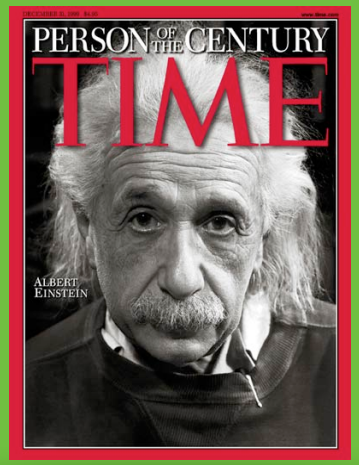
hi

aaack!

03.03.2018

Day 15, ~~27.02.2018~~

Einstein's Theory of Special Relativity, 2



housekeeping

Lectures forever now.

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 next lecture for HW! will move due date a few days later (see next slide)

MasteringPhysics registration expiration now set to March 15. My bad.

Marie Curie movie anyone?

February 2018

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	1	2	3

yadda yadda yadda

yadda yadda yadda

HW5

HW6

today

lesson 12

HW5 due

lecture

lecture

HW6 due

← midterm →

~~lecture~~

lecture!

HW7

Eastern Time Time Zone

HW7 due ~~3/16~~ 3/18

February 2018
March 2018

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
25	26	27	28	1	2	3
← midterm	midterm	midterm →		lecture!		HW7
4	5	6	7	8	9	10
← spring break	spring break	spring break	spring break	spring break	spring break	spring break →
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

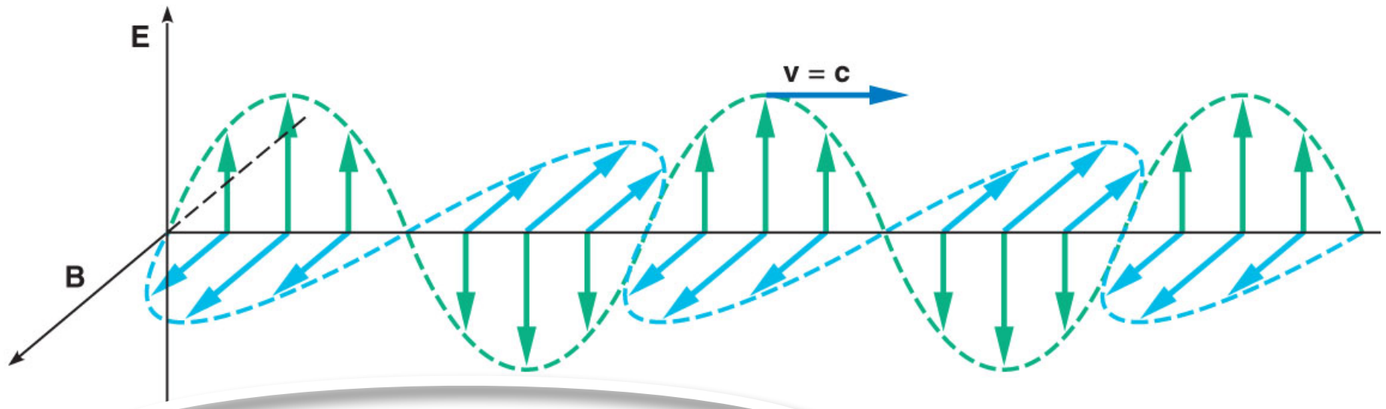
You might want to remember this:

a changing B field creates an E field

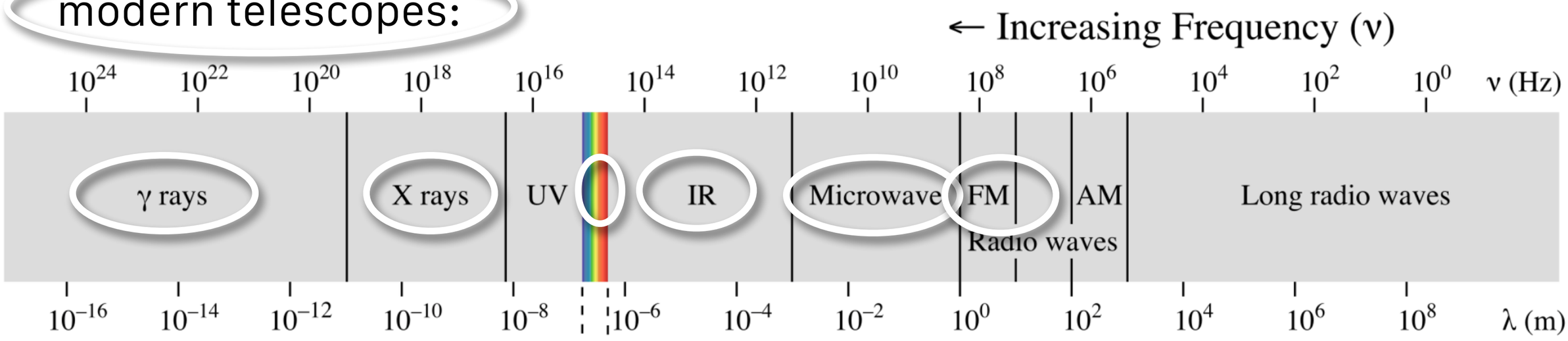
a changing E field creates a B field

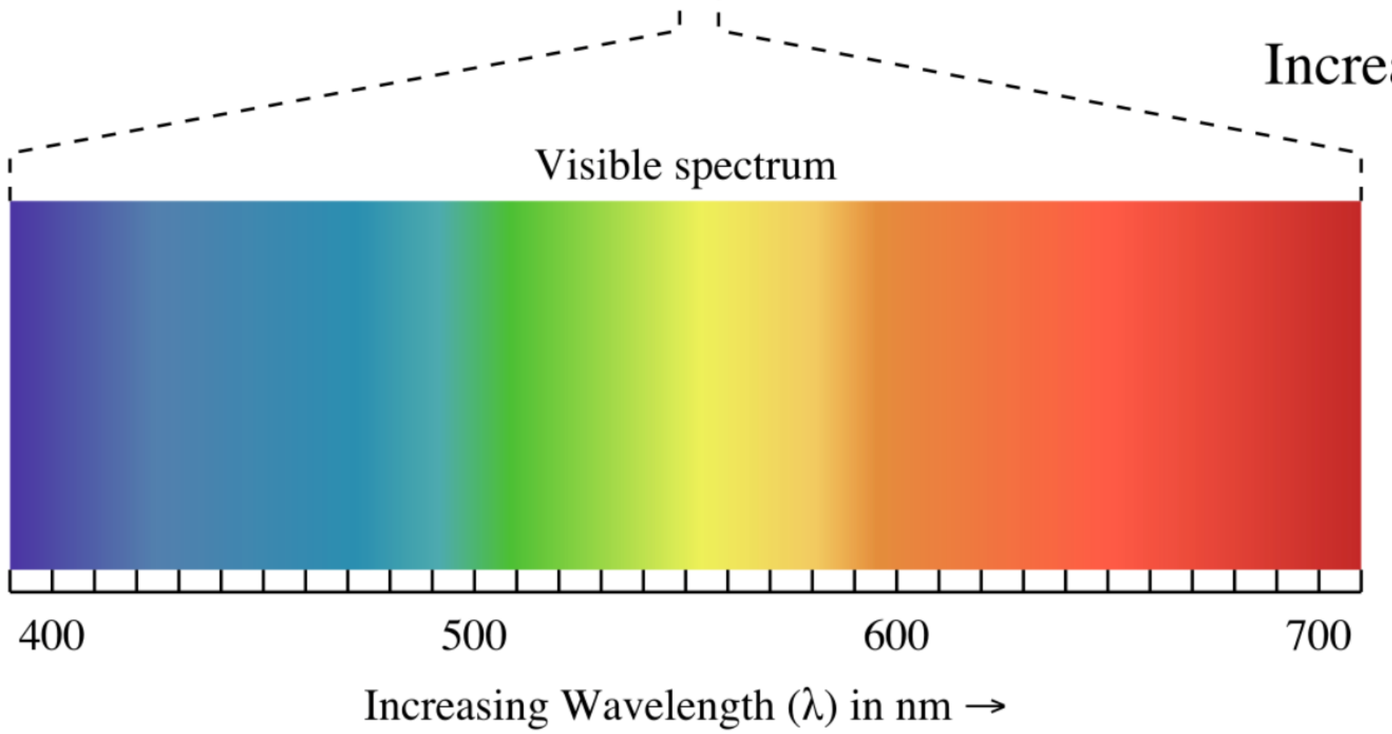
accelerated charges produce electromagnetic radiation

Modern Electromagnetic Spectrum

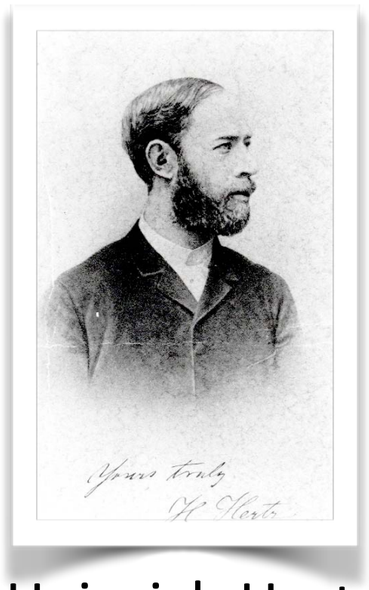


modern telescopes:





all travel at c = 3 x 10^8 m/s



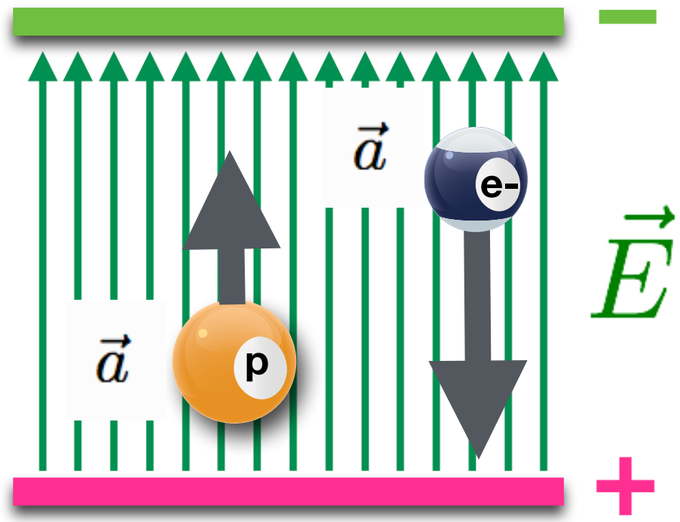
Heinrich Hertz

1857 – 1 January 1894

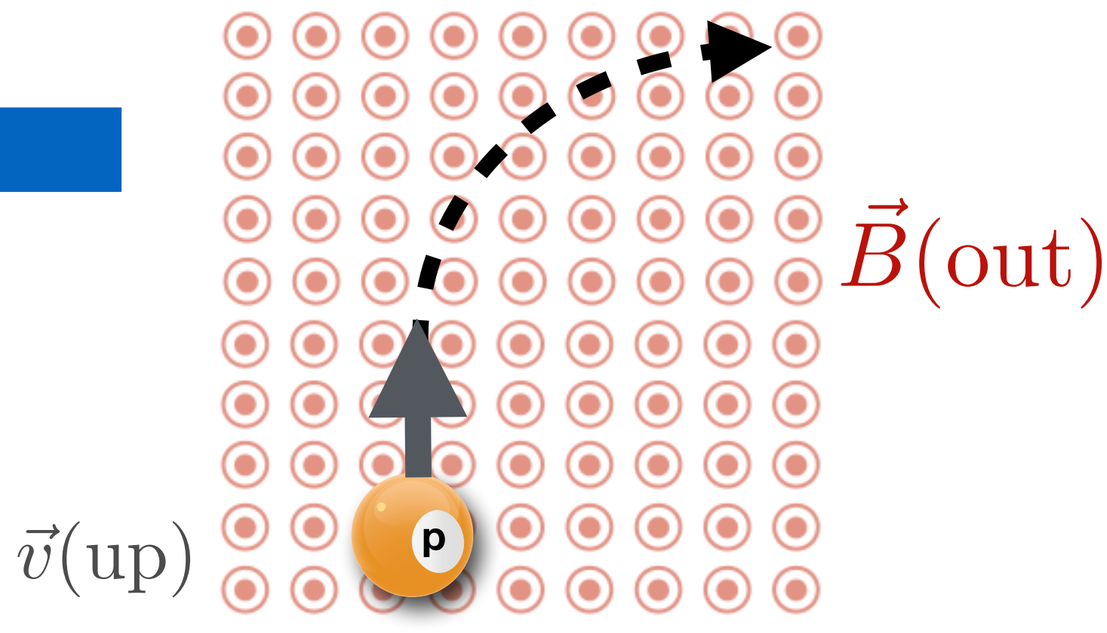
Accelerator ingredients: E and B

for two configurations of charges and currents

Electric Fields
accelerate



Magnetic Fields
bend



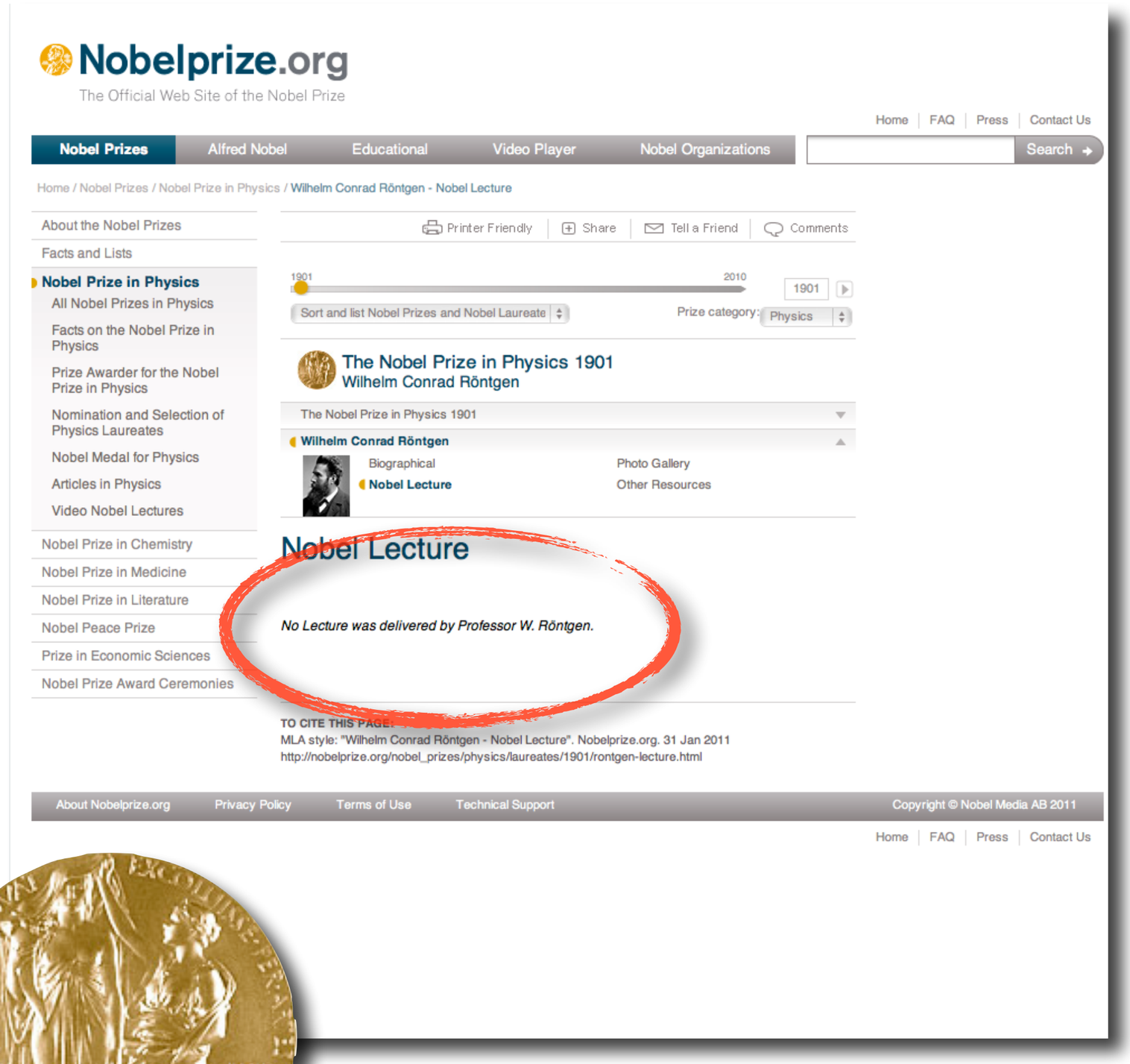
our first Nobel

1 talk

1 publication

no profit

suffered terribly during WWI



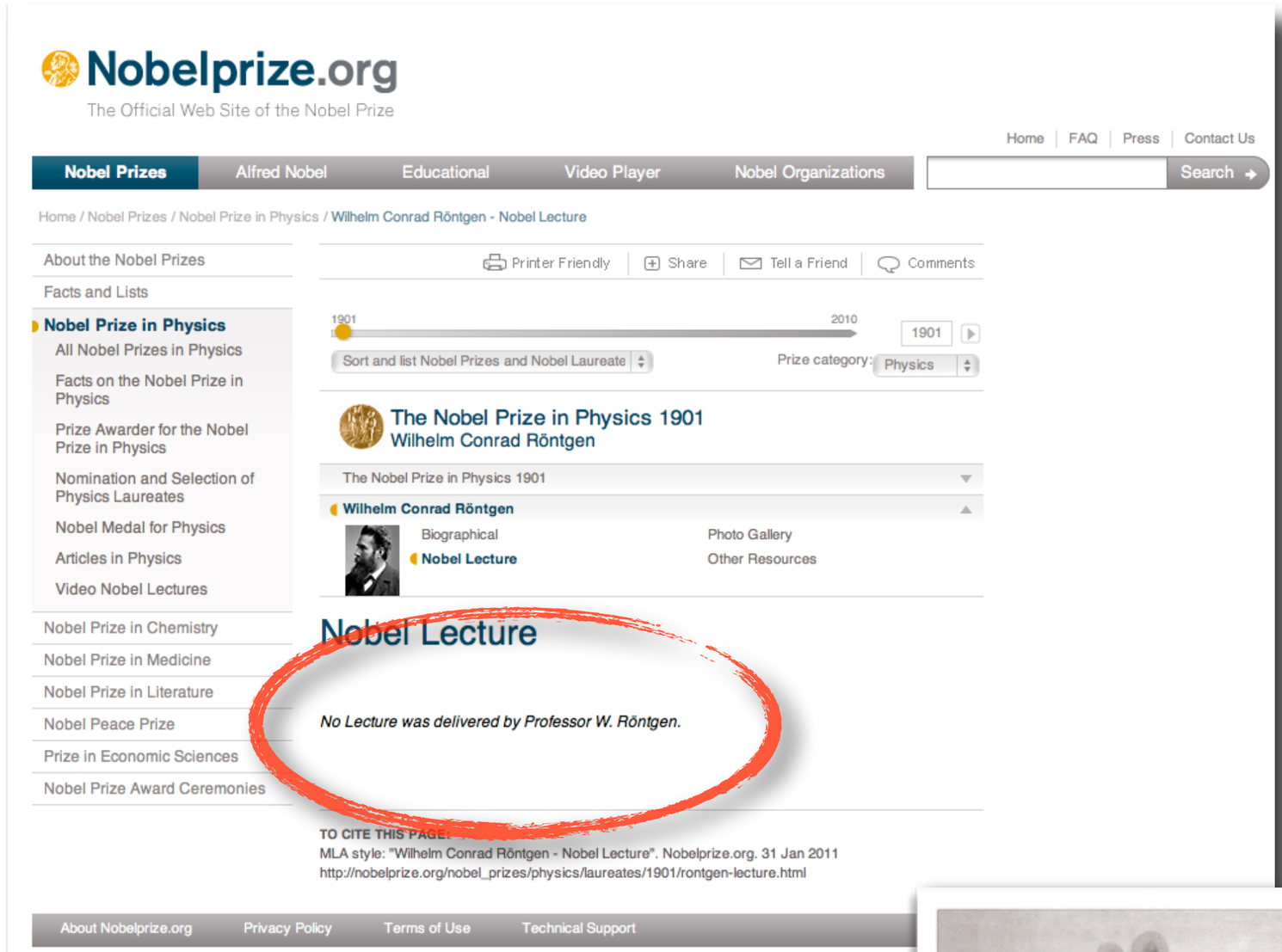
our first Nobel

1 talk

1 publication

no profit

suffered terribly during WWI



then

it got strange

Nobel 1906

The Nobel Prize in Physics 1906
J.J. Thomson

Share this:

The Nobel Prize in Physics 1906

Joseph John Thomson

Prize share: 1/1

The Nobel Prize in Physics 1906 was awarded to J.J. Thomson *"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".*

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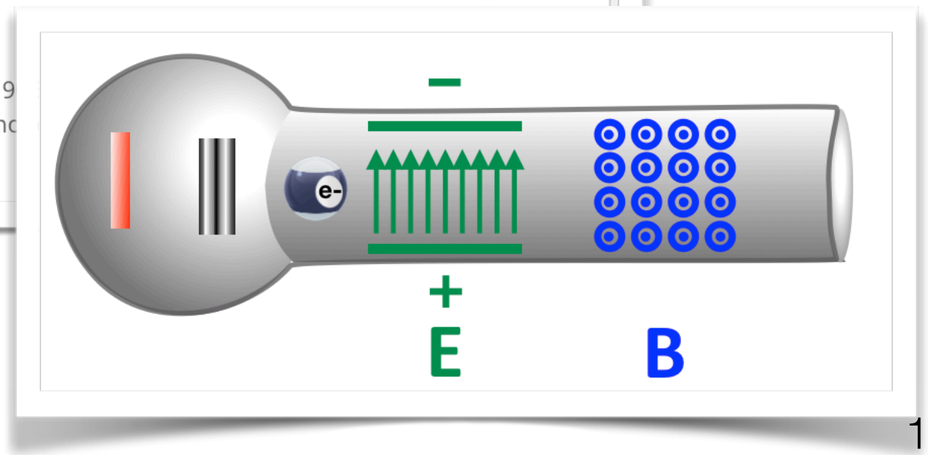
is page
"The Nobel Prize in Physics 19
http://www.nobelprize.org/nc



then

it got strange

Nobel 1903

tragically Pierre kille a street accident 1

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- Nobel Peace Prize
- Prize in Economic Sciences
- Nobel Prize Award Ceremonies

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1901 — 2010 — 1911

Sort and list Nobel Prizes and Nobel Laureate — Prize category: Chemistry

The Nobel Prize in Chemistry 1911
Marie Curie

The Nobel Prize in Chemistry 1911

Marie Curie

Marie Curie, née Sklodowska

The Nobel Prize in Chemistry 1911 was awarded to *her services to the advancement of chemistry by th radium and polonium, by the isolation of radium and compounds of this remarkable element".*

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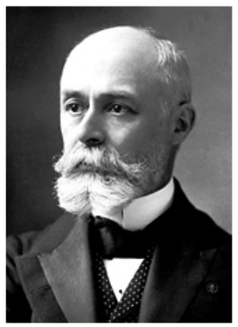
The Nobel Prize in Physics 1903
Henri Becquerel, Pierre Curie, Marie Curie

The Nobel Prize in Physics 1903

Henri Becquerel

Pierre Curie

Marie Curie



Antoine Henri Becquerel

Pierre Curie

Marie Curie, née Sklodowska

The Nobel Prize in Physics 1903 was divided, one half awarded to Antoine Henri Becquerel *"in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity"*,the other half jointly to Pierre Curie and Marie Curie, née Sklodowska *"in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel".*

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Nobel 1903

tragically Pierre kille a street accident 1

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The Nobel Prize in Chemistry 1911
Marie Curie

- **The Nobel Prize in Chemistry 1911**
- Marie Curie

Marie Curie, née Sklodowska

The Nobel Prize in Chemistry 1911 was awarded to
her services to the advancement of chemistry by th
radium and polonium, by the isolation of radium and
compounds of this remarkable element".

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- **The Nobel Prize in Physics 1903**
- Henri Becquerel
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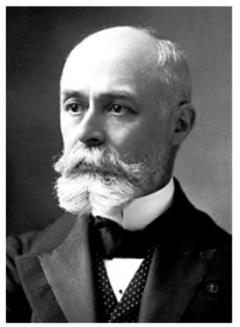

Antoine Henri Becquerel

Pierre Curie

Marie Curie, née Sklodowska

The Nobel Prize in Physics 1903 was divide
Becquerel *"in recognition of the extraordina*
discovery of spontaneous radioactivity",the
Marie Curie, née Sklodowska *"in recognitio*
have rendered by their joint researches on
by Professor Henri Becquerel".

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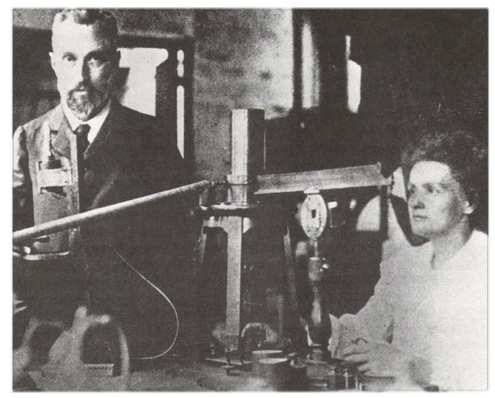
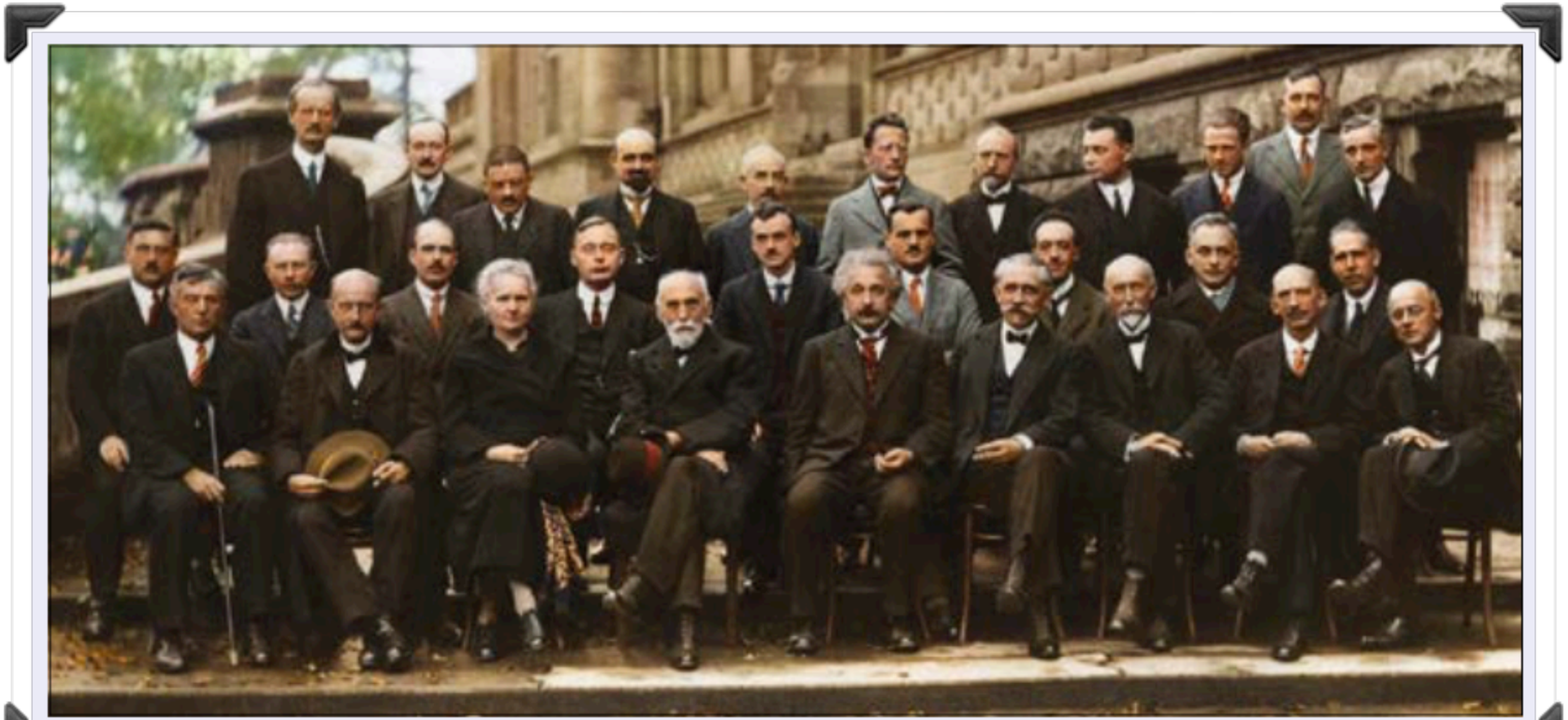


famous photograph Solvay Conference 1927

famous photograph Solvay Conference 1927



updated:

Italian Physical Society in Trento, 2017

but

it had already been strange

1887

Albert Michelson (1852-1931)

and

Edward Morley

The Nobel Prize in Physics 1907
Albert A. Michelson

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The Nobel Prize in Physics 1907

Albert Abraham Michelson
Prize share: 1/1

The Nobel Prize in Physics 1907 was awarded to Albert A. Michelson *"for his optical precision instruments and the spectroscopic and metrological investigations carried out with their aid".*

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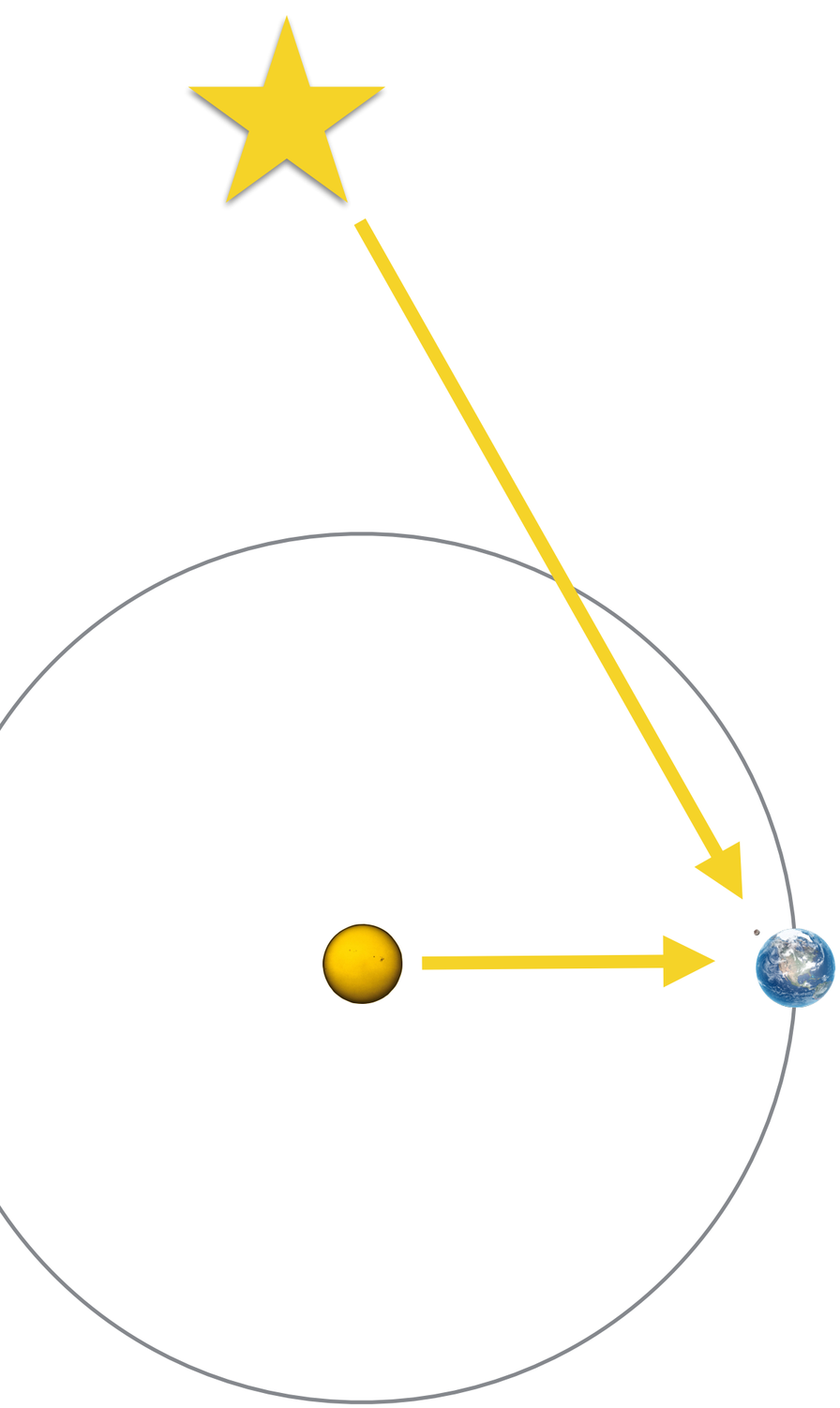
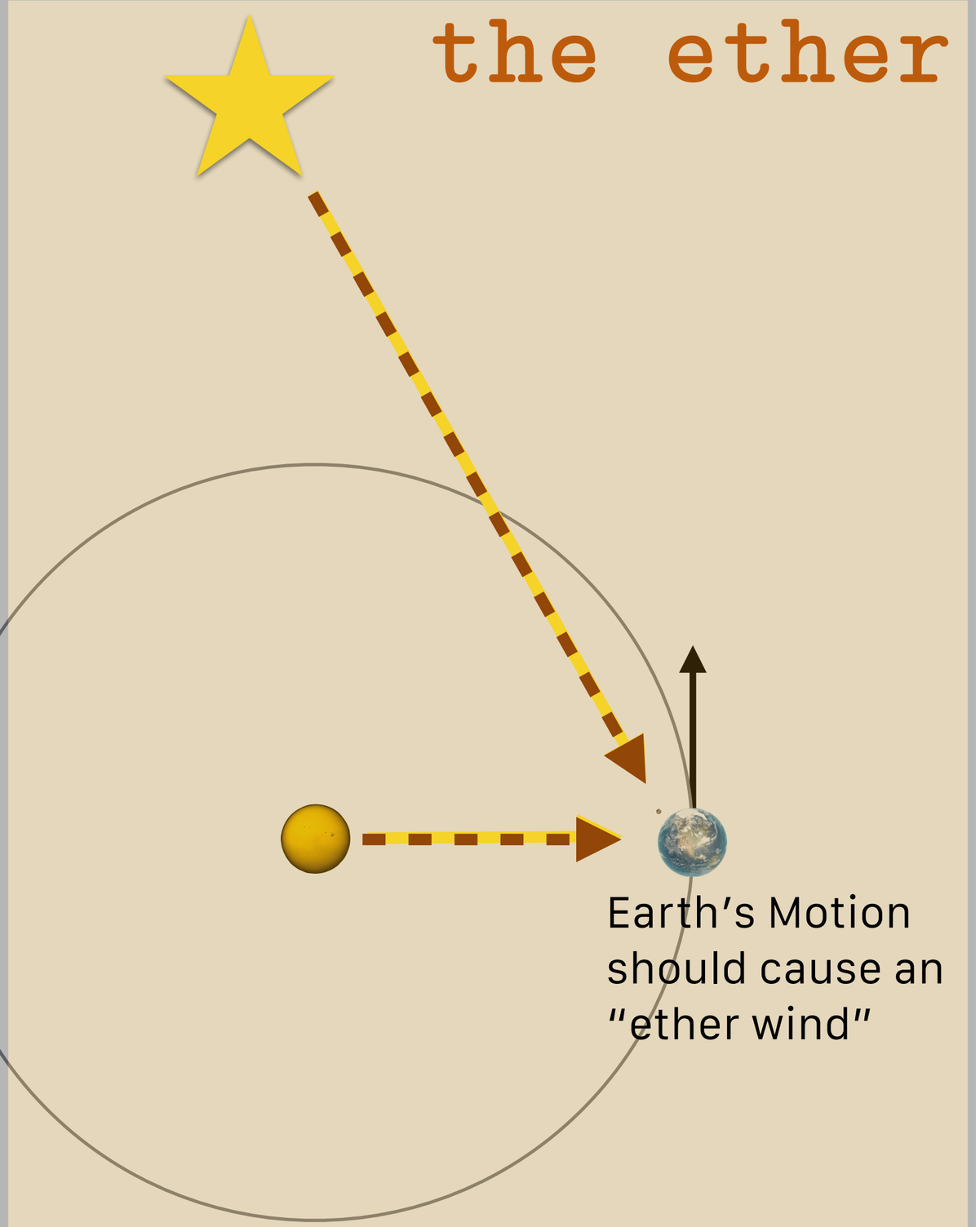
We remember him for the most important measurement of nothing ever.



any problem seeing stars or the sun?

the ether



stationary, Newtonian-like
Absolute rest frame

any problem seeing stars or the sun?

everyone knew that light was vibrations of the "luminiferous ether".
<u>everyone</u>.

light going upstream should take a different time to go a distance than going downstream

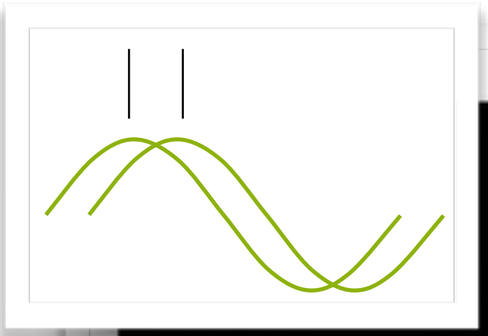
‘‘Michelson Morley Experiments’’

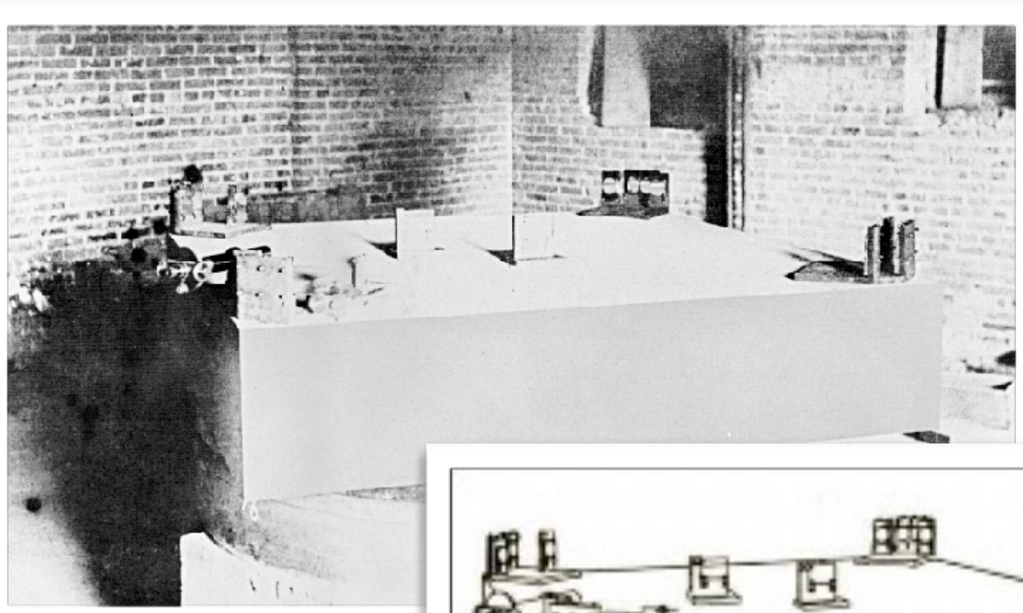
trying to measure the speed of Earth relative to Ether

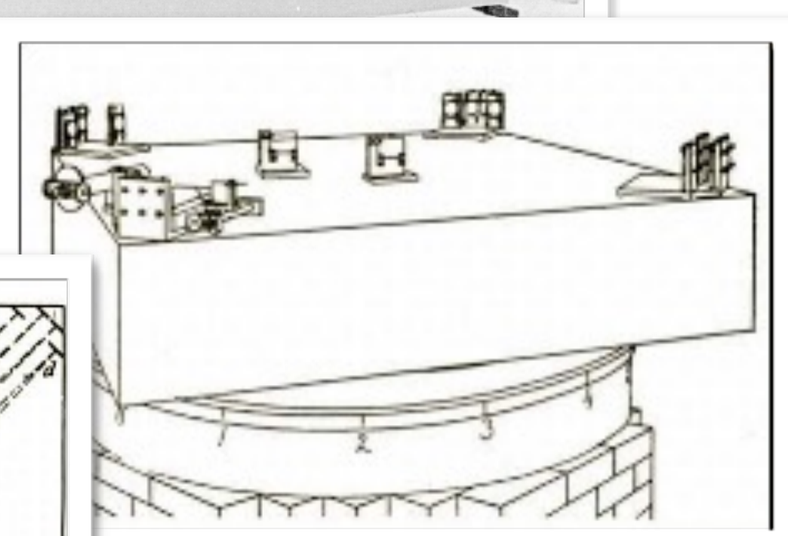
This technique was perfected by cowboy, Albert Michelson and eventually his sidekick, Edward Morley at Case Western Reserve in Cleveland between 1880 and 1888

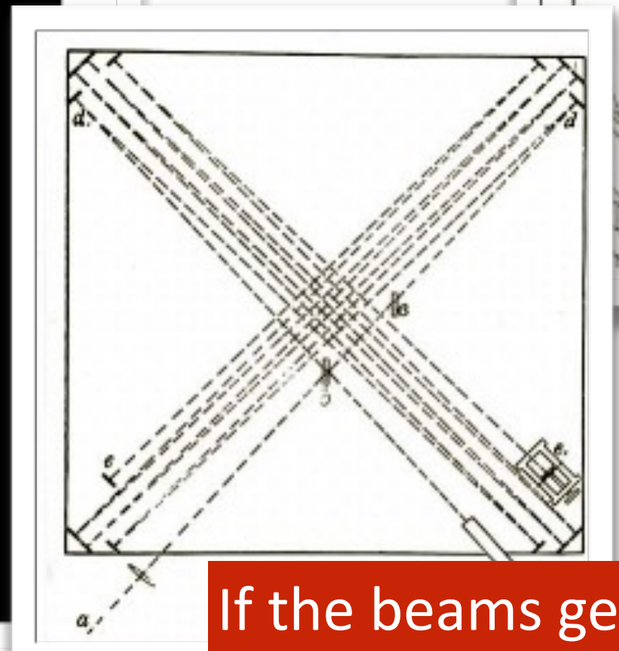
measure the fringes in light interfering from the two paths...then rotate the instrument 90 degrees - and do it again.

The differences between the two configurations is related to the time difference





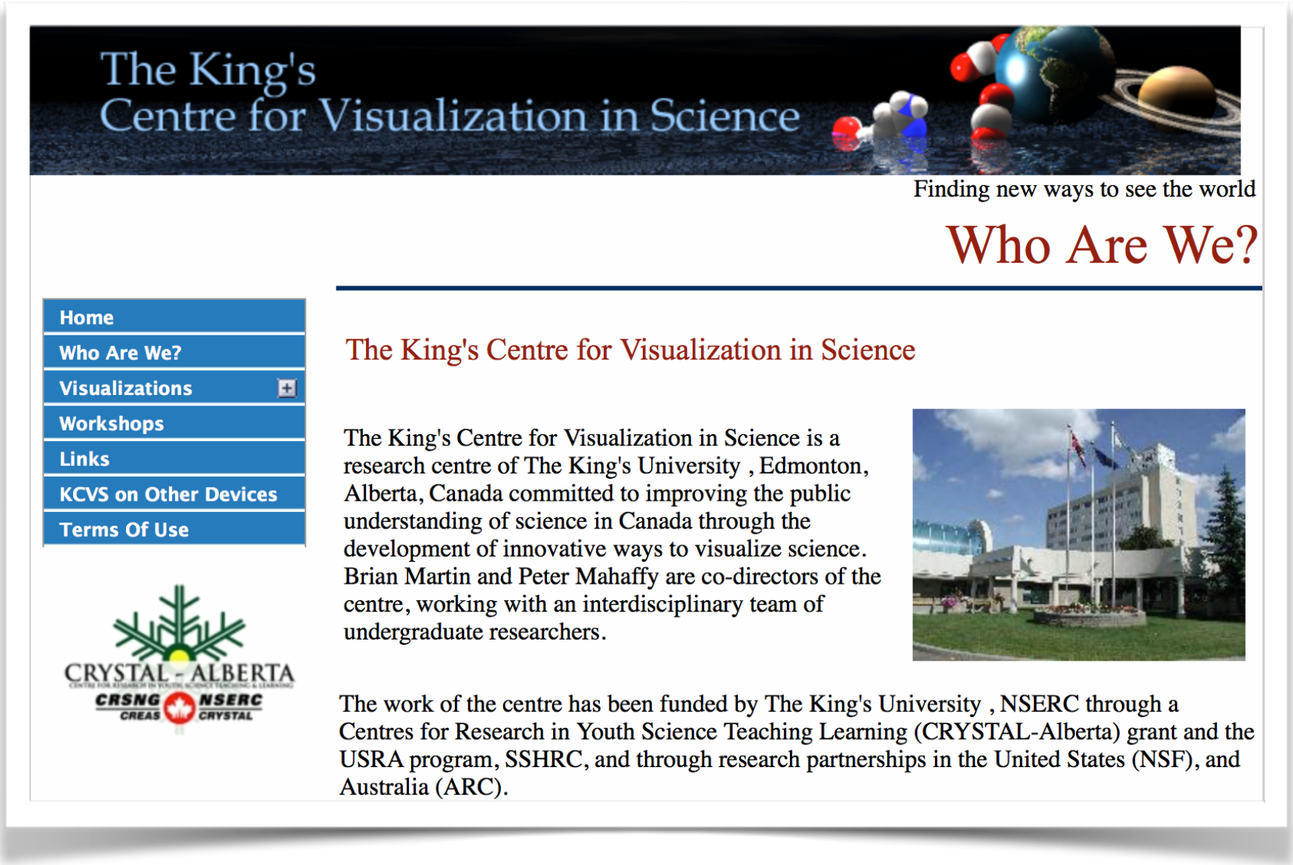




If the beams get back out of phase...one traveled through the ether differently from the other.

neat simulation

http://www.kcvs.ca/site/projects/physics_files/specialRelativity/michelsonMorley/mmExperiment.swf



repeated results for Earth-ether speed:

0

zero. zip. nada. nothing. uh-uh. zilch. naught. diddly-squat.

repeated results for Earth-ether speed:

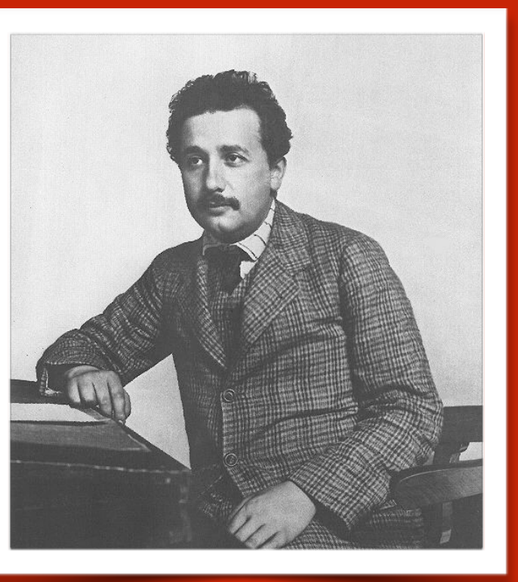
0

zero. zip. nada. nothing. uh-uh. zilch. naught. diddly-squat.

The earth did not appear to be moving through an Ether.
The question: did Einstein know of the MM experiment?
He always said “no.”

back to Einstein

following his nose



March, 1905: The photoelectric effect paper.

May, 1905: Brownian Motion...
http://www.aip.org/history/einstein/brownian.htm

} couple of weeks

June, 1905: The Special Theory of Relativity

September, 1905: $E = mc^2$ paper

} this week

This? ...a pretty good year.

1907, 1911, 1912, 1915, 1917: General Relativity

General Relativistic Cosmology

} after break

Lots of Einstein on the web. This is good:
http://www.aip.org/history/einstein/index.html

The Einstein House in Bern
http://www.einstein-bern.ch/index.php?lang=en&show=start

he moved around

1905: patent clerk at the Swiss Patent office

1915 4 lectures with complete GR theory

1916 publishes GR theory

1917 1st paper on Cosmology
introduces Cosmological Constant
moves in with Elsa

1919 divorces Mileva, marries Elsa
Solar Eclipse data confirmed by Eddington

1920 anti-relativity lectures in Berlin

1922 Nobel Prize

1931 rejects Cosmological Constant

1933 Hitler elected Chancellor
Einstein renounces German citizenship
Moves to Princeton

1913 Professor
separates from Mileva

1911 Professor

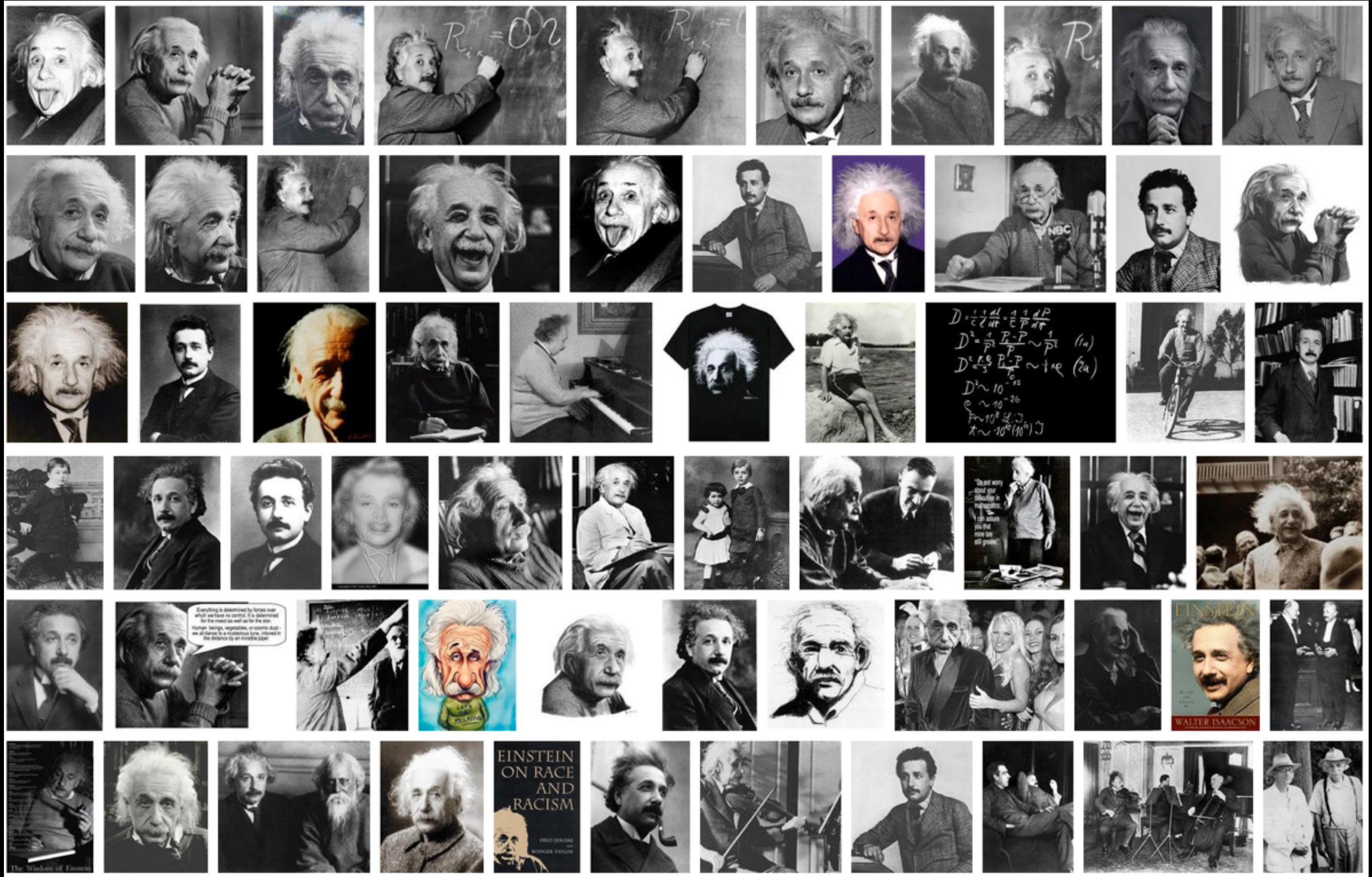
1907 University Bern? nope

1906 Doctorate

1909 Professor

1912 Professor
work with Grossman

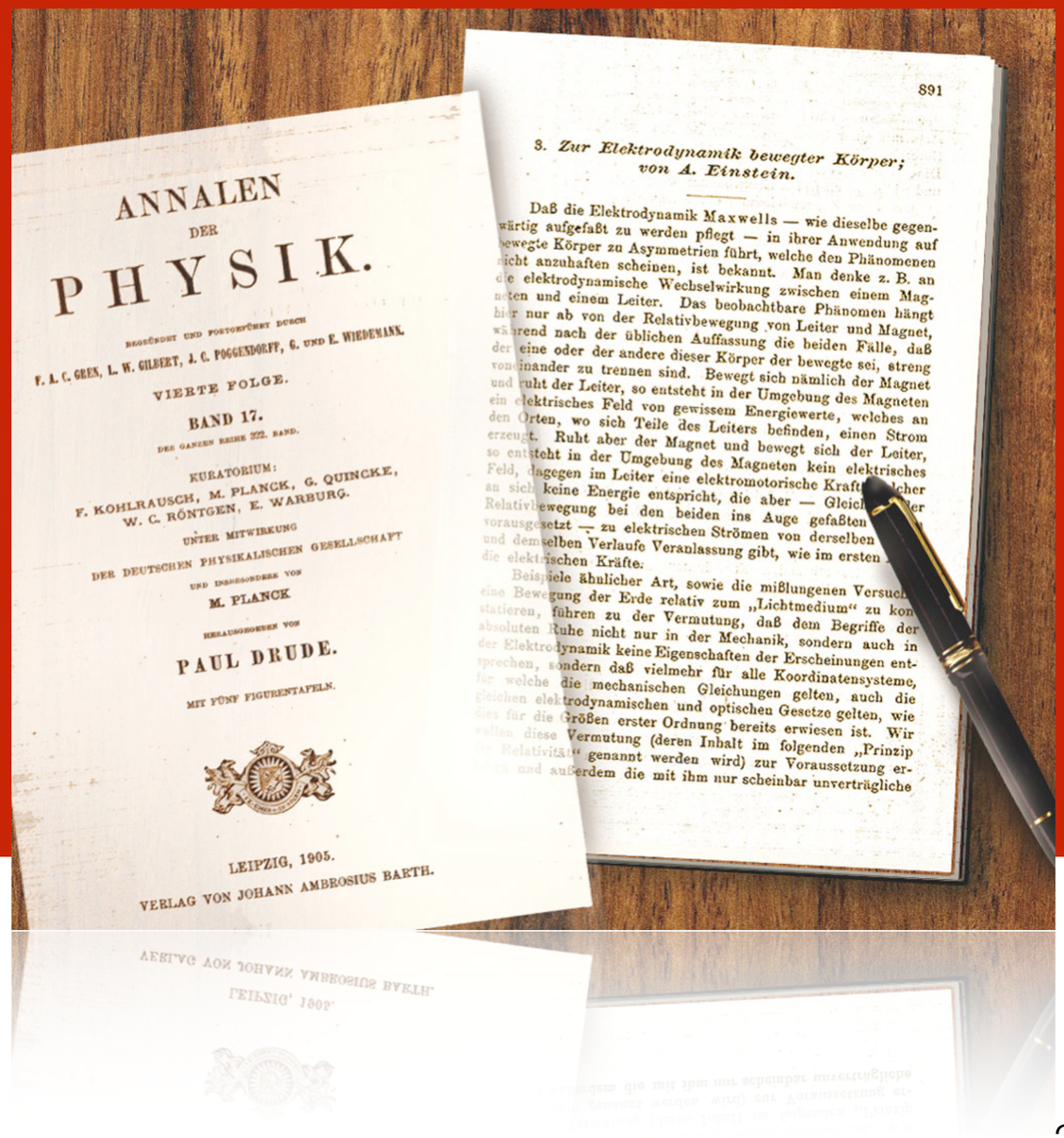
1913 1st GR paper


Everything is determined by forces over which we have no control. It is determined for the insect as well as for the star.
Human beings, vegetables, or cosmic dust - we all dance to a mysterious tune, intoned in the distance by an invisible piper.
EINSTEIN ON RACE AND RACISM
FRED JEROME
RODGER TAYLOR
EINSTEIN
WALTER ISAACSON
The Wisdom of Einstein

His 1905 Relativity paper:

On the Electrodynamics of Moving Bodies

"A storm broke loose in my mind."



Galileo had solved a serious problem

The bus/train/car-beside-you-illusion

you've all had the sensation:

you're in a bus/train/car next to a bus/train/car

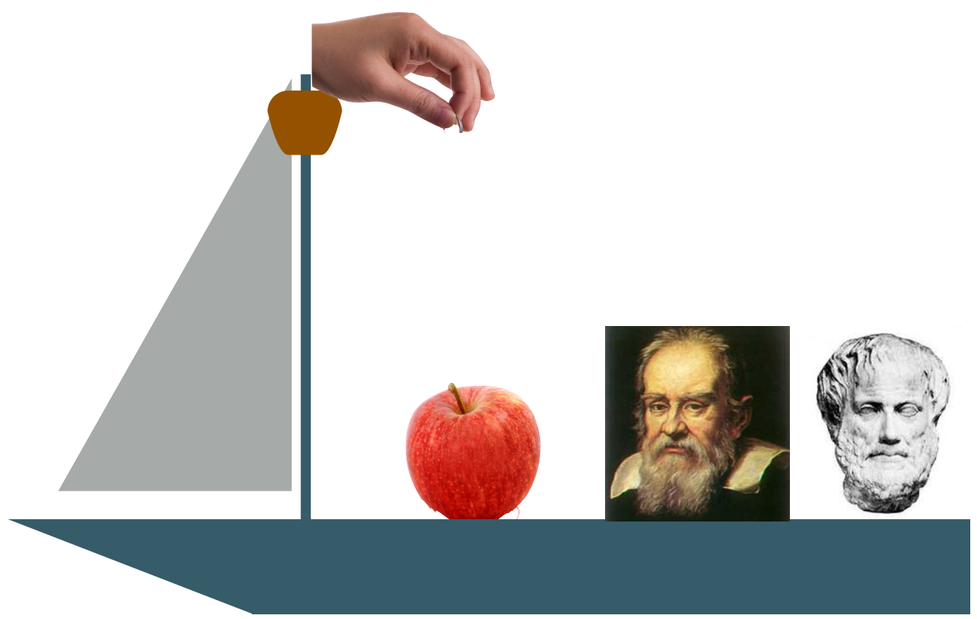
one of them moves...you instantly wonder if it's your bus/train/car or the other bus/train/car...right?

Aristotle would not have been amused

they disagreed about what would be the case

between two different frames of reference

“Galilean Relativity”



G and A: standing on deck, boat still

Aristotle would not have been amused

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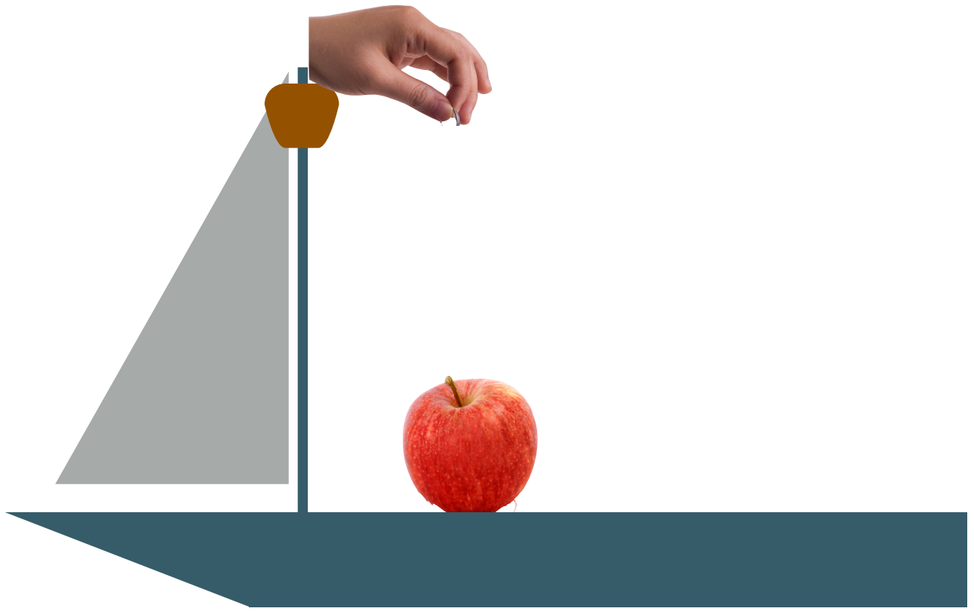
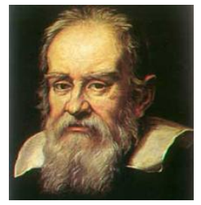
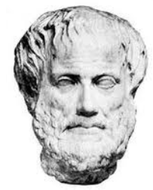
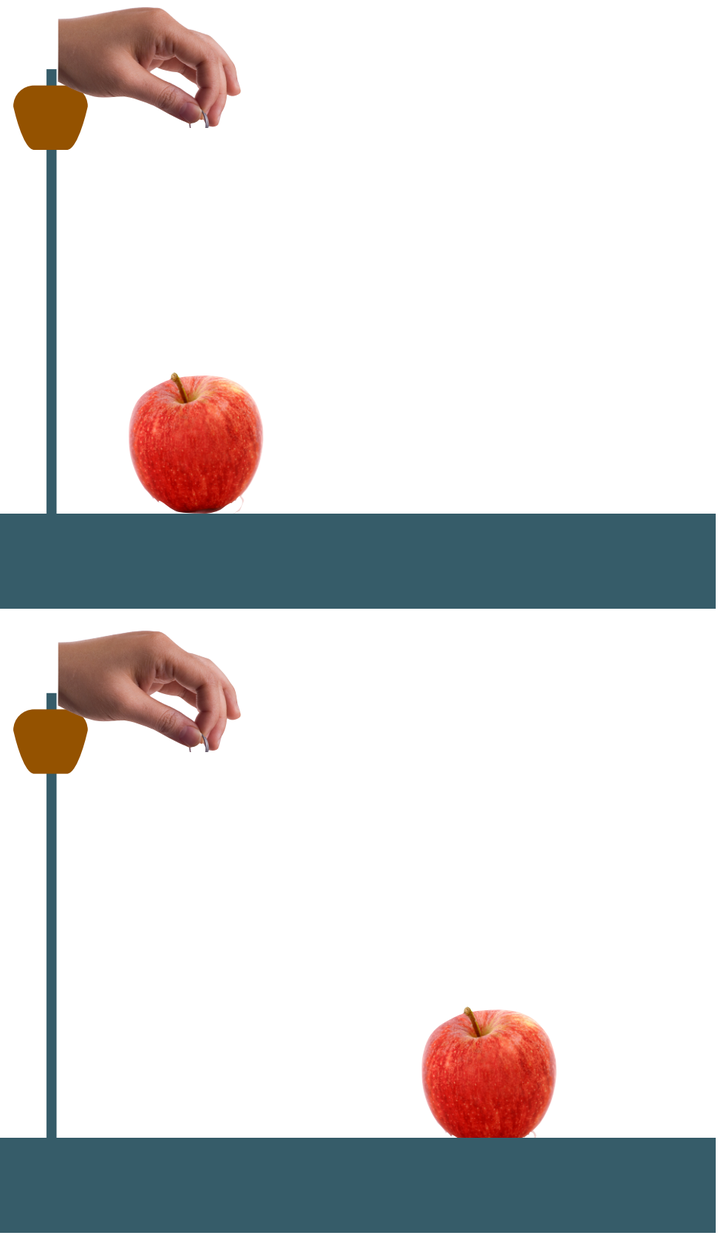
"Galilean Relativity"



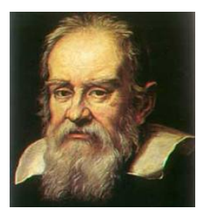
G and A: standing on deck, boat still
Same on shore

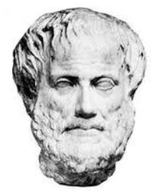






G: standing on shore, boat moving





A: standing on shore, boat moving

Galileo

1632

"Shut yourself up with some friend in the main cabin below decks on some large ship, and have with there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed these things carefully (though there is no doubt that when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. **You will discover not the least change in all the effects named,** nor could you tell from any of them whether the ship was moving or standing still."

Galileo

1632

He says that the physics doesn’t know the difference between moving at constant speed and not moving at all

"Shut yourself up with some friend in the main cabin below decks on some large ship, and have with there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed these things carefully (though there is no doubt that when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. **You will discover not the least change in all the effects named,** nor could you tell from any of them whether the ship was moving or standing still."

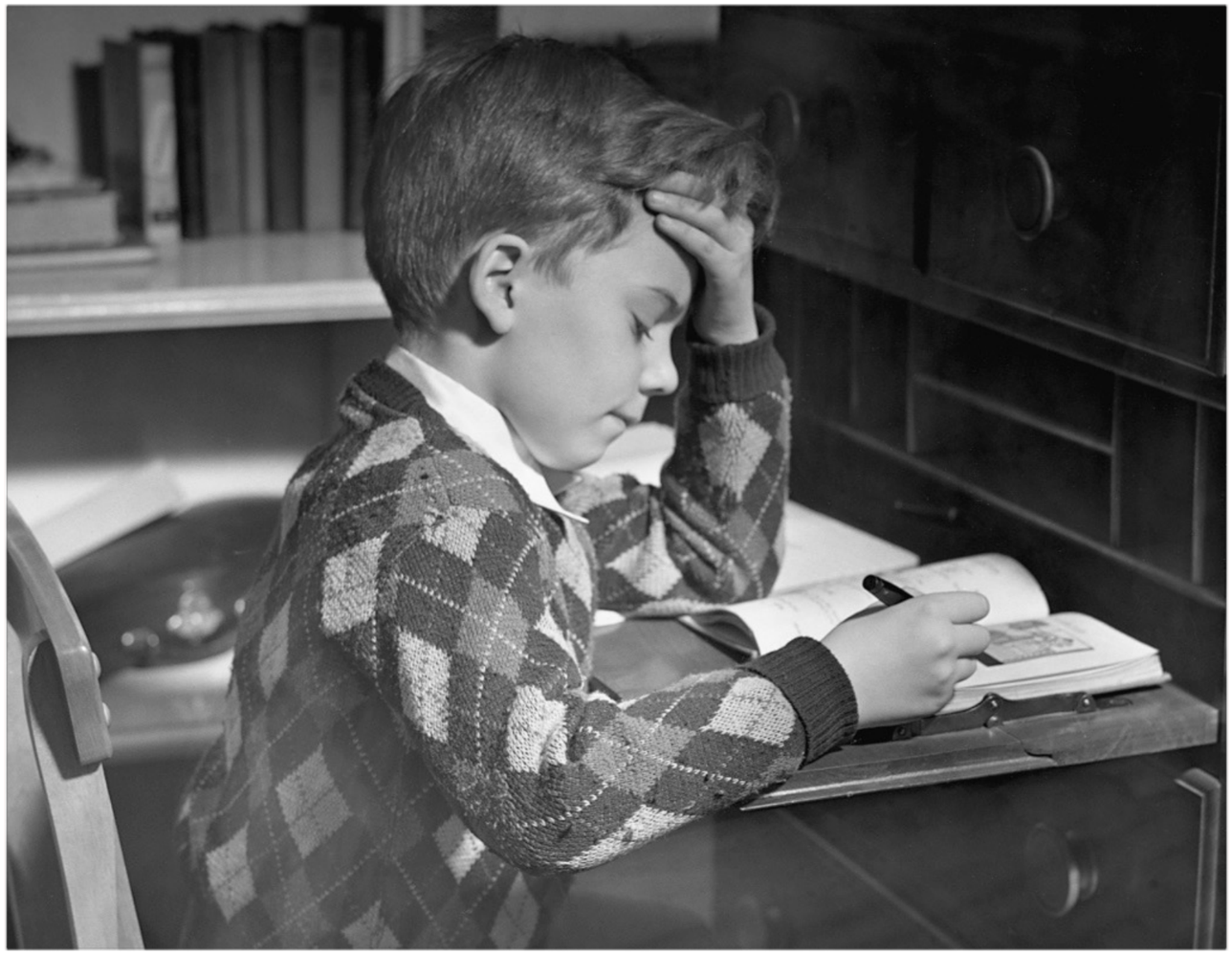
let’s think

hard about

SPACE and TIME

~~moving~~ coordinate systems

relatively moving



a frame of reference: Cool Guy and Old Guy.

They each have a coordinate system attached

They each have a clock attached

Each is at rest in his own frame of reference –

his unique **Rest Frame**

If the relative speed of Cool Guy is constant with respect to Old Guy...

a frame of reference: Cool Guy and Old Guy.

They each have a coordinate system attached

They each have a clock attached

Each is at rest in his own frame of reference –

his unique **Rest Frame**

If the relative speed of Cool Guy is constant with respect to Old Guy...

They are each in an **Inertial Frame of Reference**

What does Cool Guy see?
(when he's not looking in a mirror)

Old guy moving backwards.

jargon alert: **Inertial Frame of Reference**

refers to: a Frame of Reference moving at a constant, linear velocity

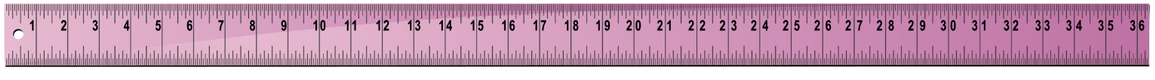
entomology: from Newton’s First Law idea

example: a spaceship at constant speed

for measurement of motion, all you have are

clocks and rulers.

that might move relative to one another



for measurement of motion, all you have are

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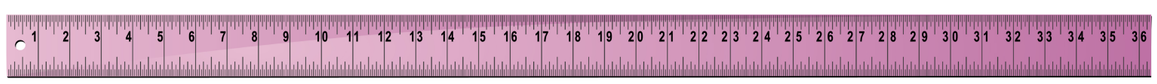
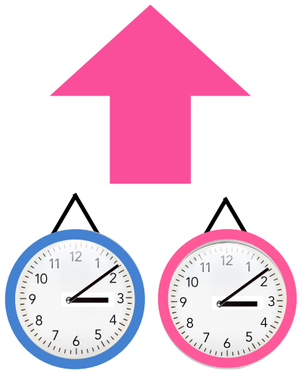
frame

frame



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

the airport

sidewalk velocity relative to concourse: $u = 2\ \mathrm{m/s}$

after 2 s, how far has the sidewalk moved relative to the concourse?

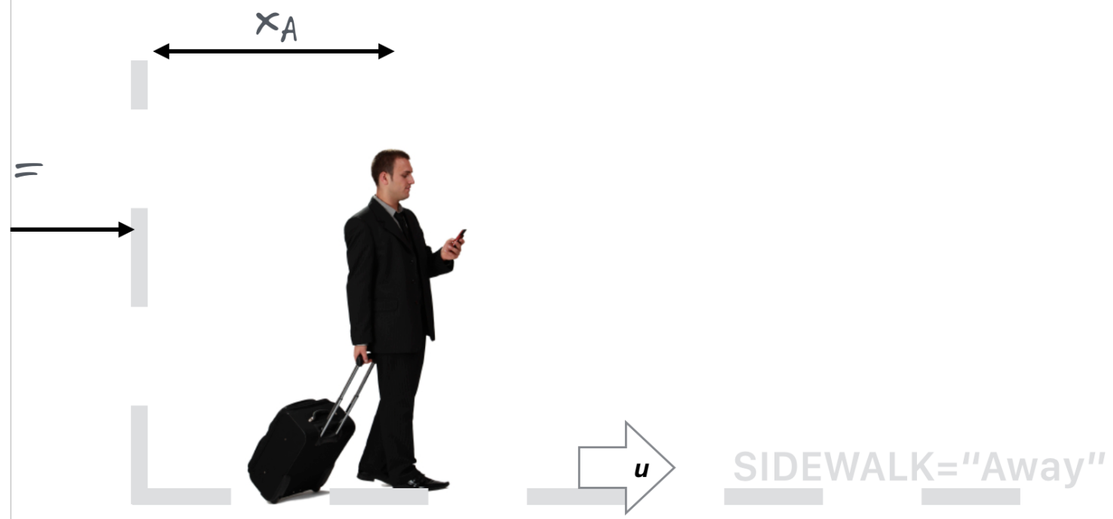
traveler is at x_A = 2 m, what's traveler's position relative to the concourse after 2 s?

"Away Frame":
the frame being watched

"Home Frame":
watching a moving frame

moving at velocity u

move the sidewalk paper edge to here



x_A

u

SIDEWALK="Away"

ome"

move the sidewalk
paper edge to here

x_A

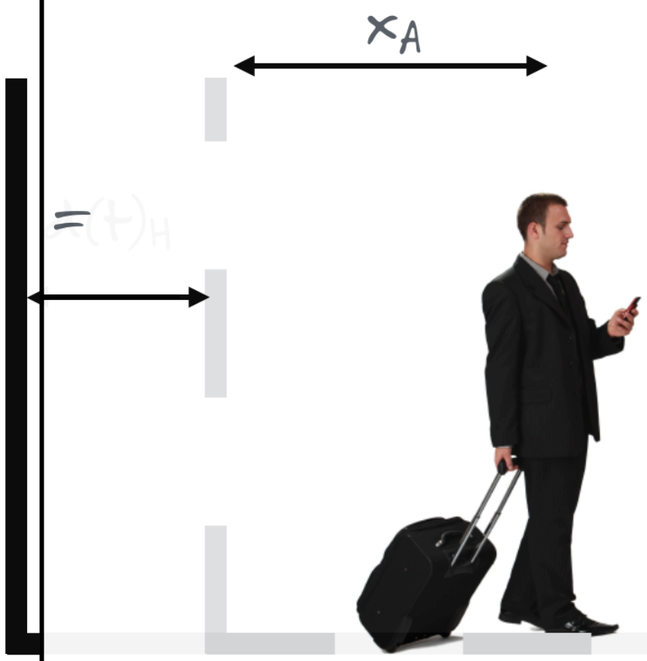
$= d(t)_H$

u

SIDEWALK="Away"

AIRPORT="Home"

move the sidewalk paper edge to here



SIDEWALK="Away"

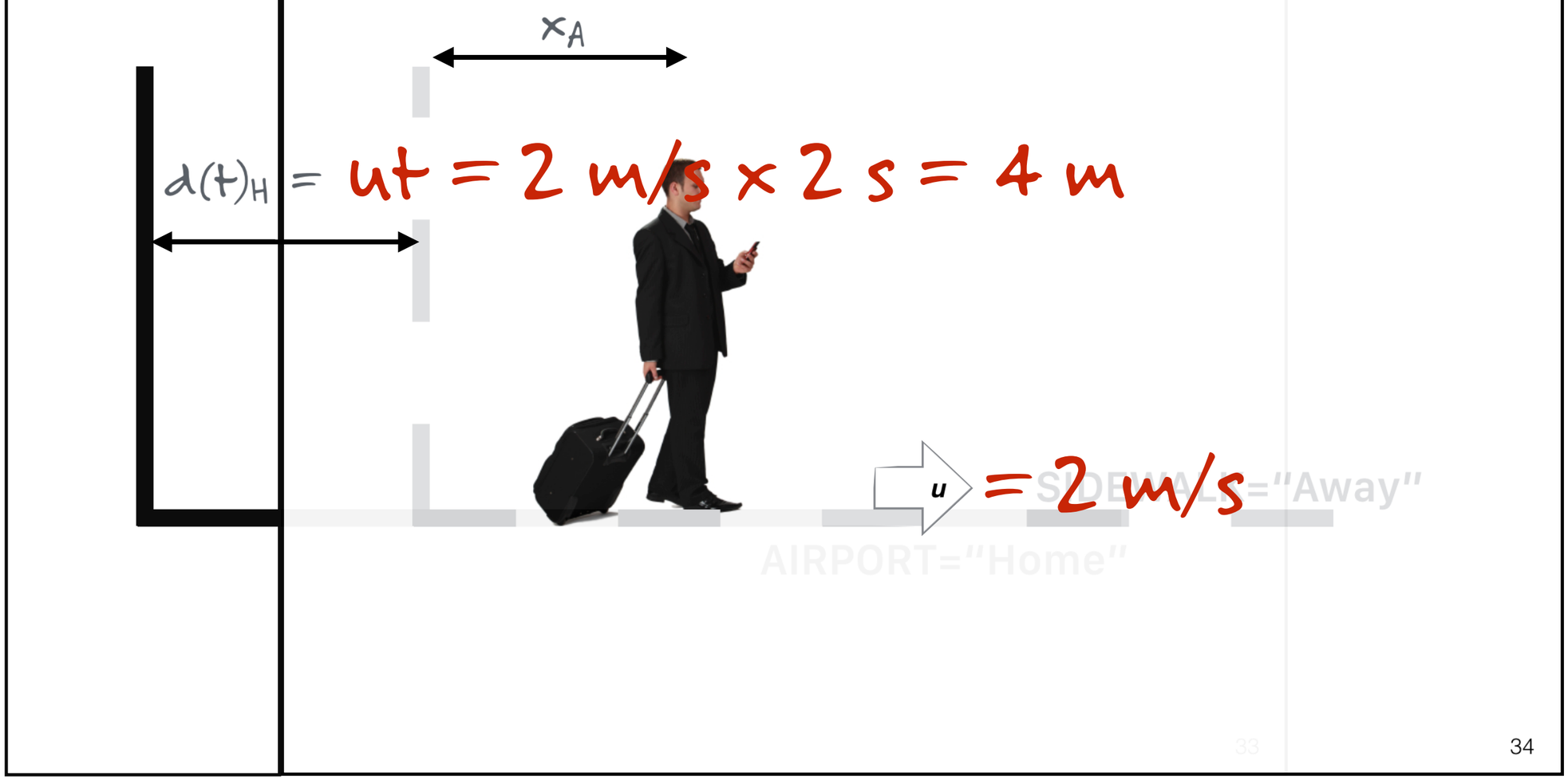
AIRPORT="Home"

sidewalk velocity relative to concourse: $u = 2\ \mathrm{m/s}$

after 2 s, how far has the sidewalk moved relative to the concourse?

4 m

traveler is at x_A = 2 m, what's traveler's position relative to the concourse after 2 s?



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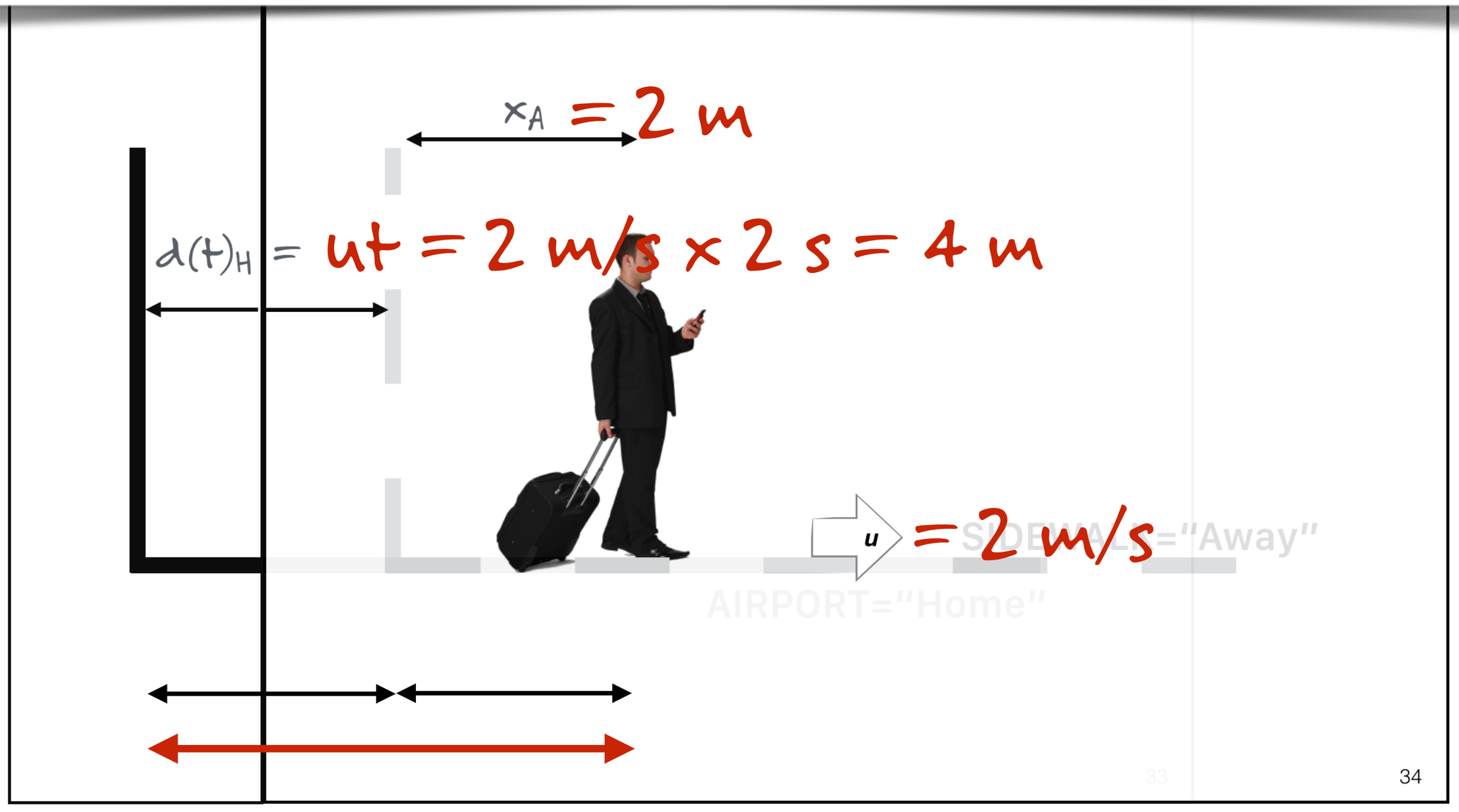
6 m



$x_H = d(t)_H + x_A = 4 + 2 = 6$ m

‘‘coordinate transformation’’

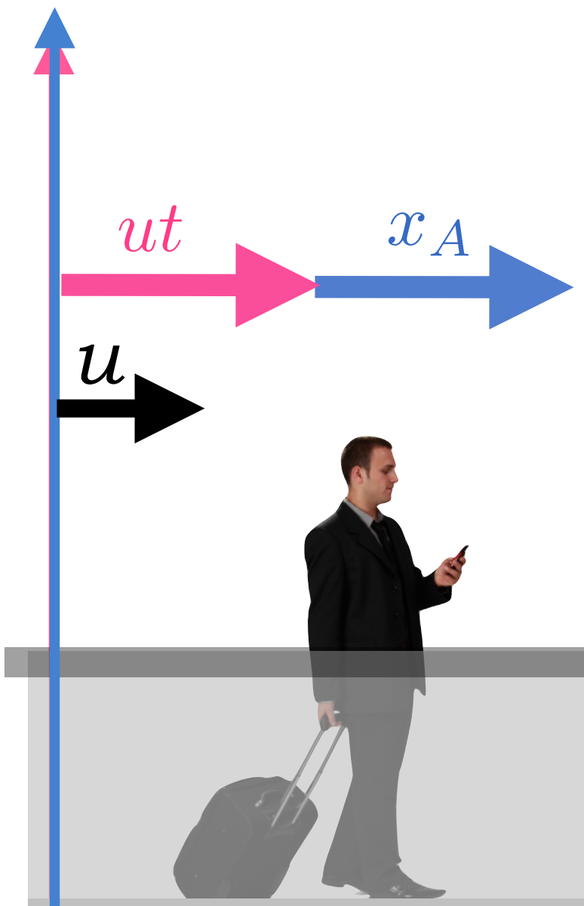
take the coordinates in one Frame and
write them in a different Frame

here, Home and Away

the airport

"Galilean Transformation"

$$x_H = x_A + ut$$



"Away Frame":
the frame being watched

x_A

x_H

x_H

"Home Frame":
watching a moving frame

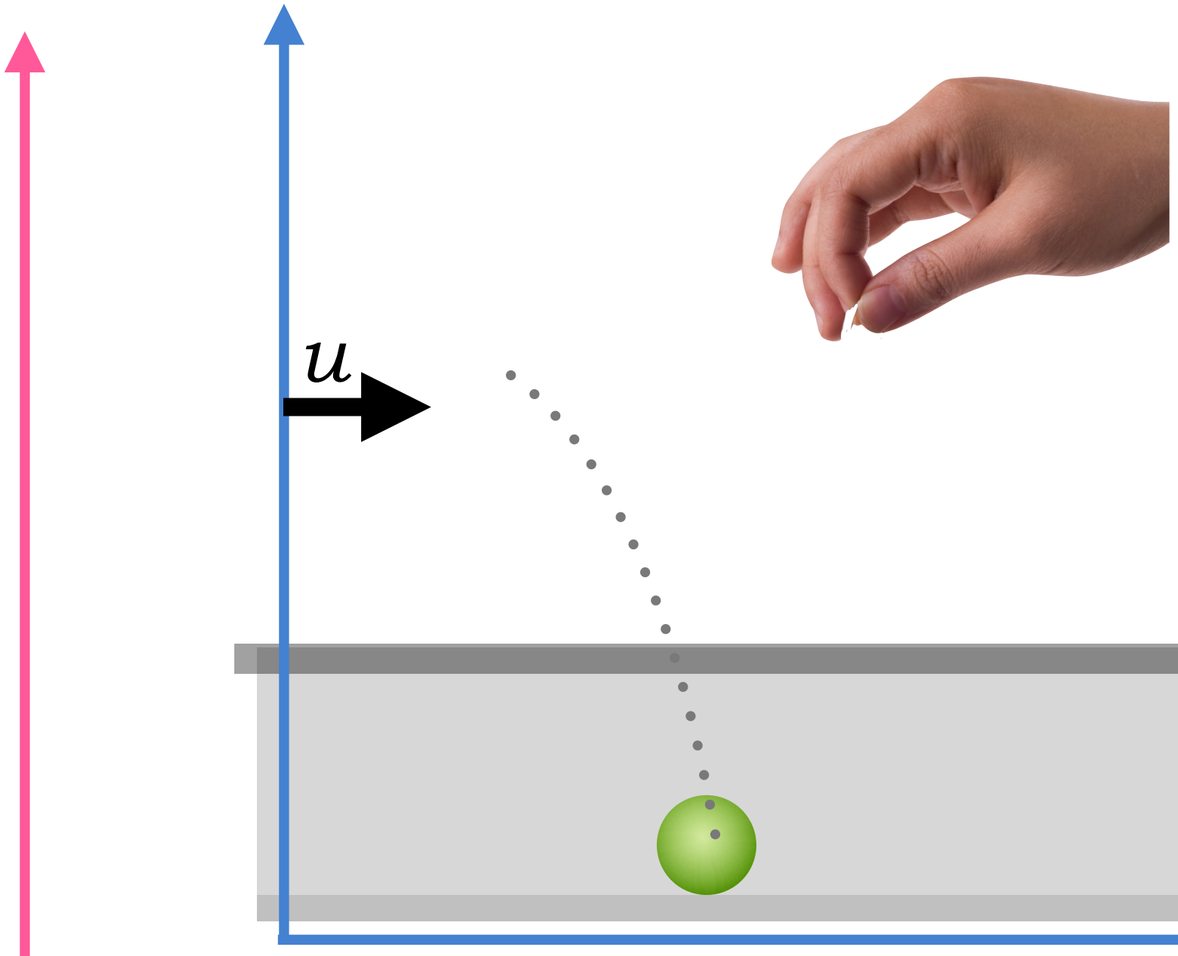
moving at velocity u

Remember, what Galileo said was:

the physics doesn’t care

about constant-velocity motion

view from the concourse:



“Away Frame”:
the frame being watched

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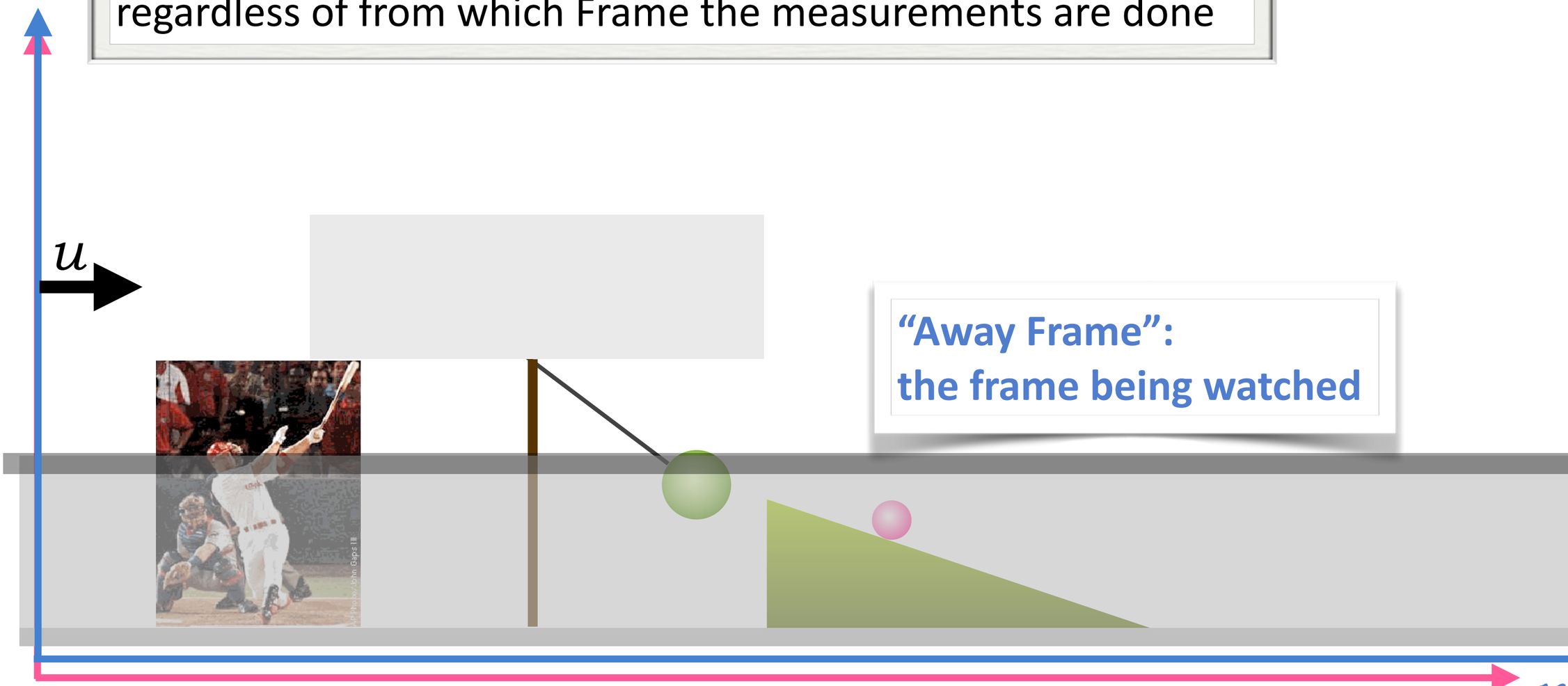
the physics should be the same

Do any mechanical experiment, and the results are the same, regardless of from which Frame the measurements are done



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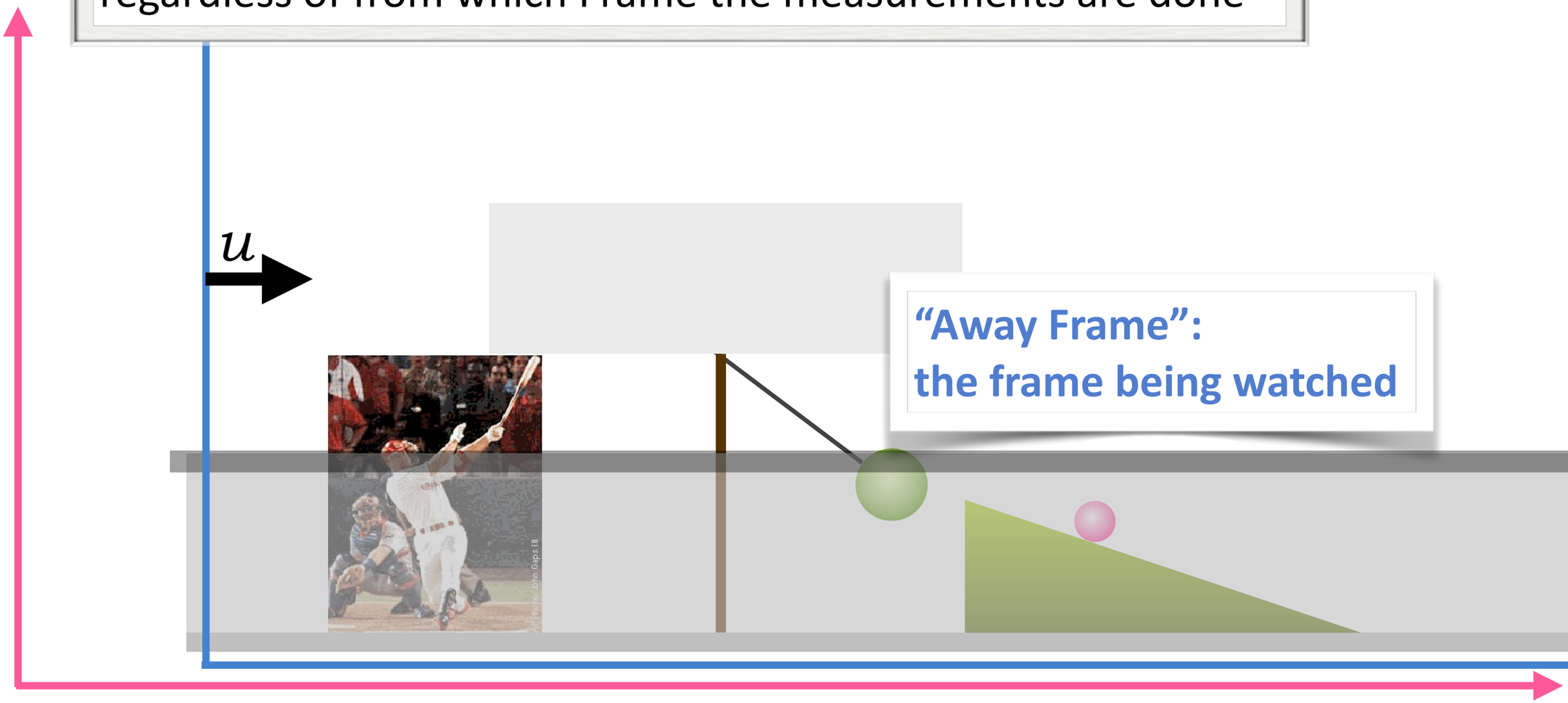

"Home Frame":
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Do any mechanical experiment, and the results are the same, regardless of from which Frame the measurements are done

Says:

“Away Frame”:
the frame being watched

“Home Frame”:
watching a moving frame

moving at velocity u

what does it mean to say that the ‘‘physics is the same’’

the “laws”...the equations are no different if you do a Galilean Transformation

everywhere there’s an x_H , substitute $x_H = ut + x_A$ and $t_H \rightarrow t_A$

$$F_H = m\frac{\Delta}{\Delta t}\left(\frac{\Delta x_H}{\Delta t}\right) \rightarrow$$

what does it mean to say that the “physics is the same”

the “laws”...the equations are no different if you do a Galilean Transformation

everywhere there’s an x_H , substitute $x_H = ut + x_A$ and $t_H \rightarrow t_A$

$$F_H = m\frac{\Delta}{\Delta t}\left(\frac{\Delta x_H}{\Delta t}\right) \rightarrow F_A = m\frac{\Delta}{\Delta t}\left(\frac{\Delta x_A}{\Delta t}\right)$$

In many ways “Relativity” theory is mis-named.
It’s not about what changes...but what stays the same.

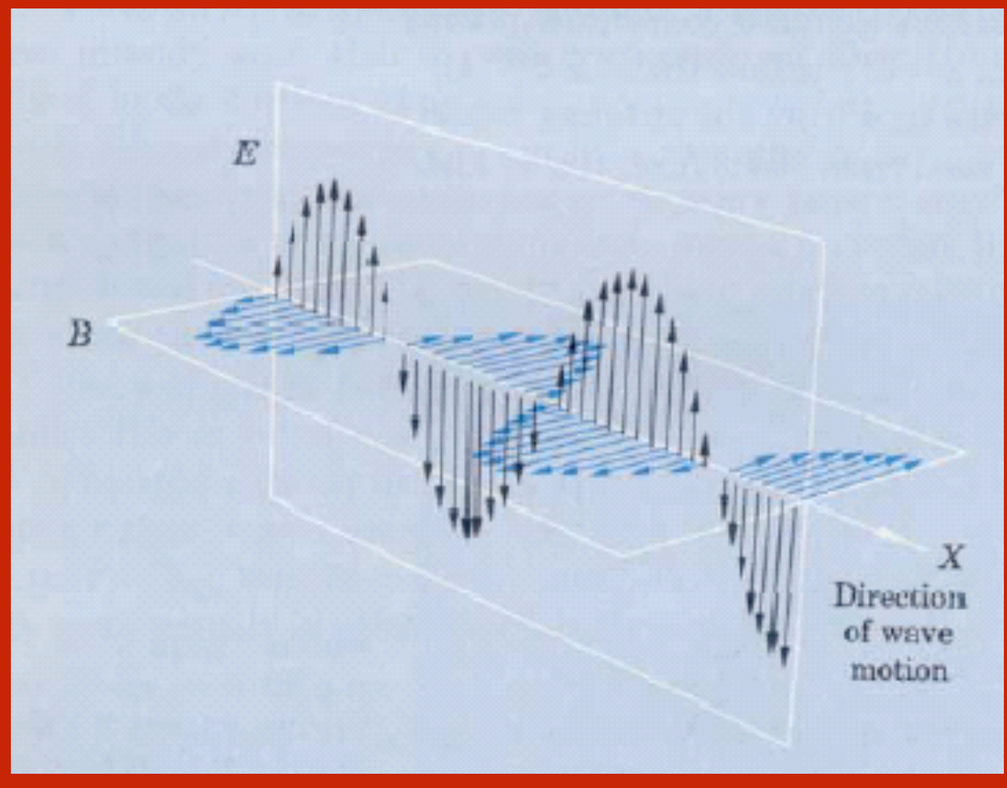
Here, it’s the form of the equations that stay the same...labels don’t matter

So mechanical physics seems not to care

what about the other Big System:

Electromagnetism?

Einstein always asked



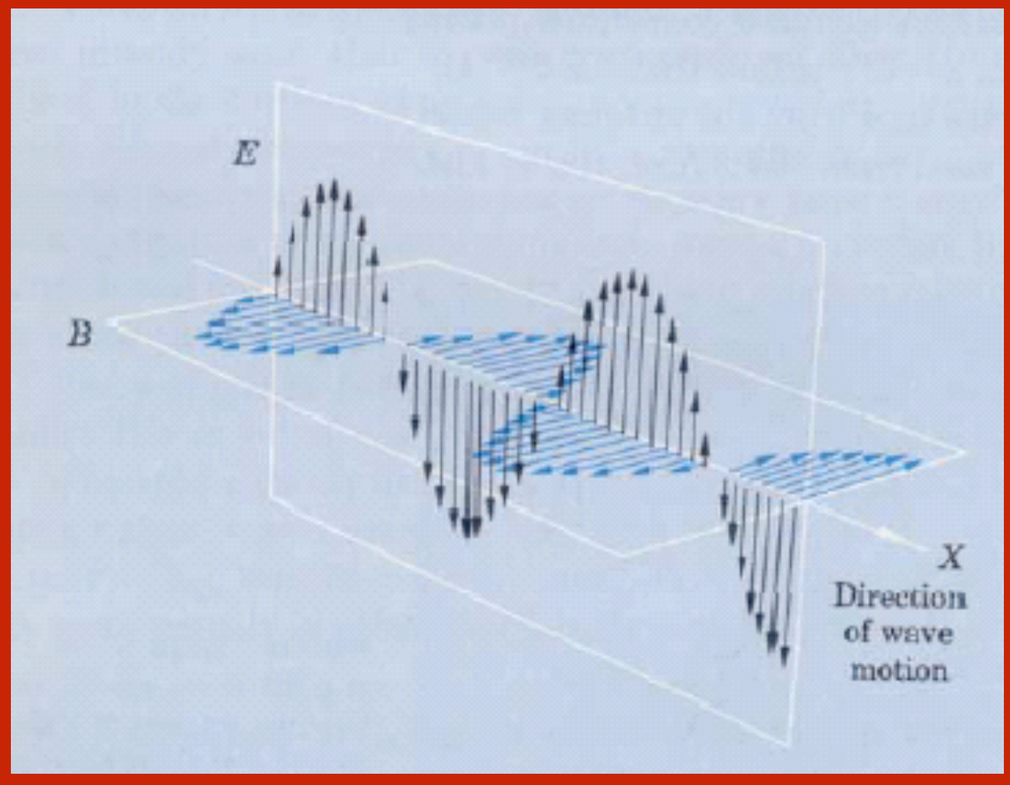
Einstein always asked

simple questions.

what if you traveled at c alongside of a light beam?

It’s stopped! No changing E, B!

No wave any more!



since it’s a traveling pair of waves

changing E creating changing B

changing B creating changing E

if there’s no “changing”…is there light?

in fact

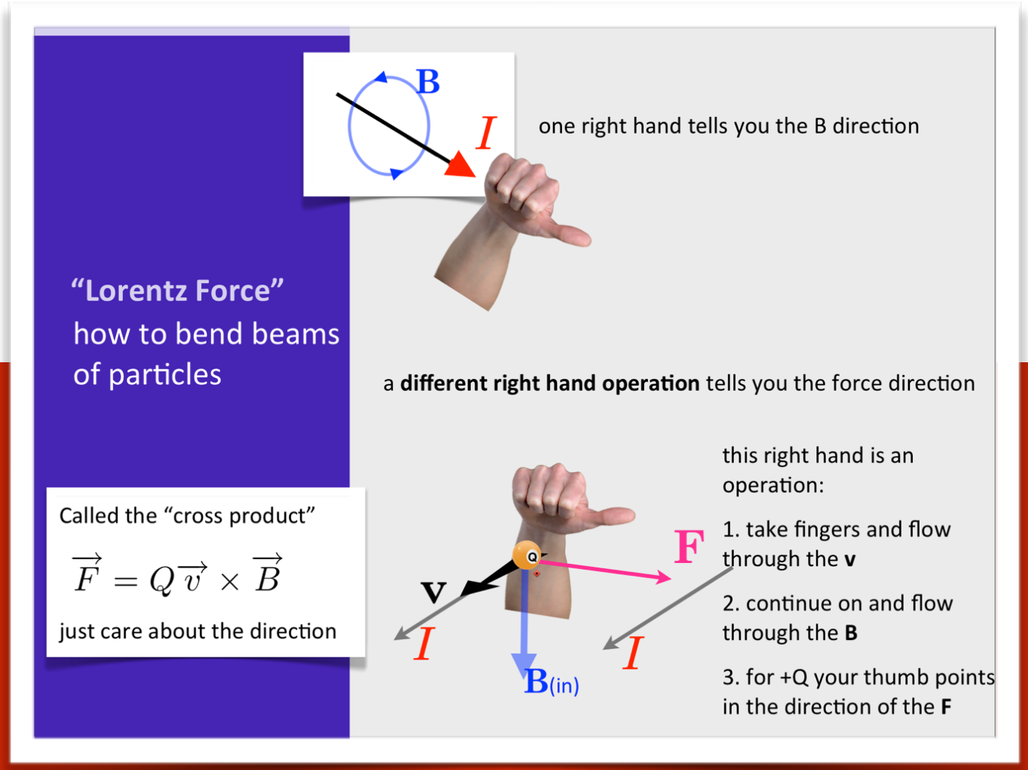
the faster in space you would travel

time would appear to stop

a light beam from the clock could not keep up

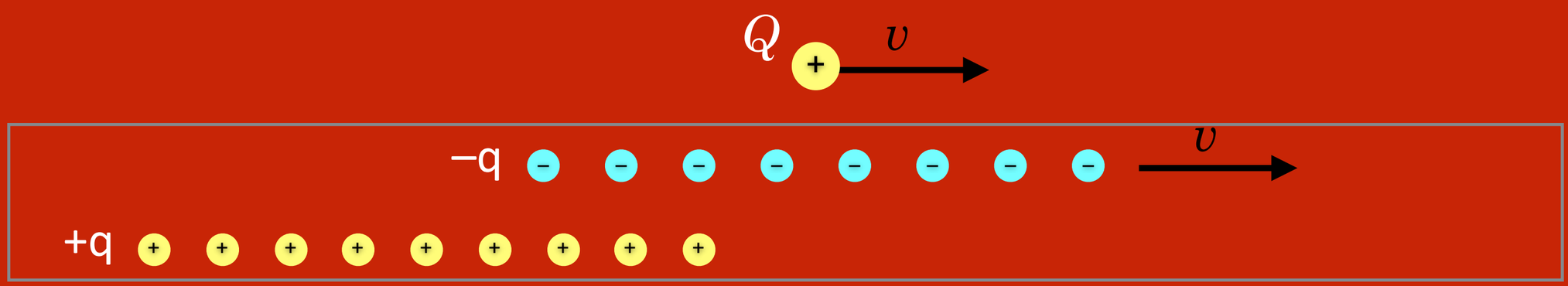
The famous clock tower in Bern, Switzerland
that Einstein mused about

a simple question



how about a charge next to a current?

Situation #1



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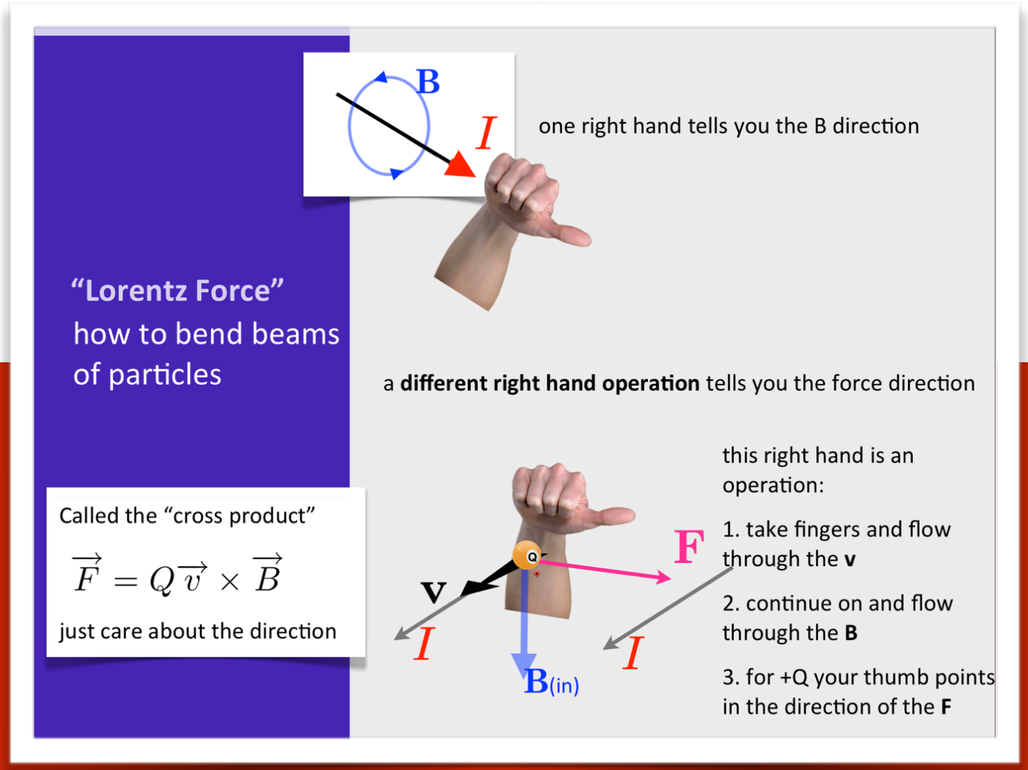

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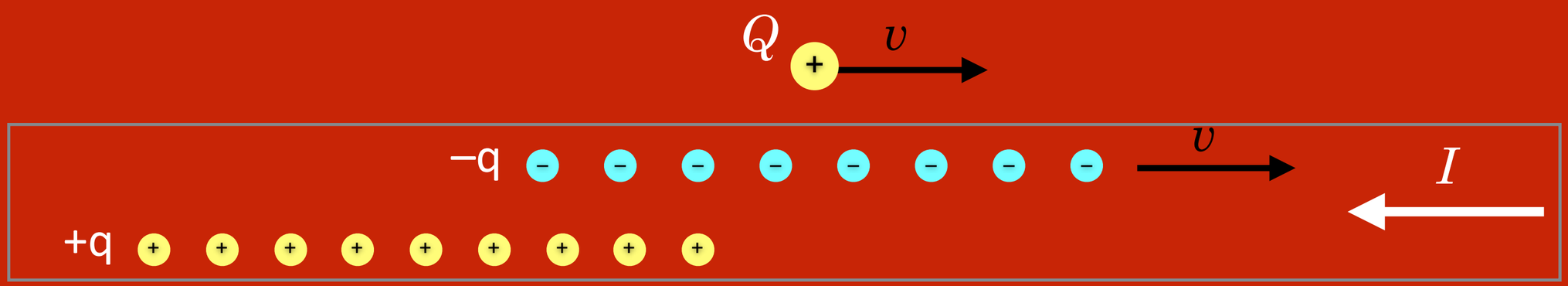

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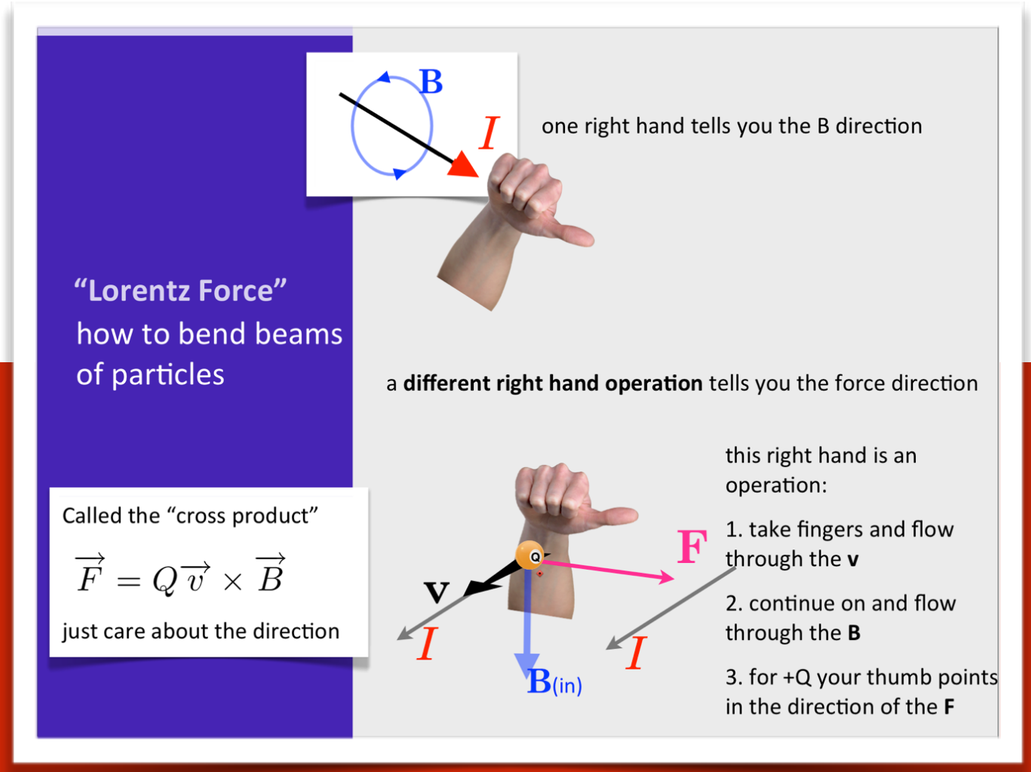

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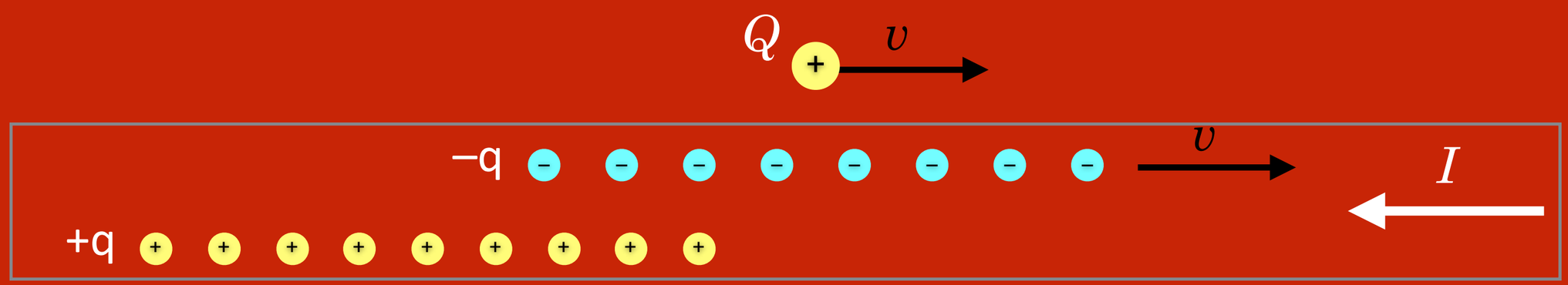

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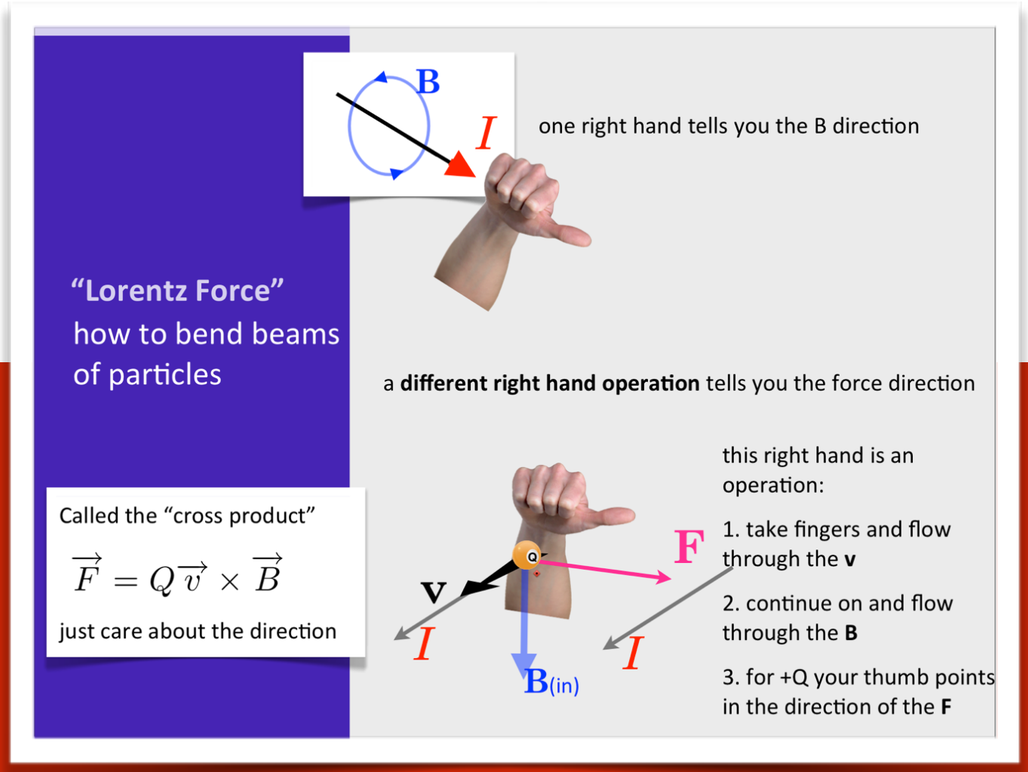

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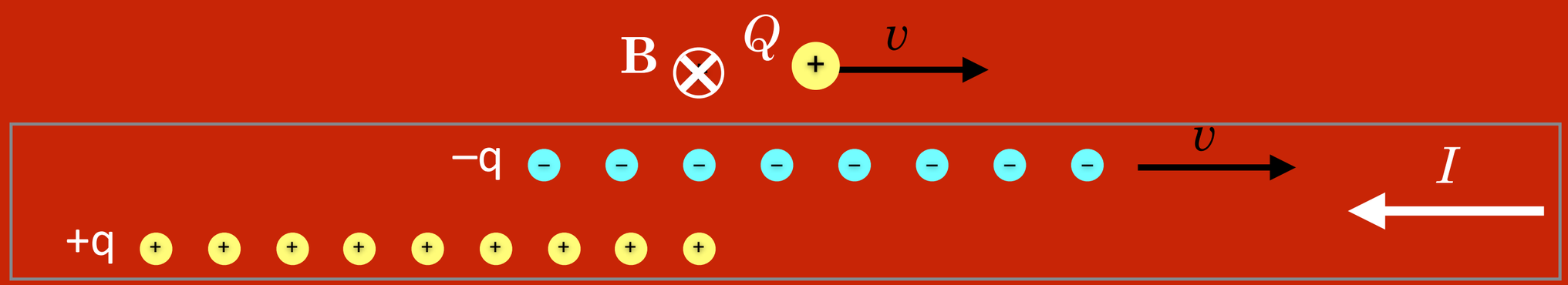

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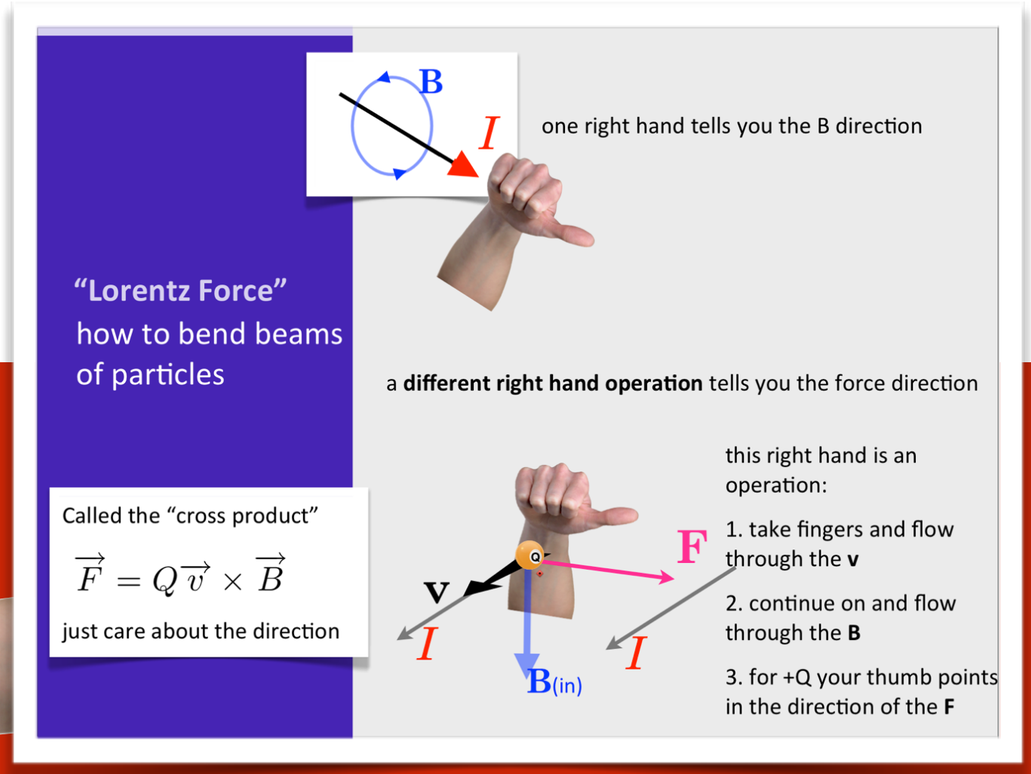

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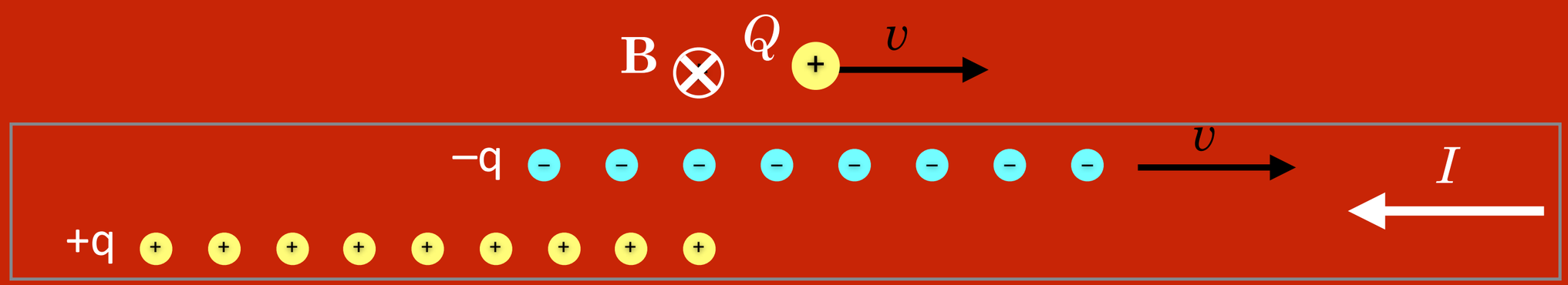

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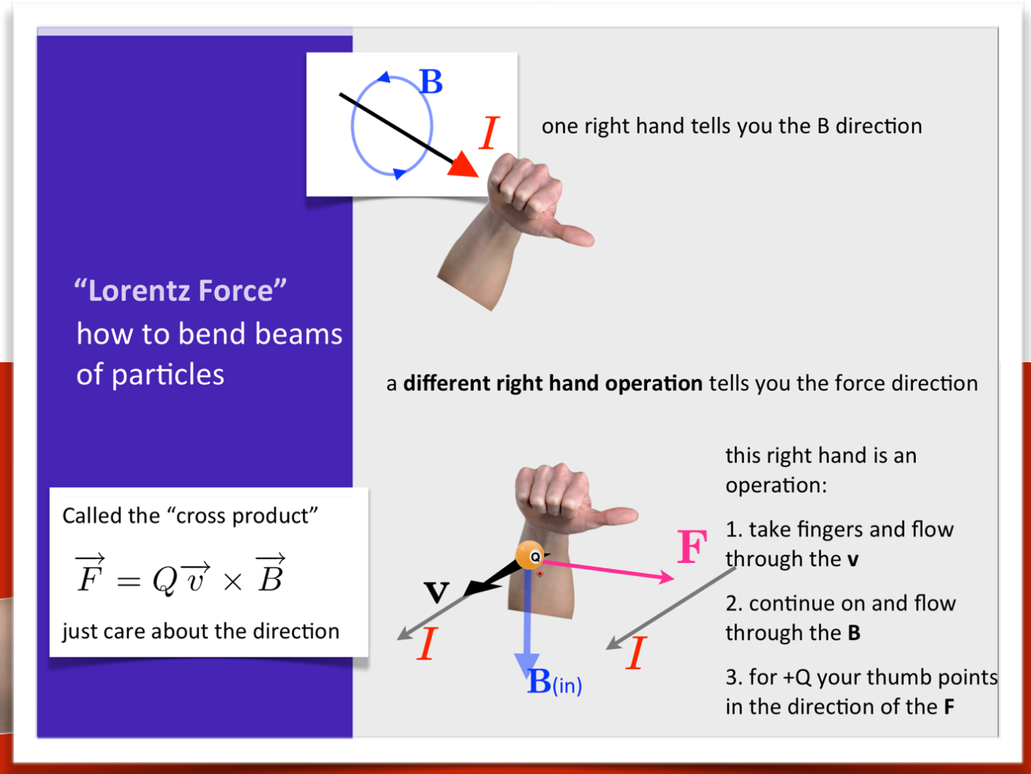

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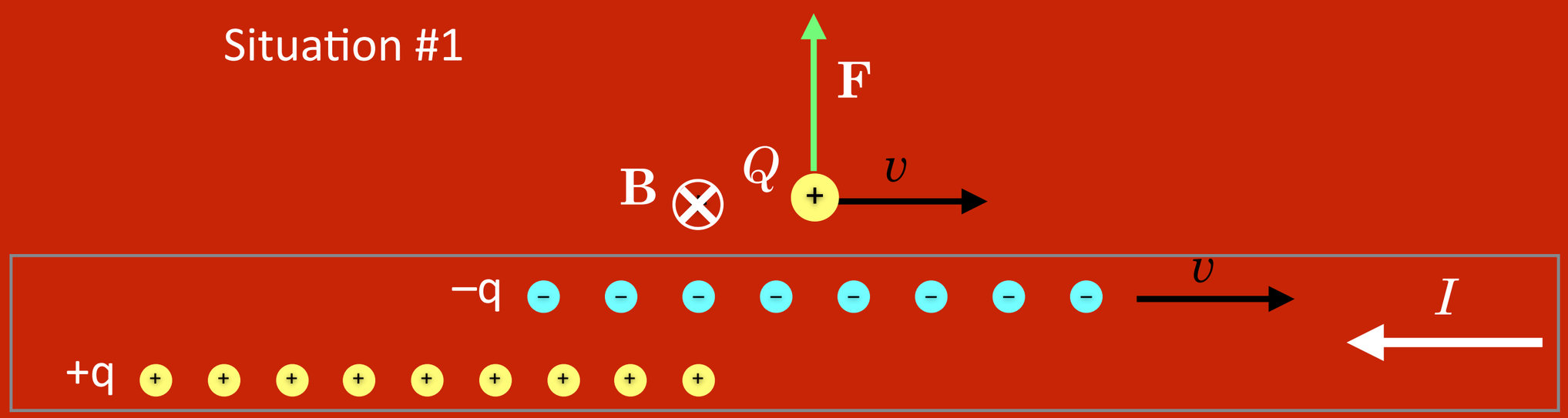

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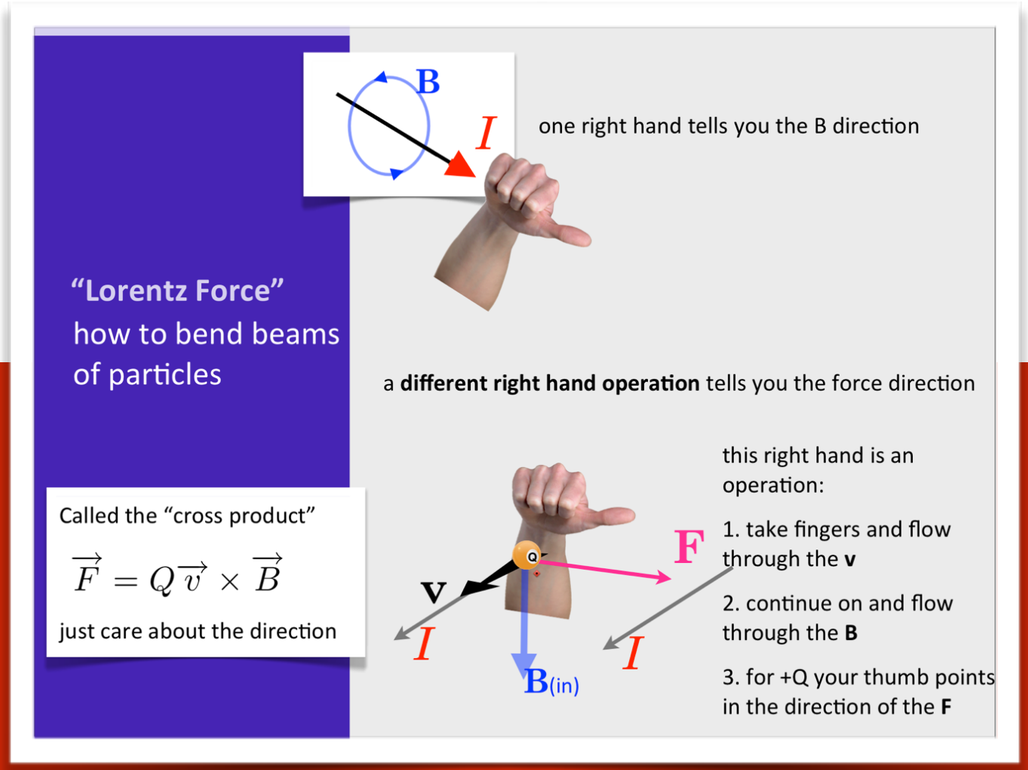

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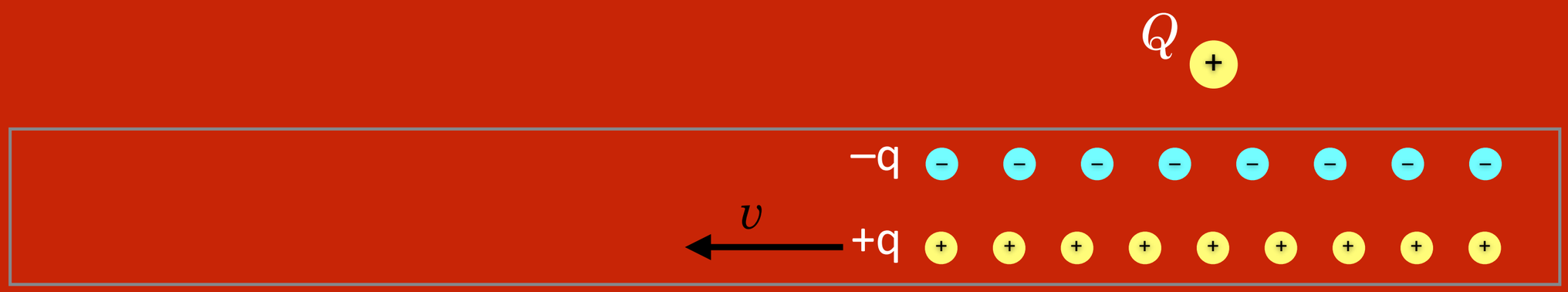
Situation #2



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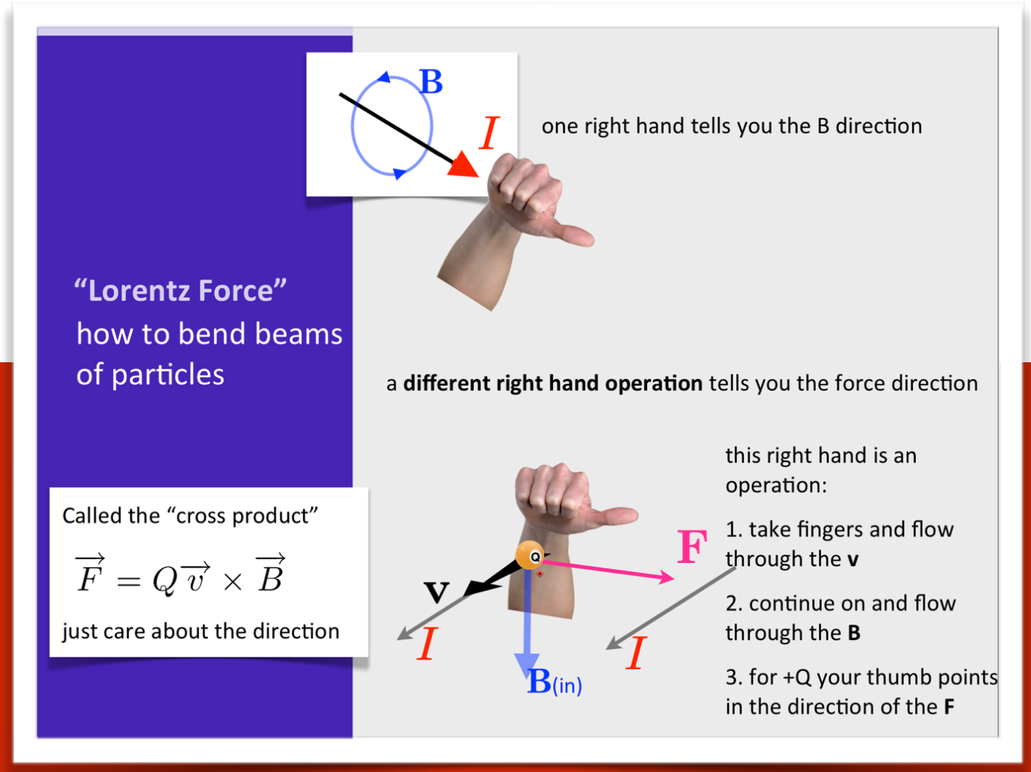

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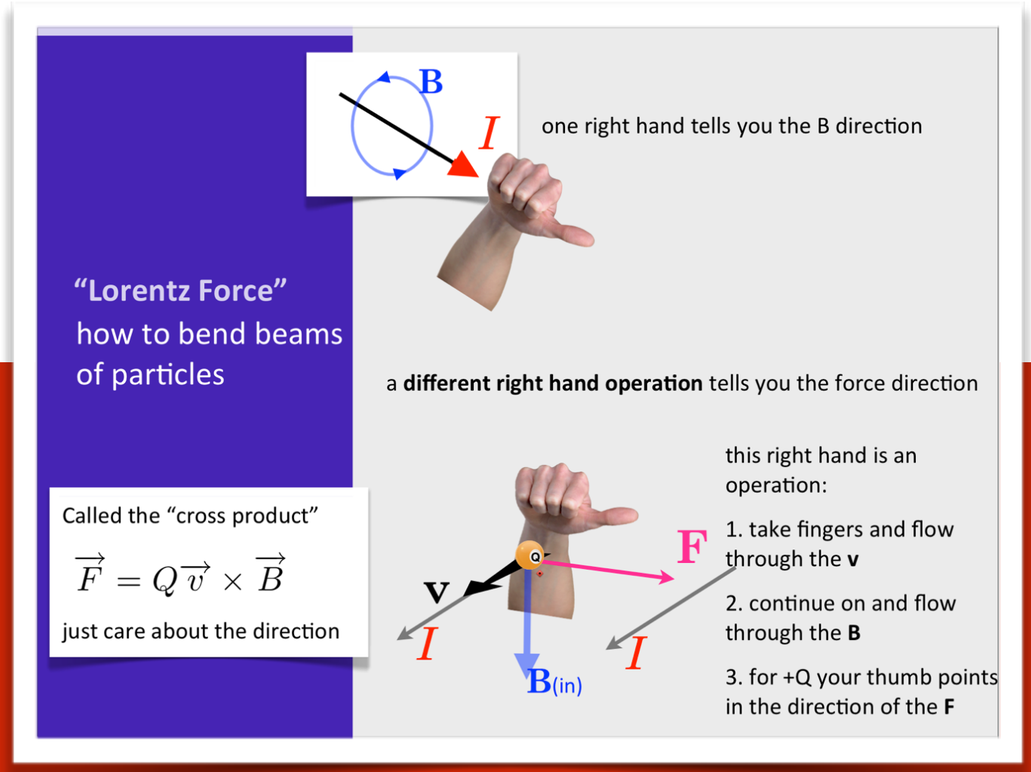
Situation #2

a simple question

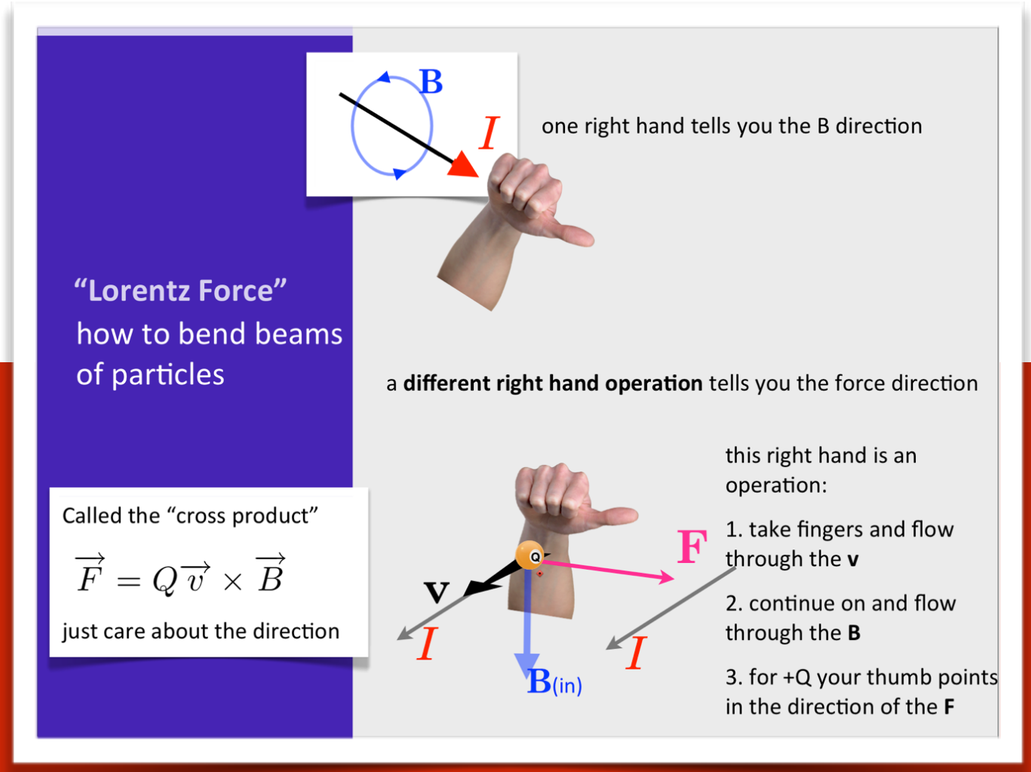


how about a charge next to a current?

Situation #2

These situations differ only in the reference frame...

a simple question



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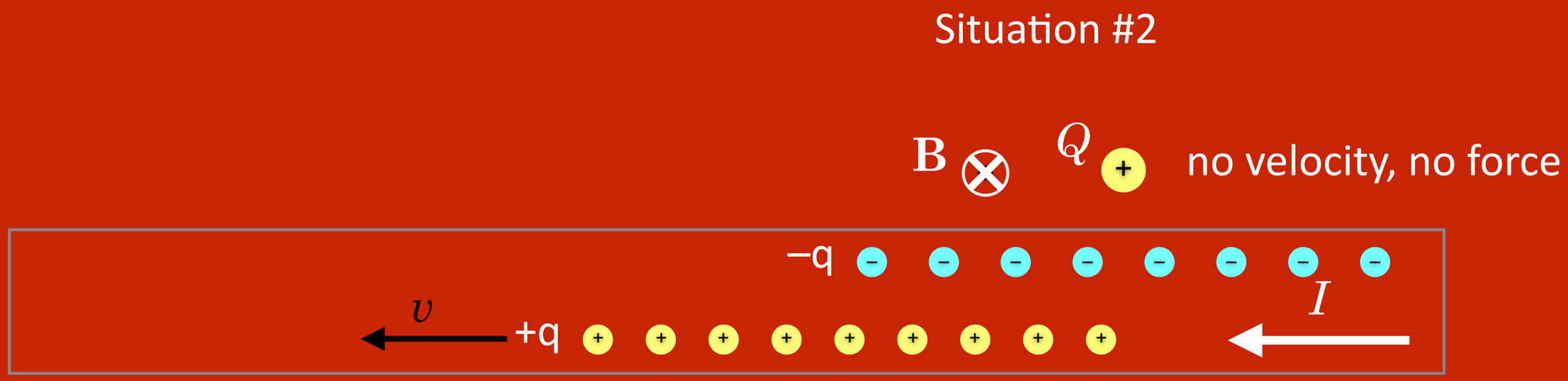
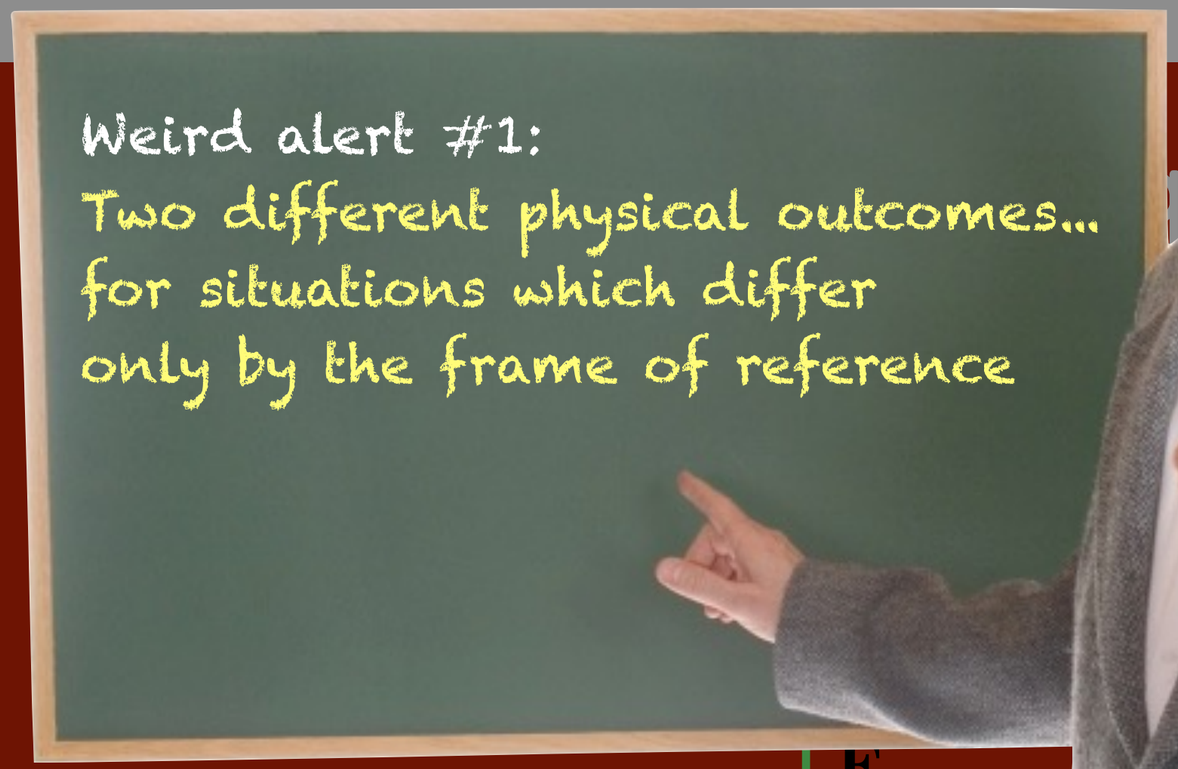
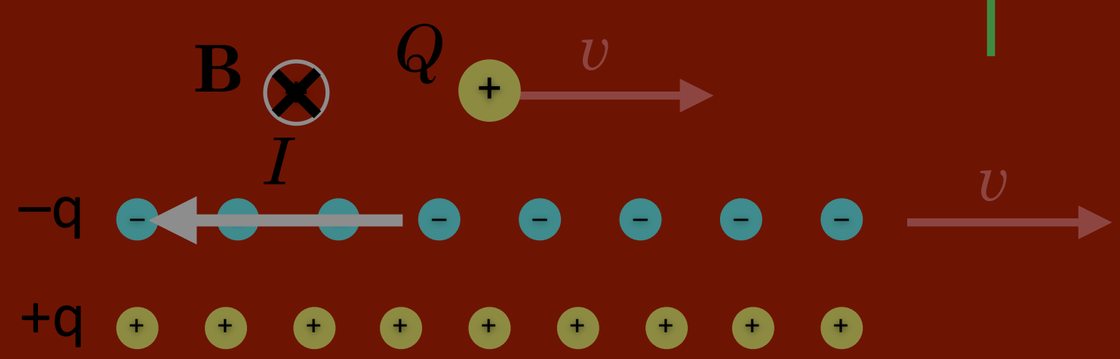


These situations differ only in the reference frame...

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

hold the phone.





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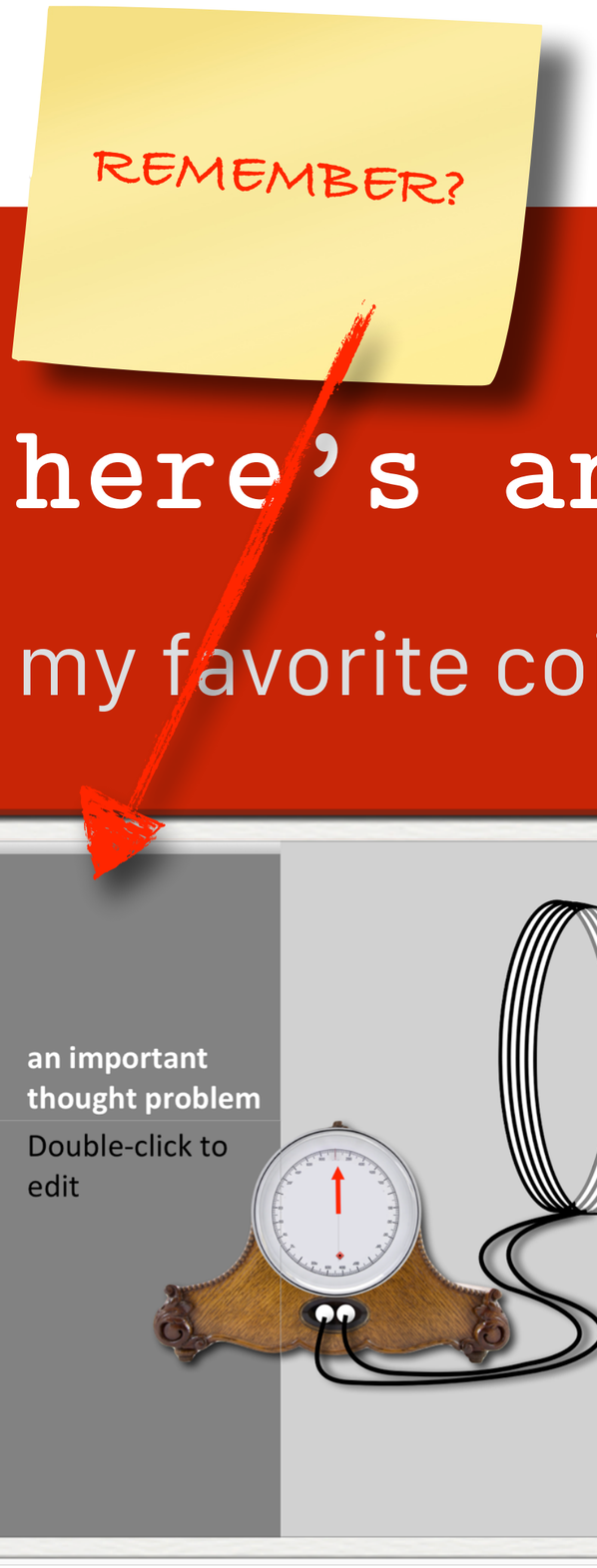
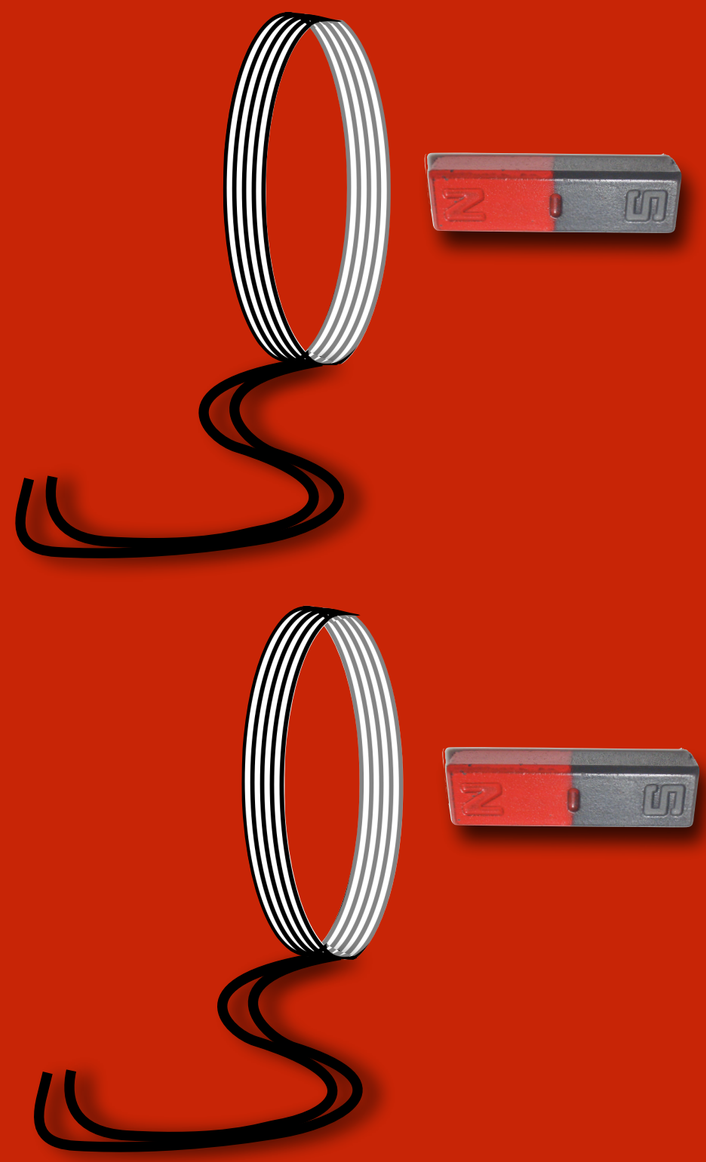


here's another one

my favorite coil-magnet



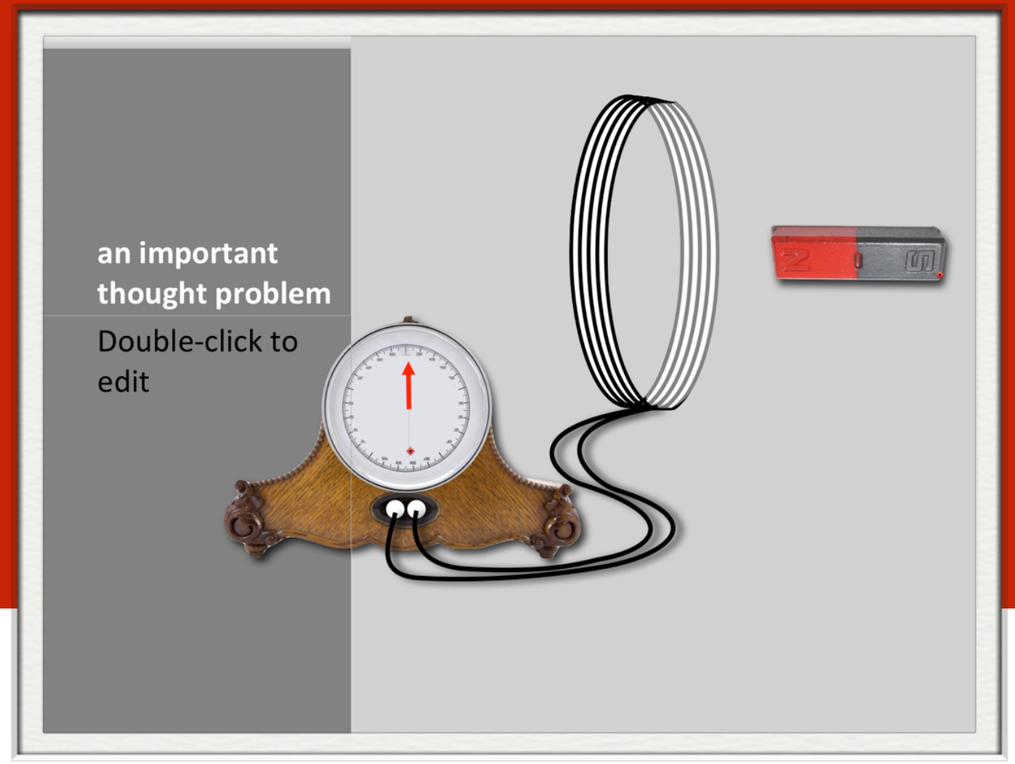
The changing magnetic field creates an electric field in wire

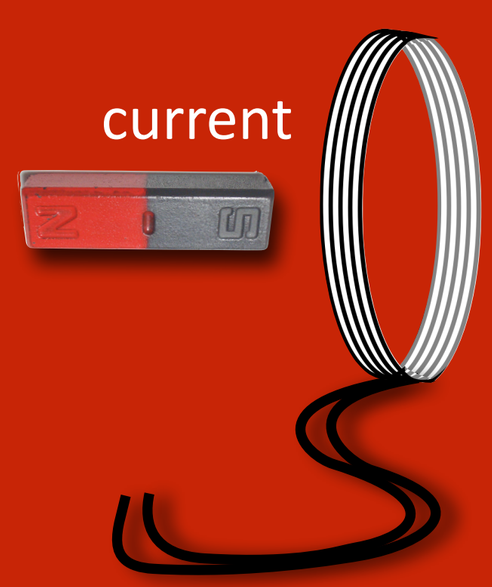
That produces a force on electrons

which moves them in the wire – **which is a current**

here's another one

my favorite coil-magnet





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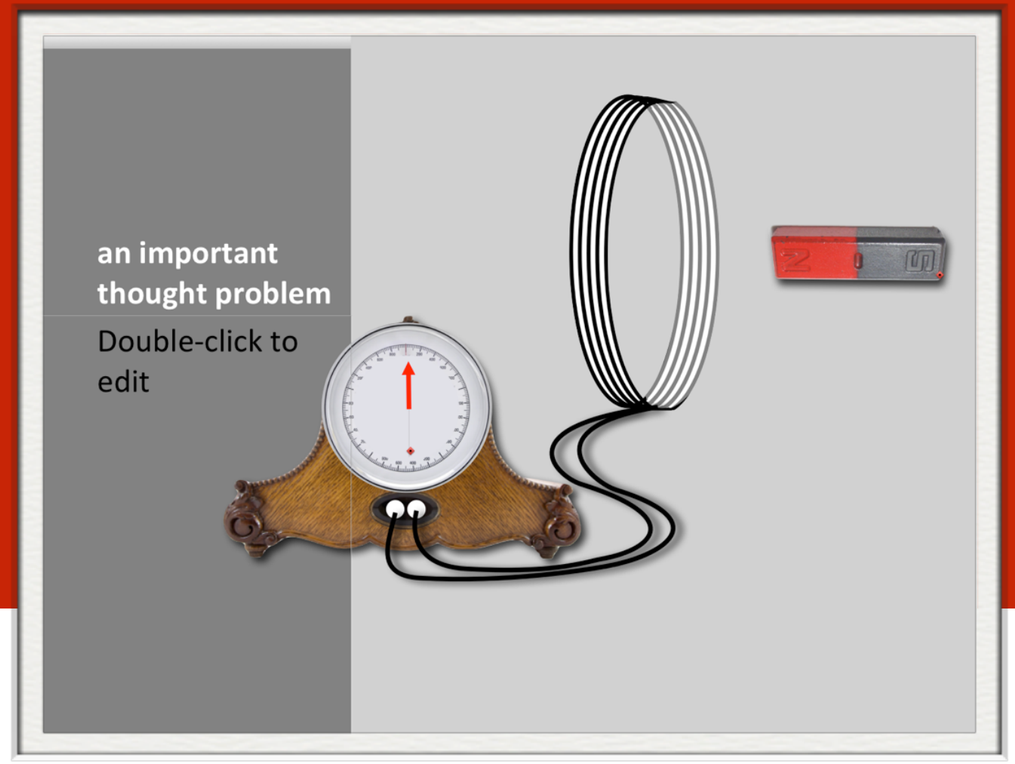

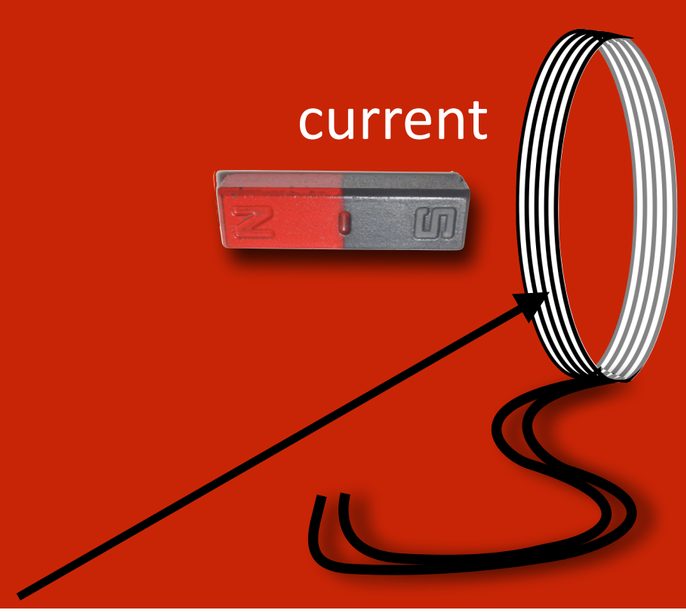

Magnetic field is constant – no electric fields

The changing magnetic field creates an electric field in wire
That produces a force on electrons
which moves them in the wire – **which is a current**

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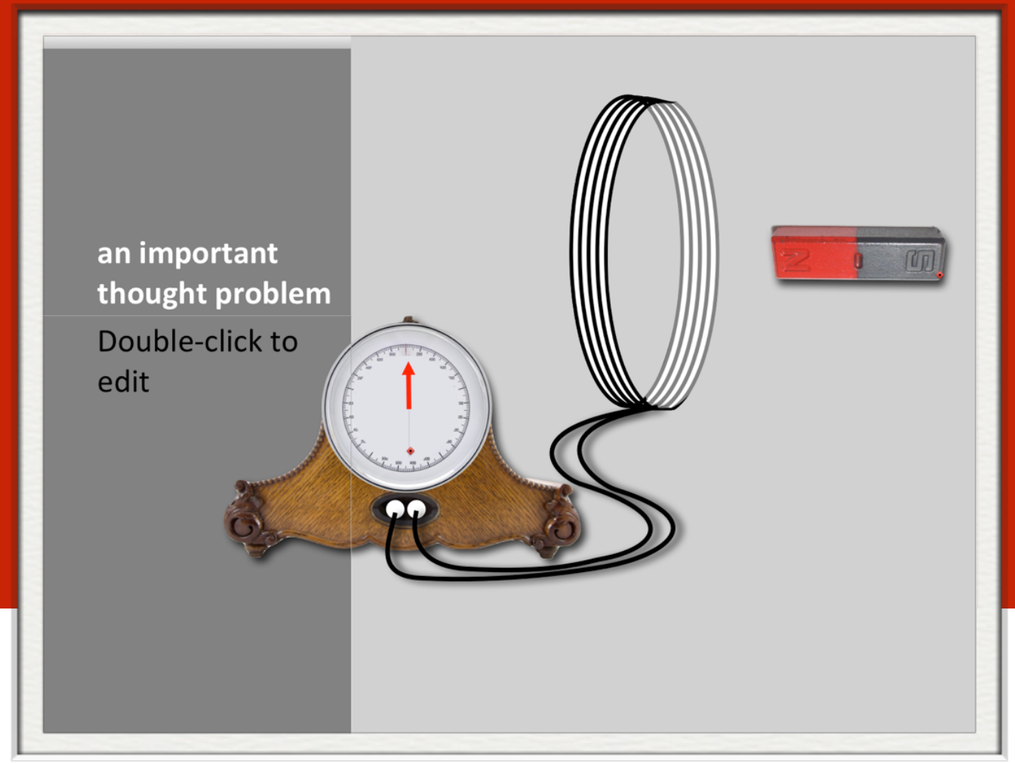
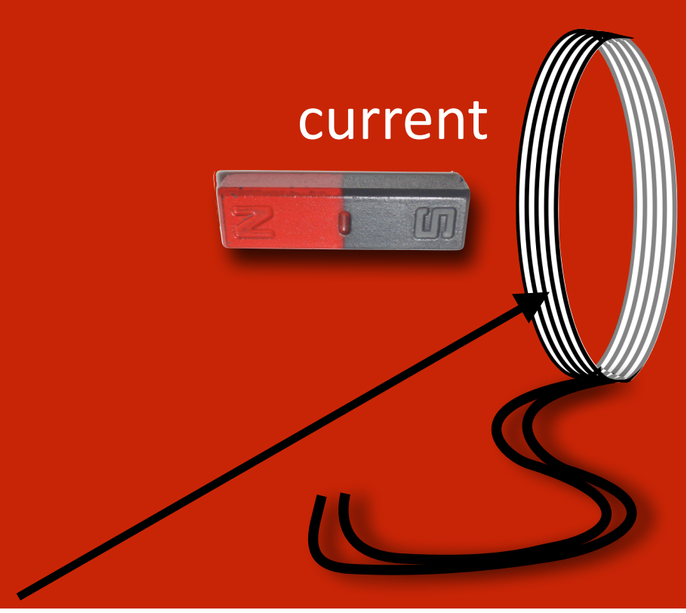




Magnetic field is constant – no electric fields
The electrons in the wire have a velocity passing by a magnetic field...

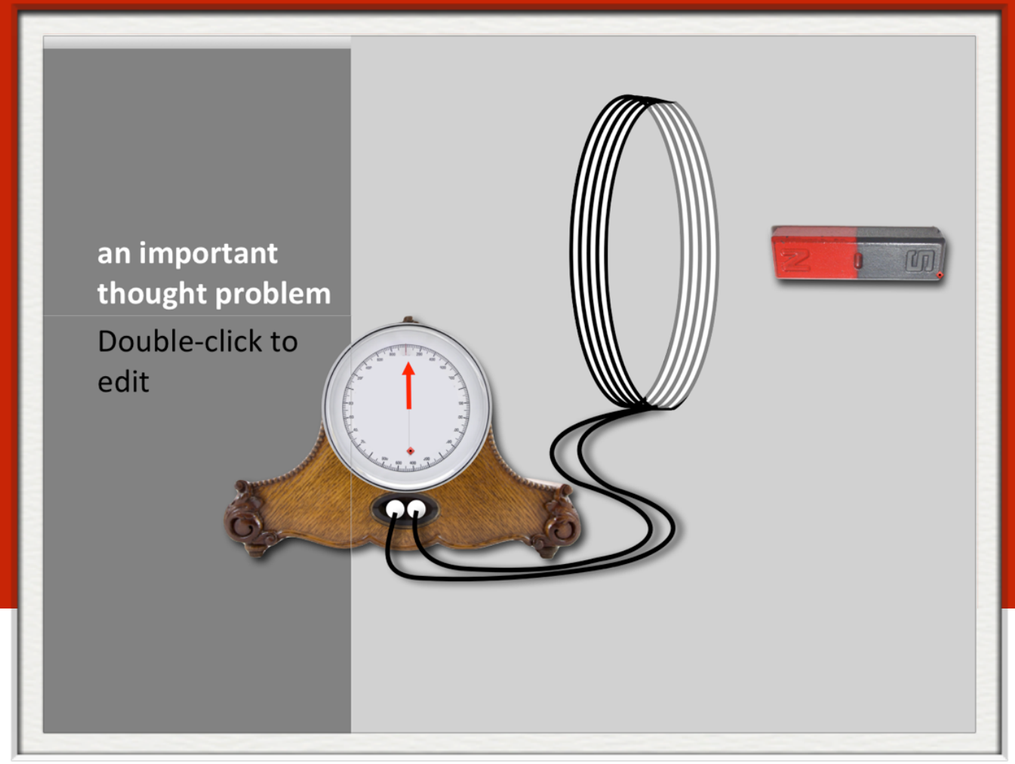
The changing magnetic field creates an electric field in wire

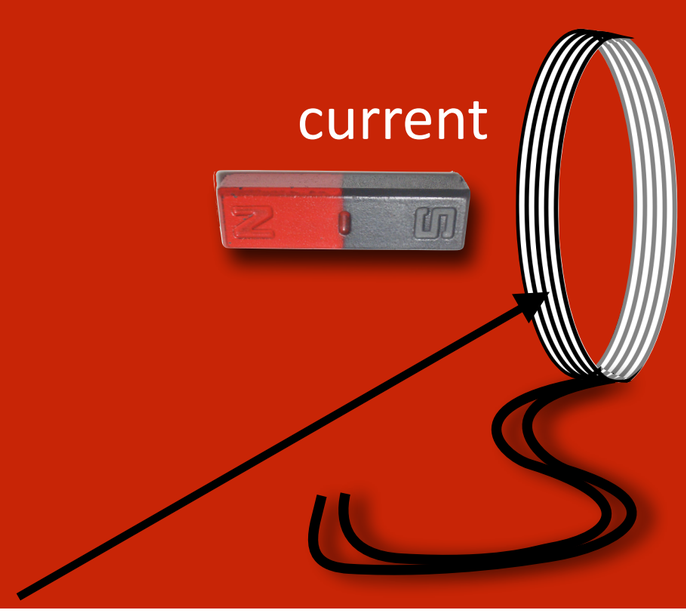
That produces a force on electrons

which moves them in the wire – **which is a current**

here's another one

my favorite coil-magnet





Magnetic field is constant – no electric fields

The electrons in the wire have a velocity passing by a magnetic field...

That produces a force on them – **which is a current**

The changing magnetic fie an electric field in wire

which moves the electro t

Weird alert #2:
Two identical physical outcomes... from entirely different physical causes for situations which differ only by the frame of reference

an important thought problem

Double-click to edit

rent

Magnetic field is constant – no electric fields

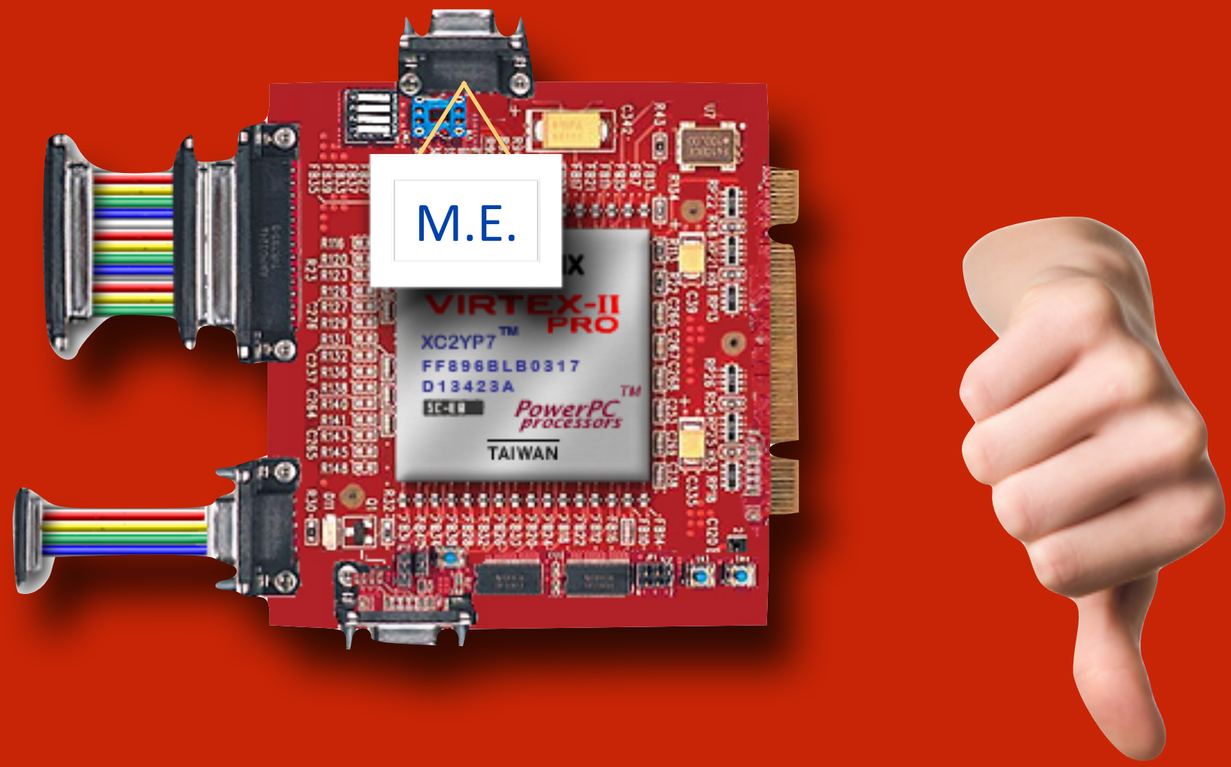
The electrons in the wire have a velocity

That produces a force on them – a current

so Maxwell's Equations

seem to fail between

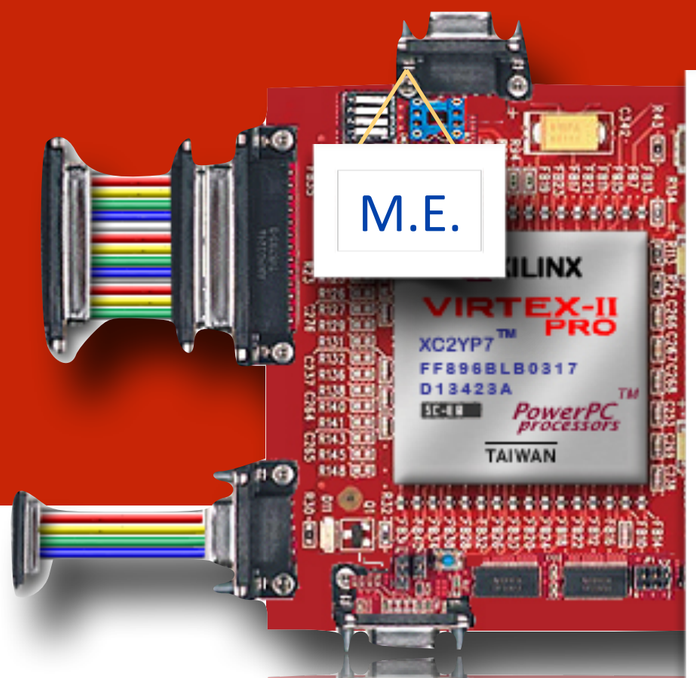
relatively moving inertial frames



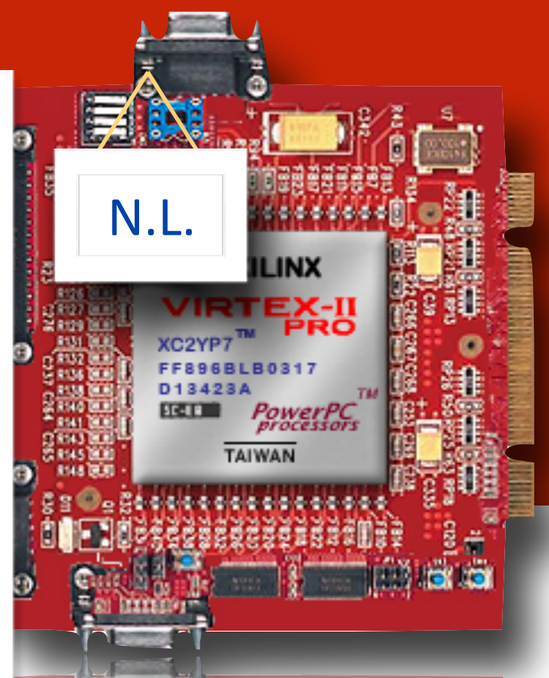
this is crazy! the two models of the world differ

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

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

c! the **speed of light!**

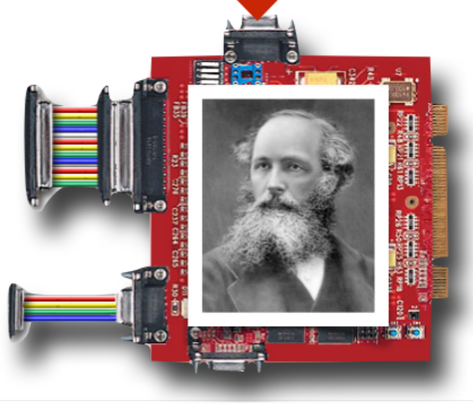
Which Maxwell knew.

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

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

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

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



8

This offended the young Einstein.

He took the Maxwell prediction seriously:

light moves at a constant speed

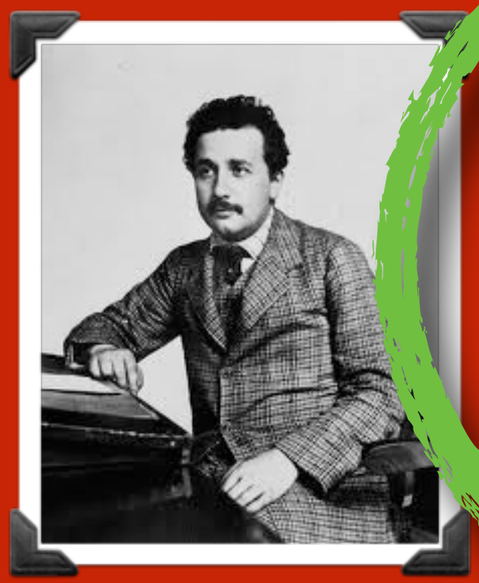
and proposed that c is special

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

Principle of Relativity

2 Postulates:

"inertial frame": constant velocity

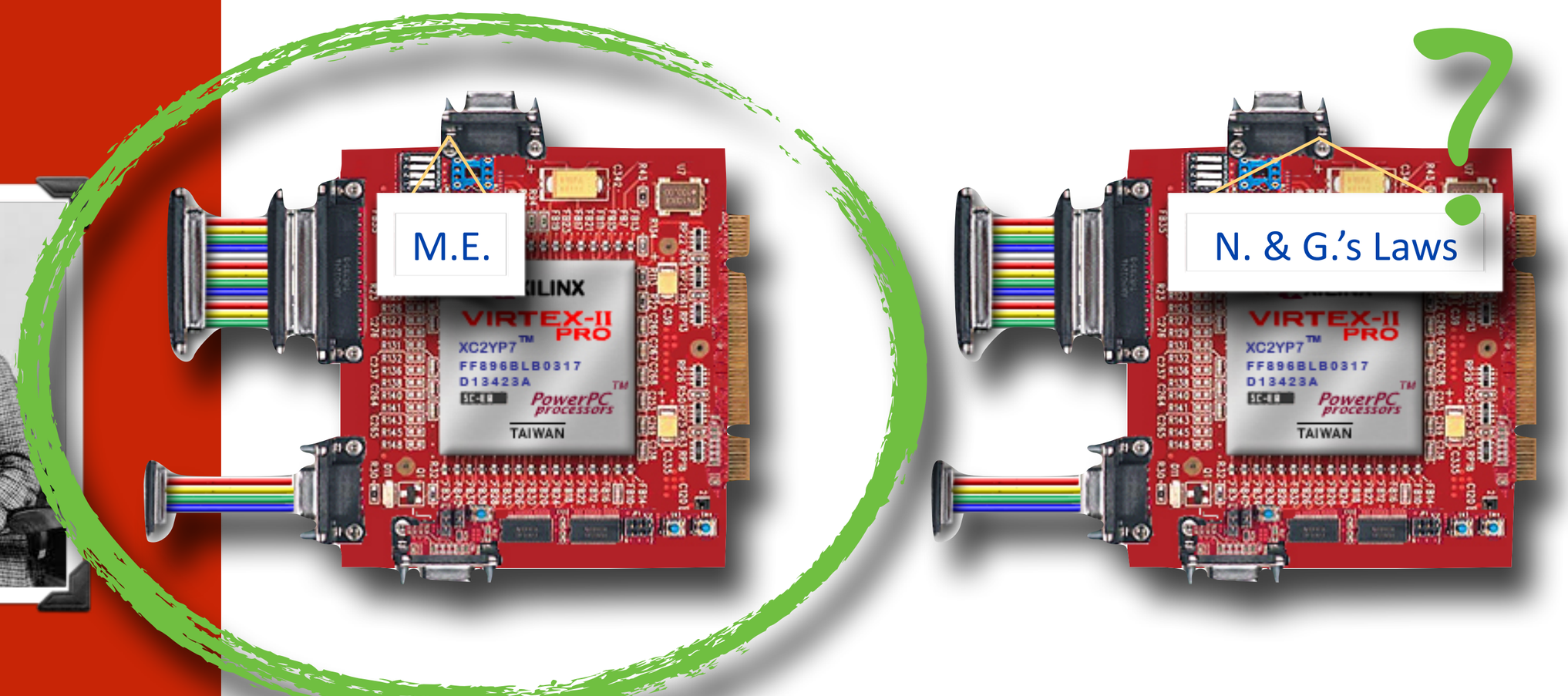


1. All laws of physics – mechanical and electromagnetic – are identical in co-moving inertial frames.

taking Galileo seriously, and then adding Maxwell

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

taking Maxwell seriously



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.

and then

he played the two postulates out

to see what would result

“A storm broke loose in my mind.”

his concern:

simultaneity

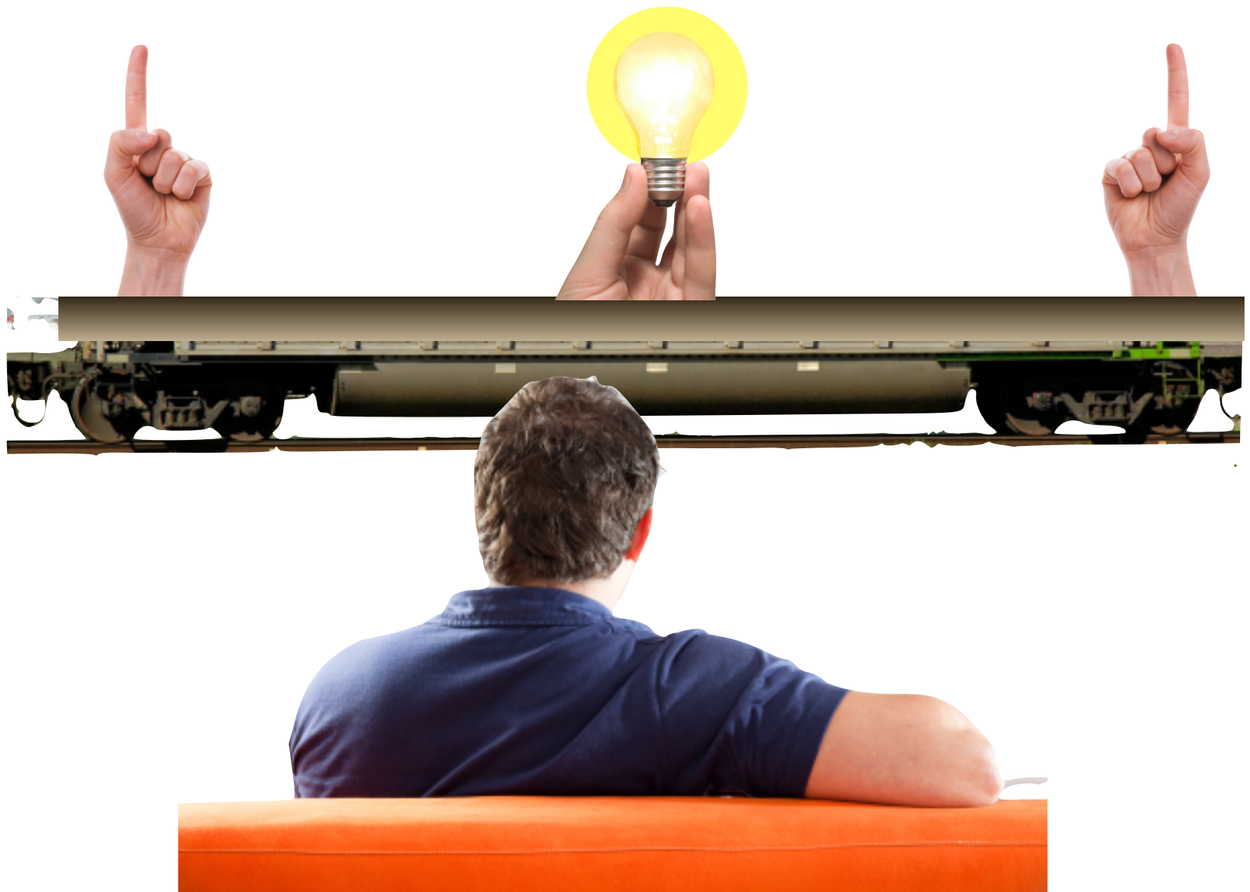
because that’s how two observers would synchronize their watches

put on your seatbelt

philosophical issues

and

very pragmatic issues

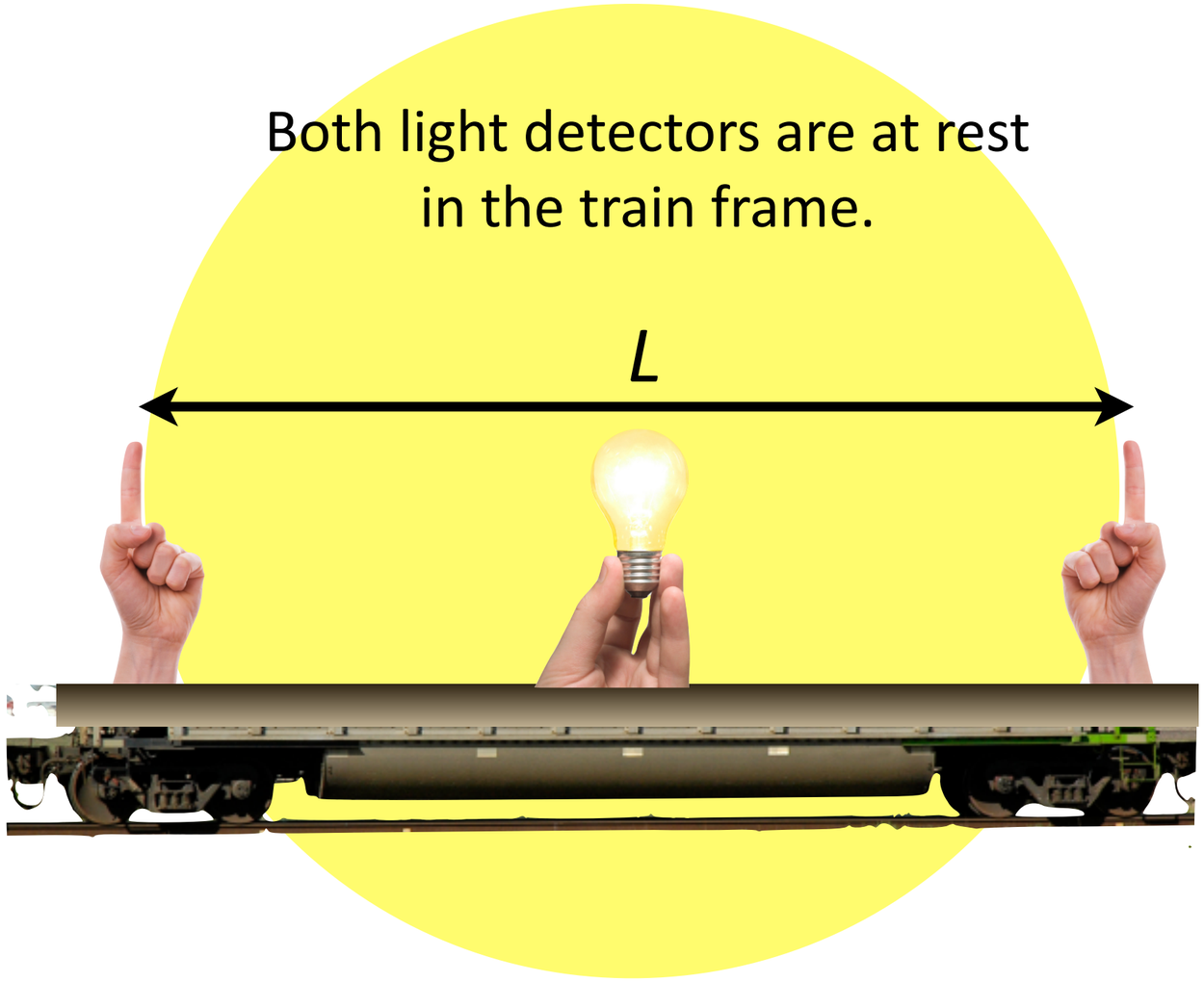


thinking simple

philosophical issues

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

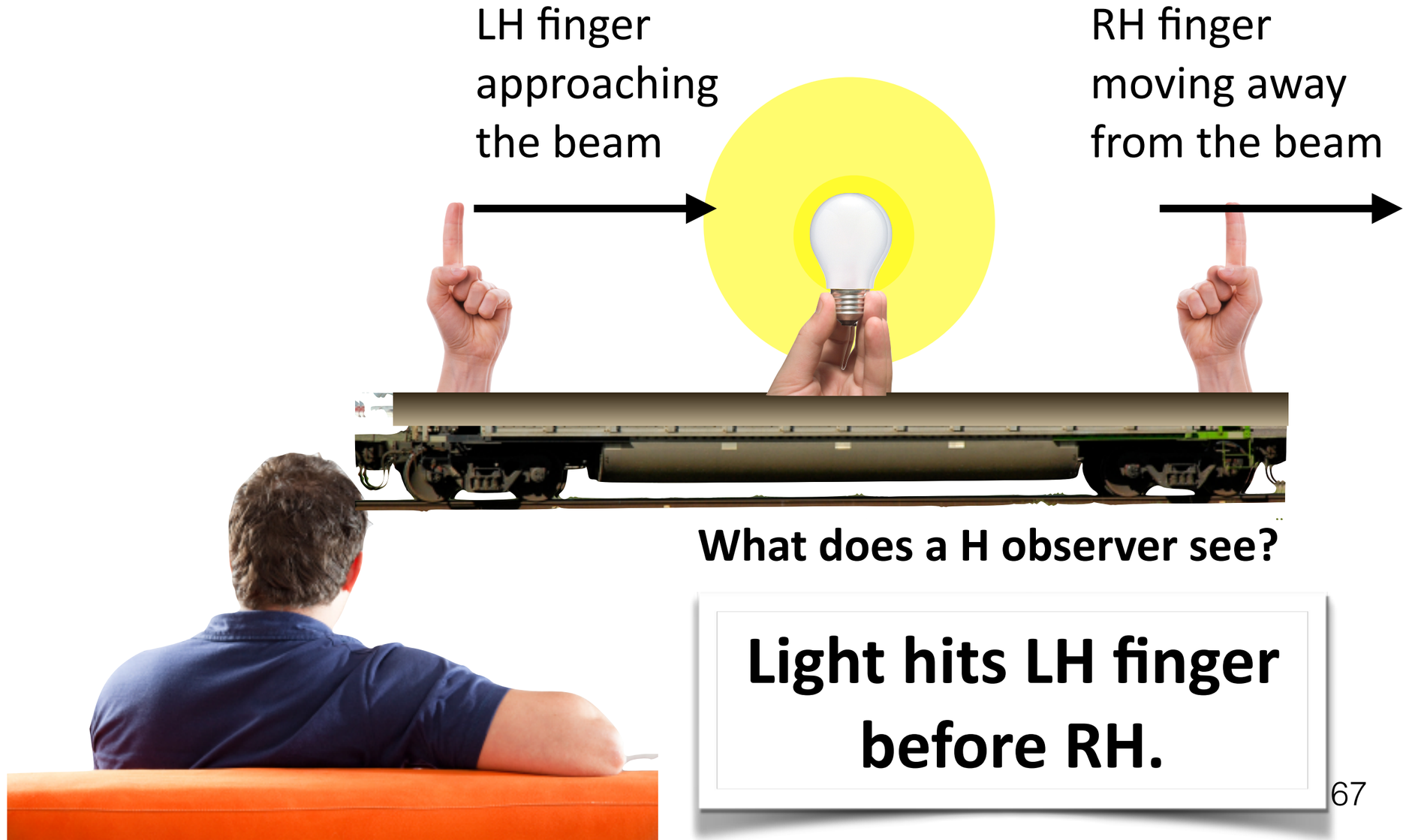
The train observer would declare: the beams arrived simultaneously



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

simple is hard

Notice that the Second Postulate disallows the addition of the train's motion to the light speed.



What does a H observer see?

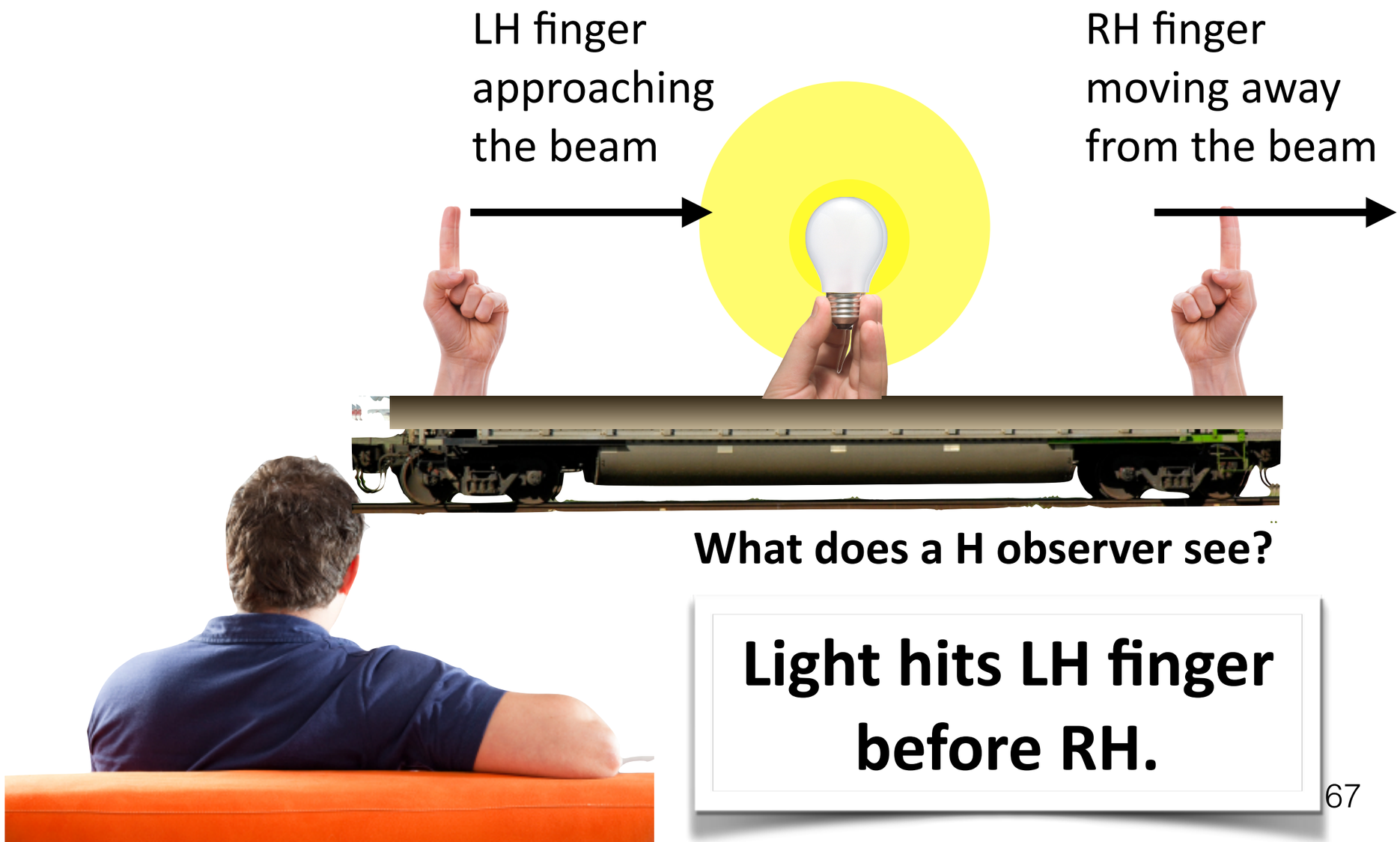
Light hits LH finger before RH.

simple is hard

the 1st of three odd things about space and time

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

Notice that the Second Postulate disallows the addition of the train's motion to the light speed.

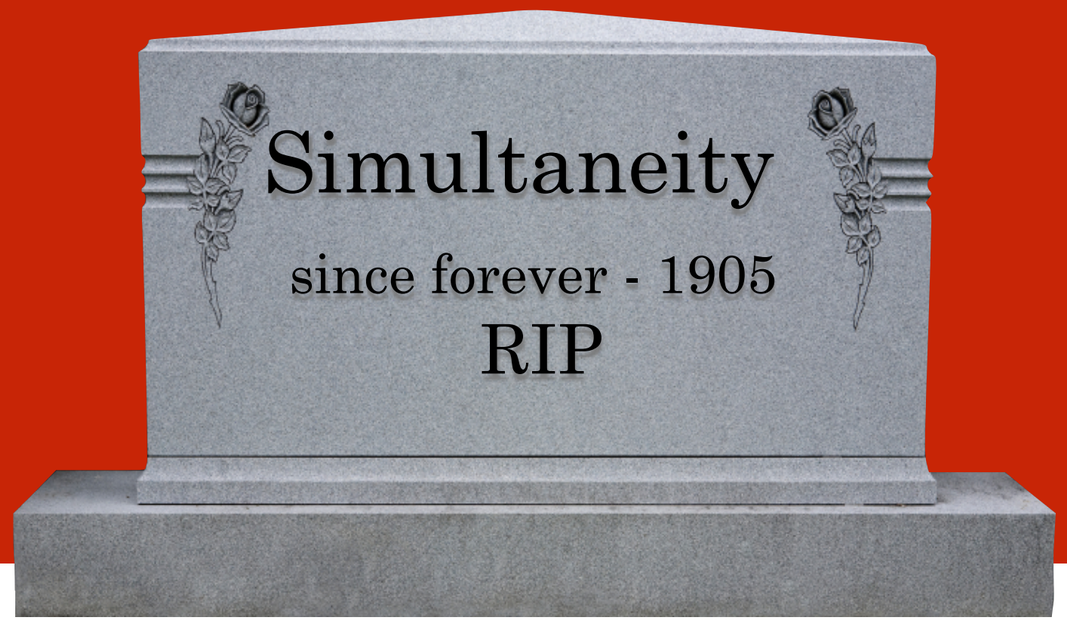


What does a H observer see?

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:

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 from one frame to another

So.

No inertial frame is special.

All are equivalent.

So.

No inertial frame is special.

All are equivalent.

Why?

because no measurement can be made to tell otherwise

2. “Causality” requires care

Two 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?

2. “Causality” requires care

is CAUSALITY

Two 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 movie going backwards be a first cry, then I’m born?

a casualty!?

the 2nd postulate

makes things strange

because c

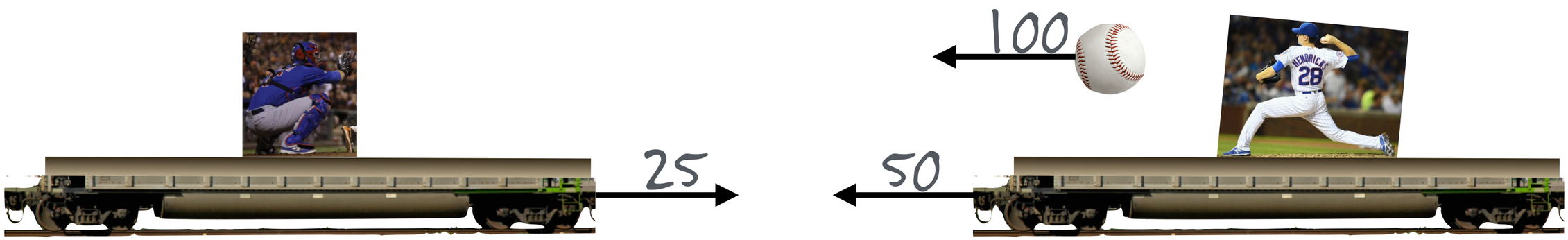
the speed of light is constant in all inertial frames:

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

c = 671 million mph

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

---

case 2: v(catcher)=0 v(ball)=100 v(pitcher)=50

what's v(ball) that catcher experiences: v(caught)=150

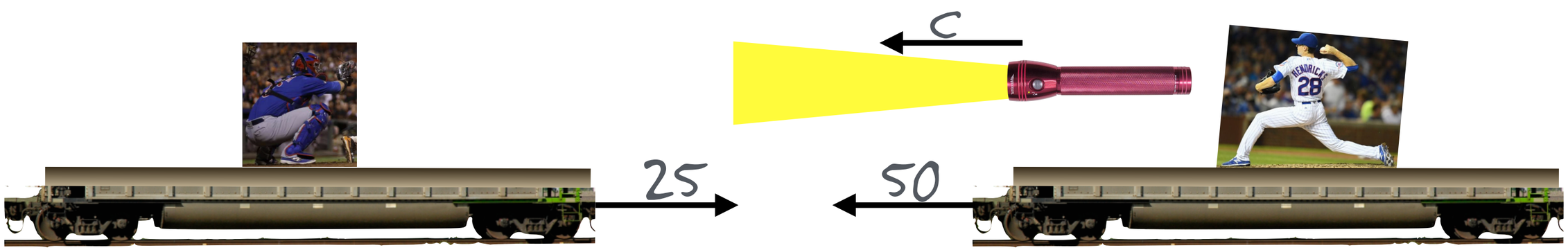
---

case 3: v(catcher)=25 v(ball)=100 v(pitcher)=50

what's v(ball) that catcher experiences: v(caught)=175

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

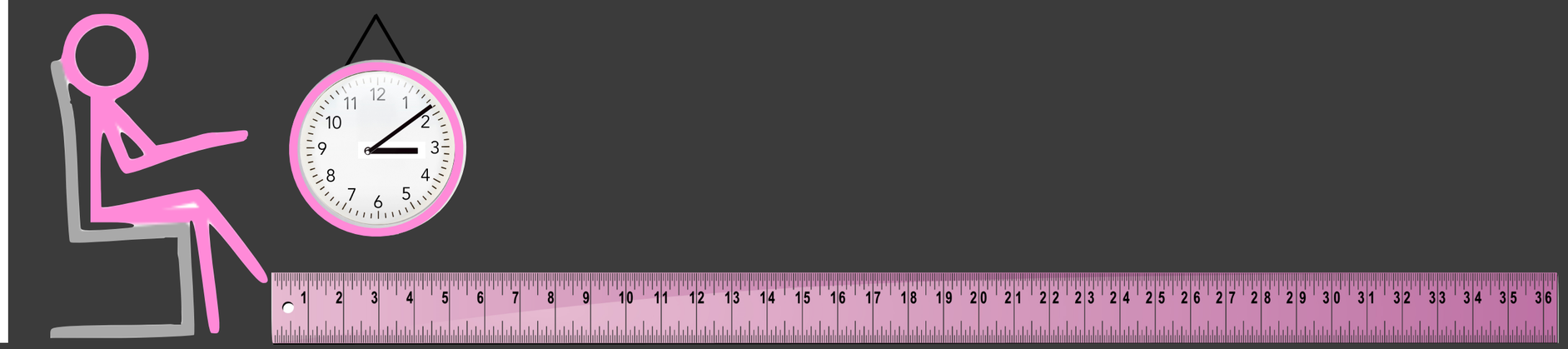
what's v(light) that catcher experiences: v(caught)=c

---

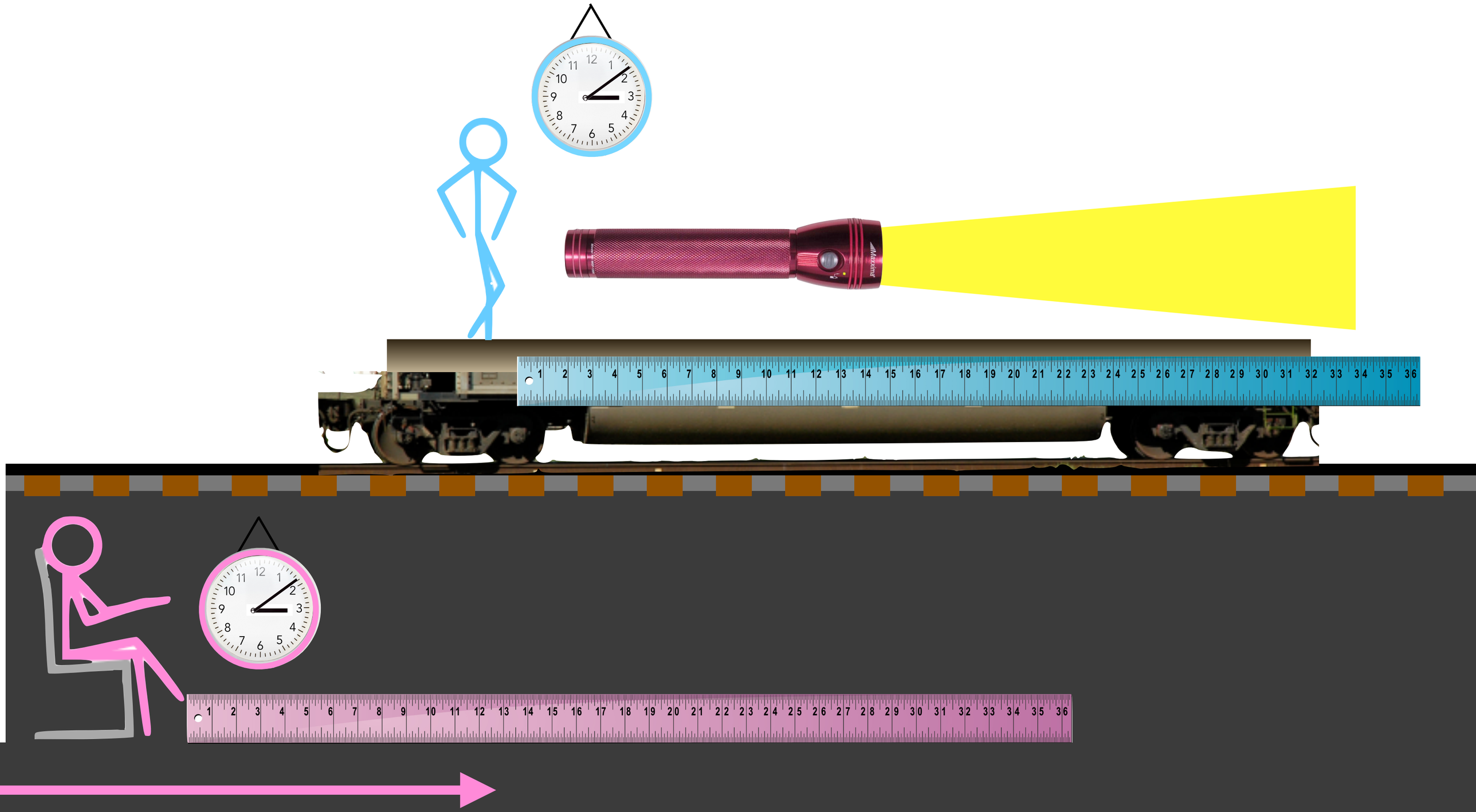
case 3: v(catcher)=25 v(light)=c v(pitcher)=50

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

light is constant speed everywhere

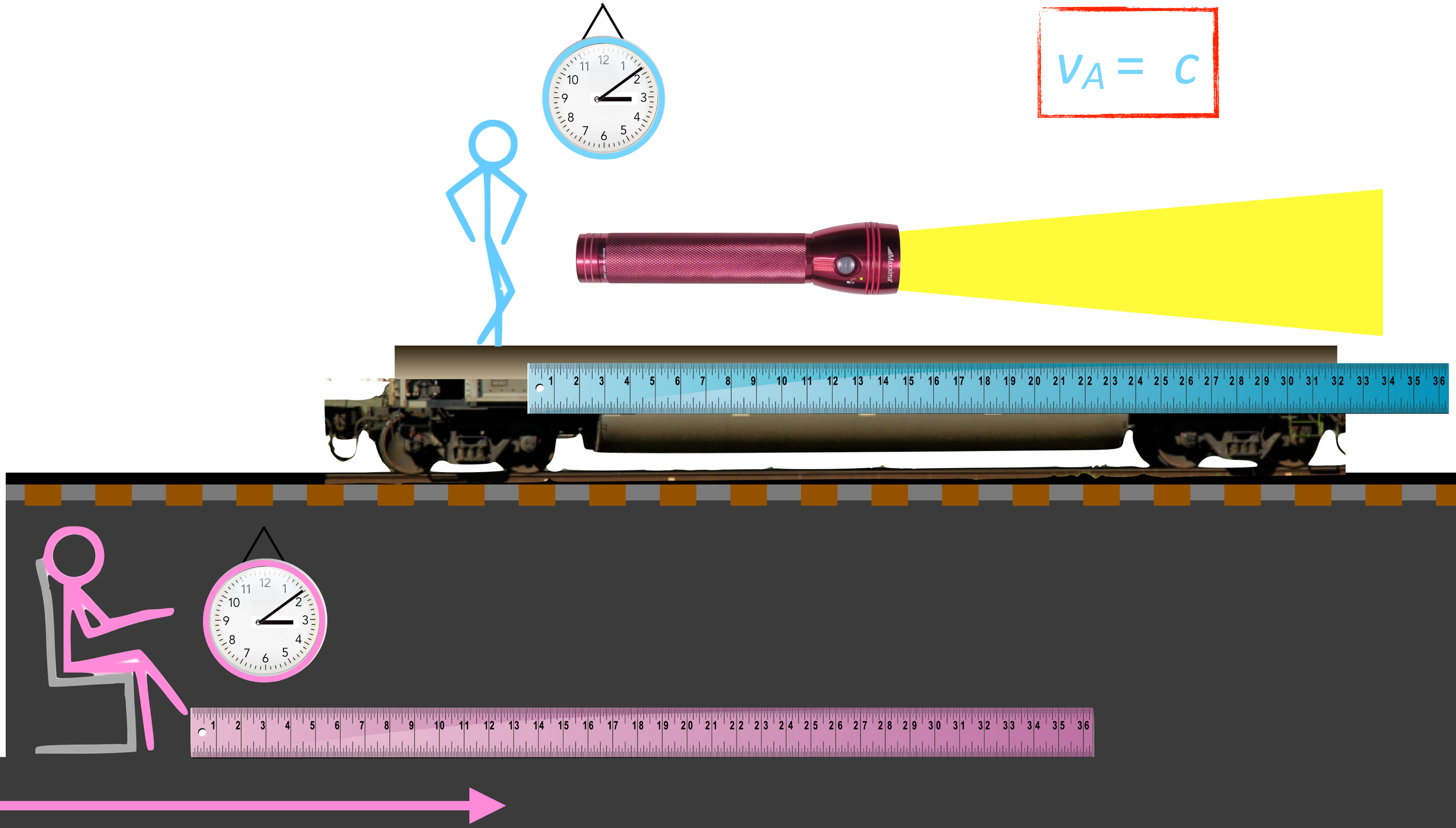


light is constant speed everywhere

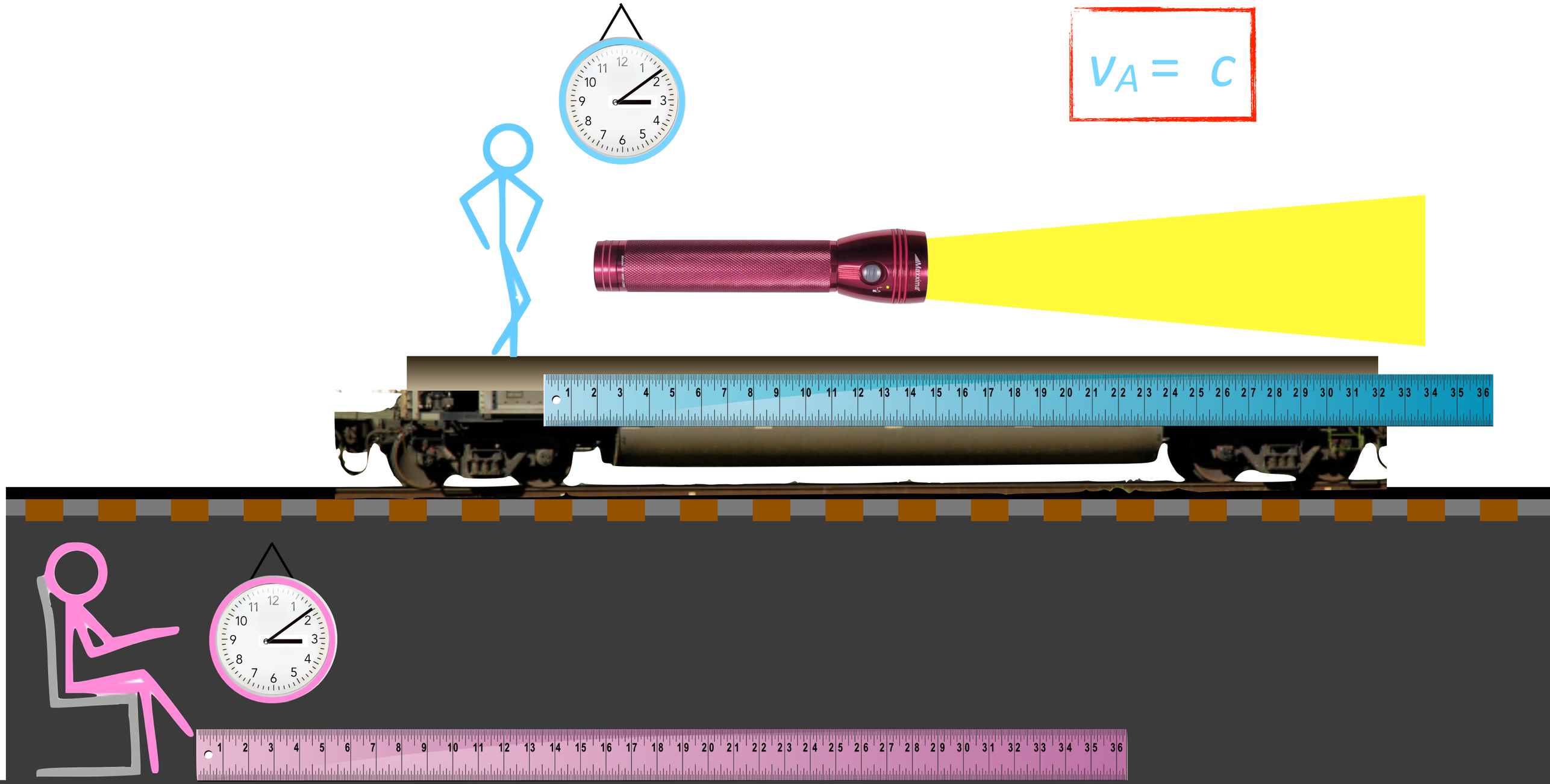


light is constant speed everywhere

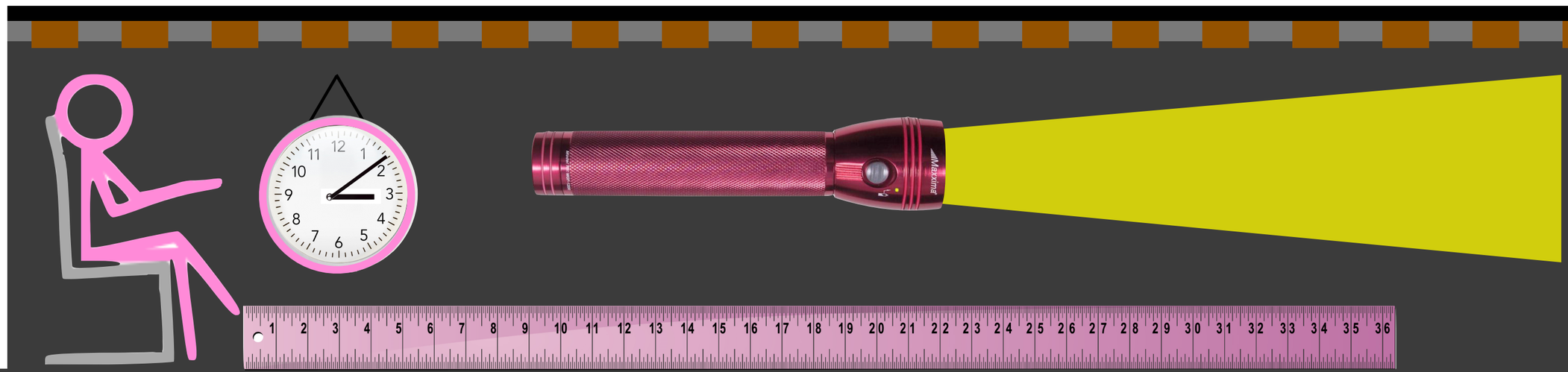
$v_A = c$



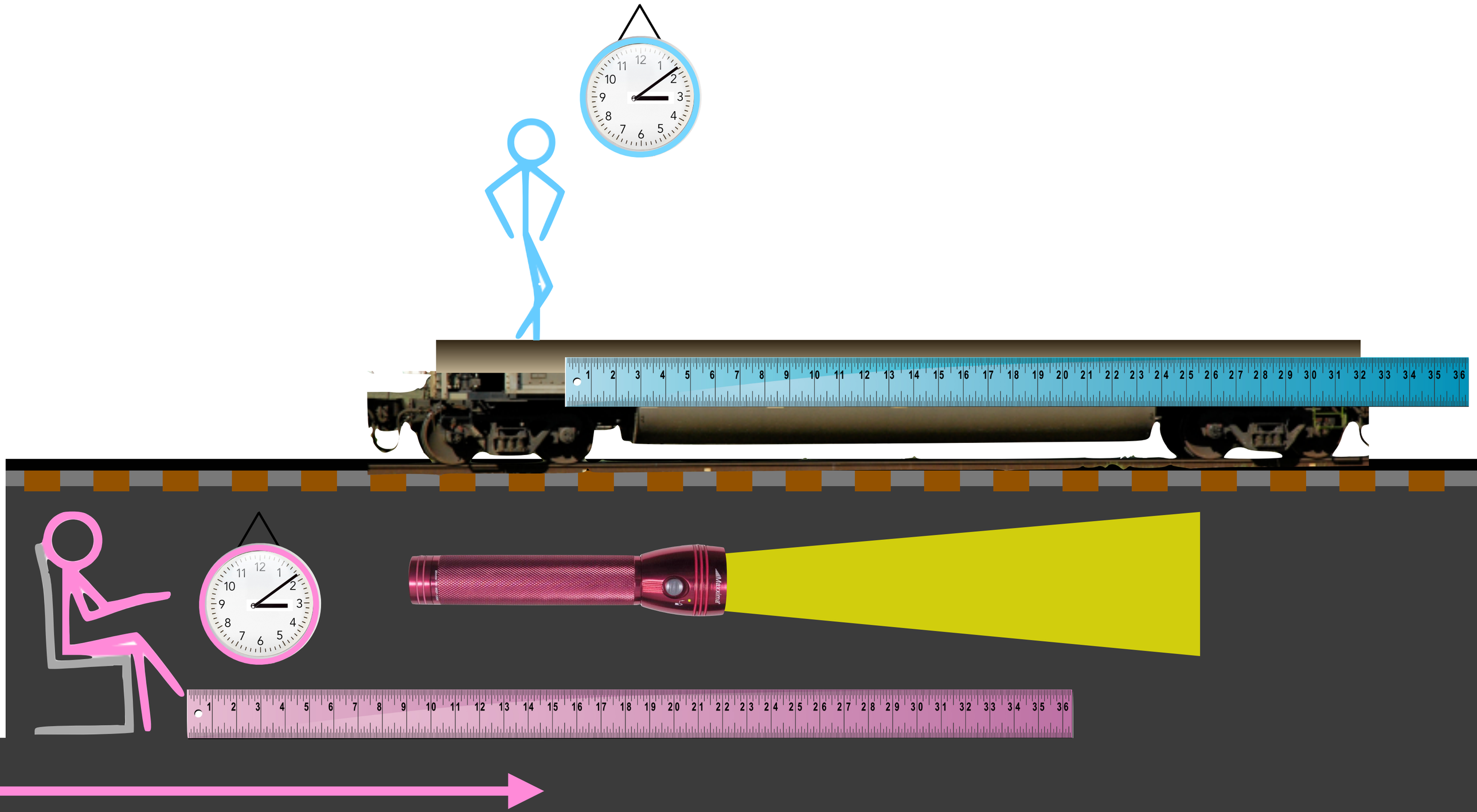
light is constant speed everywhere



and the other way as well.



and the other way as well.



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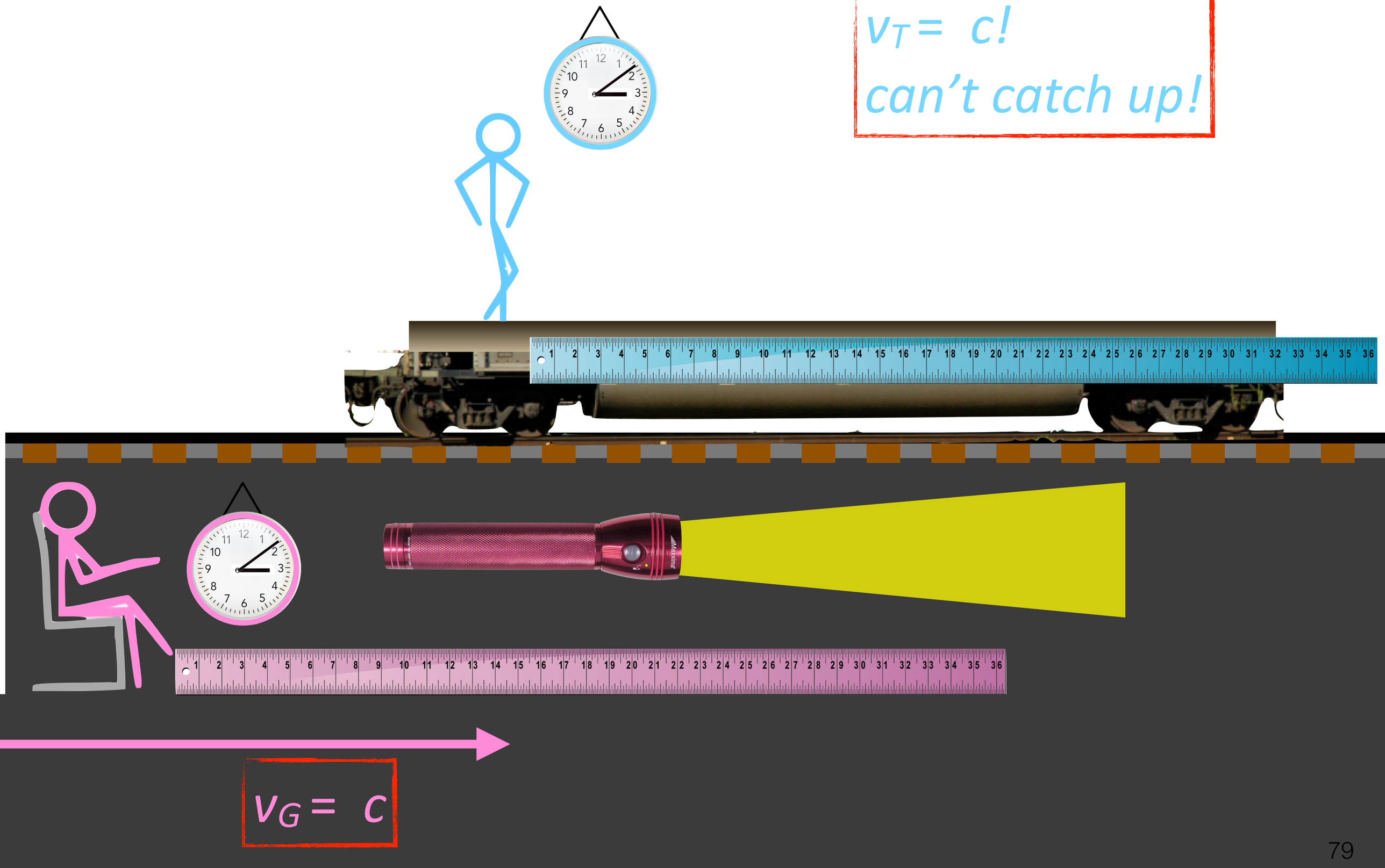
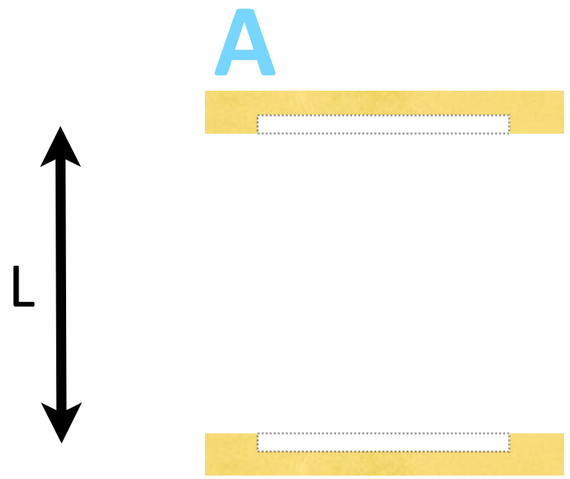


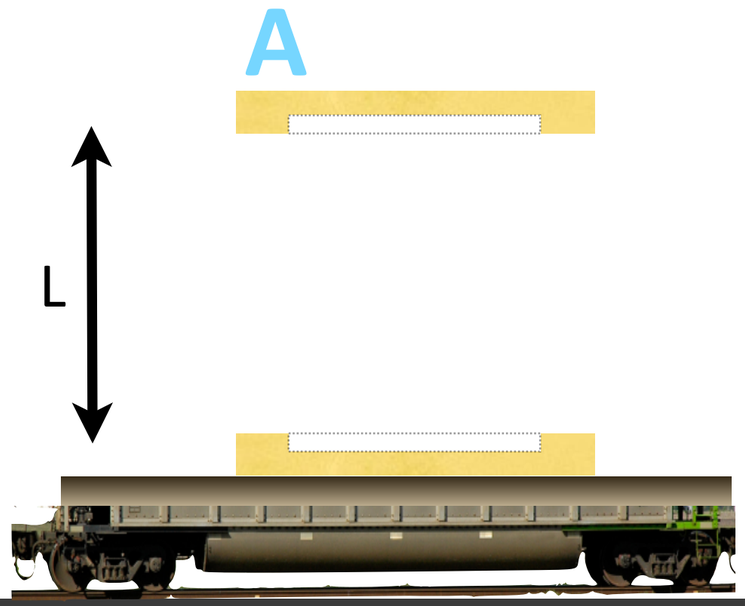
there are consequences to this

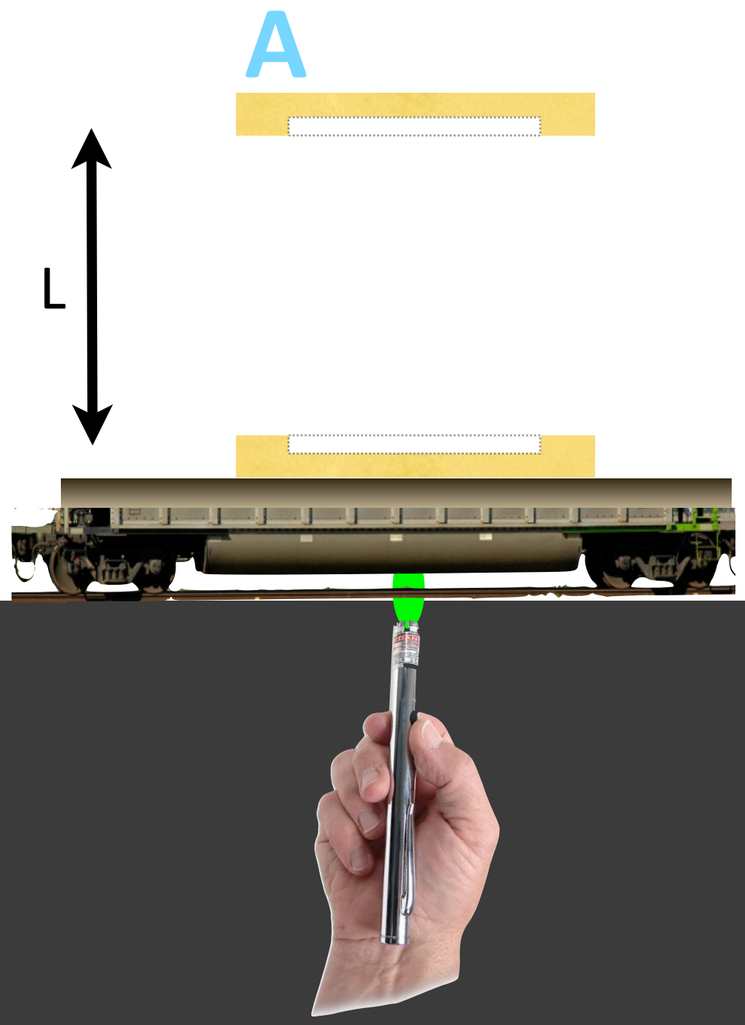
let’s make a light clock

and follow the mathematics

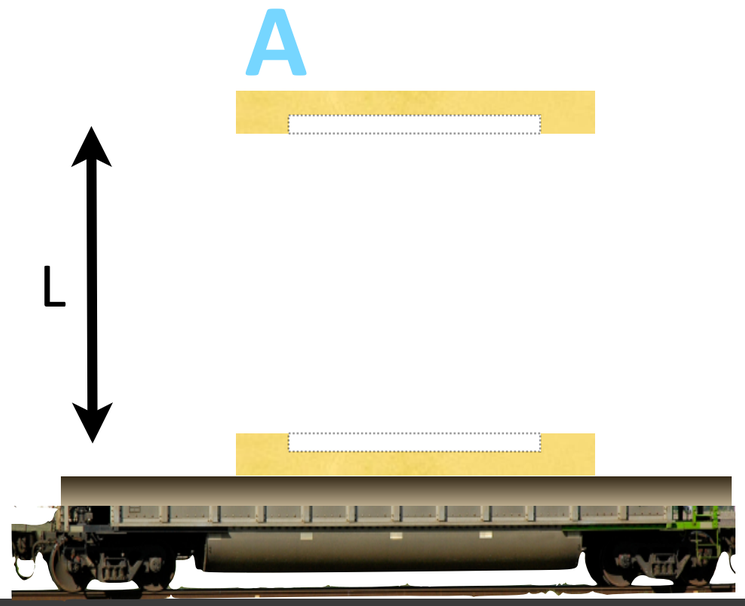


H


A
L
H



H


A
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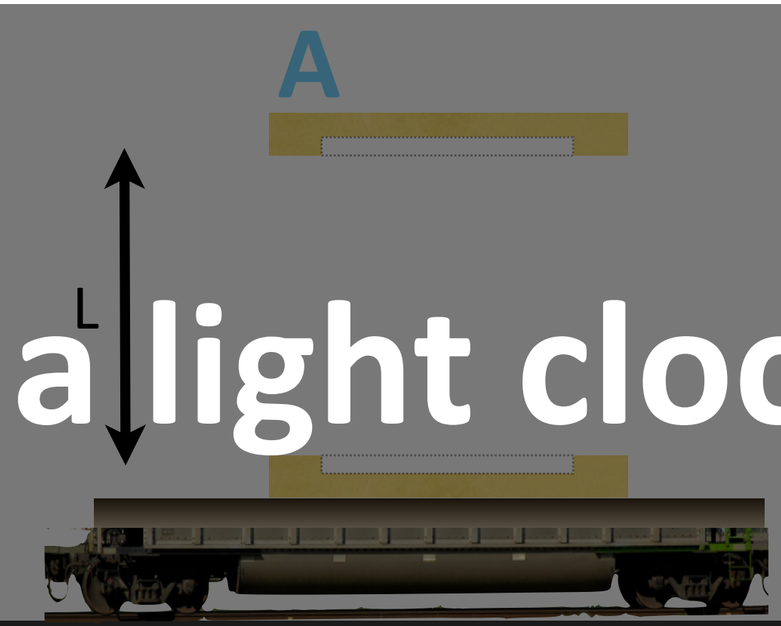
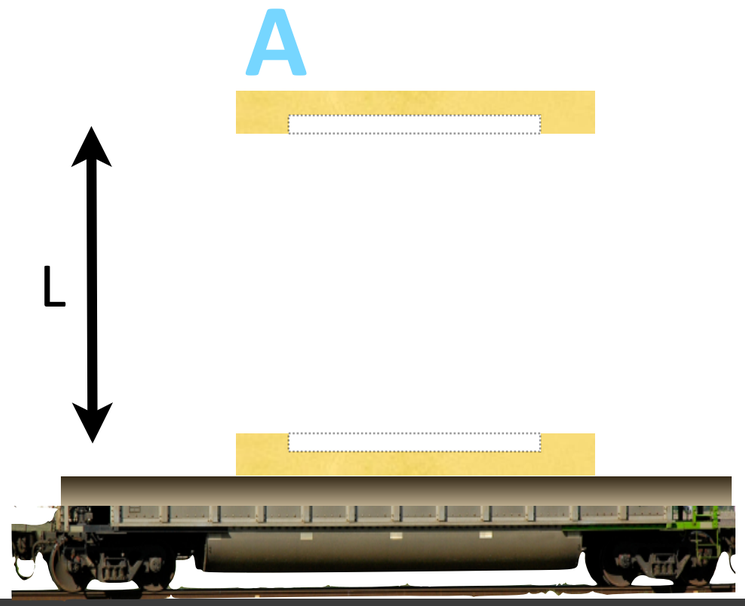

A
L
a light clock!
H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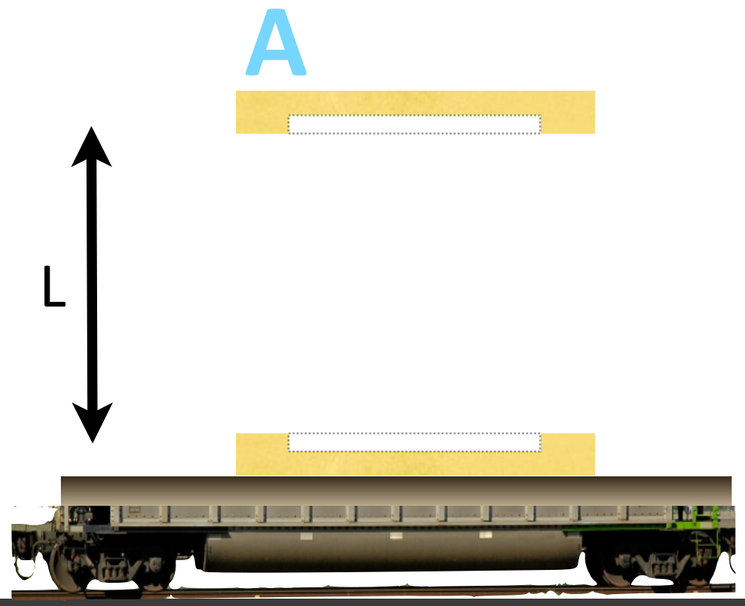

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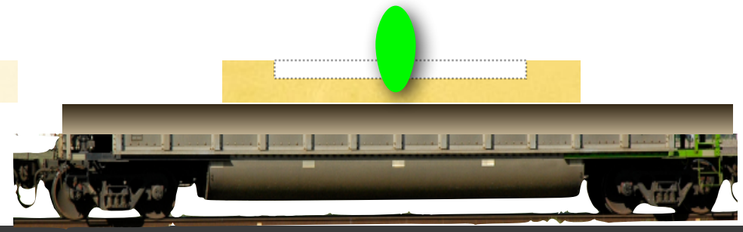
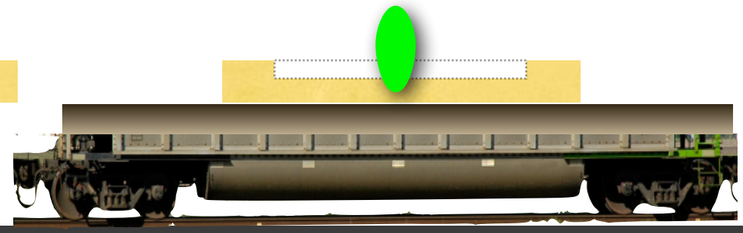


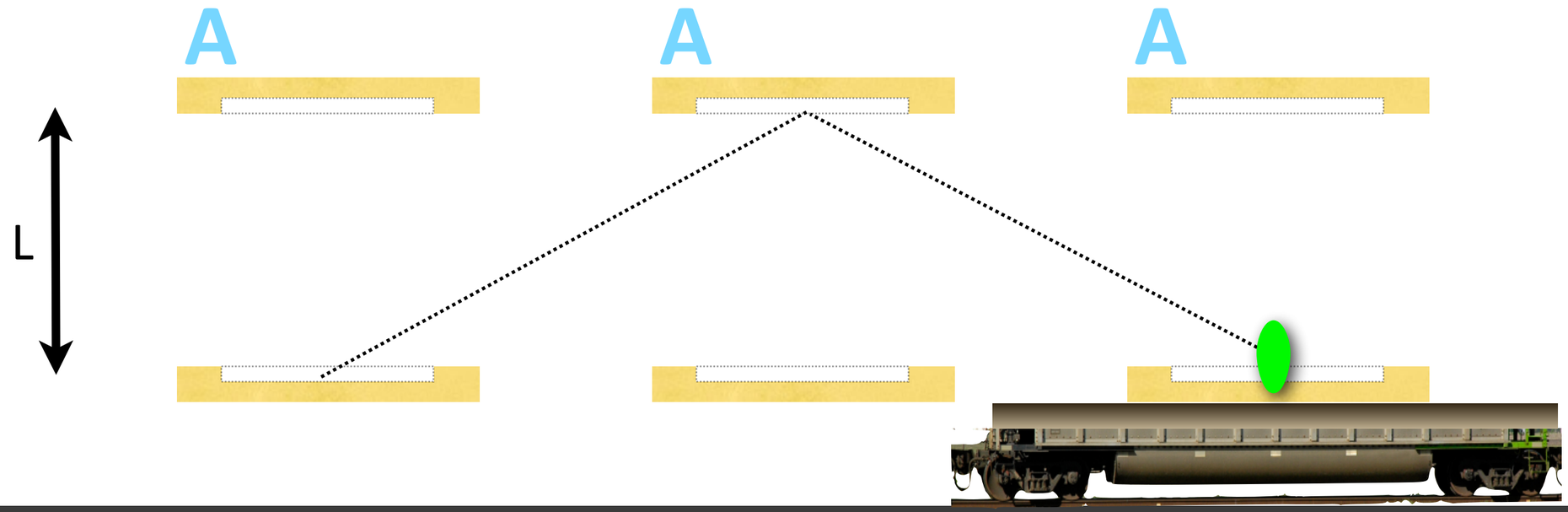
H

A A A

L



H


A
A
A
L
H

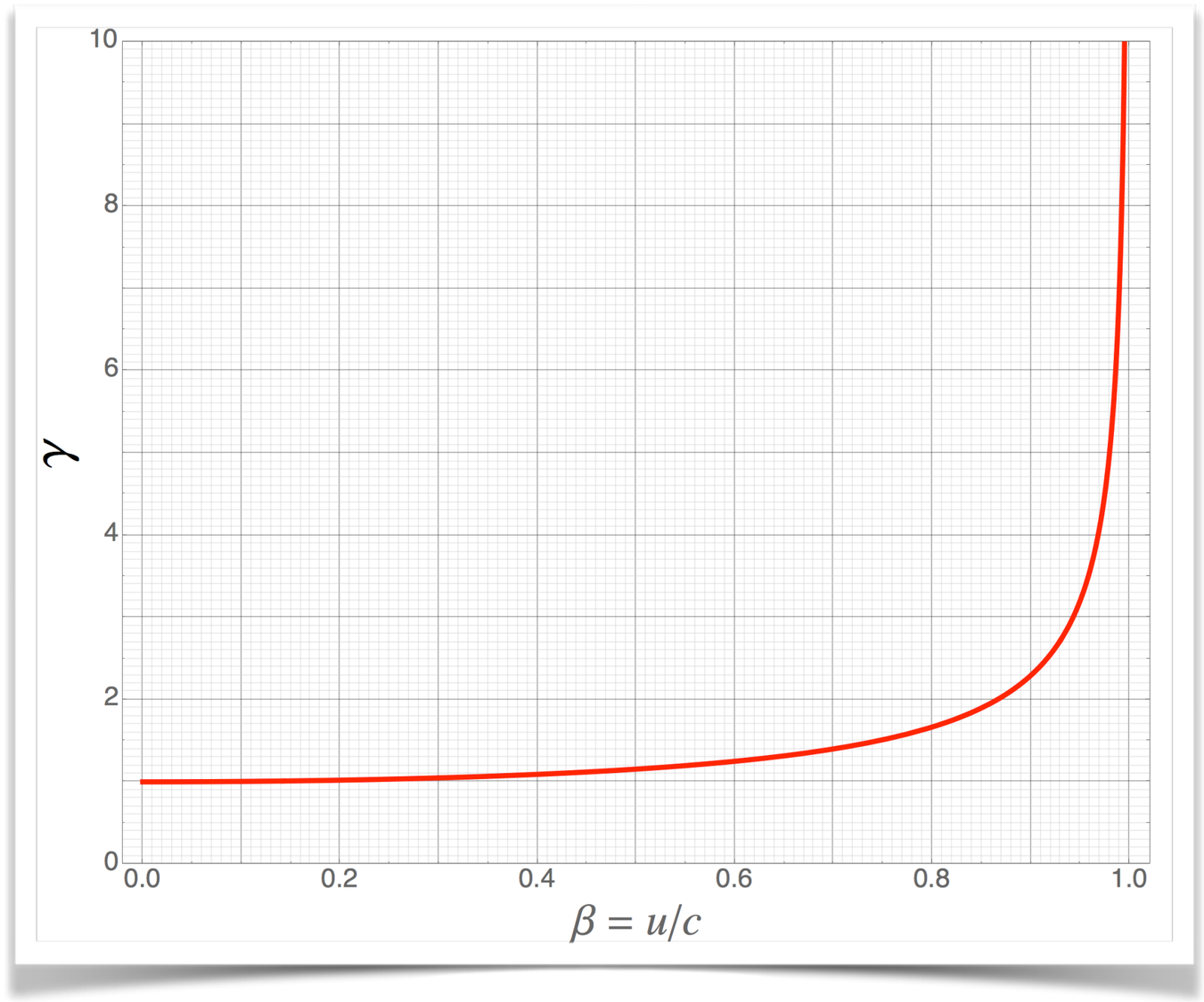
Moving clocks appear to run slower as seen by a relatively stationary observer

time dilation

the second of 3 strange things about space and time

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

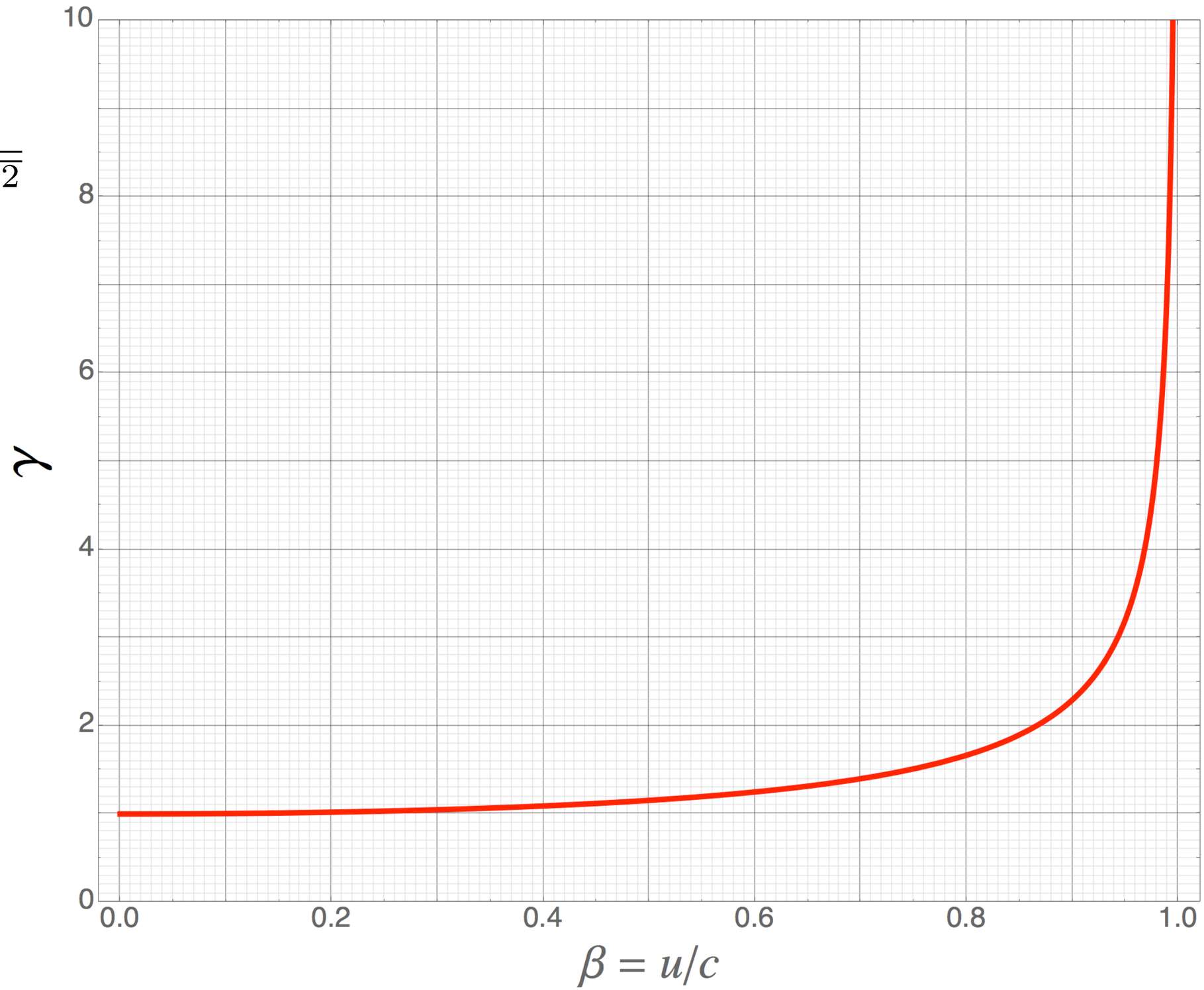
$$t_H = \gamma t_A$$



‘‘relativistic gamma’’

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

$$\beta = u/c$$



‘‘relativistic gamma’’

$$\beta = u/c$$

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