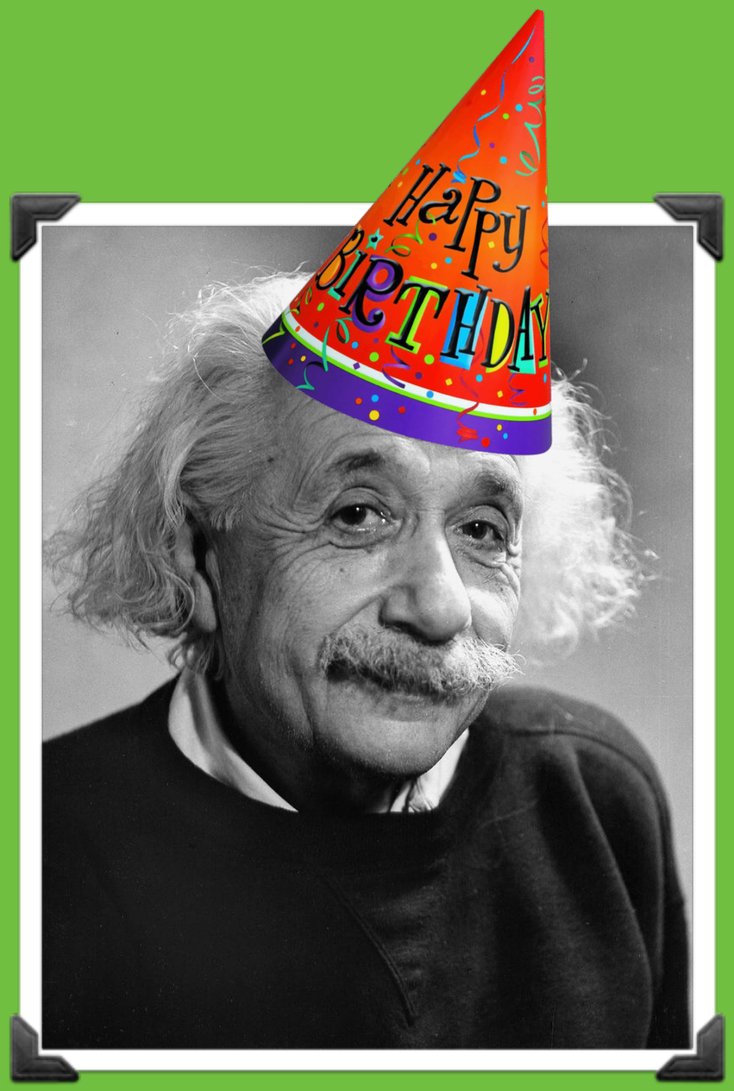
hi

Day 16, 13.03.2018

Einstein’s Theory of

Special Relativity, 3



housekeeping

Gotta come to class

question about anything? I'll make a movie for you:

Special Relativity:

Hobson_Relativity.pdf is chapter 10 out of Hobson

Also, chapter 2 in Oerter is good.

need this and next lecture for HW! So HW7 due Sunday, rather than Friday

MasteringAstronomy registration expiration now set to March 15.

February 2018
March 2018

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
25	26	27	28	1	2	3
	midterm	~~lecture~~		lecture!		
4	5	6	7	8	9	10
		spring break				HW7
11	12	13	14	15	16	17
		lecture		lecture		HW8
18	19	20	21	22	23	24
HW7 due					HW8 due	

honors project begins

https://qstbb.pa.msu.edu/storage/Homework_Projects/honors_project_2018/

contains the first instructions: the plan & tutorial

MinervaInstructions1_2018.pdf

dates:

complete first part, March 16

analyze data and complete writeup, April 20

You might want to remember this:

a changing B field creates an E field

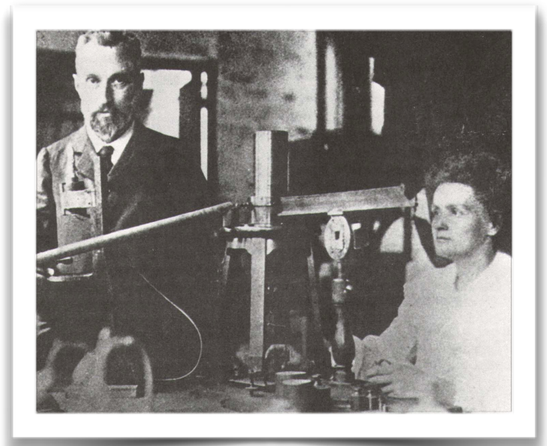
a changing E field creates a B field

accelerated charges produce electromagnetic radiation

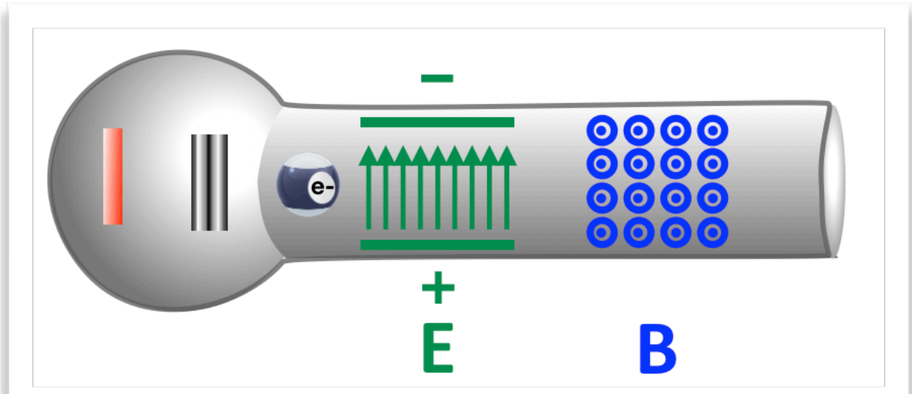
weirdnesses of 1890s

1. X-rays

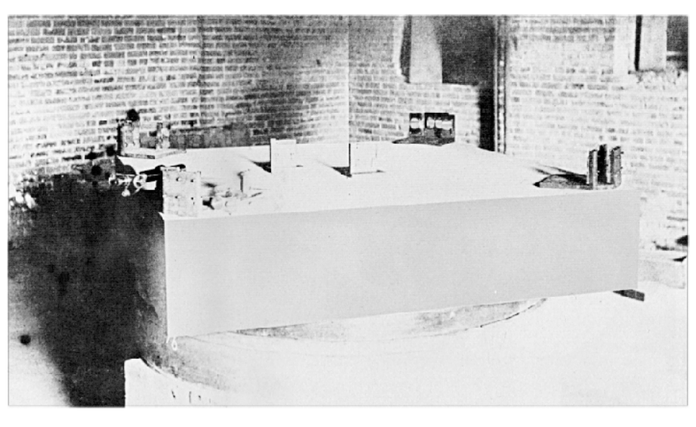
2. radioactivity



3. discovery of the electron



4. no motion wrt ether



‘‘frames of reference’’

co-moving systems

relative motion between them

uniform speeds: “inertial frames of reference”

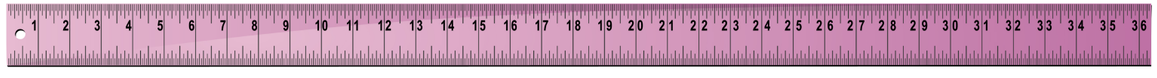
for measurement of motion, all you have are

clocks and rulers.

that might move relative to one another

AWAY frame

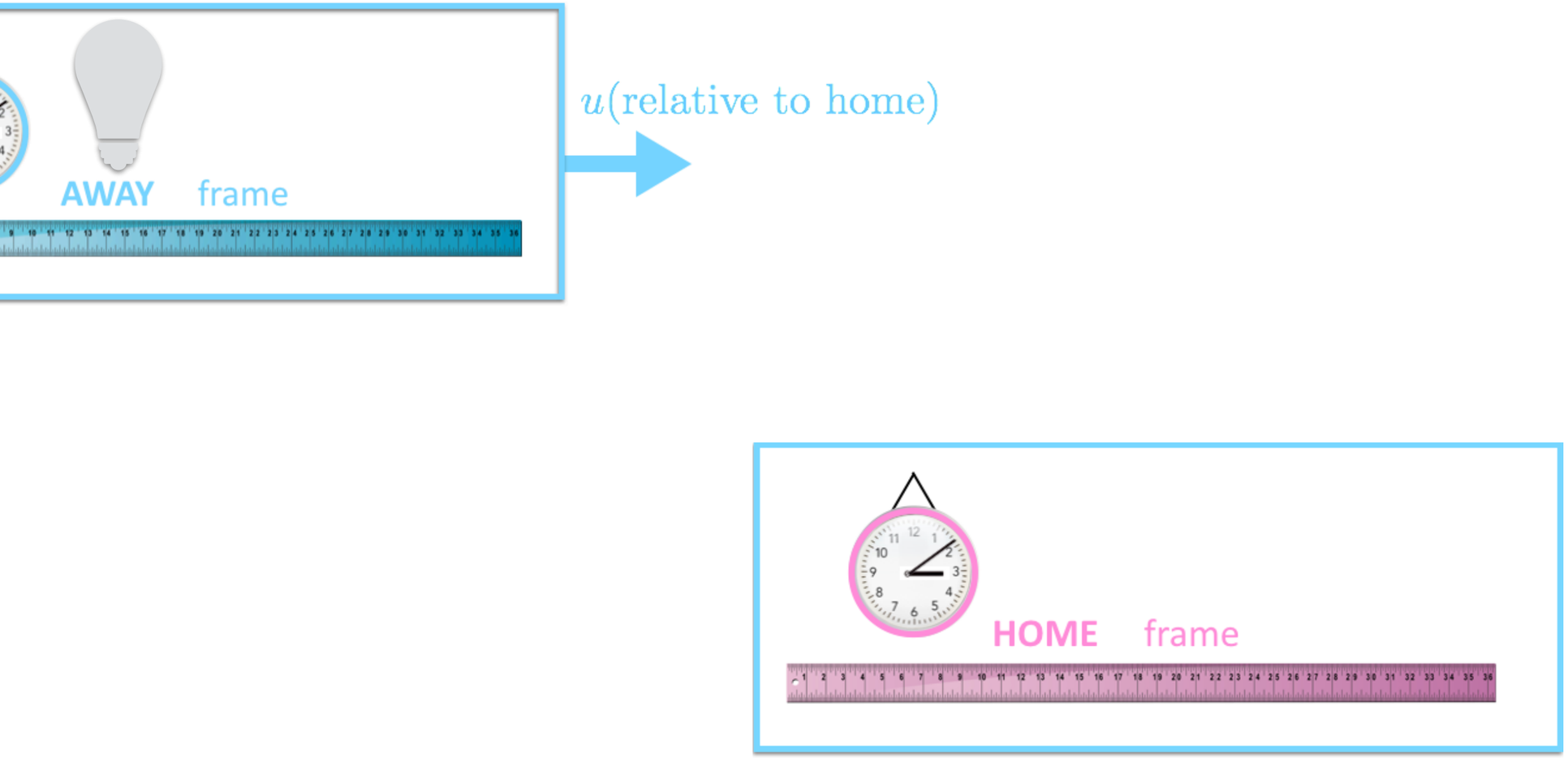
HOME frame



events and intervals

events happen once at 1 space and 1 time location

intervals happen once at 2 space and/or 2 time locations



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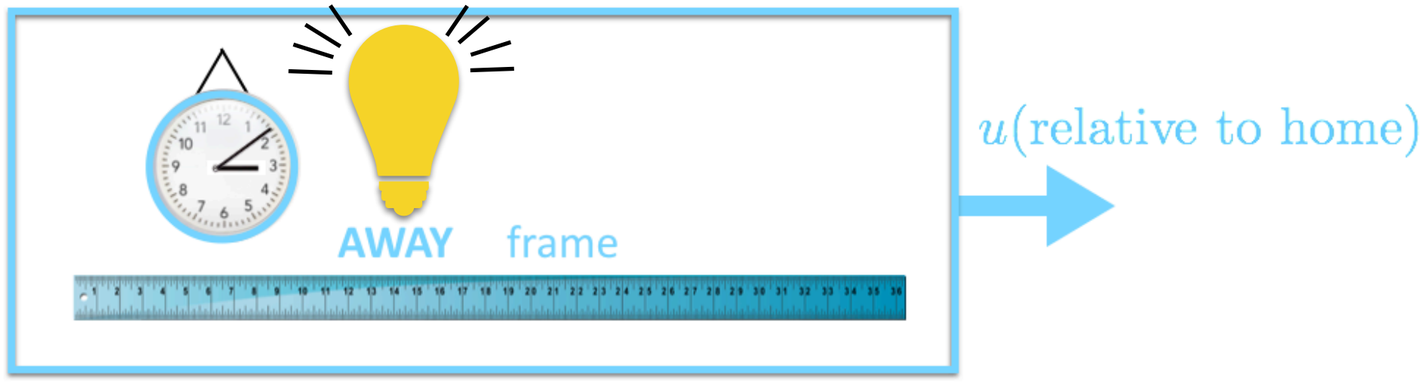

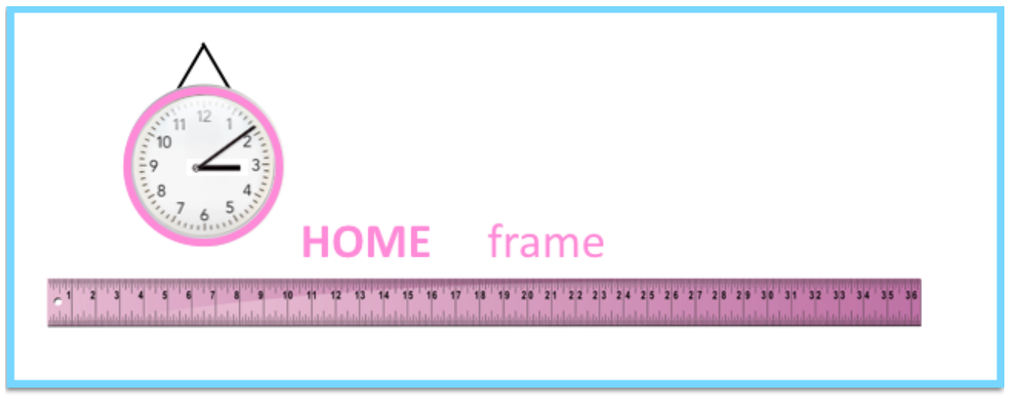

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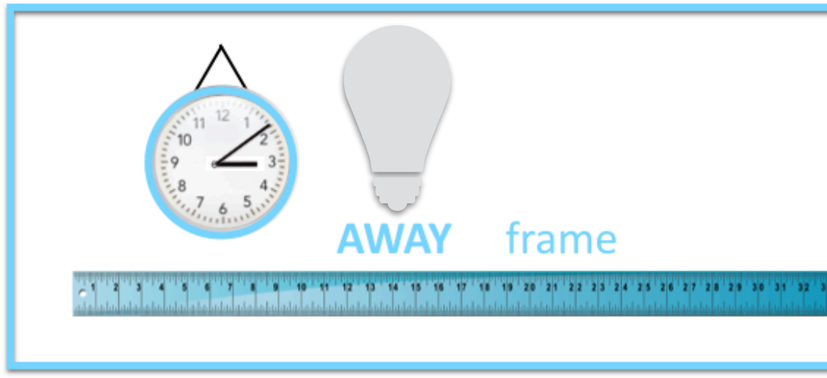

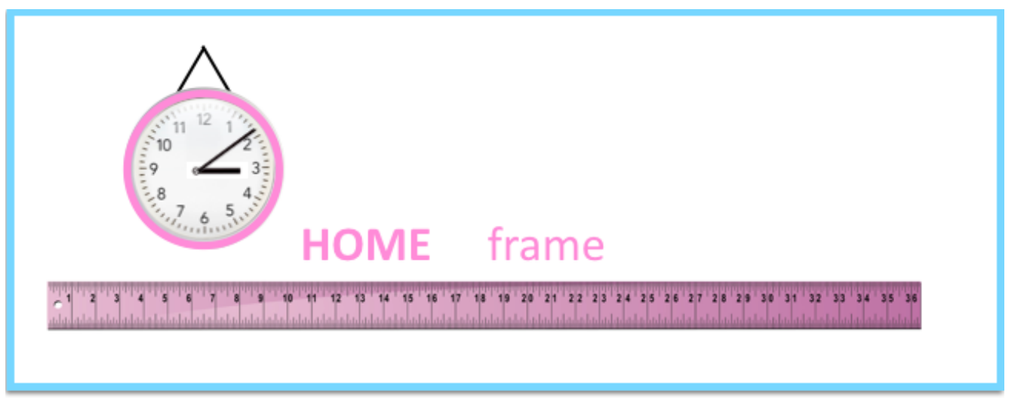

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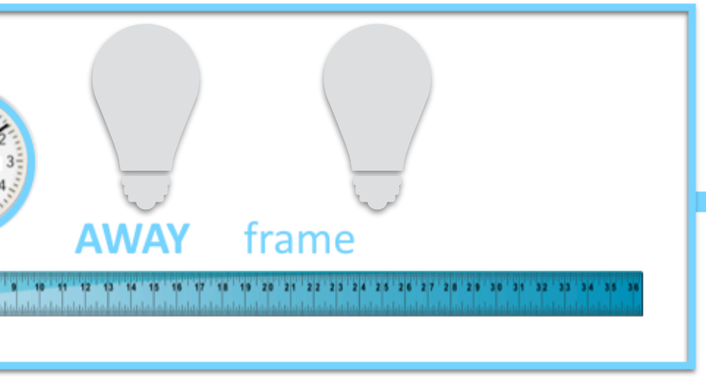
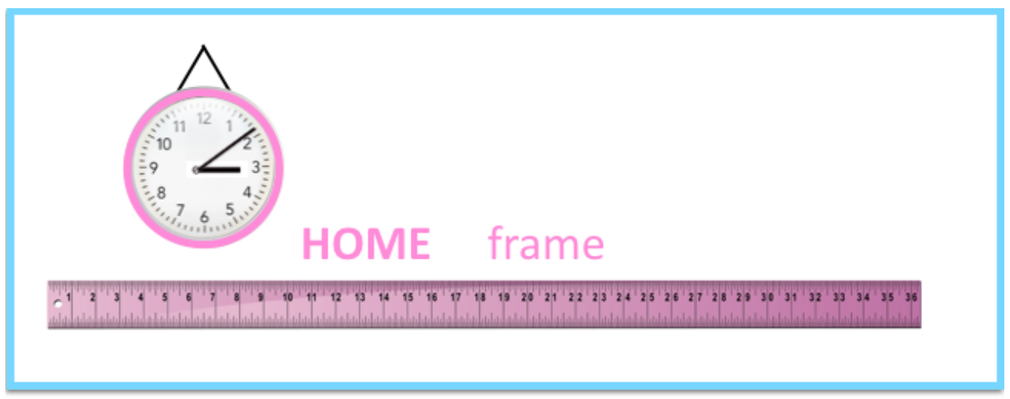


u(relative to home)



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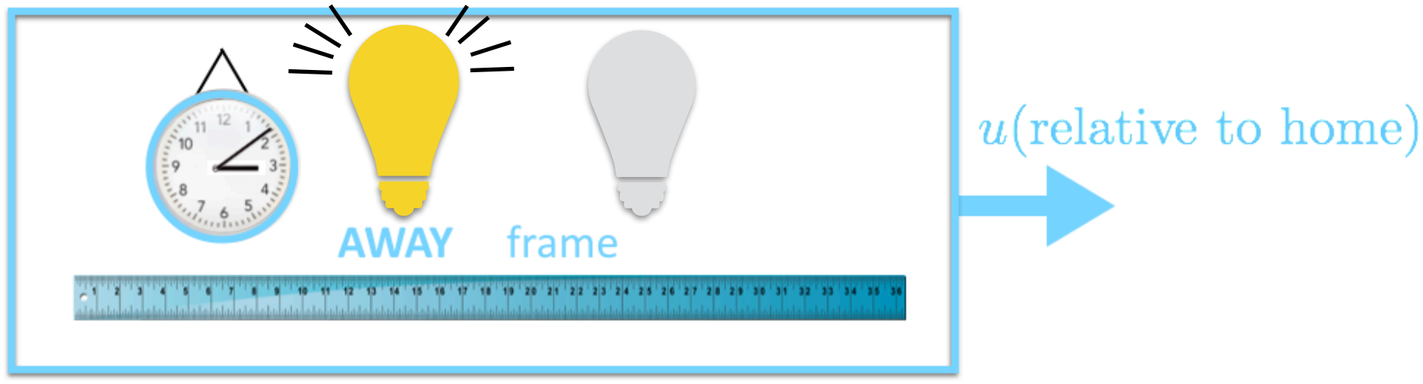

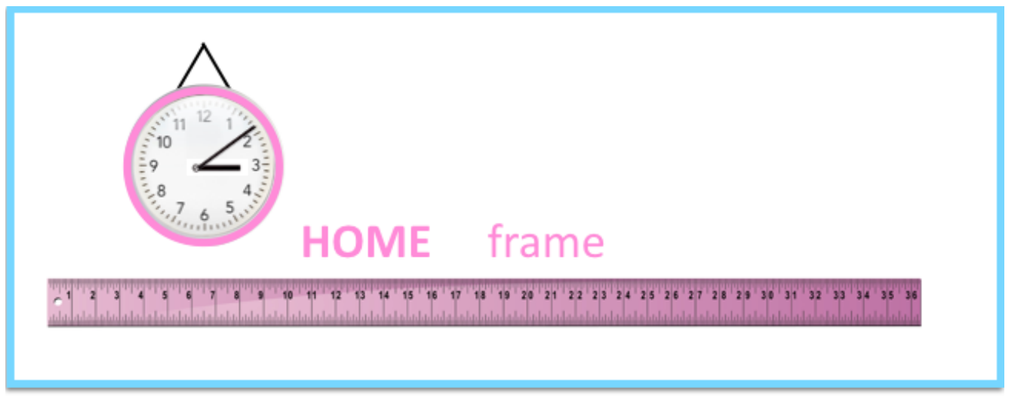

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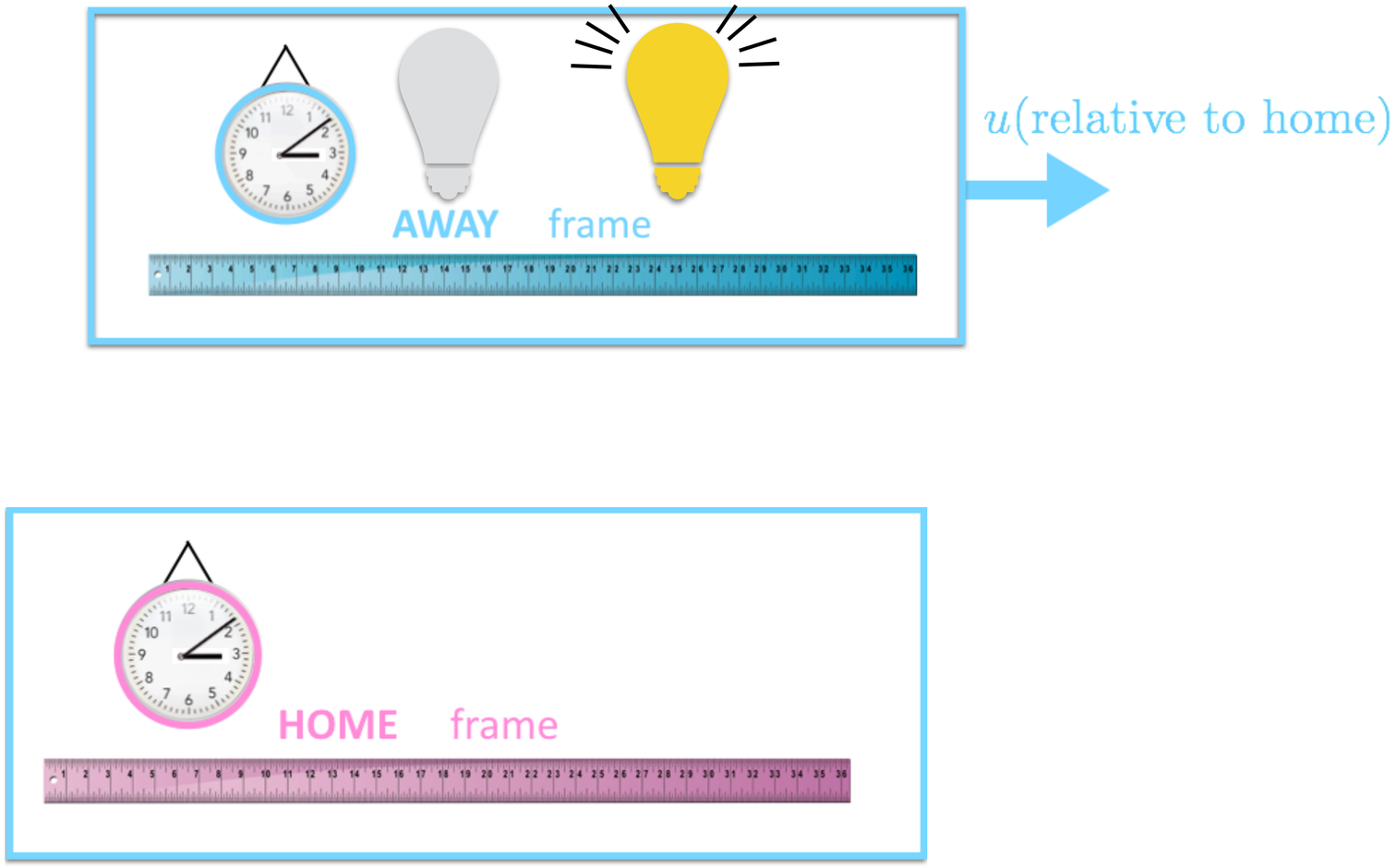

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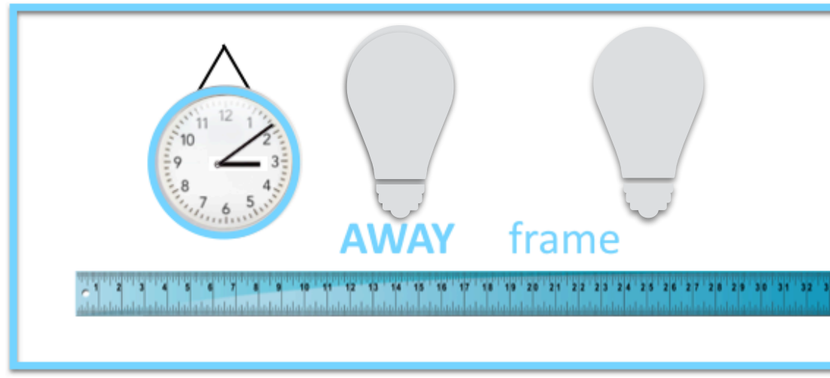
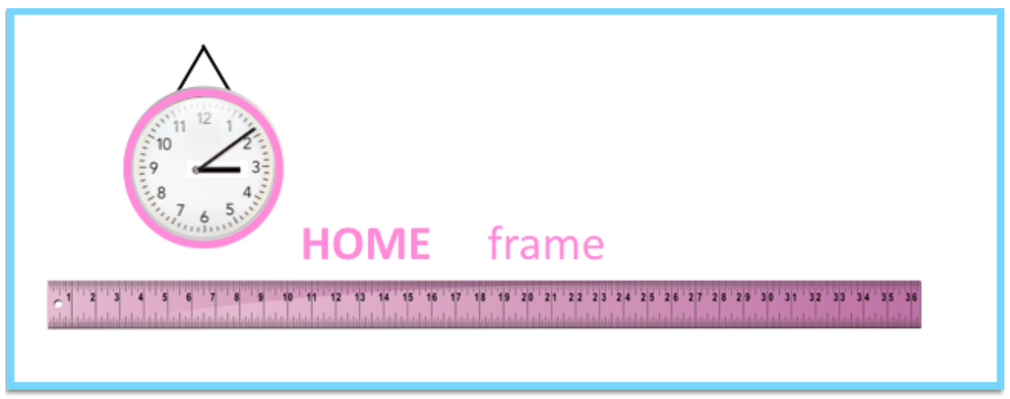




Home and Away

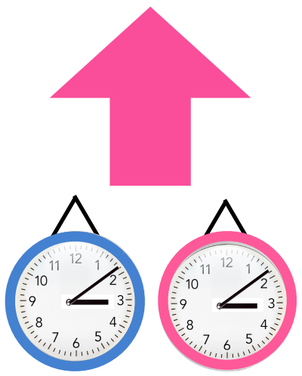
can agree on an event's x and t

may disagree on an interval's $(x_2 - x_1)$ and/or $(t_2 - t_1)$

Δx Δt

the airport

“Away Frame”:
the frame being watched



= 0

When the origins cross...
define that as $t = 0$

“Home Frame”:
watching a moving frame

moving at velocity u

‘‘coordinate transformation’’

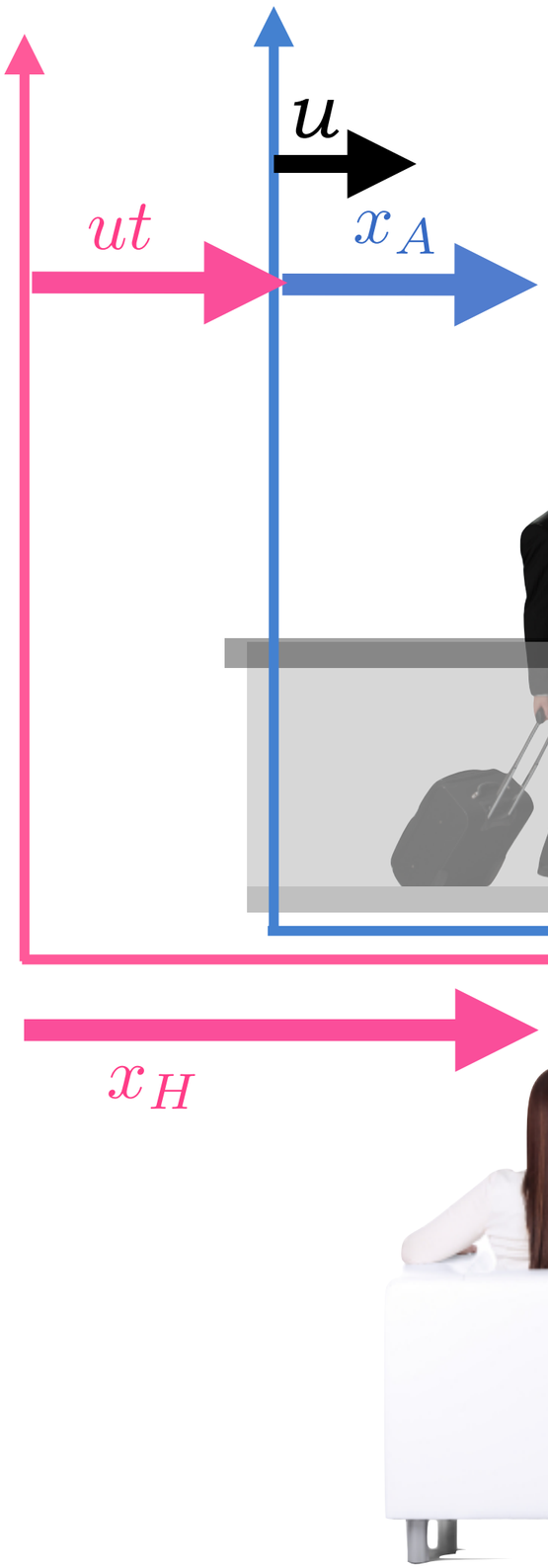
take the coordinates in one Frame and
write them in a different Frame

here, Home and Away

the airport, after t

"Galilean Transformation"

$$x_H = x_A + ut$$



"Away Frame":
the frame being watched

"Home Frame":
watching a moving frame

moving at velocity u

Galileo & Newton:

no mechanical experiment can reveal

constant-velocity motion

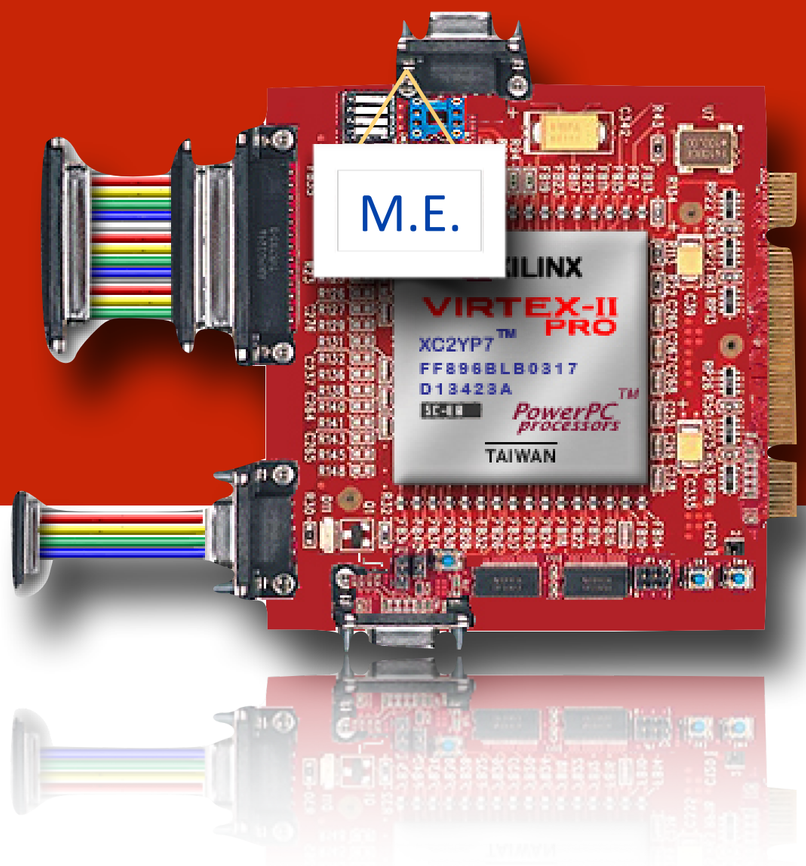
BUT: Maxwell’s theory suggested that light

leads to inconsistencies between inertial frames

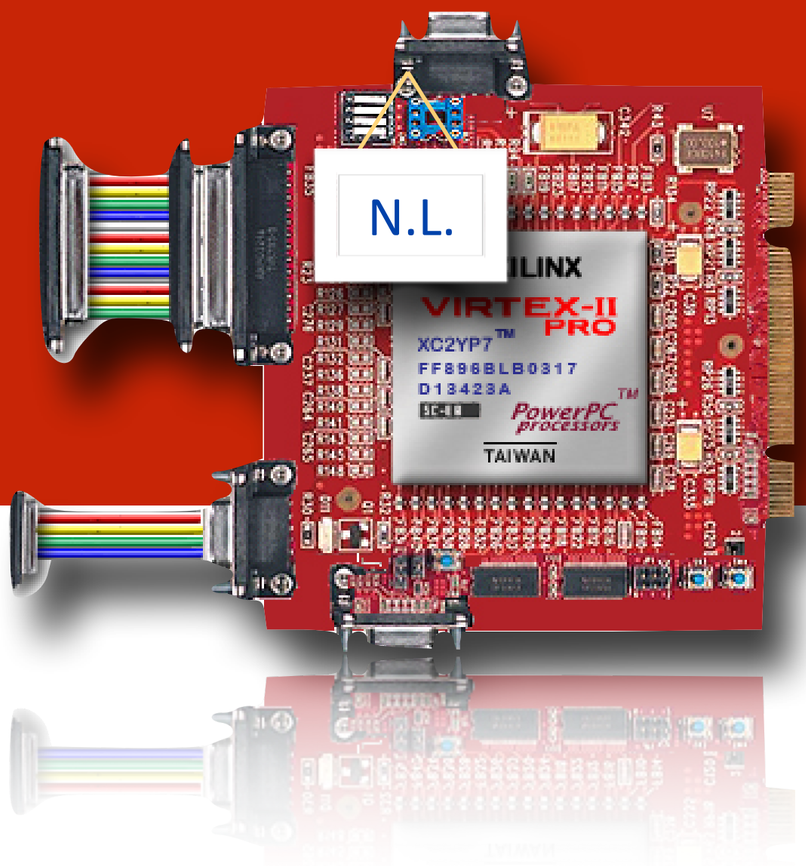
the two models of the world differ

in their treatment of relatively-moving frames of reference!

Seems to depend on Frame:



Don’t appear to depend on Frame:



remember what Maxwell found?

Maxwells aha! moment

→

$\text{stuff} \times \vec{E} = 0$

$\text{stuff} \times \vec{B} = 0$

$\text{stuff} \times \vec{B} = \text{rate of change of } \vec{E}$

$\text{stuff} \times \vec{E} = \text{rate of change of } \vec{B}$

differential equations

remove the explicit sources, Q & I

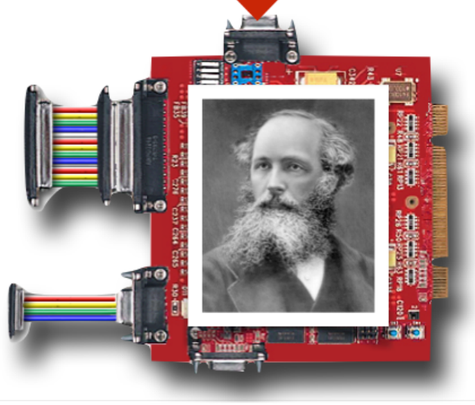
Look how the equations are symmetric: E ↔ B

$\text{stuff} \times \vec{E} = 0$

$\text{stuff} \times \vec{B} = 0$

$\text{stuff} \times \vec{B} = \text{rate of change of } \vec{E}$

$\text{stuff} \times \vec{E} = \text{rate of change of } \vec{B}$



$$\frac{E}{B} = 3 \times 10^8 \text{ m/s}$$

c! the **speed of light!**

Which Maxwell knew.

8

This offended the young Einstein.

He took the Maxwell prediction seriously:

light moves at a constant speed

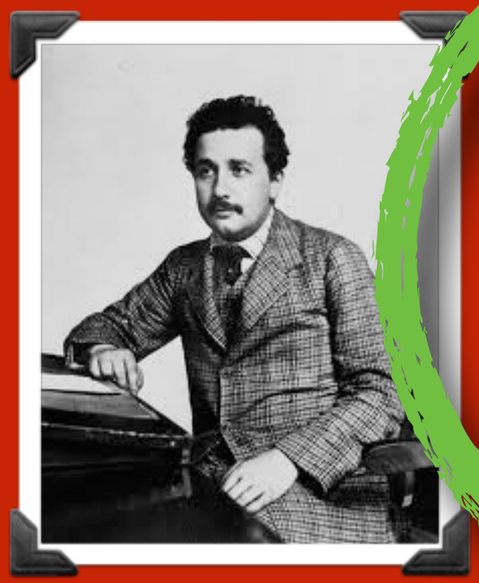
and proposed that c is special

he elevated c to be an **invariant parameter**

Principle of Relativity

2 Postulates:

"inertial frame": constant velocity

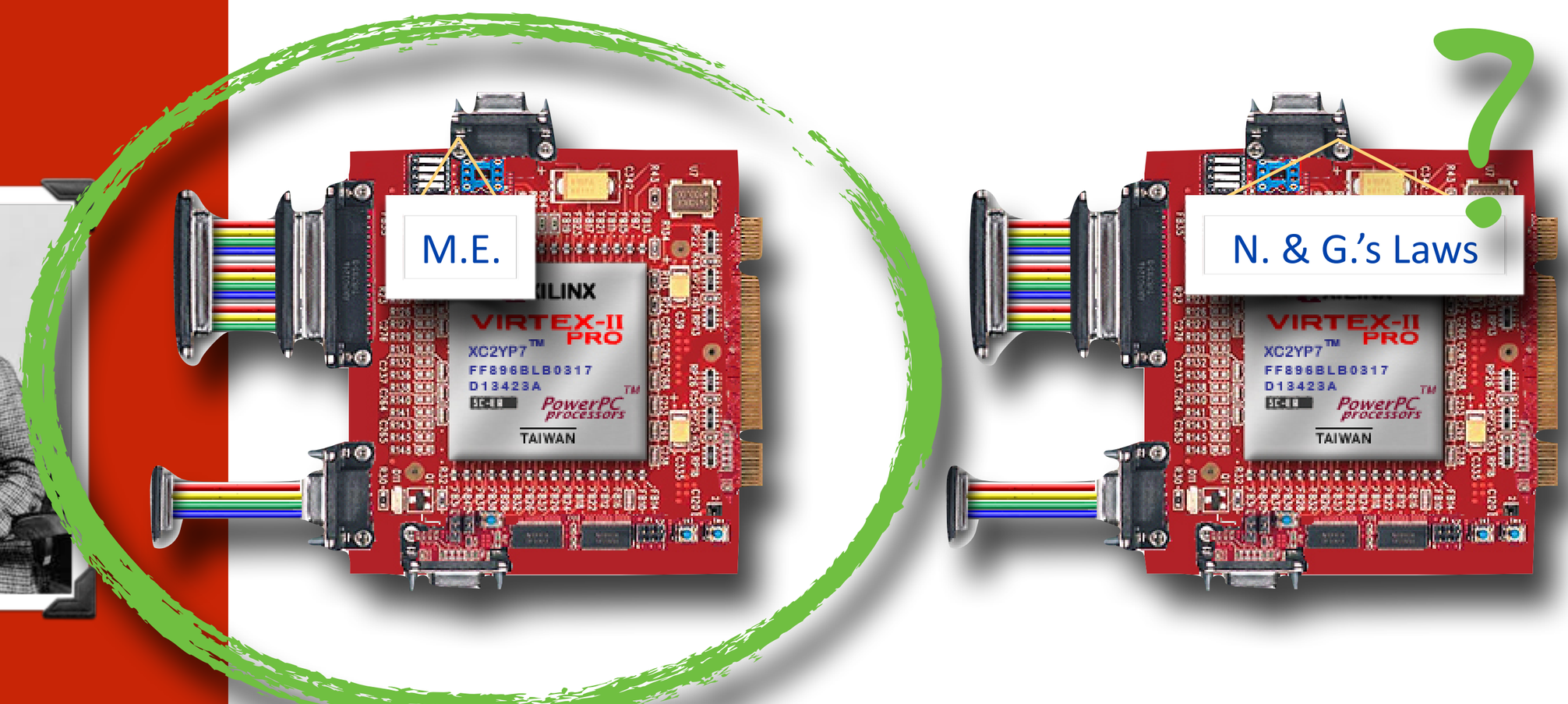


1. All laws of physics – mechanical and electromagnetic – are identical in co-moving inertial frames.

taking Galileo seriously, and then adding Maxwell

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

taking Maxwell seriously



and then

he played the two postulates out

to see what would result

“A storm broke loose in my mind.”

the 2nd postulate

makes things strange

because c

the speed of light is constant in all inertial frames:

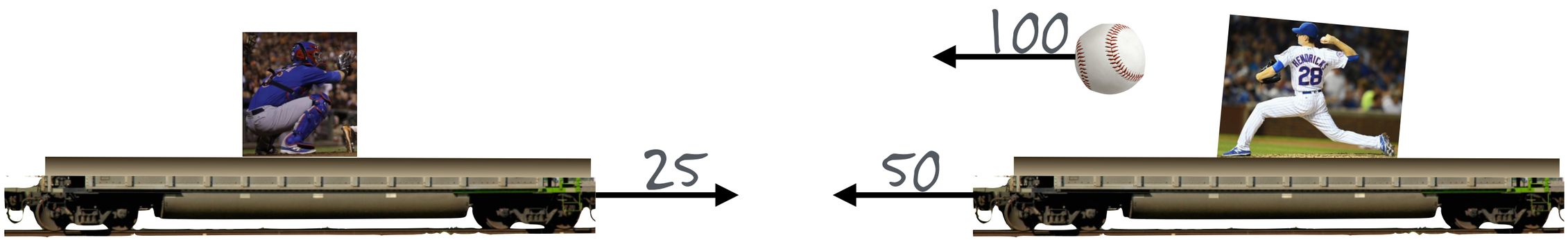
$c = 3 \times 10^8$ m/s = 300 million m/s = 1,080 million km/h

c = 671 million mph

what’s ‘‘now’’?

this seems reasonable:

a trap.



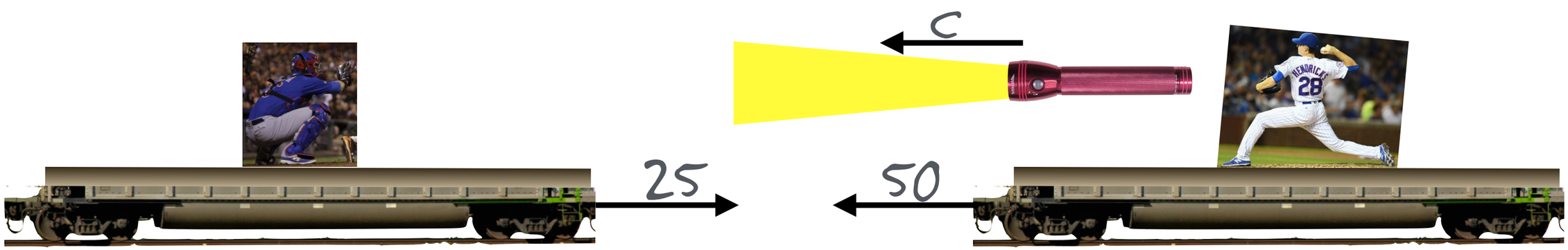
case 1: v(catcher)=0 v(ball)=100 v(pitcher)=0

what's v(ball) that catcher experiences: v(caught)=100

---

this seems strange:

light's different.



case 1: v(catcher)=0 v(light)=c v(pitcher)=0

what's v(light) that catcher experiences: v(caught)=c

---

case 2: v(catcher)=0 v(light)=c v(pitcher)=50

what's v(light) that catcher experiences: v(caught)=c

---

case 3: v(catcher)=25 v(light)=c v(pitcher)=50

what's v(light) that catcher experiences: v(caught)=c

his concern:

synchronizing clocks

on a train

she arranges for light detectors to be equidistant from light source

train lady sees:

simultaneous hits

on a train

she arranges for light detectors to be equidistant from light source

train lady sees:

still: simultaneous hits

her motion doesn't matter to her

beside the tracks

he arranges for light detectors to be equidistant from light source

track man sees:

simultaneous hits

but

what does he see on the train

if the light source goes by him?

beside the tracks

track man sees:

beside the tracks

track man sees:

they both agree:
light turns on t=0

beside the tracks

track man sees:

beside the tracks

track man sees:

back finger catches up
front finger runs away

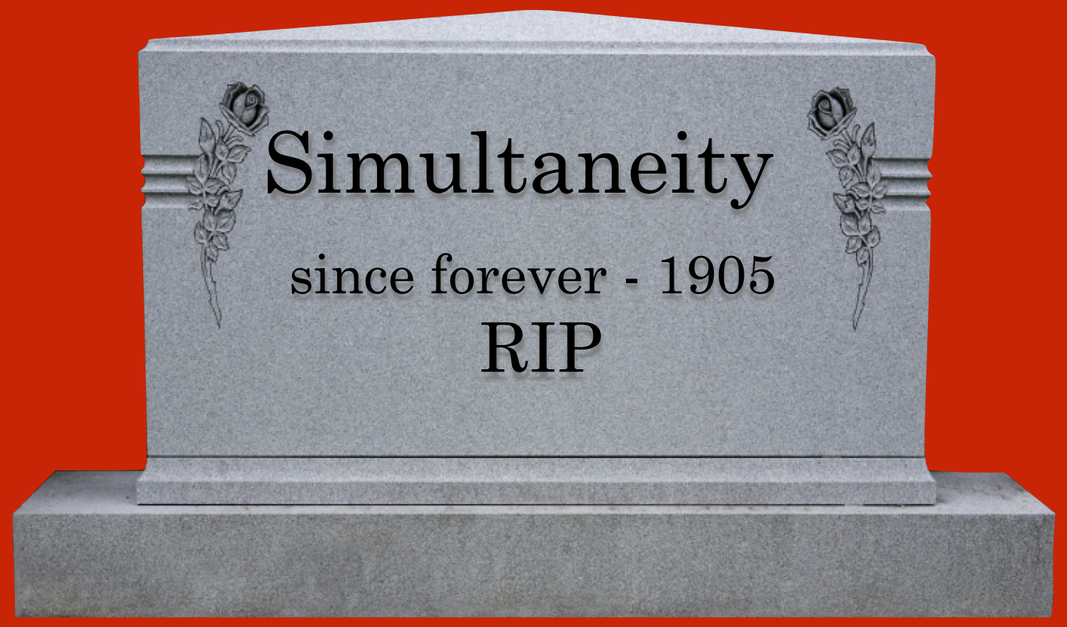
a consequence

of the second postulate:

if two events are simultaneous in one frame

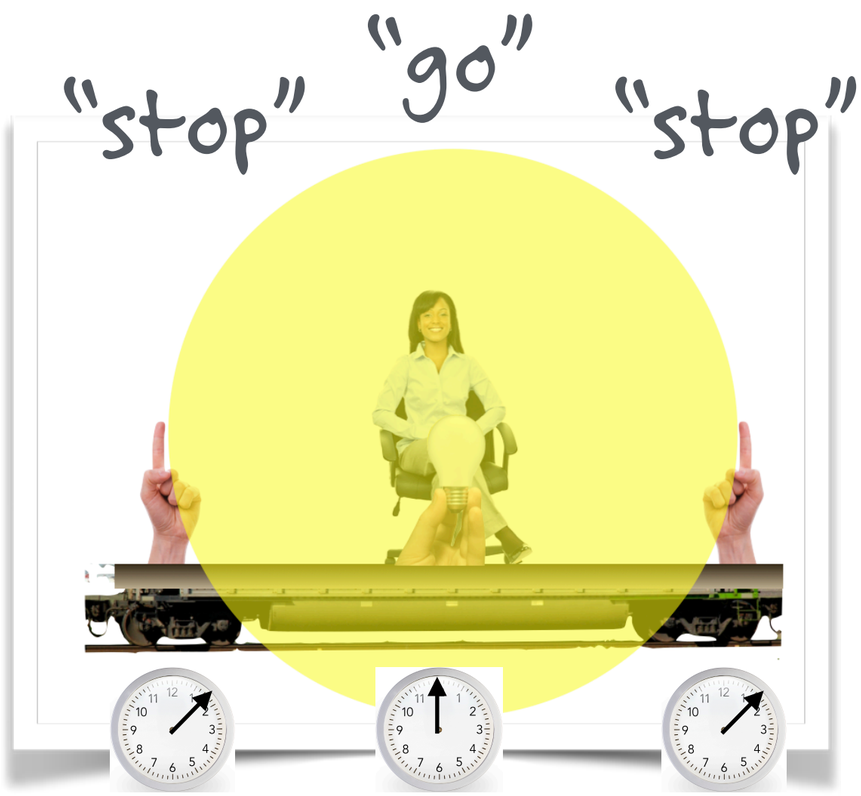
they are not for a co-moving inertial frame

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



this bothered Einstein

how would you synchronize two clocks?



"stop" "go" "not yet"

without "simultaneity"…you can't

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 one can never confirm or disconfirm the reality of a special frame of reference*

2. The notion that a *cause* always precedes an *effect* seems threatened.

*critical,... queue soapbox:

to the logic of science: disconfirmation

not “proof”

not “belief”

Unsure about someone’s “scientific” assertion?

Ask what it would take to change their mind.

So.

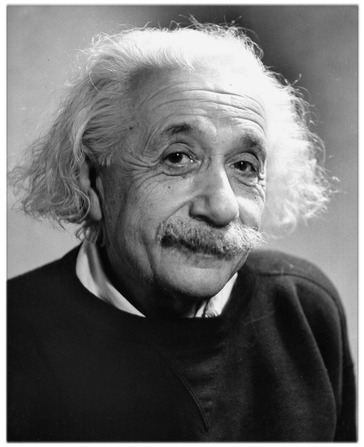
No inertial frame is special.

All are equivalent.

Why?

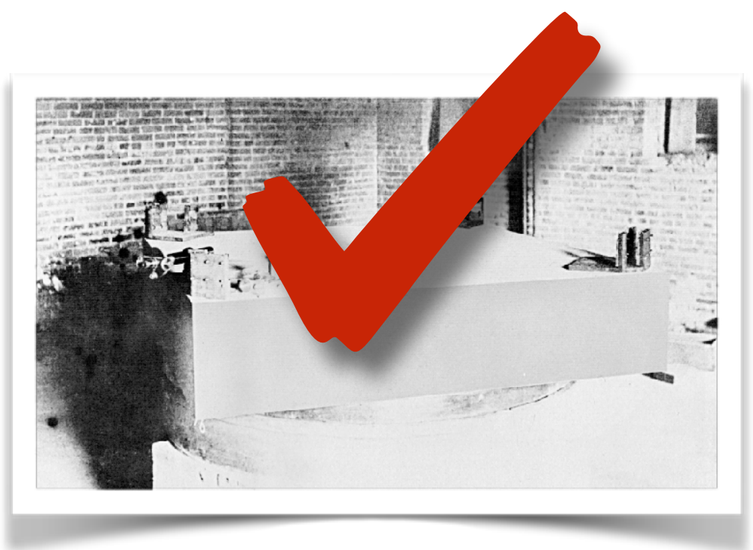
because disconfirmation of a state of absolute rest is impossible

new criterion for physical reality:



If it can’t be measured it can’t be real

The ether can’t be measured, so it cannot be real…



26 yo Einstein:

“The introduction of a “luminiferous ether” will prove to be superfluous inasmuch as the view here to be developed will not require an “absolutely stationary space” provided with special properties…”

2. “Causality” requires care

is CAUSALITY

Two observers disagree about whether events happen the same time? at different times?

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

would a moving observer see me first cry, then I’m born?

a casualty!?

there are consequences to this

let’s make a light clock

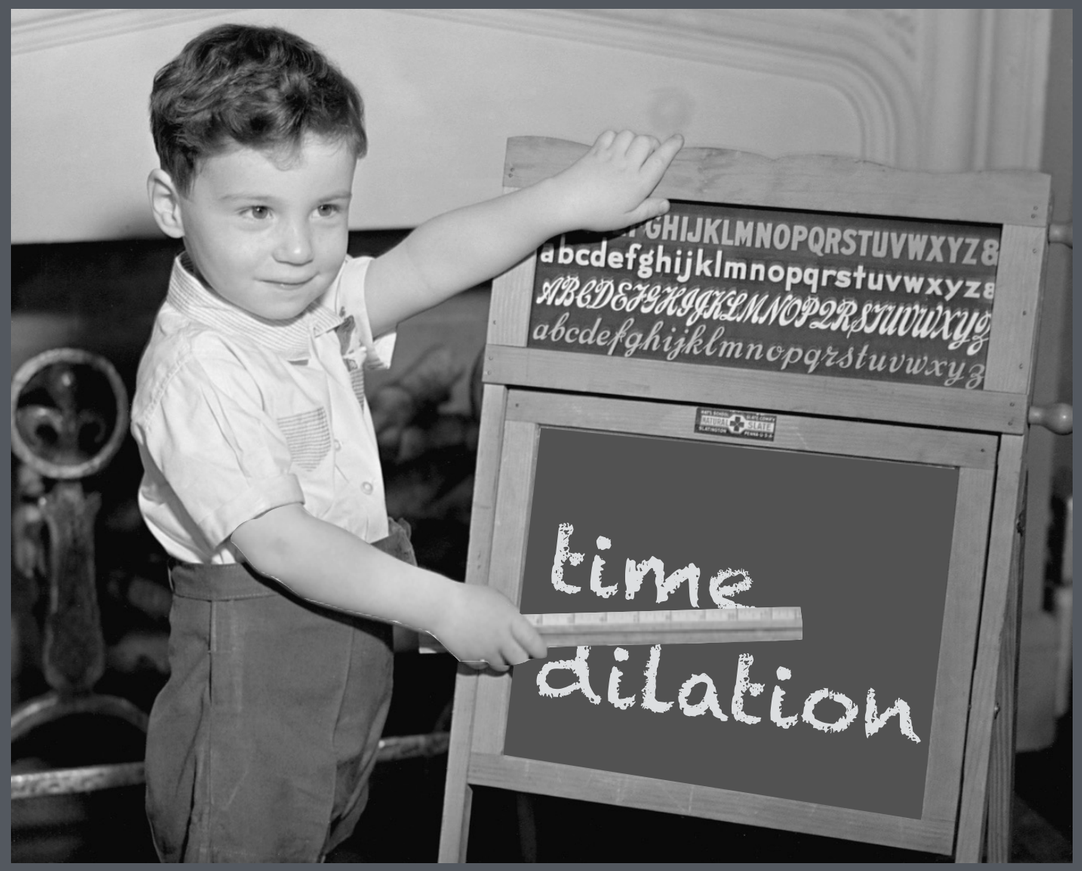
and follow the mathematics

A A A

a light clock!

L

H



sketch the calculation of the light clock

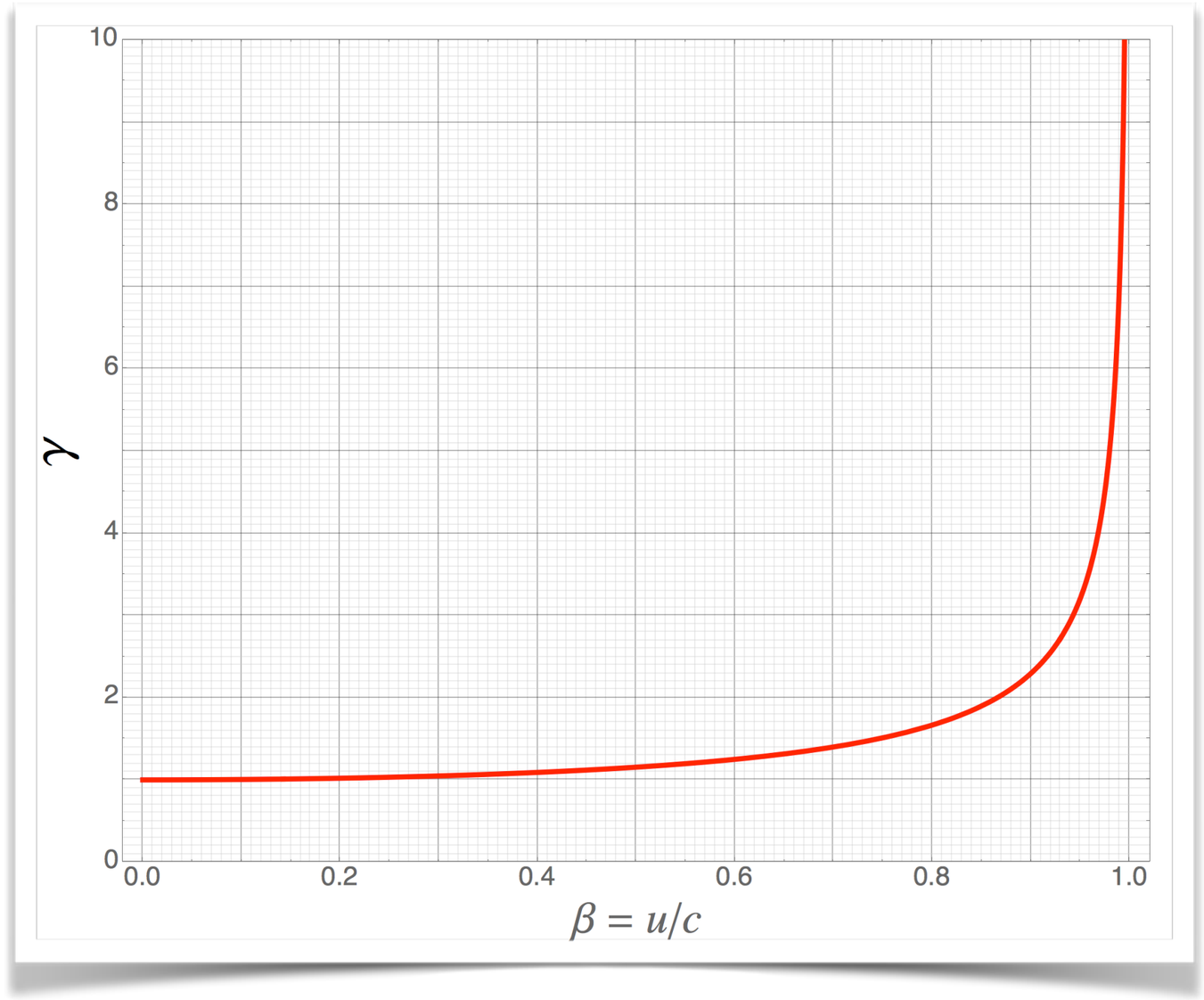
Moving clocks appear to run slower as seen by a relatively stationary observer

$$t_H = \frac{t_A}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

$$t_H = \gamma t_A$$

time dilation

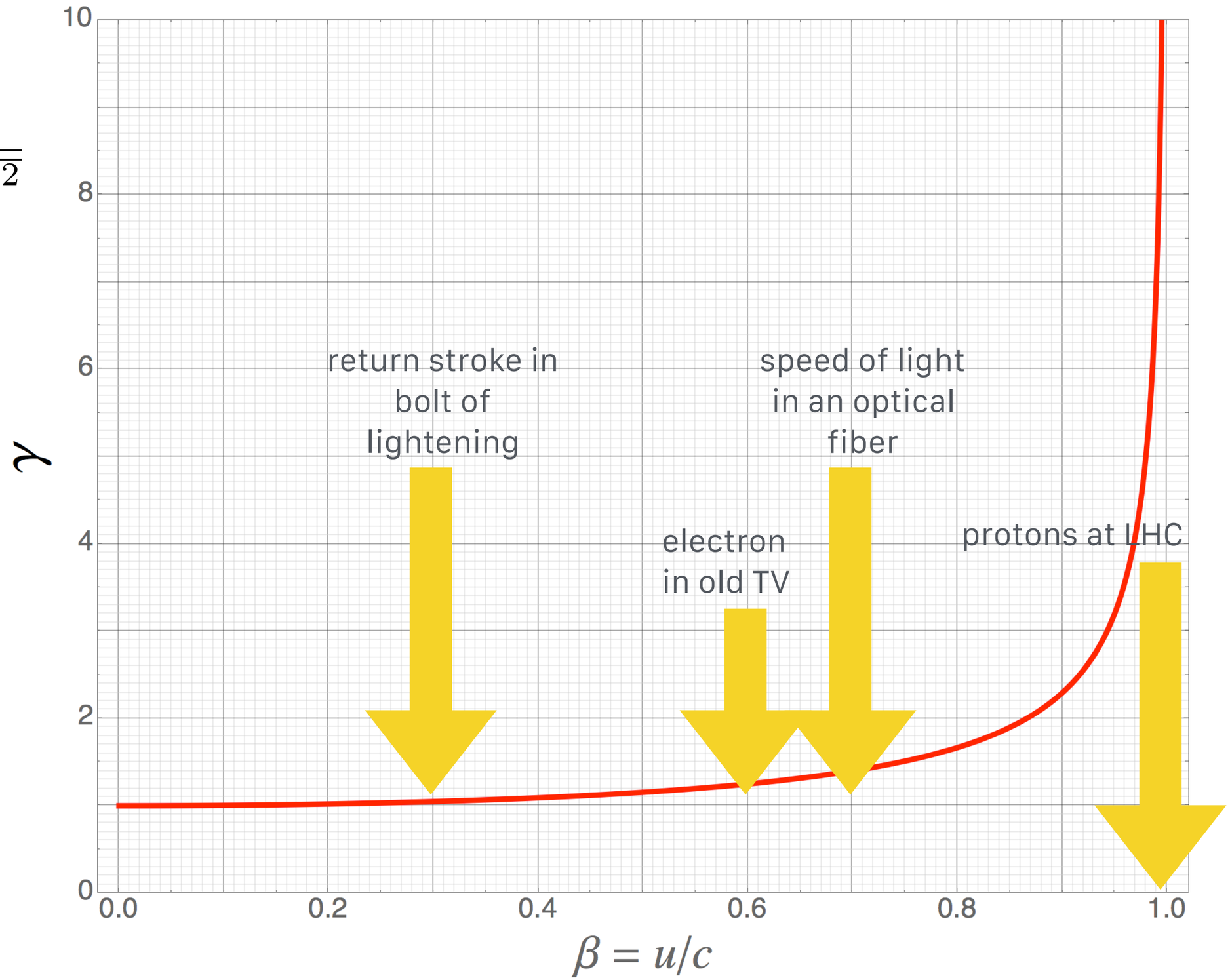
the second of 3 strange things about space and time



‘‘relativistic gamma’’

$$\gamma = \frac{1}{\sqrt{1 - (\frac{u}{c})^2}}$$

$$\beta = u/c$$



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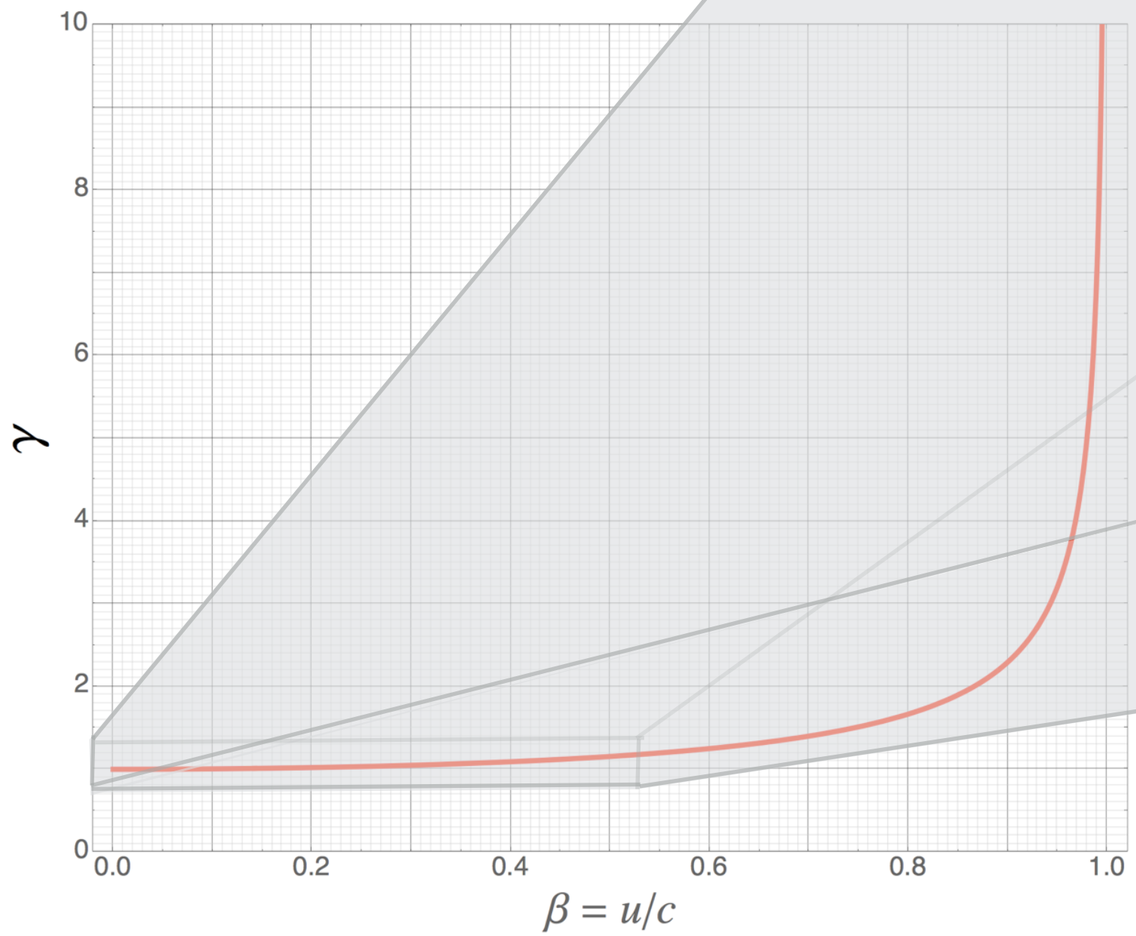

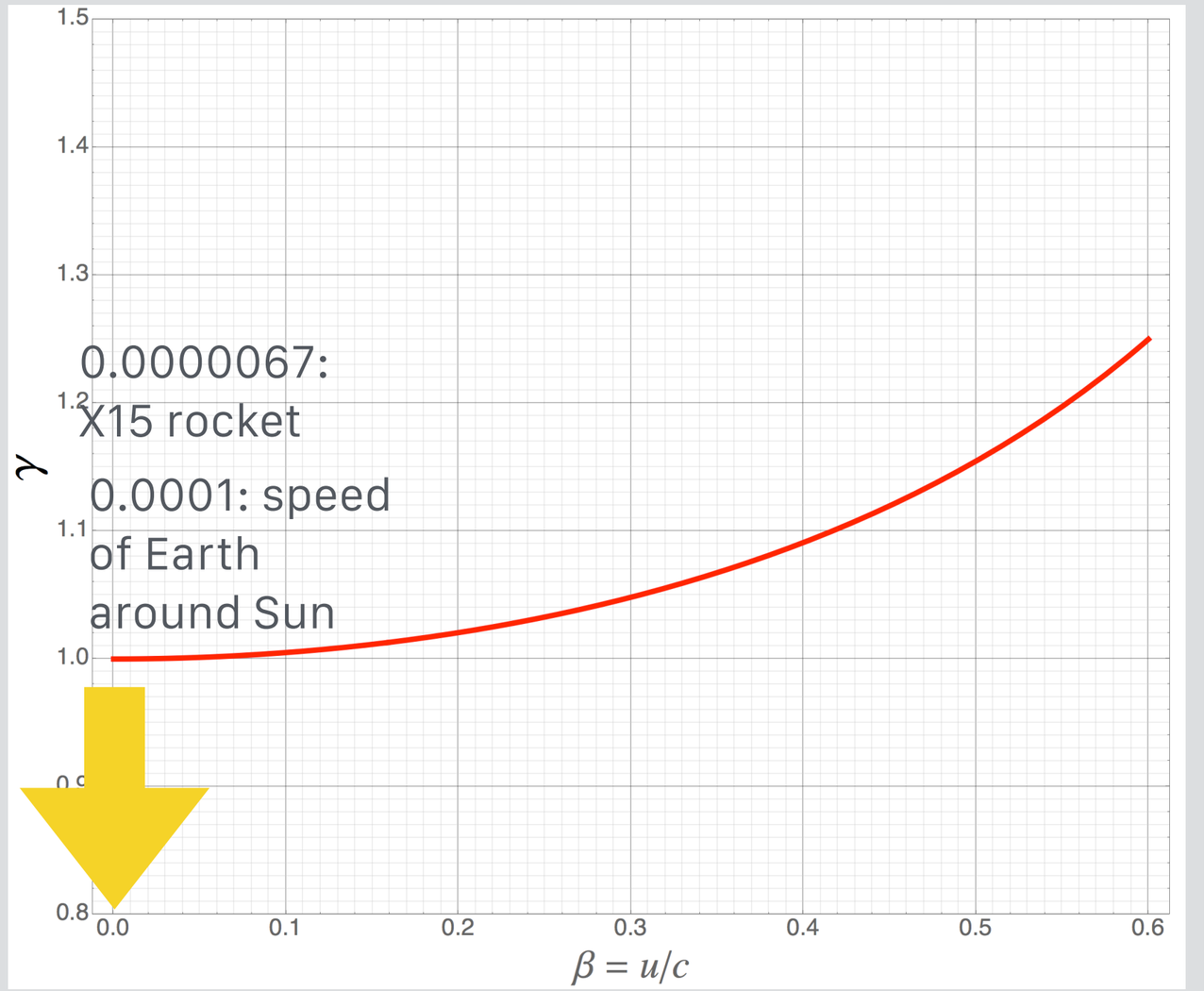

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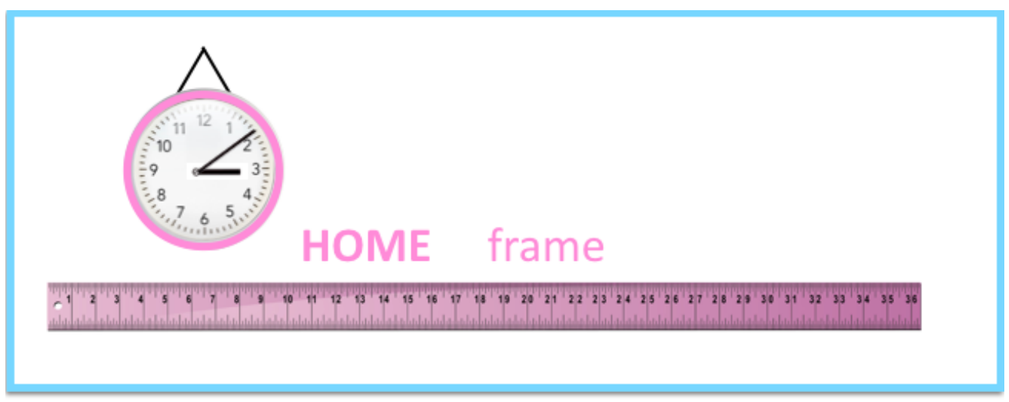

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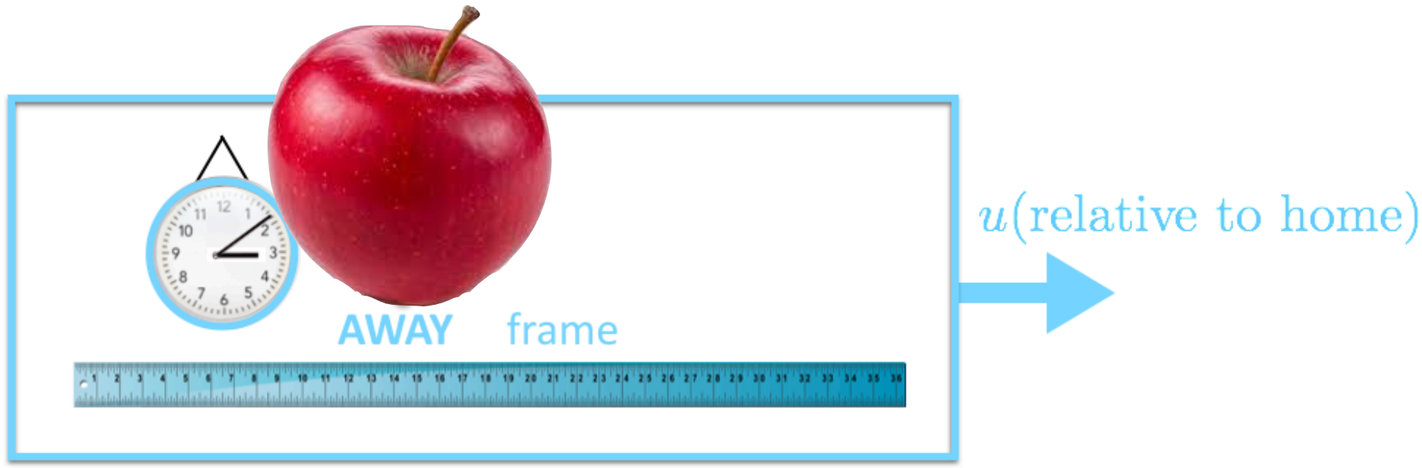

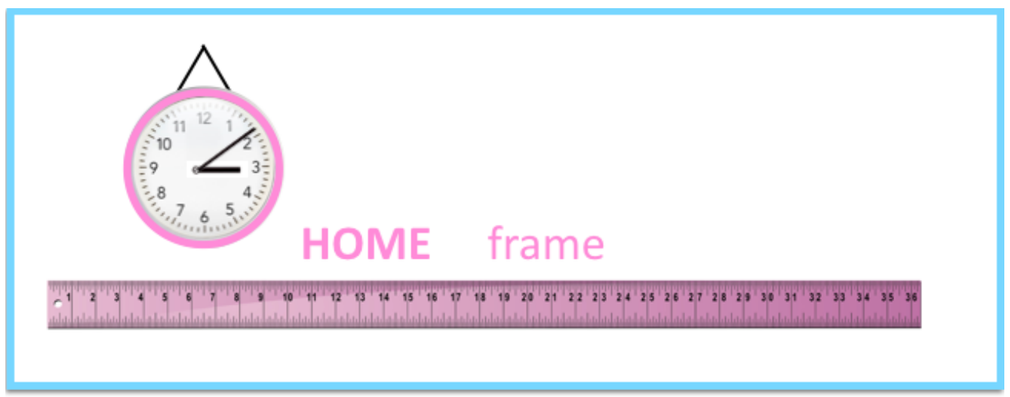

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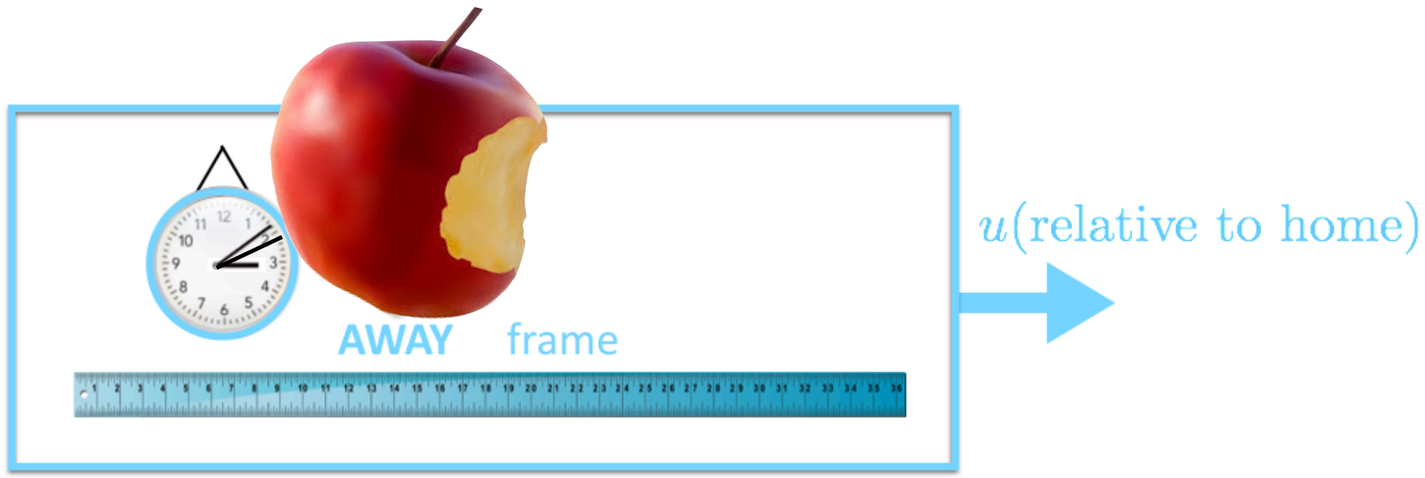

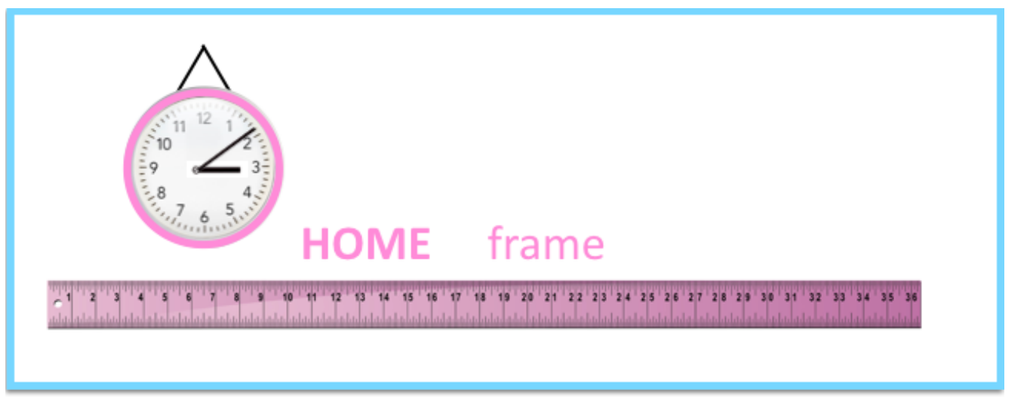

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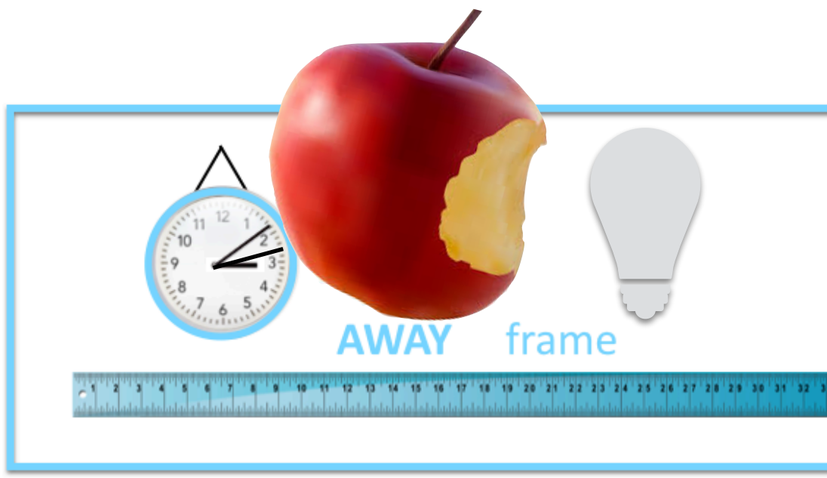

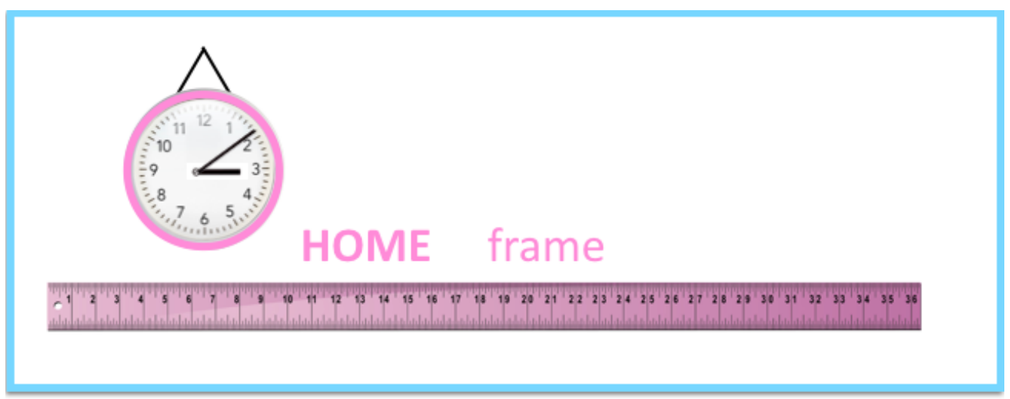

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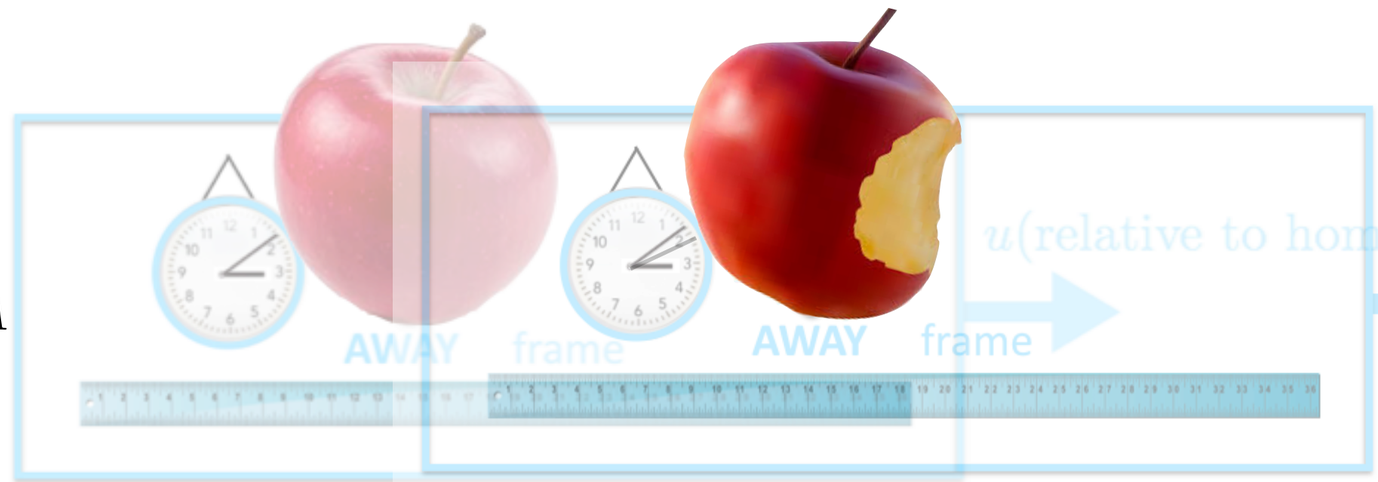
events happen once at 1 space and 1 time location

intervals happen once at 2 space and/or 2 time locations



$\Delta t(\text{in Away}) \equiv t_A$

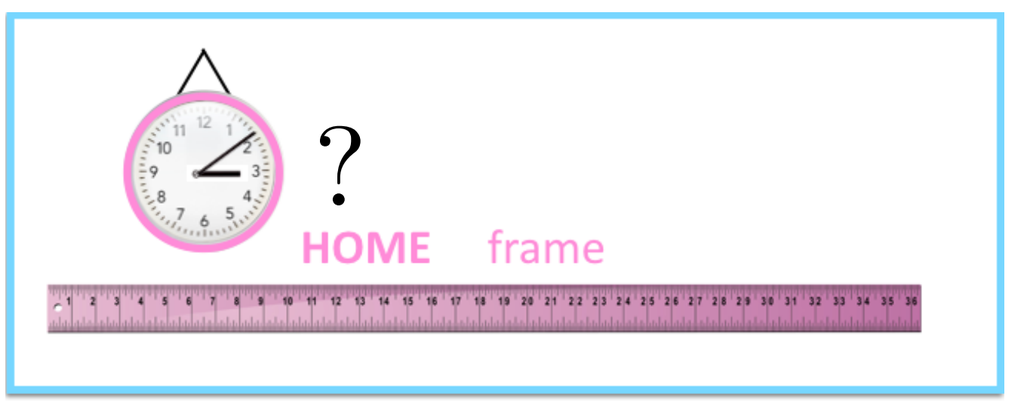
$u = 0.9c$

$t_A = 1 \text{ second}$

$t_H = \gamma t_A$

$t_H = ?$

$\Delta t(\text{as seen by Home}) \equiv t_H$



‘‘relativistic gamma’’

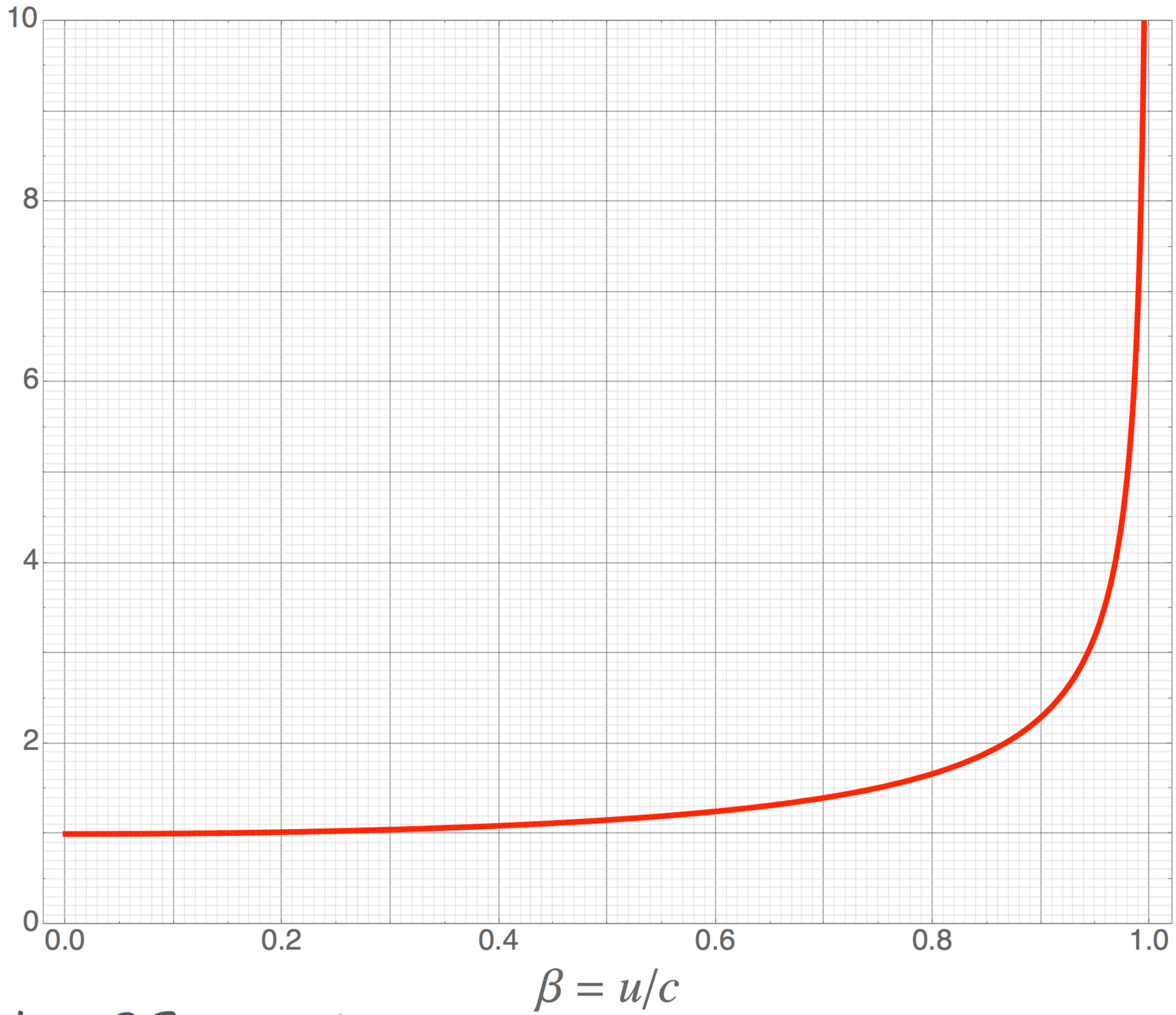
$$\gamma = \frac{1}{\sqrt{1 - (\frac{u}{c})^2}}$$

$$\beta = u/c$$

$$u = 0.9c$$

$t_A = 1$ second

$t_H = 2.3$ seconds



I second is slower than 2.3 seconds

this works for any clocks

actual clocks

atomic transitions

elementary particle lifetimes

biological clocks

You have a clock and I have a clock and they are identical. I observe yours is in an inertial frame of reference moving past my frame of reference.

I also observe that 1 hour on your clock seems to take 2 hours on my clock.

Yours appears to be slower or faster than mine?

How fast is your frame moving relative to mine?

remember what's constant...

The speed of light, c. ...a speed. $$c = \frac{\text{distance interval}}{\text{time interval}}$$

If clocks are messed with Δt depends on the frame...

and the velocity of light is constant....

Doesn't it stand to reason that lengths are also messed with...

ΔL depends on the frame…?

...shorter as viewed from the home frame:

$$L_H = \frac{L_A}{\gamma}$$

a length in the away frame will seem...

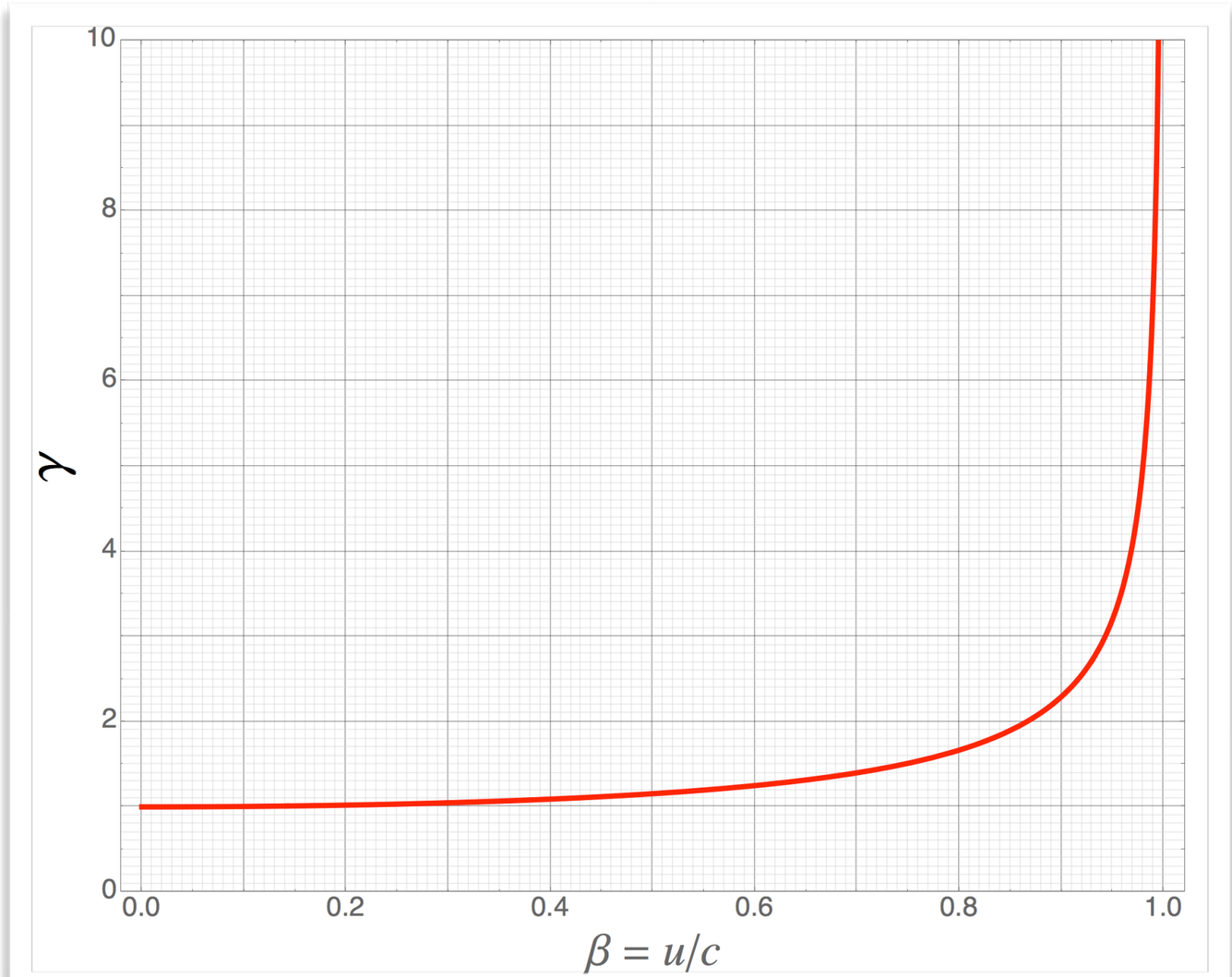
$\gamma > 1$

Moving lengths appear shorter to a relatively stationary observer

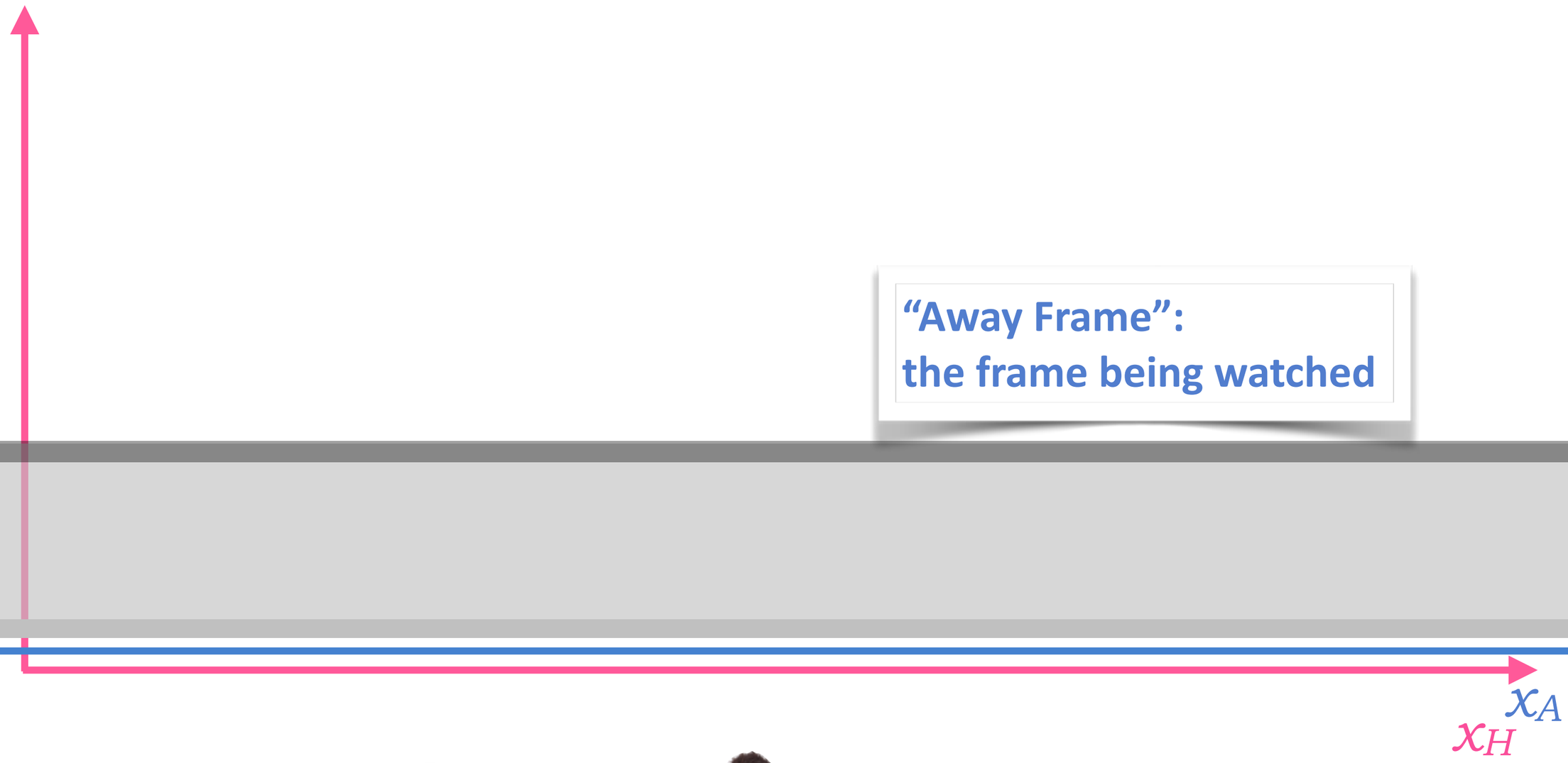
length contraction

the third of 3 strange things about space and time

$$L_H = \frac{L_A}{\gamma}$$



the airport



“Away Frame”:
the frame being watched

“Home Frame”:
watching a moving frame

moving at velocity u

what’s he see?

How fast must a meter stick be traveling relative to you in order for its length to appear to be 30 cm as measured by you?

collecting these two consequences

of the two simple postulates

"Time Dilation":

$$t_H = \gamma t_A$$

Moving clocks appear to run slower as seen by a relatively stationary observer

"Length Contraction":

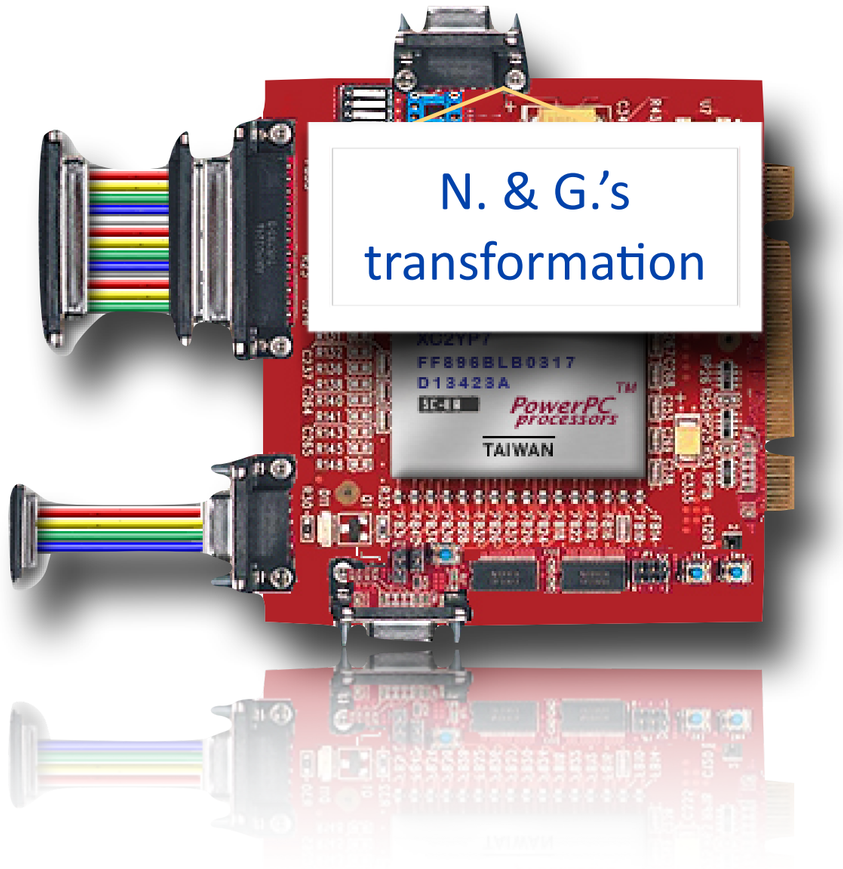
$$L_H = \frac{L_A}{\gamma}$$

Moving lengths appear shorter to a relatively stationary observer

Newton/ Galileo?

mixes space coordinates

x_A, t_A



Galilean Transformations

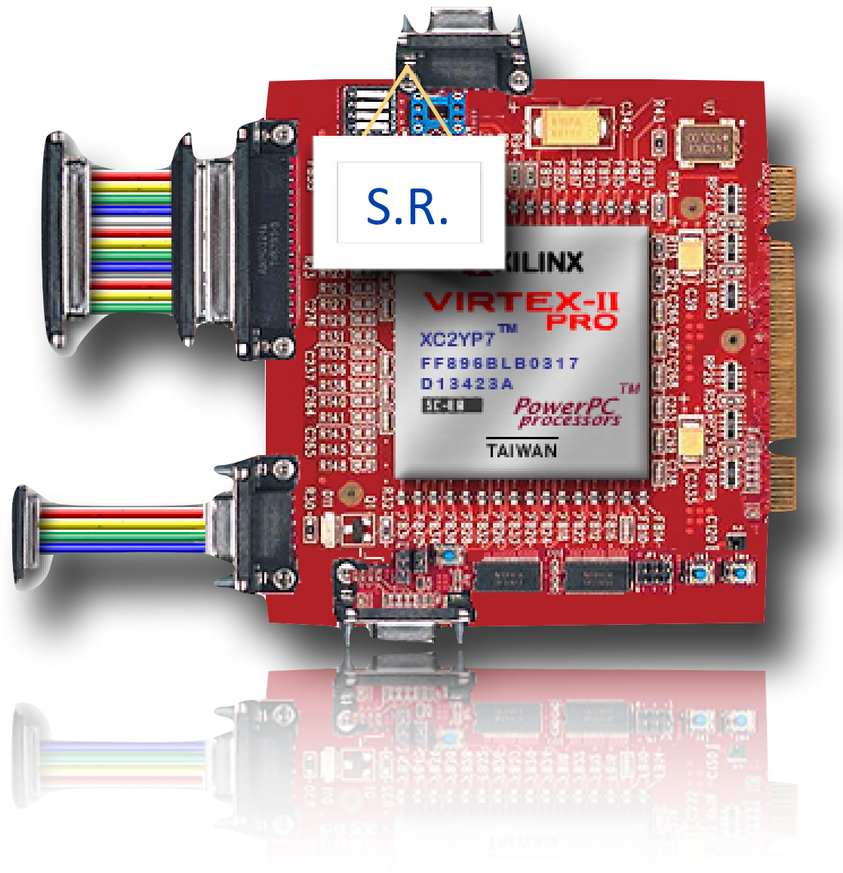
$$x_H = x_A + ut$$

$$t_H = t_A = t$$

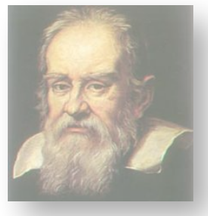
Einstein?

mixes space and time coordinates

x_A, t_A



The prescription is called the
Lorentz Transformations

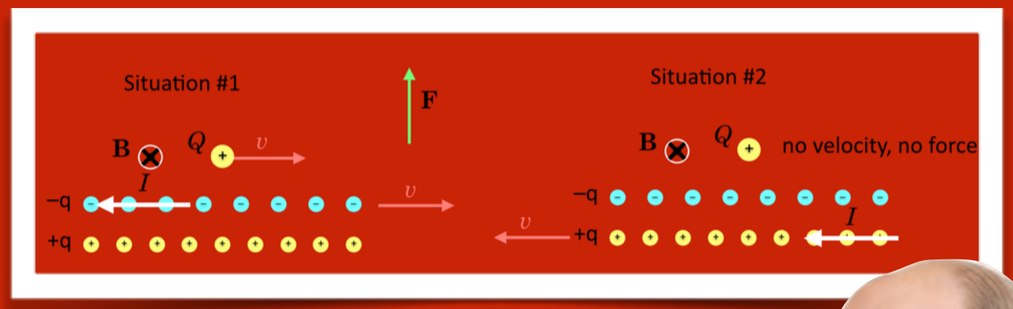


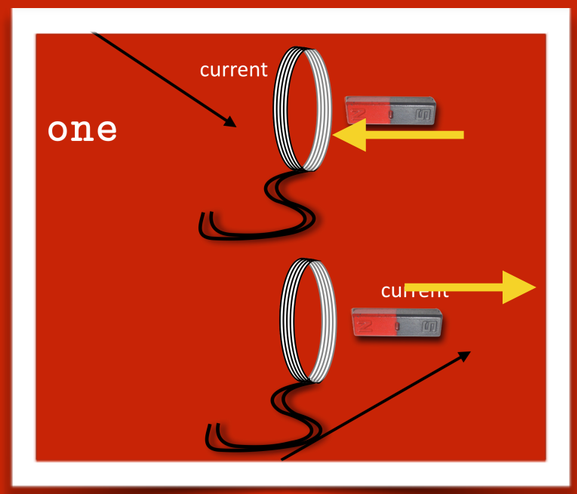
$$x_H = \gamma(x_A + ut_A) \qquad x_H = x_A + ut$$

$$t_H = \gamma(t_A + \frac{u}{c^2}x_A) \qquad t_H = t_A = t$$

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{u}{c}\right)^2}}$$

remember?

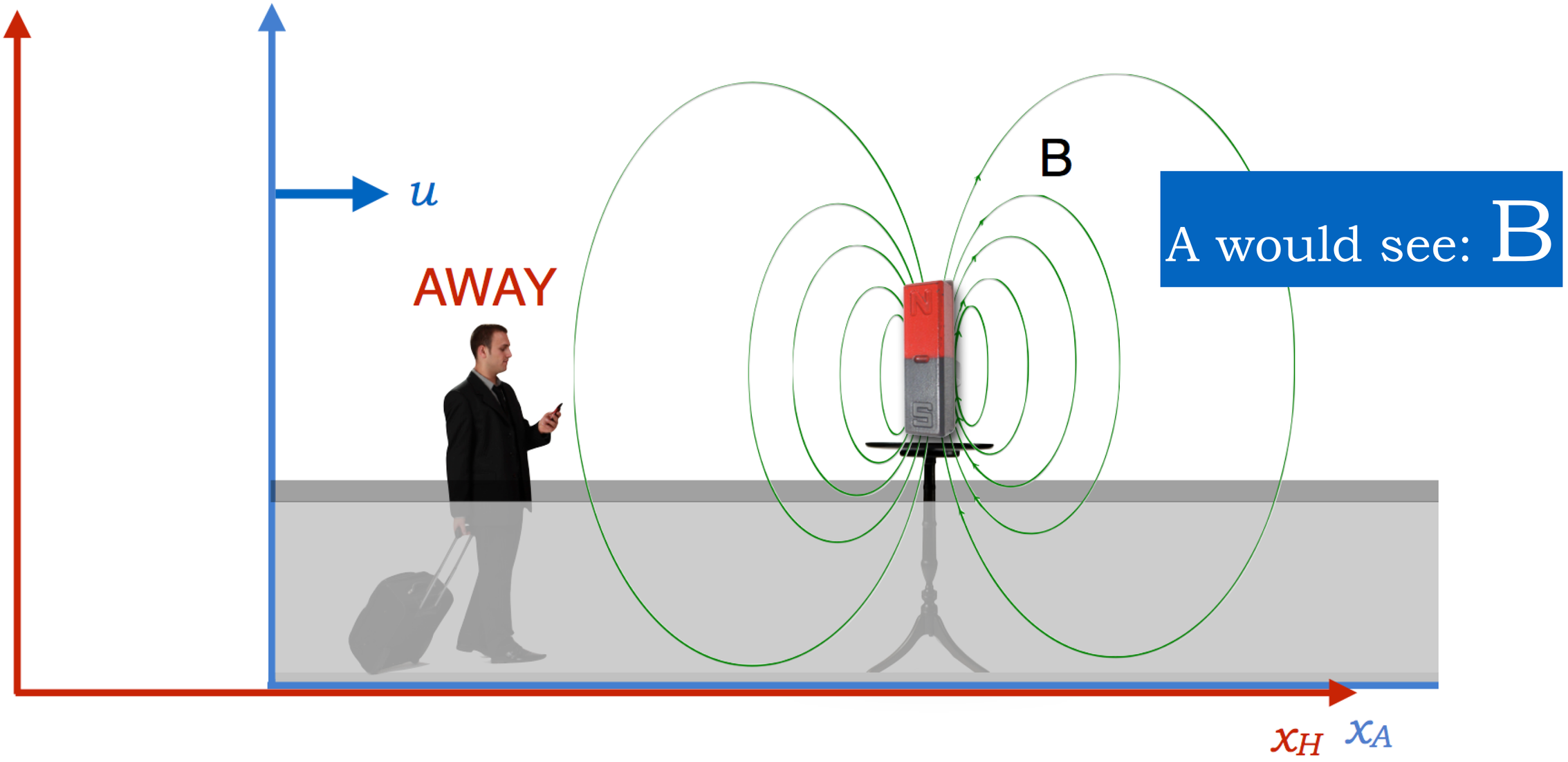




Weird alert #1:
Two different physical outcomes...
for situations which differ only by the frame of reference

Weird alert #2:
Two identical physical outcomes...
from entirely different physical causes for situations which

back to the airport



H would see: E+B!

so the original problems are solved by:

the Lorentz transformations in *x* and *t*

actually **mix** electric and magnetic fields

so

A **magnetic field** in one frame

is a **mixture of magnetic and electric fields** in another frame

An **electric field** in one frame

is a **mixture of electric and magnetic fields** in another frame

so the original problems are solved by:

E and B are two manifestations of one thing:

the Electromagnetic Field

the Lorentz transformations in x and t

mix electric and magnetic fields

A magnetic field in one frame

is a mixture of magnetic and electric fields in another frame

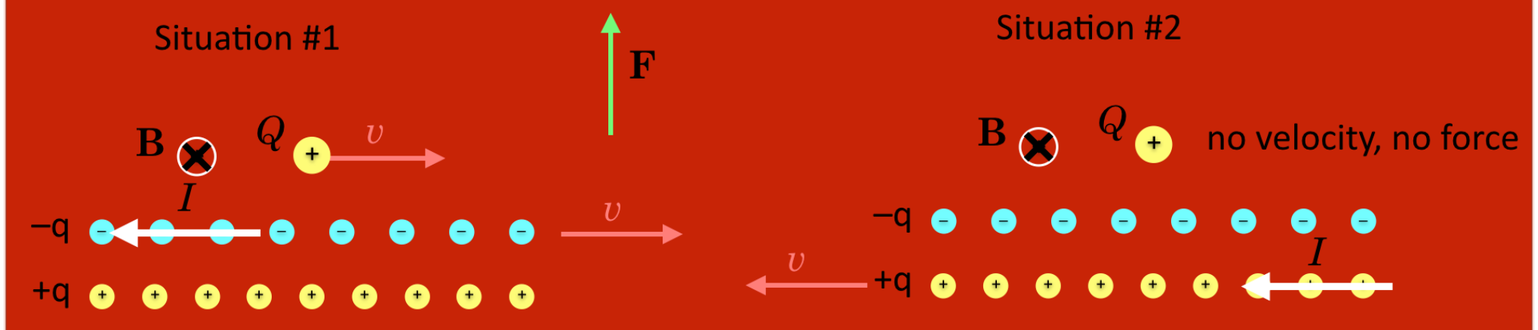
An electric field in one frame

is a mixture of electric and magnetic fields in another frame

remember:

more simple questions

how about a charge next to a current?

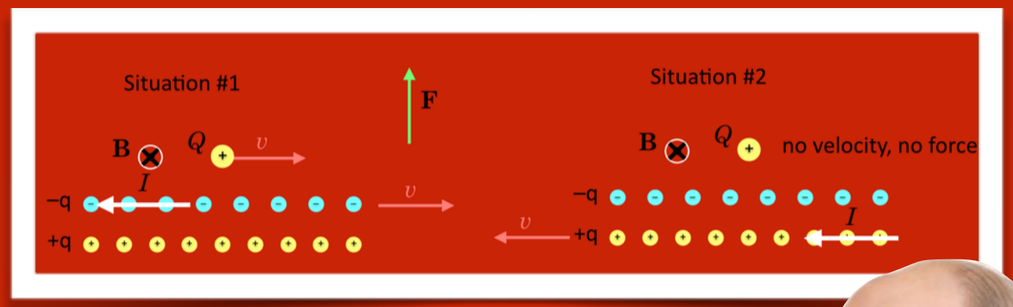


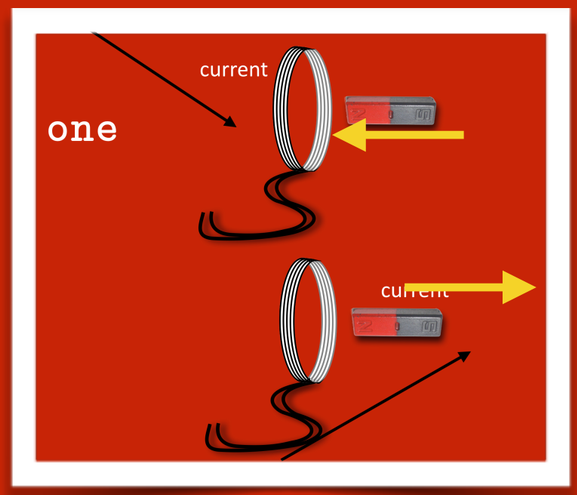
These situations differ only in the reference frame...

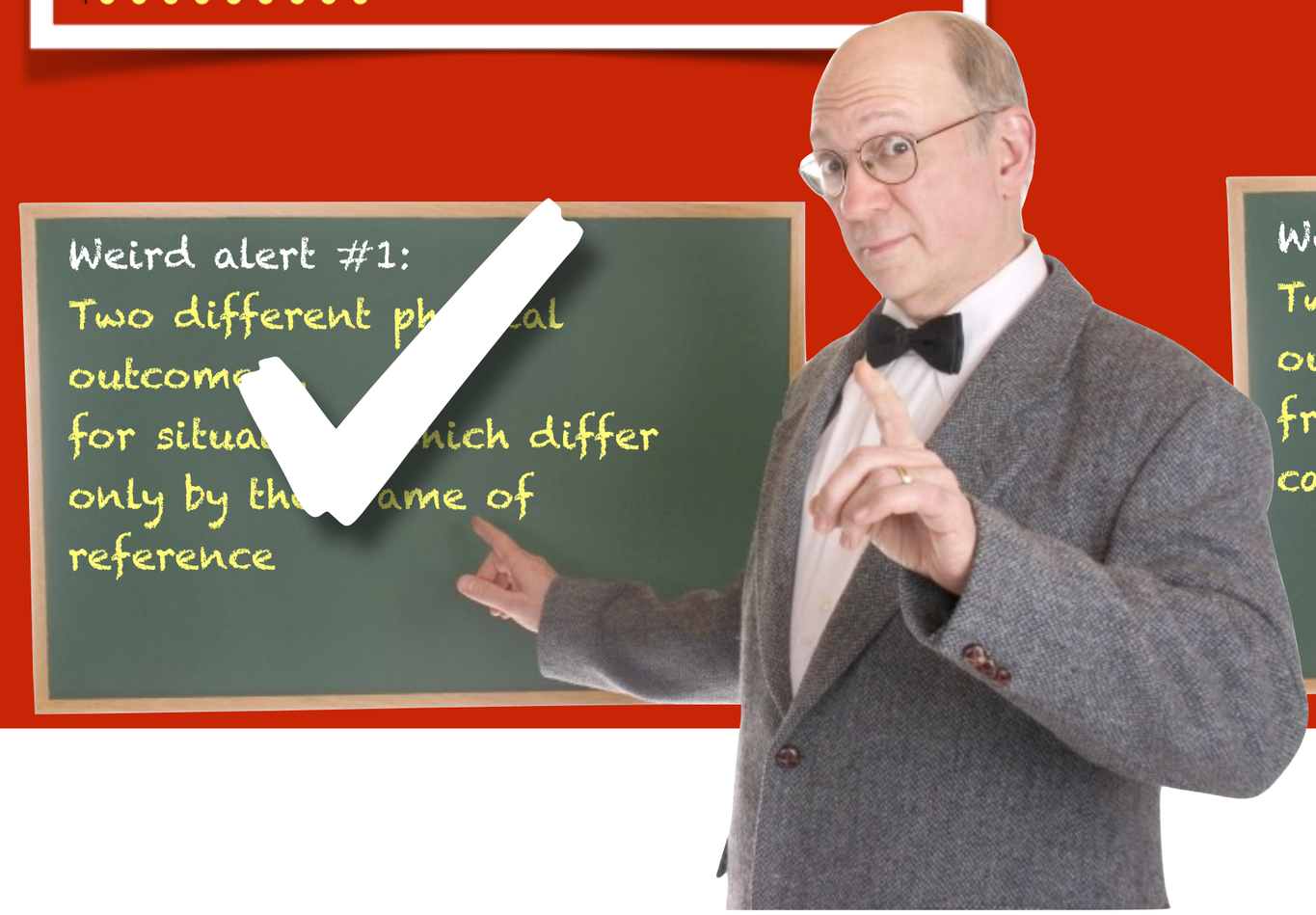
But, the physical effect – force or no force – is different!

6

remember?


Situation #1
F
B
Q
v
I
−q
+q
v
Situation #2
B
Q
no velocity, no force
−q
+q
v
I


one
current
current


Weird alert #1:
Two different ph al
outcome
for situa hich differ
only by th ame of
reference


Weird alert #2:
Two identical p cal
outcomes...
from e ifferent physical
causes f tuations which

the punch line.

Principle of Relativity

2

Postulates:

“inertial frame”:

constant velocity

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

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

good all along!

had to change!