1. Special Relativity, 3

lecture 4, September 6, 2017

housekeeping

remember to check the course page:

chipbrock.org

and sign up for the feedburner reminders

I've appropriated an old ftp area for this semester:

https://qstbb.pa.msu.edu/storage/PHY215/

here you'll find lecture pdfs and homework solutions

and any additional homework beyond the books

testing, testing:

someone please go to the syllabus and create a fake pdf according to the instructions and then try to upload it to the dropbox in the D2L site. Let me know friday. Okay?

Question: Mon or Tue?

review:

The “Michelson Morley Experiment” in 1897 and again in 1904, showed no measurable relative motion between the earth and the ether

- Michelson had trouble with this
- Lorentz and Fitzgerald showed that if the measuring device physically shrank along the direction of motion, the experimental results would be explained

Einstein began to suspect that Maxwell’s description of light contained paradoxes.

Everyone believed that Newton’s Laws were invariant with respect to differences between co-moving, inertial reference frames

- Galilean Transformations: $x_H = x_A + ut$
- a statement about the physics of mechanics not changing

What about Maxwell’s equations and Galilean Transformations?

- notsomuch.

F

who’s invariant to G.T.’s?

Newton’s equations **are**

Maxwell’s equations are **not**

This is where Special Relativity really begins:

problems with electromagnetism and invariance

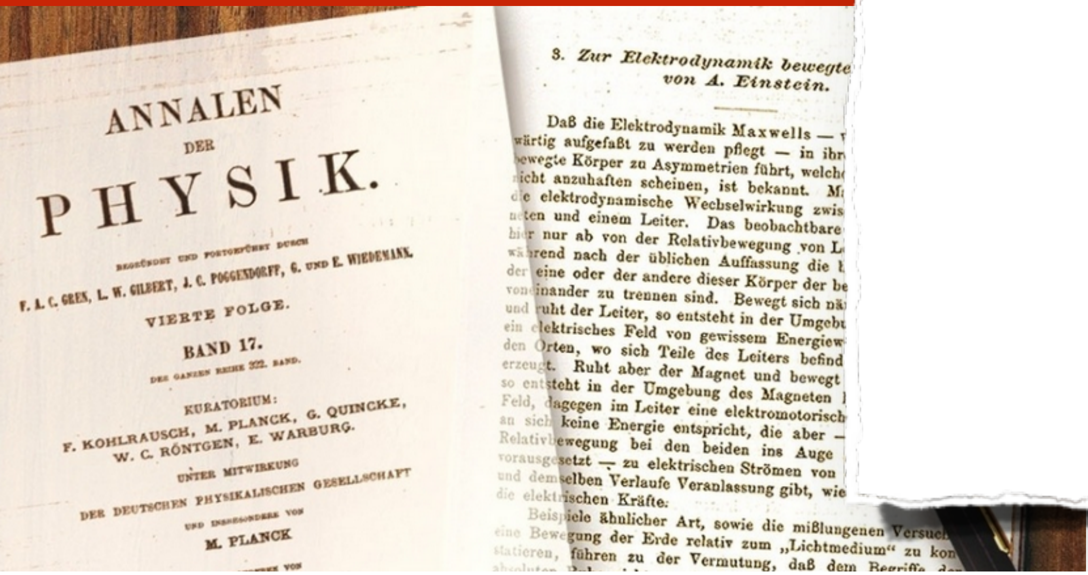
everyone knew this

Maxwell’s Equations were somehow broken.
Newton’s Laws were supreme.

Einstein writes very simply

His 1905 Relativity paper:

“On the Electrodynamics of Moving Bodies”



It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion.

For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated.

But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force… which gives rise…to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Einstein writes very simply

His 1905 Relativity paper:

"On the Electrodynamics of Moving Bodies"

not your standard physics journal introduction

Let us take a system of co-ordinates in which the equations of Newtonian mechanics hold good. In order to render our presentation more precise and to distinguish this system of co-ordinates verbally from others which will be introduced hereafter, we call it the "stationary system."

If a material point is at rest relatively to this system of co-ordinates, its position can be defined relatively thereto by the employment of rigid standards of measurement and the methods of Euclidean geometry, and can be expressed in Cartesian co-ordinates.

If we wish to describe the motion of a material point, we give the values of its co-ordinates as functions of the time. Now we must bear carefully in mind that a mathematical description of this kind has no physical meaning unless we are quite clear as to what we understand by "time." We have to take into account that all our judgments in which time plays a part are always judgments of simultaneous events. If, for instance, I say, "That train arrives here at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events."

It might appear possible to overcome all the difficulties attending the definition of "time" by substituting "the position of the small hand of my watch" for "time." And in fact such a definition is satisfactory when we are concerned with defining a time exclusively for the place where the watch is located; but it is no longer satisfactory when we have to connect in time series of events occurring at different places, or—what comes to the same thing—to evaluate the times of events occurring at places remote from the watch.

his concern:

simultaneity

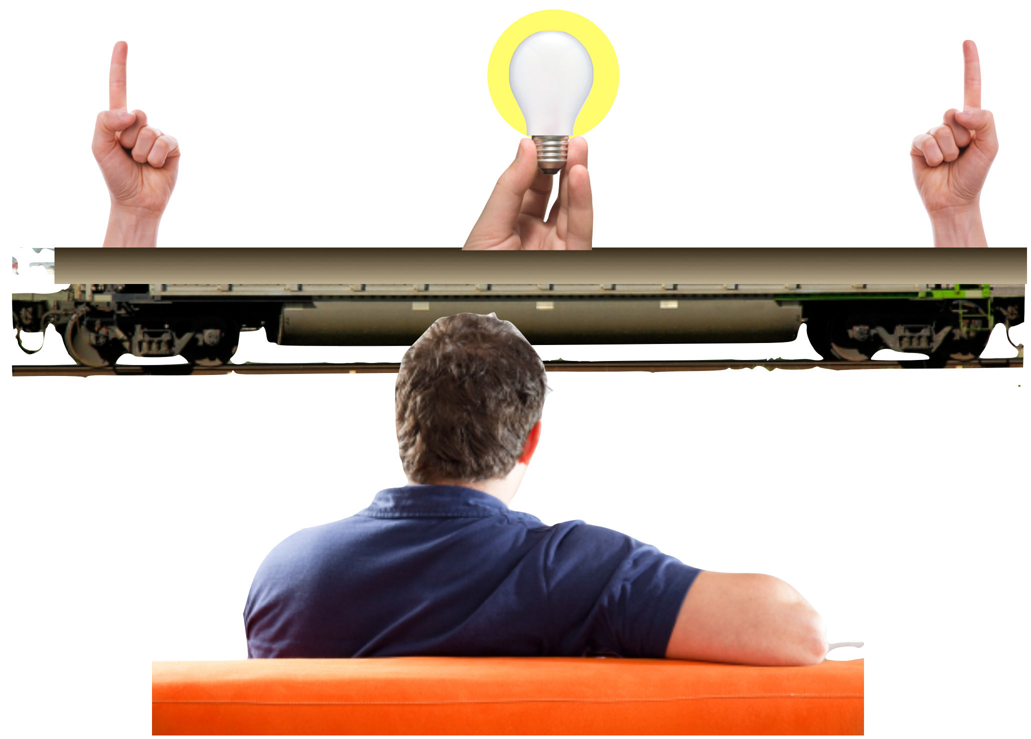
“a storm broke loose in my mind”

put on your seatbelt

philosophical issues

and

very pragmatic issues

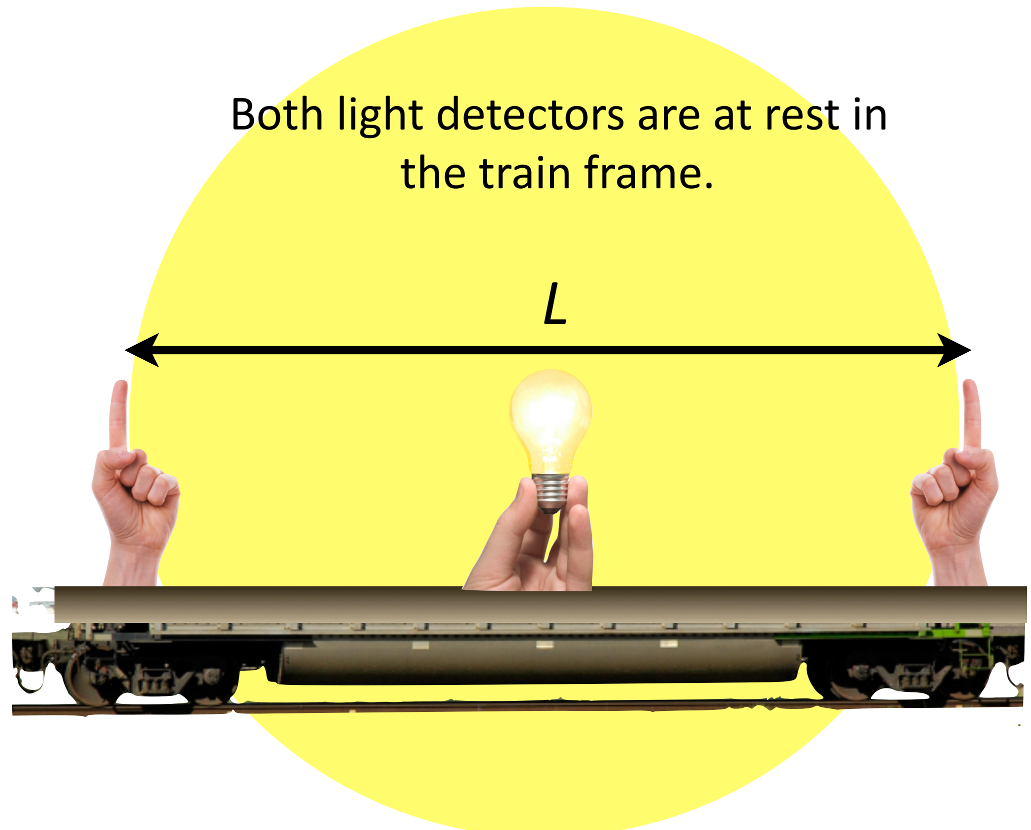


thinking simple

philosophical issues

imagine a frame in which a light beam is emitted in the center and detected in that frame equal distances away

The train observer would declare: the beams arrived simultaneously

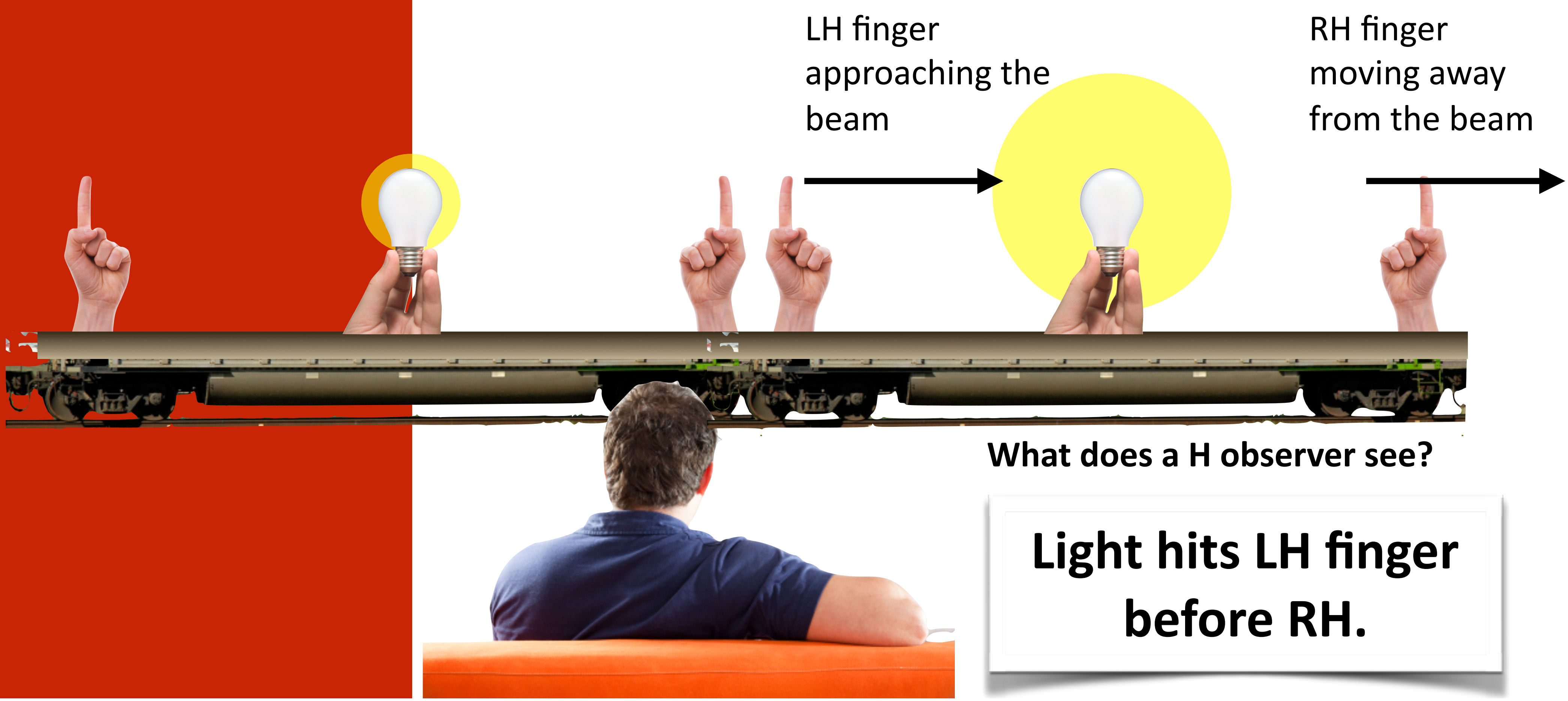


Left and Right hands register receipt of the light beam at the same time.

simple is hard

space and time are odd

The ground observer would declare: the beams did not arrive simultaneously

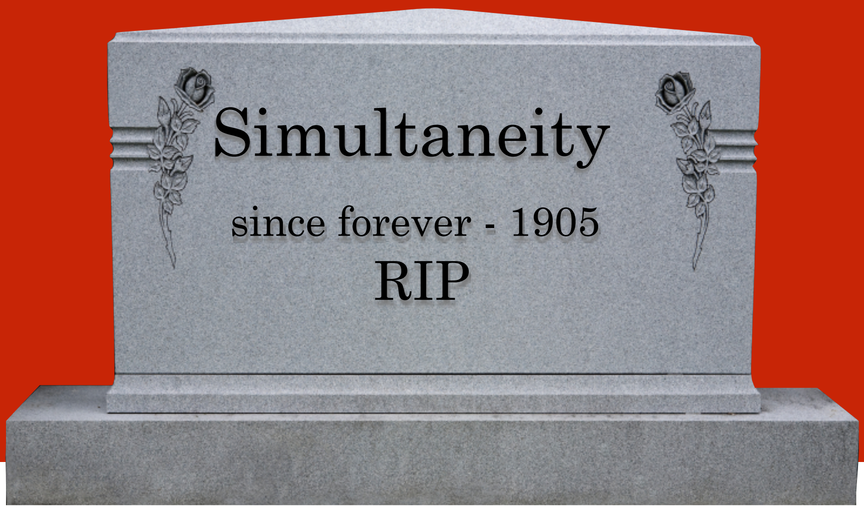


What does a H observer see?

Light hits LH finger before RH.

There is no such thing as the *concept of* simultaneous events

between co-moving frames of reference



two problems with this:

1. Since there is no way to determine that something is simultaneous in one frame and also in another

one can never synchronize clocks between co-moving frames of reference

so no meaningful translation of clock references from one frame to another what is now?

So.

No inertial frame is special.

All are equivalent.

Why?

because no measurement can be made to tell otherwise

2. "Causality" requires care

is CAUSALITY a casualty!?

wo observers disagree about when events happen

the same time? at different times?

Suppose the hospital order is: first I'm born, then I cry

would a moving observer observe that first I cry, then I'm born?

26 year old, completely unknown, second class patent clerk Albert Einstein was offended

that the two all-encompassing theories of the world

- would behave so differently under G.T.

everyone assumed that the fault lay with Maxwell's Equations

- everyone "knew"…light moved at c only in the ether
  - right?

Einstein thought differently…

- he worked deductively from two "postulates"

Postulates of Special Relativity

1. All laws of physics – mechanical and electromagnetic – are identical in co-moving inertial frames.

    taking Galileo seriously, and then adding Maxwell

    called "The Principle of Relativity"

2. The speed of light is the same for all inertial observers.

    taking Maxwell seriously…that "c" in M.E. is a constant.

and then

he played the two postulates out

to see what would result

the 2nd postulate

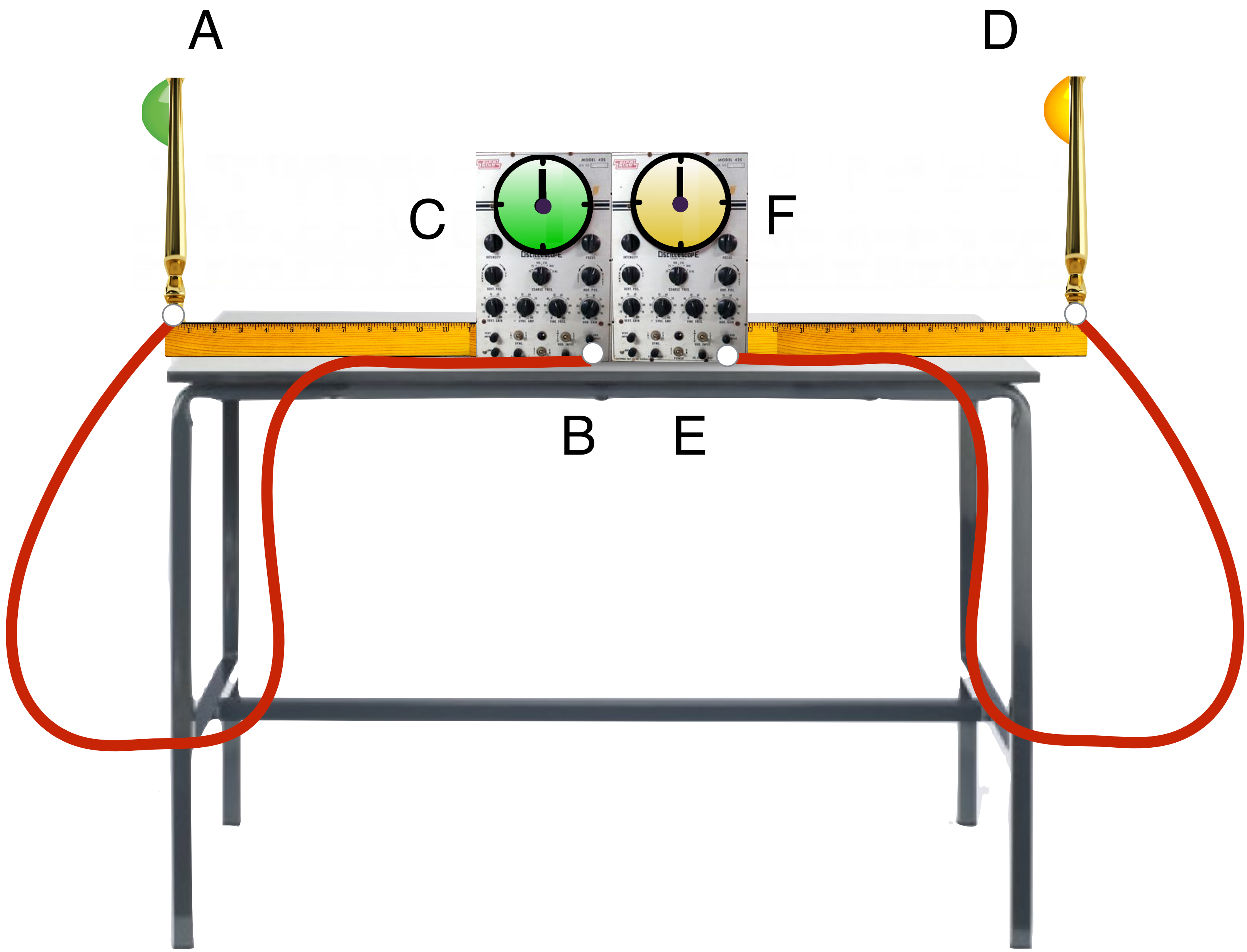
makes things strange

because c

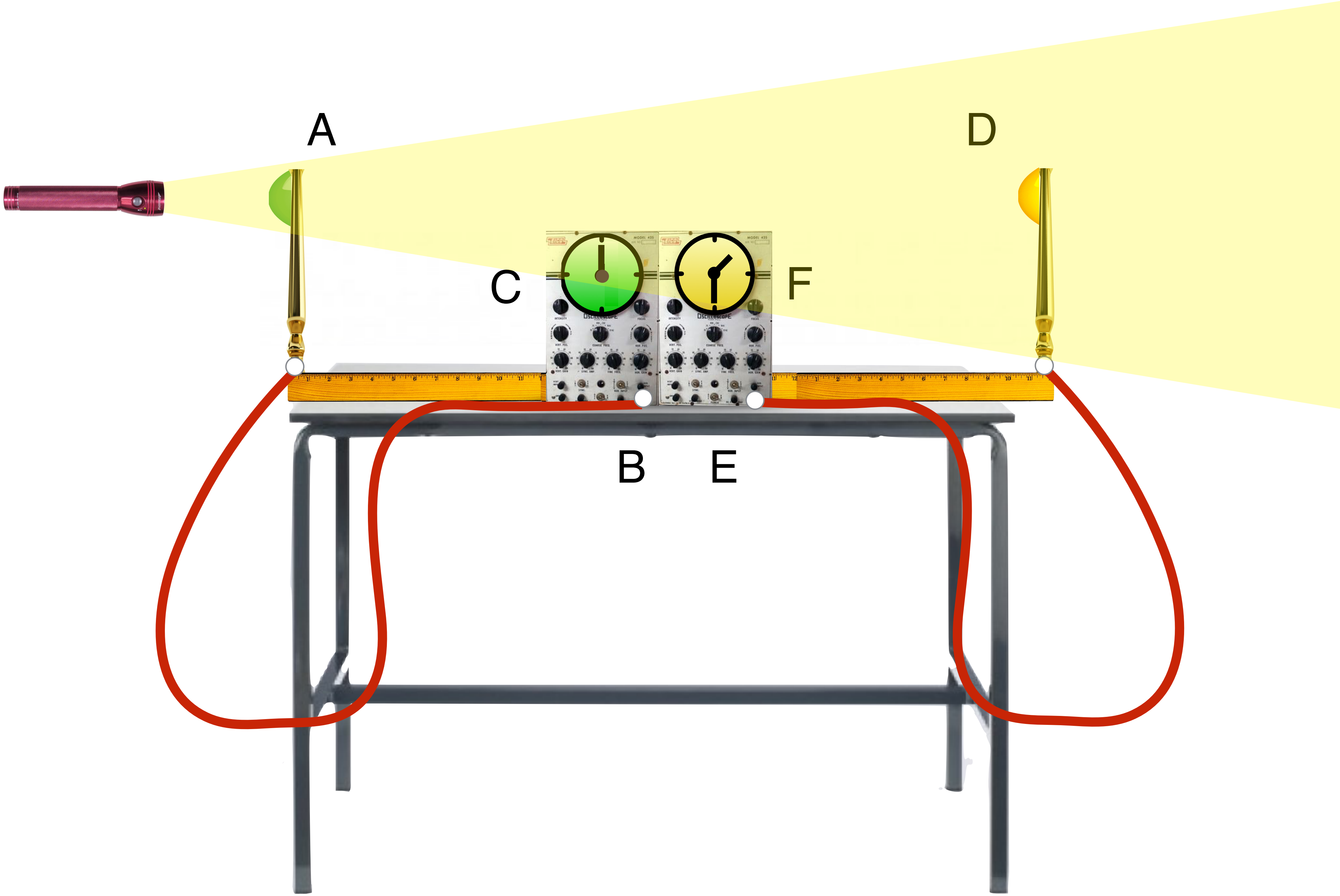
the speed of light is constant in all inertial frames:

$c = 3 \times 10^8$ m/s = 300 million m/s = 1,080 million km/h

$c = 671$ million mph



A
D
C
F
B
E



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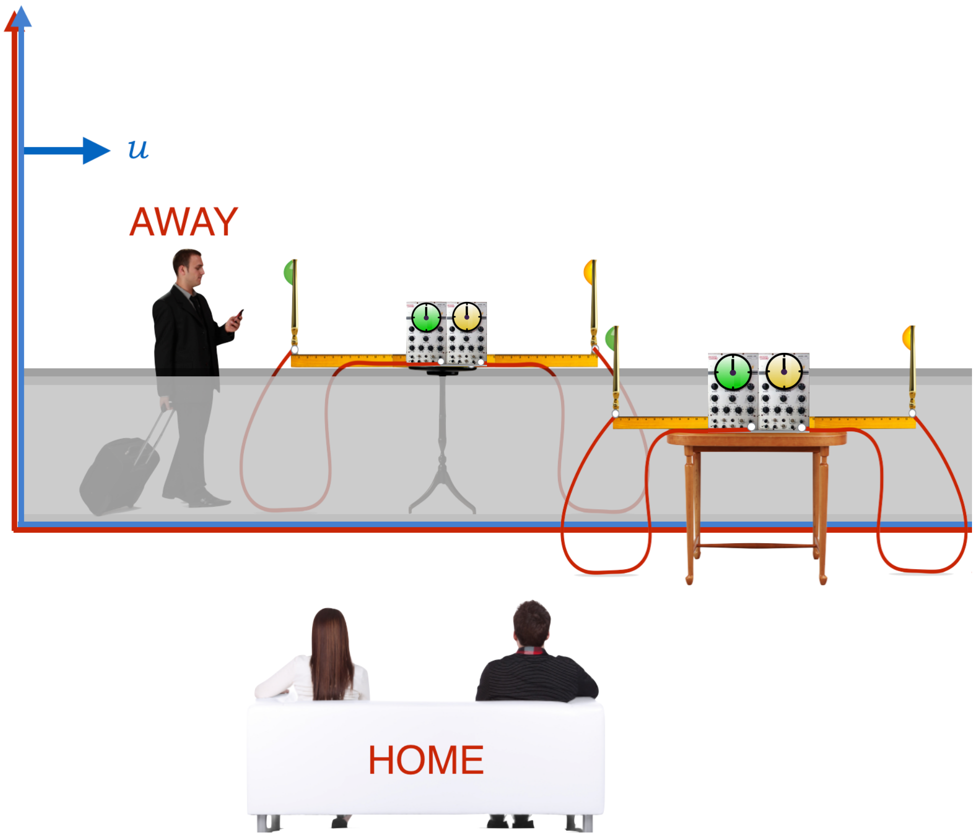
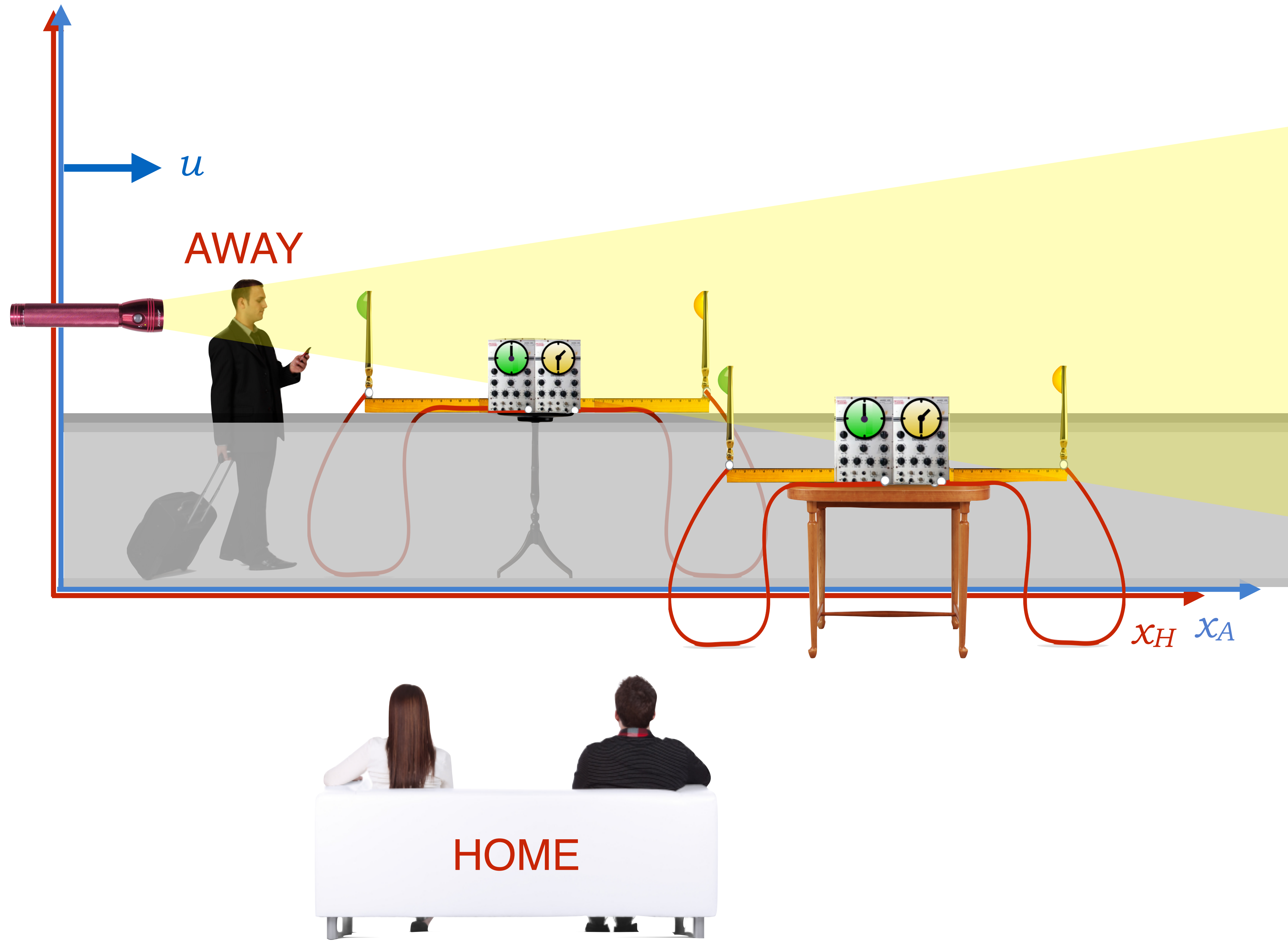
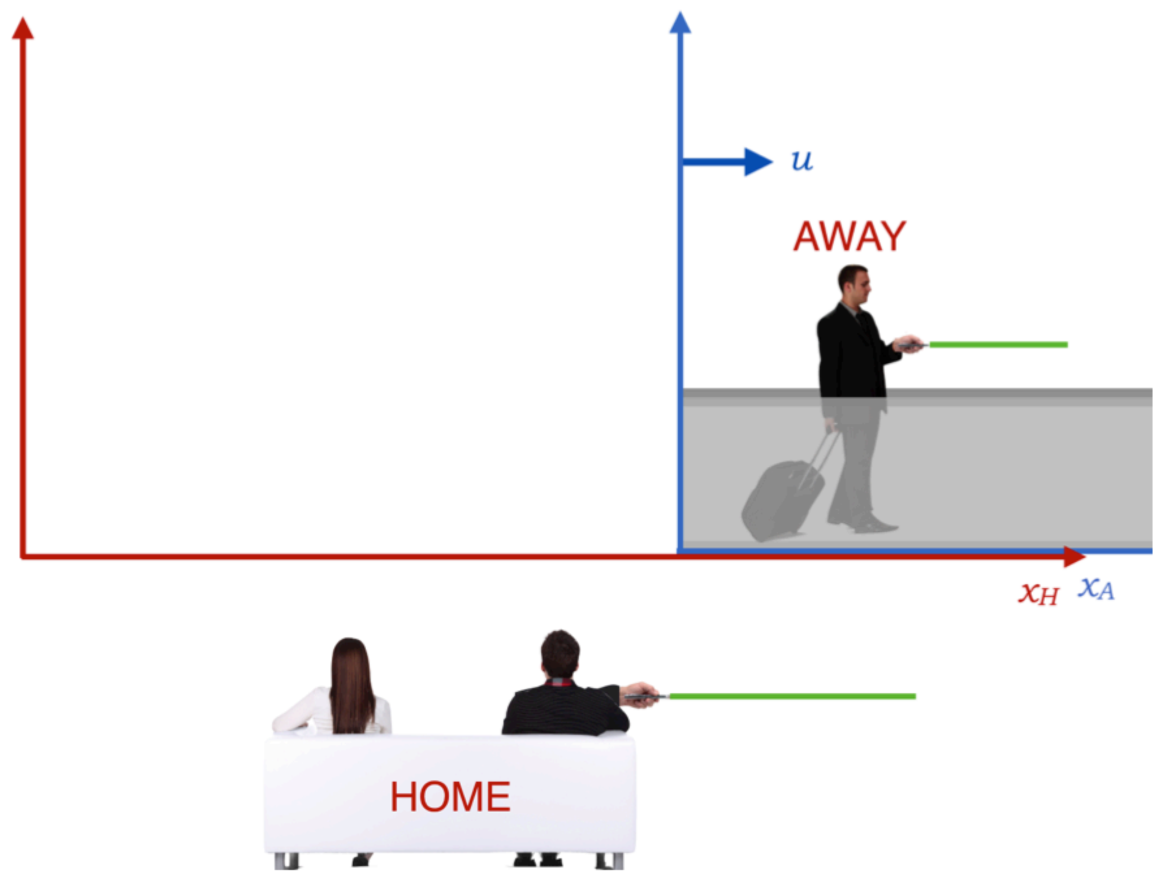


(a)

(b)

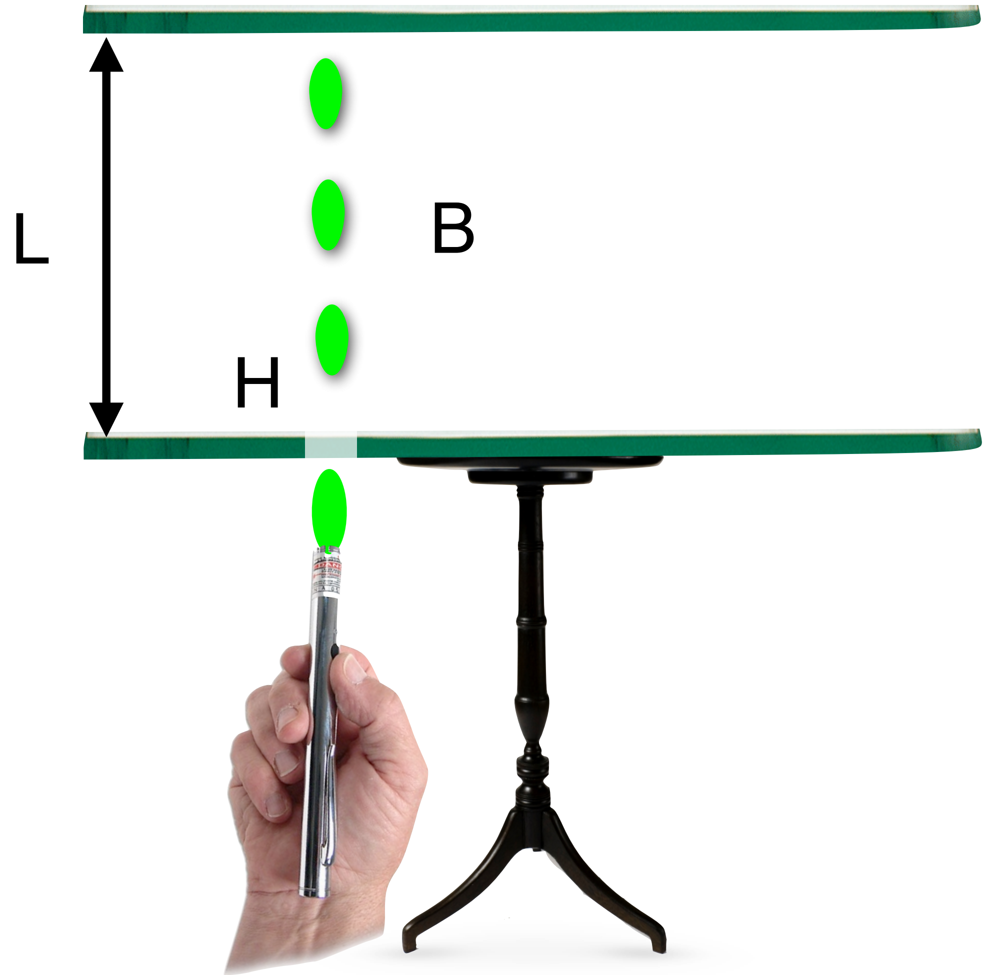


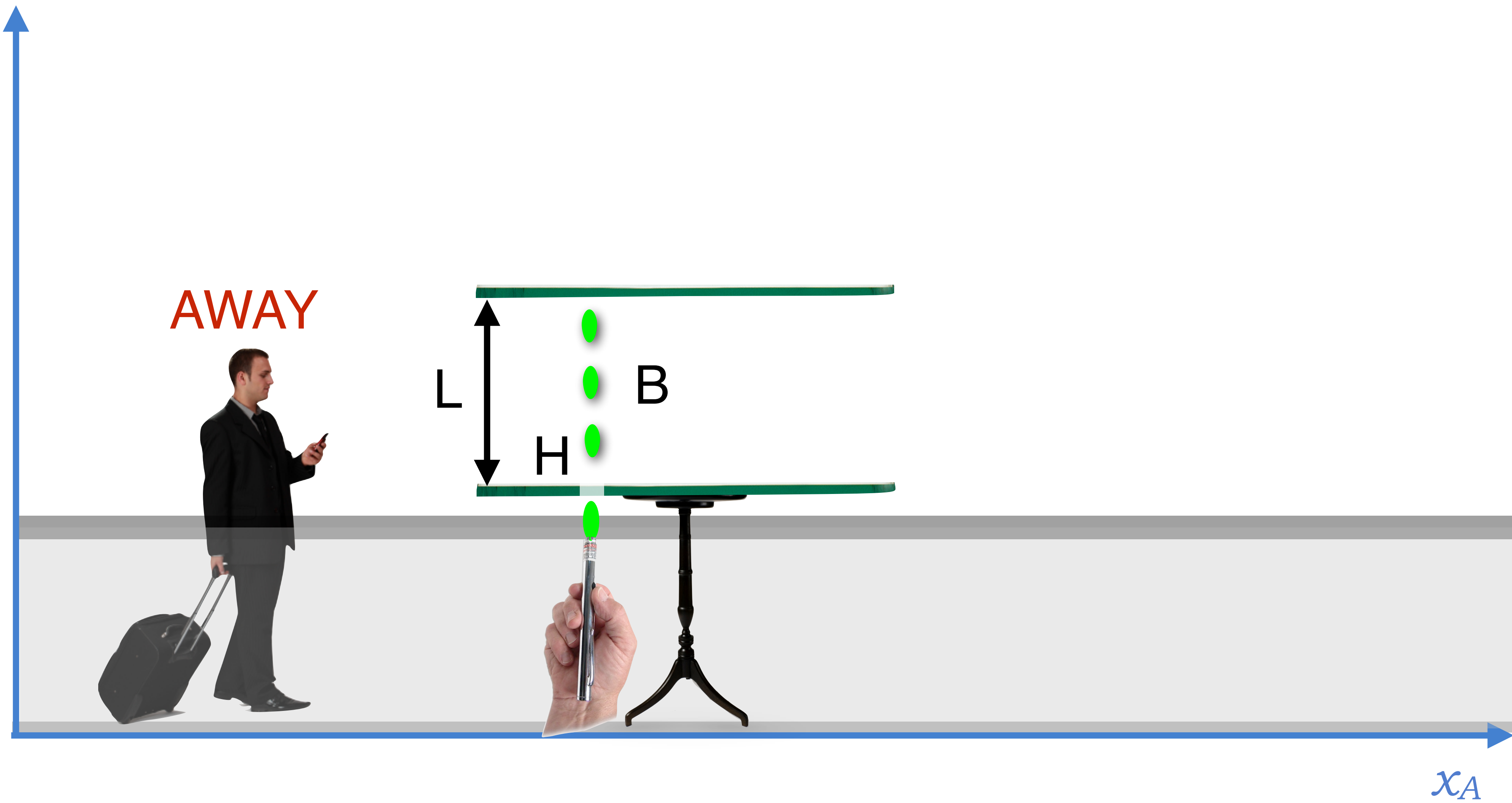
u
AWAY
HOME
x_H
x_A



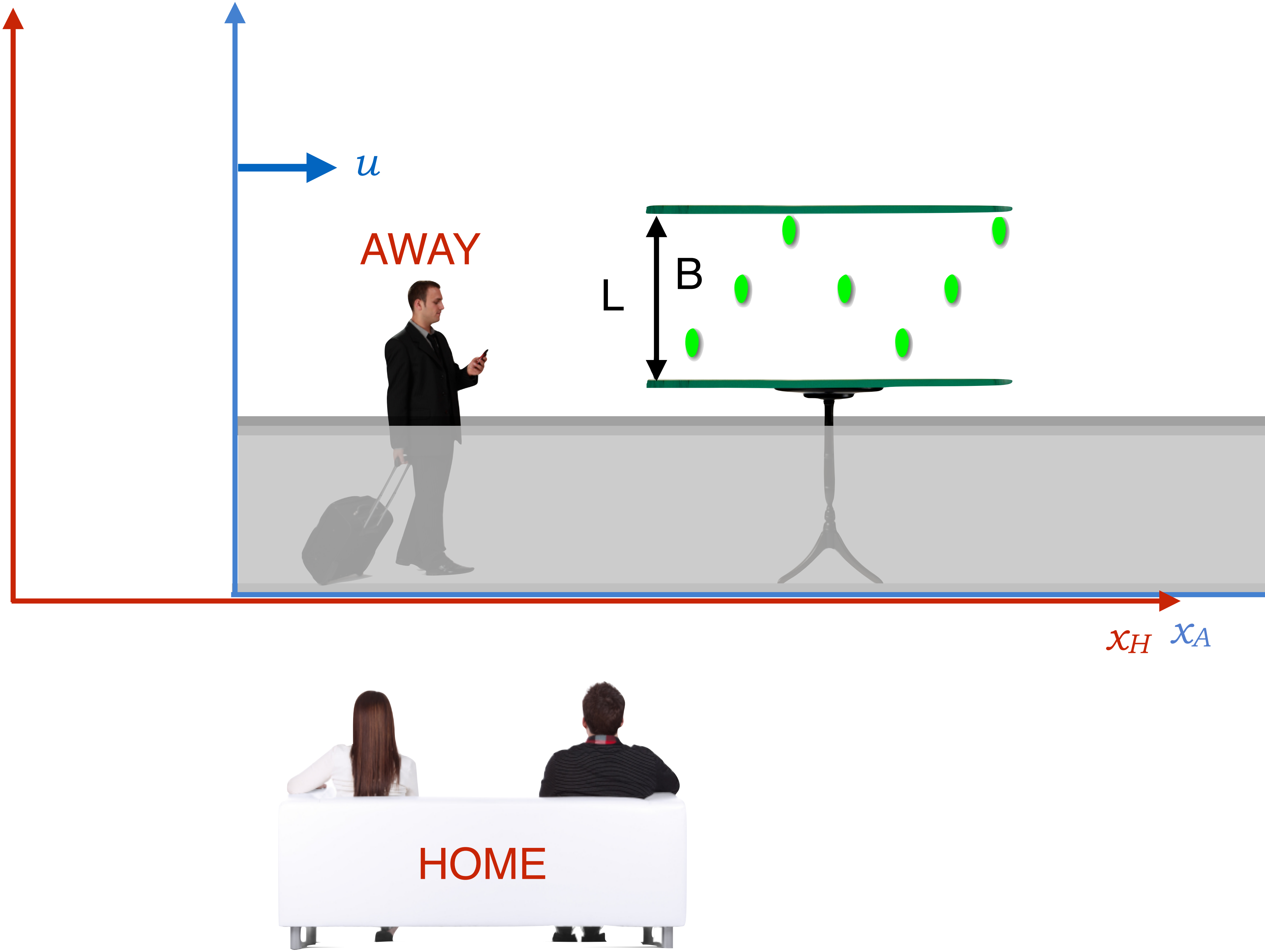
laser beams' speed is c relative to airport, sidewalk, downtown, cars on the highway, planes overhead, moon, Alpha Centauri, Milky Way center, ...

but wait, there’s more.


L
B
H

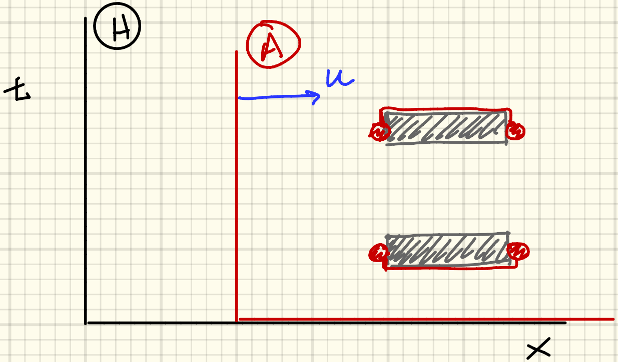


AWAY
L
B
H
x_A

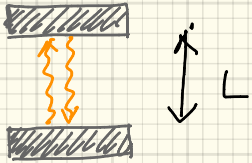


u
AWAY
L
B
x_H
x_A
HOME

G

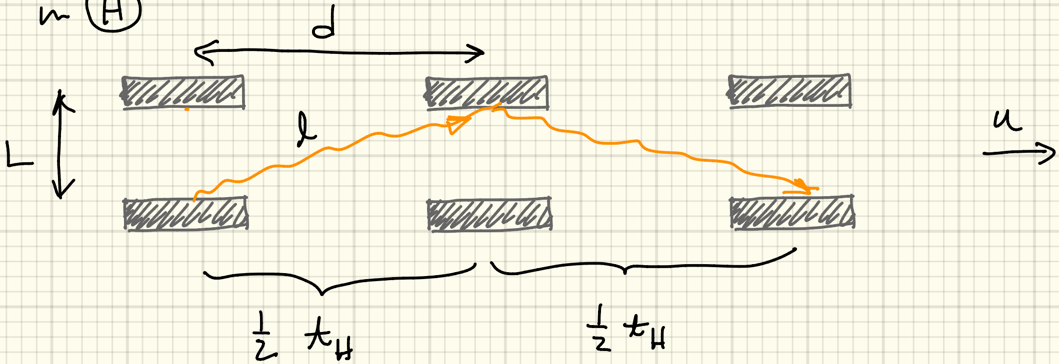


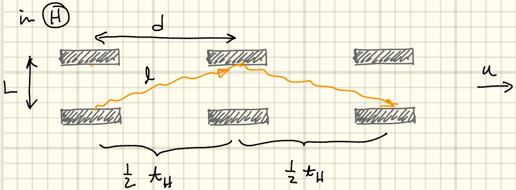
in A



$$t_A = \frac{2L}{c_A}$$

in H





$$t_H = \frac{2l}{c_H} \qquad l = \frac{t_H c_H}{2}$$

$$d = \frac{1}{2} u\, t_H$$

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

$$\frac{t_H^2 c_H^2}{4} = L^2 + \frac{1}{4} u^2 t_H^2$$

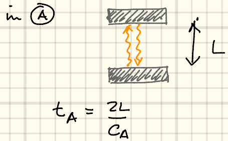
$$t_H^2 \left(\frac{c_H^2}{4} - \frac{u^2}{4} \right) = L^2$$

$$t_H^2 \frac{c_H^2}{4} \left(1 - \frac{u^2}{c_H^2} \right) = L^2$$

$$t_H^2 = \frac{4L^2}{c_H^2} \frac{1}{1 - u^2/c_H^2}$$

$$t_H = \frac{2L}{c_H} \frac{1}{\sqrt{1 - u^2/c_H^2}}$$

A Galilean view: $t_H = t_A$



so $$t_H = t_A$$

$$\cancel{\frac{2L}{c_H}} \frac{1}{\sqrt{1 - \frac{u^2}{c_H^2}}} = \cancel{\frac{2L}{c_A}}$$

$$c_A = c_H \sqrt{1 - u^2/c_H^2}$$

like L-F length contraction

But 2nd Postulate: $c_H = c_A = c$

$$t_A = \frac{2L}{c} \qquad t_H = \frac{2L}{c}\frac{1}{\sqrt{1-u^2/c^2}} \qquad \Rightarrow t_H \neq t_A$$

eliminate L

$$L = \frac{t_A \cancel{c}}{\cancel{2}} = \frac{t_H \cancel{c}}{\cancel{2}}\sqrt{1-u^2/c^2}$$

$$t_A = t_H\sqrt{1-u^2/c^2} \longrightarrow$$

standard notation:

$\beta \equiv u/c \leftarrow$ frame speed.

$$\gamma = \frac{1}{\sqrt{1-u^2/c^2}} = \frac{1}{\sqrt{1-\beta^2}}$$

$\gamma > 1$

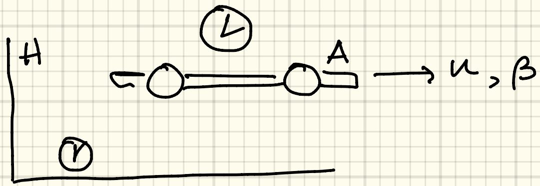
$$t_A = \frac{t_H}{\gamma}$$

$$t_H = t_A\gamma$$

$$t_H > t_A$$

measured in HOME

measured in AWAY



H says that A's clock runs slower than A would report.

TIME DILATION $\qquad T_H = T_A \gamma \qquad T_H = \tau \gamma$

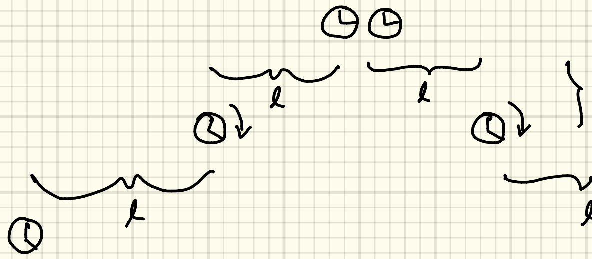
A definition: "proper time" $\rightarrow$ here, A's time of clock in her own rest frame $\rightarrow$ 1 clock

sometimes t_0

usually "τ"

BACK TO SYNCHRONIZATION.. E's original inspiration

How?

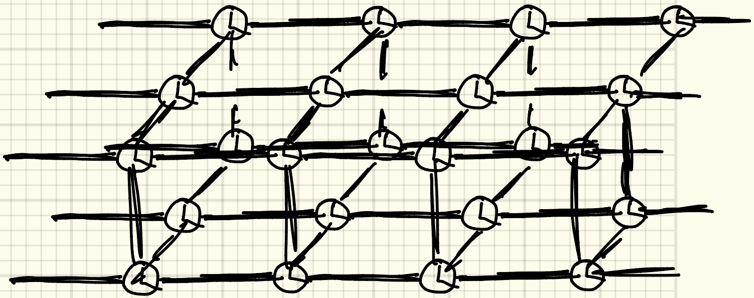


adjust by $\Delta t = \frac{l}{c}$

again

Think of a whole grid:

clocks & rulers



can measure
simultaneous events

But not by a co-moving
grid.

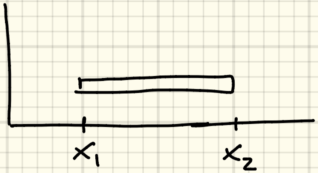
So: no frame can be "at rest" ... special.

Because .. no measurement can be made to determine "at rest"

So, ether is superfulous .. unnecessary $\Rightarrow$ $\boxed{\text{can't exist}}$

meter stick, L_0

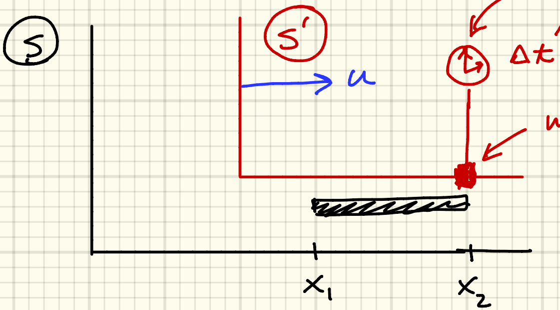
in an inertial frame:



$x_2 - x_1 = L_0$

"proper length"

observer here, 1 clock $\Rightarrow$ proper time



marker, starts & stops clock in S'

$\rightarrow \Delta t'$

S' goes by: starts clock when marker hits x_1
stops when marker hits x_2 $\Big\}$ $\Delta t' = \tau$

S' knows $\underline{\underline{u}}$, so can calculate L'

$$L' = u\,\Delta t' = u\,\tau$$

Meanwhile (S) has a clock and measures when marker hits x_1 and x_2 $\rightarrow$ Δt

converts that into a length $L_0 = u\,\Delta t$

Divide

$$\frac{L'}{L_0} = \frac{u\,\Delta t'}{u\,\Delta t} = \frac{\Delta t'}{\Delta t}$$

$$L' = L_0 \left(\frac{\Delta t'}{\Delta t}\right)$$

Pre Einstein?
$\Delta t' = \Delta t \Rightarrow L' = L_0$

But $\Delta t = \Delta t' \gamma \;(= \tau \gamma)$

$$L' = L_0 \left(\frac{\Delta t'}{\Delta t' \gamma}\right)$$

$$L' = L_0 \frac{1}{\gamma}$$

Lorentz Contraction

$\longrightarrow$ just like F-G original guess BUT FOR ENTIRELY WRONG REASONS