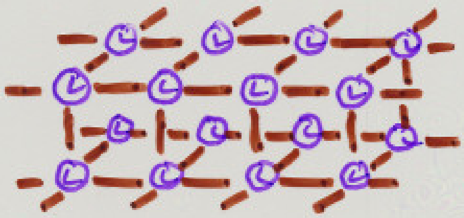
$t_{AB} = \frac{v}{L}$ time elapsed

and so on... → use light as m.

BY CALCULATION... synchronization

an observer @ B can determine if 2 events... D & A ?... happen simultaneously

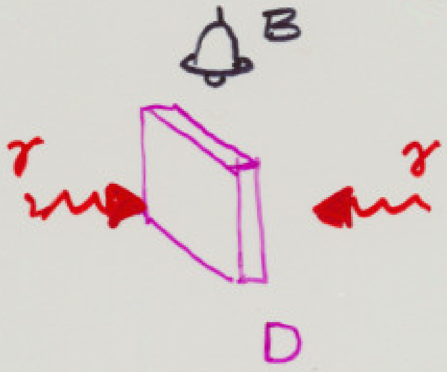
A REST FRAME FOR US...



A GRID OF CLOCKS & METER STICKS

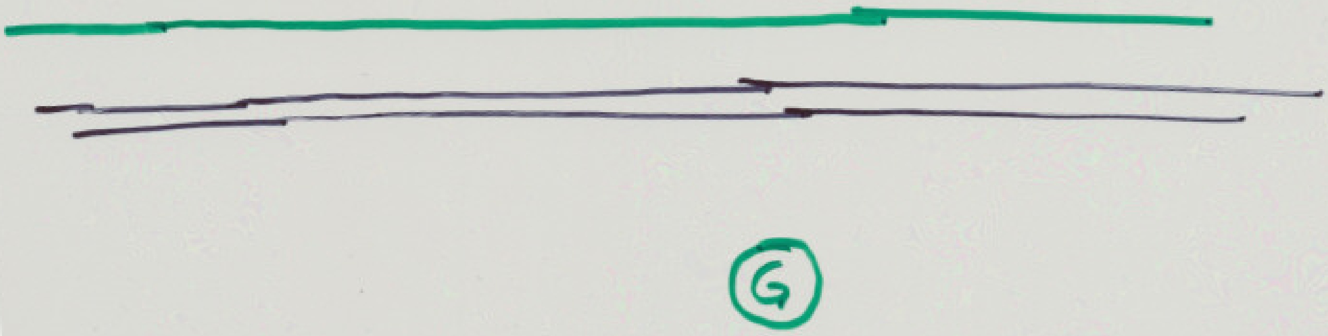
HERE'S THE RUB:

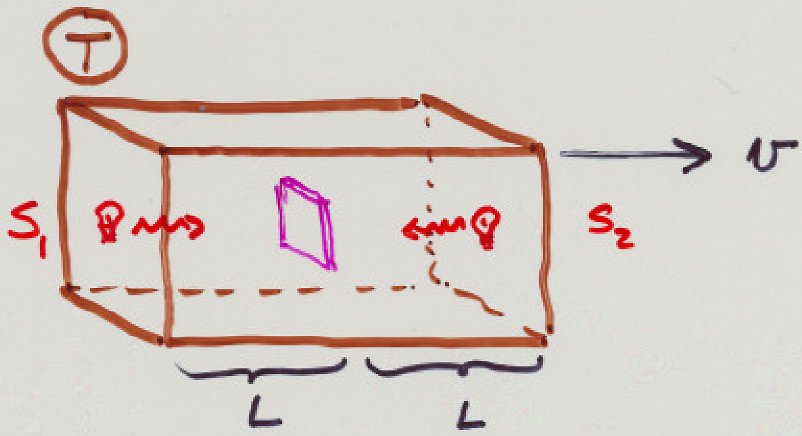
imagine a device :



if struck on both sides → Bell rings

• BELL RINGS OR IT DOESN'T •

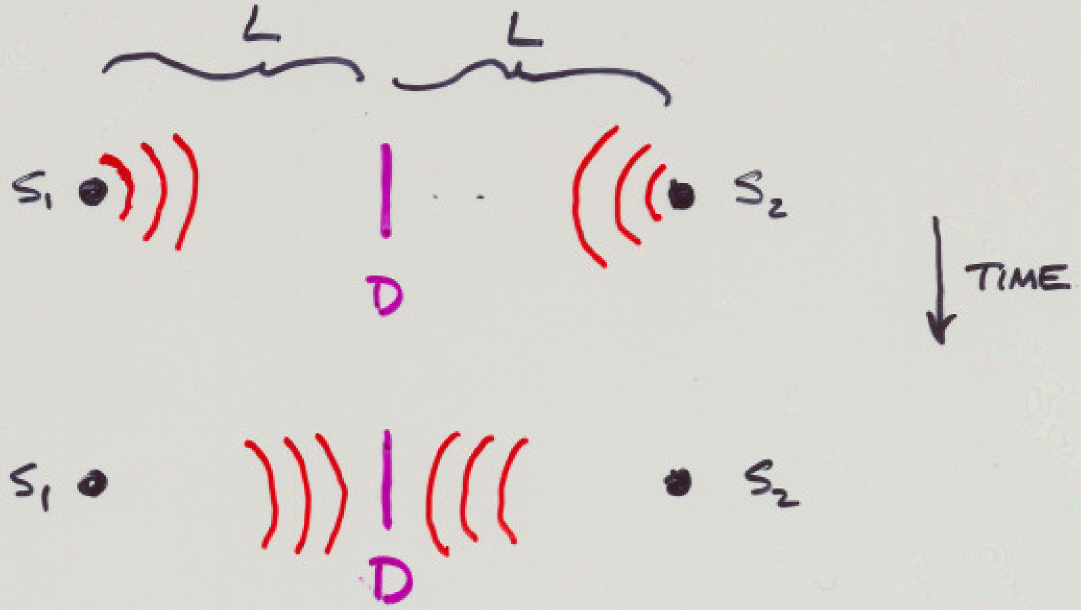




inside Ⓣ operator causes S_1 and S_2 to emit light simultaneosly

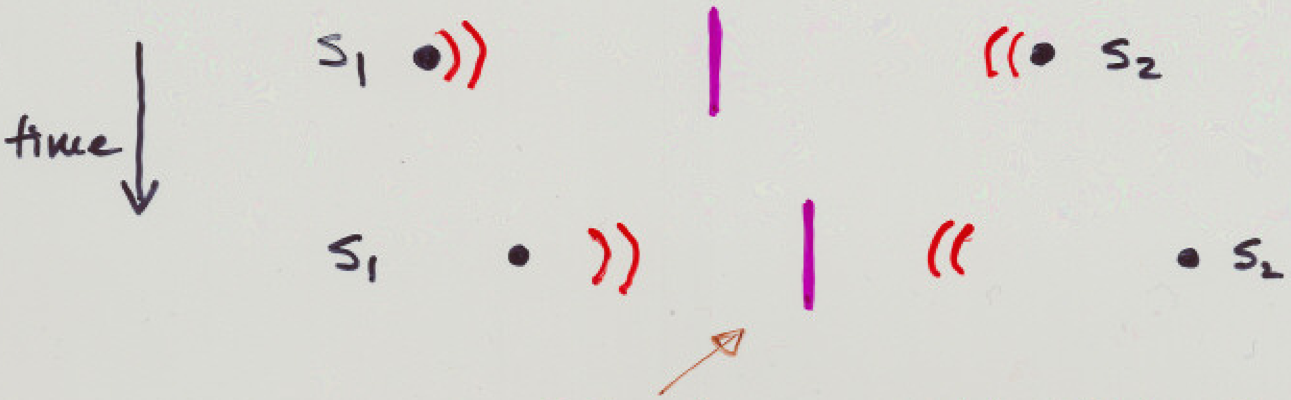
WHICH RINGS THE BELL AFTER $t = \frac{c}{L}$

IN (T):



IN (G): THE BELL RINGS... SO LIGHT BEAMS DO REACH D AT SAME TIME

BUT



SCREEN MOVED AWAY FROM S₁ IN (T)

&

TOWARD S₂

BBB_UT, YOU SPUTTER...

NOW, S_1 HAS TO TRAVEL FARTHER

AND S_2 HAS TO TRAVEL SHORTER

THAN L.

THEY TRAVEL DIFFERENT DISTANCES

BUT REACH D TOGETHER

THEY HAVE TO HAVE LEFT AT DIFFERENT TIMES... BECAUSE THEY BOTH HAVE SPEEDS OF C.

IN Ⓣ: S_1 & S_2 EMITTED SIMULTANEOUSLY

IN Ⓖ: S_1 & S_2 ARE NOT SIMULTANEOUS

THE VERY CONCEPT OF SIMULTANEITY IS

RELATIVE

to your state of motion...