hi

Day 11, 19.02.2019

Einstein’s Special Theory of Relativity, 1

full squad practices yesterday

Tower of Power week

housekeeping

Lectures forever now: Gotta come to class

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

Please remember – especially true starting now:

need to take hand-written notes

No computers or phones are allowed.

Midterm…before Spring Break

available: Saturday, 23 February midnight

due: Tuesday, 26 February midnight

covering: material beginning through HW4 content

#attempts = 1

weight = 2 x HW

Some LON-CAPA

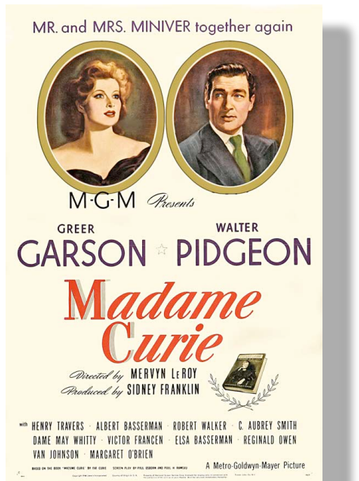
still!

I've not adjusted grades for the Kepler problem yet

LON-CAPA "essay" question fields

work okay?

Madame Curie movie - we have a quorum in favor



I'll post another FB poll targeting the week after break

You "vote" for evenings when you CANNOT attend

parameters: 6:30 on an evening; I'll bring pizza (another poll for kind of pizza); you get liquids

February 2019

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
27	28	29	30	31	1	2
		yadda yadda yadda				HW2
3	4	5	6	7	8	9
		lessons 10,11,12		lesson 13	HW2 due	HW3
10	11	12	13	14	15	16
		lecture		lecture	HW3 due	HW4
17	18	19	20	21	22	23
		lecture		lecture	HW4 due	HW5
24	25	26	27	28	1	2
←	midterm	→ lecture		lecture	HW5 due	

Eastern Time Time Zone


KEEP
CALM
AND
LET'S
REVIEW

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


in 1895
the wheels came off

a series of

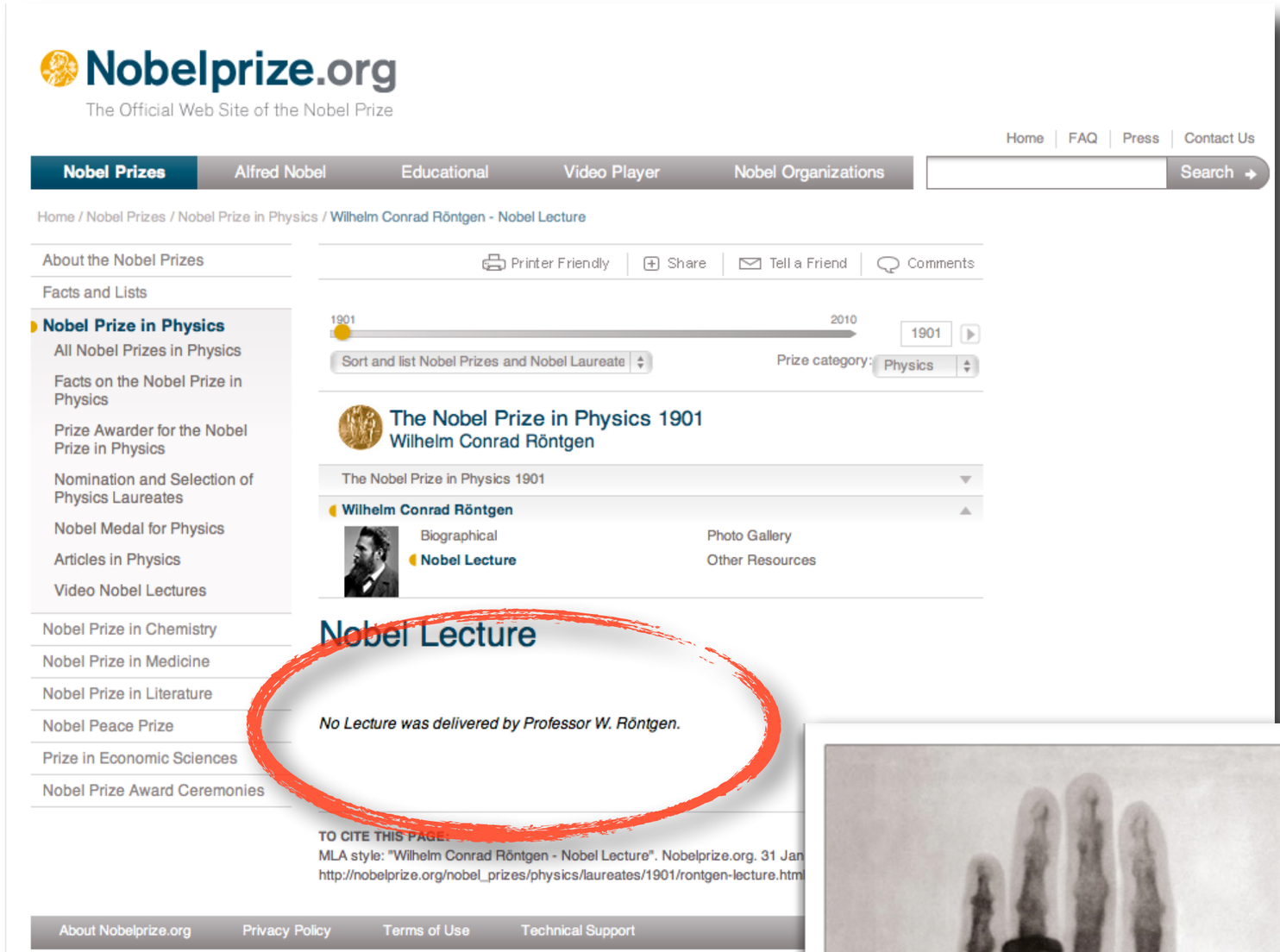
our first Nobel

1 talk

1 publication

no profit

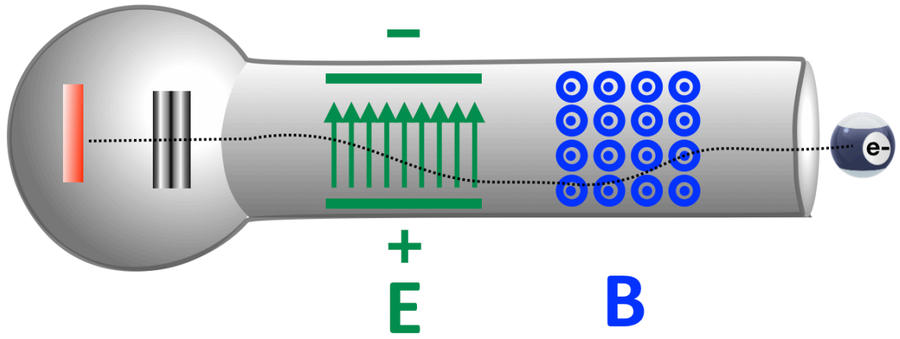
suffered terribly during WWI



then

it got strange

Nobel 1906



The Nobel Prize in Physics 1906
J.J. Thomson

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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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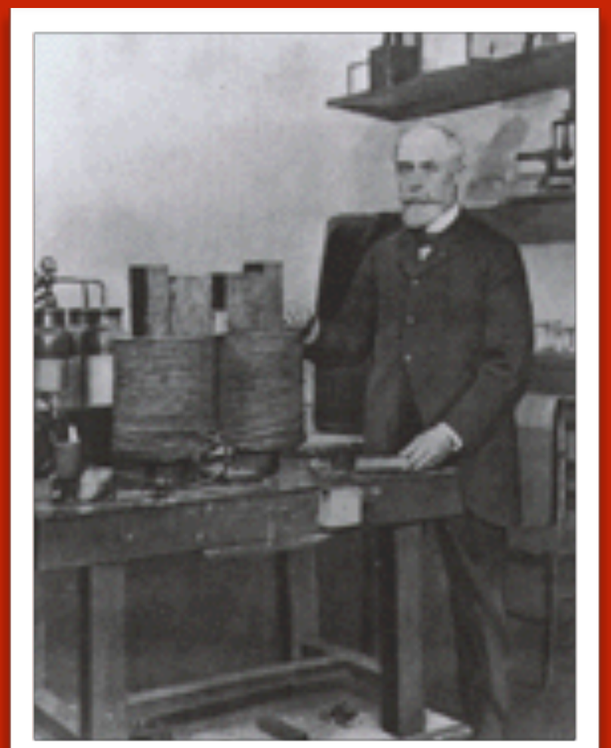
is page
"The Nobel Prize in Physics 1906". *Nobelprize.org.* Nobel Media AB 2014. Web. 10
http://www.nobelprize.org/nobel_prizes/physics/laureates/1906/>

then it got stranger

1896 Antoine-Henri Becquerel

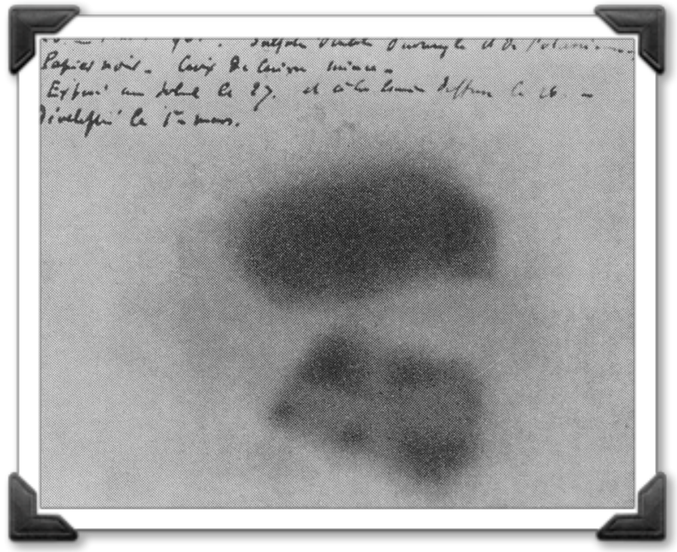
1852-1908



In the audience when X-rays were announced...

Expert in phosphorescence...thought X-rays were phosphorescence. wrong.

Wrapped up piece of Uranium when it got cloudy in Paris. When he unwrapped it:



Energy created out of nothing?

“Becquerel Rays”...didn’t catch on.

But: the idea of matter spontaneously emitting energy did!

He studied it and found the emanations ionized air and could be deflected by a magnet...so, it consisted of charged particles & not X-rays

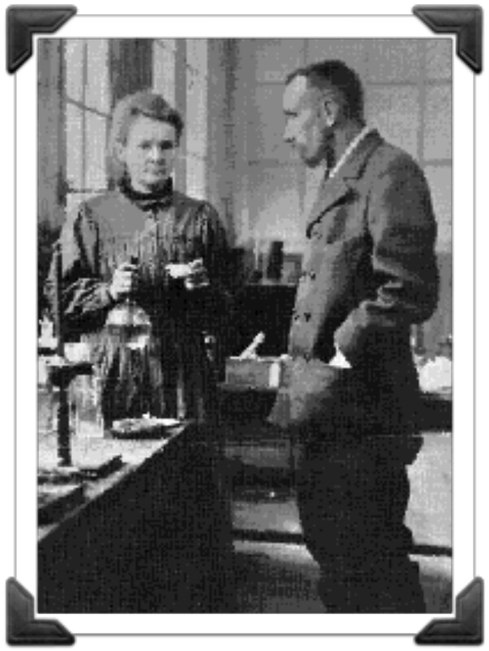
then it got even stranger still

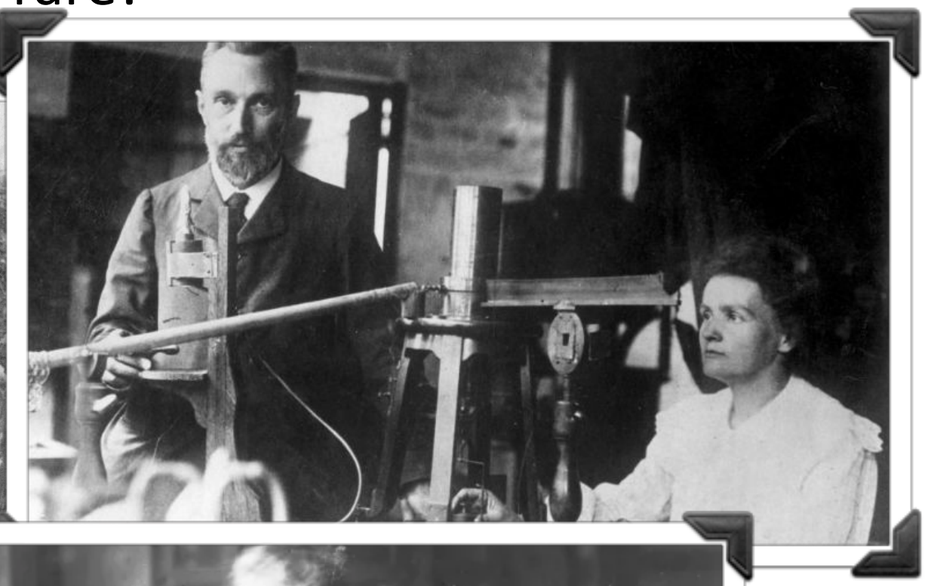
1898
Marie
Skodowska
Curie

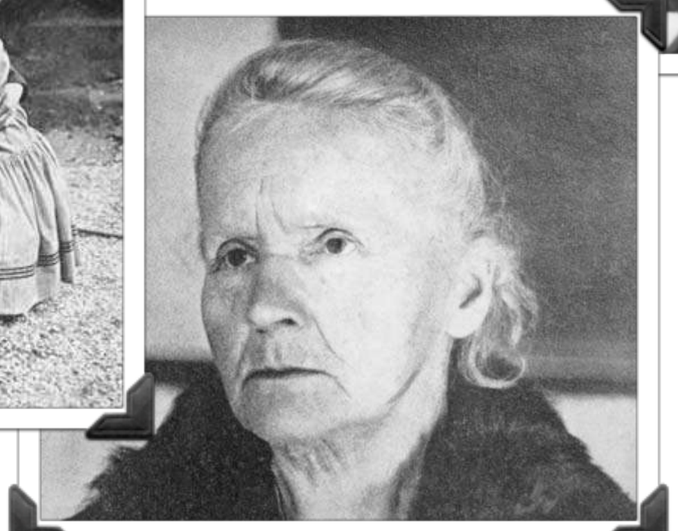
1857-1934

believe it or not

true-love stories in physics are rare!







2 labs

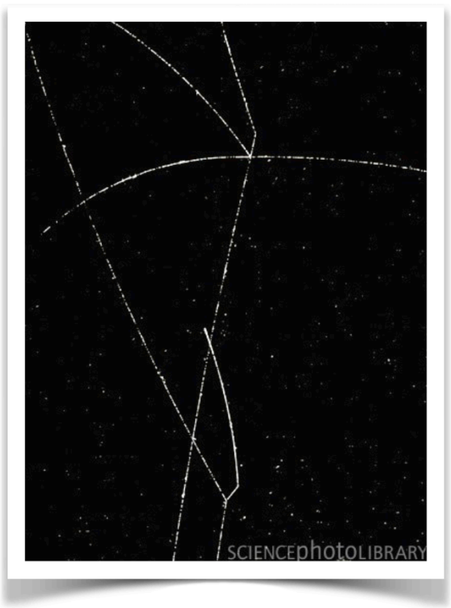
2 accelerators

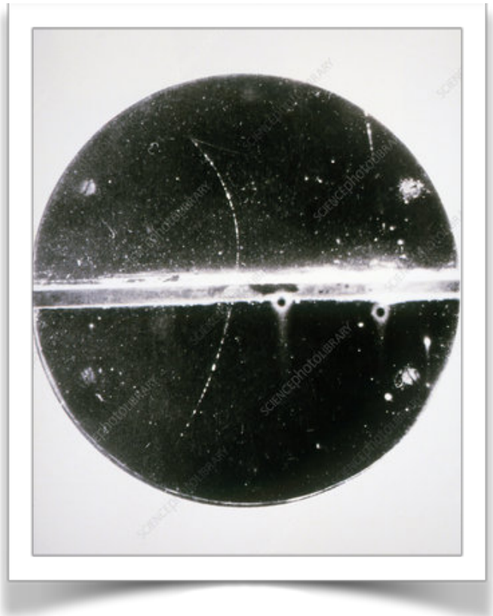
Fermilab in Batavia, IL

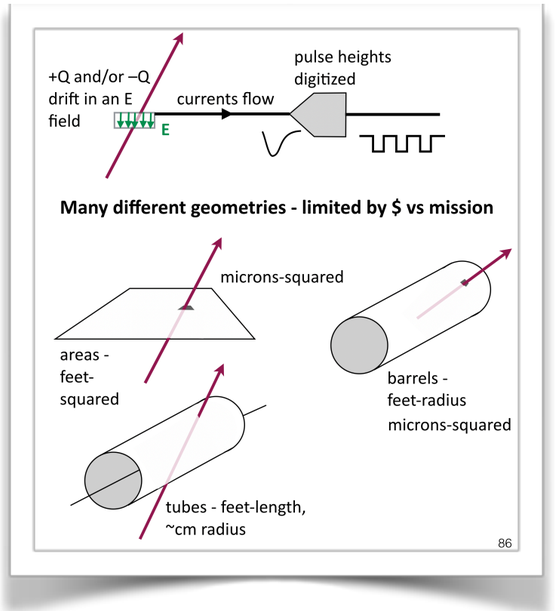
CERN in Geneva, Switzerland

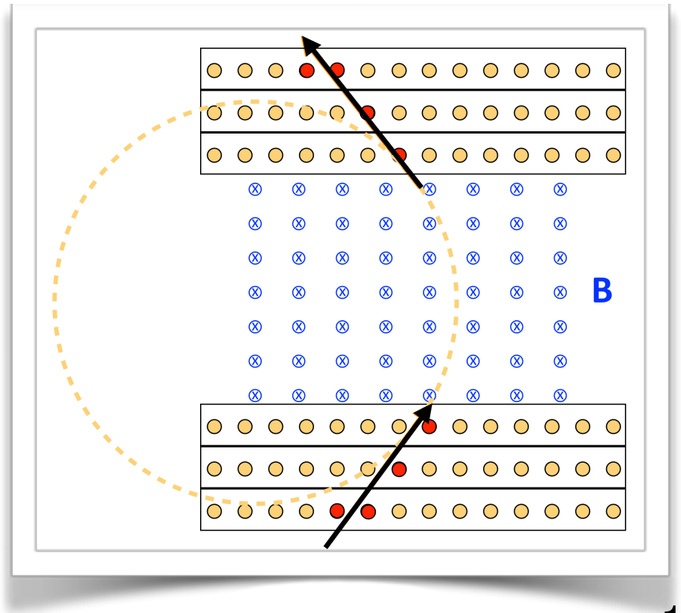
Tools of the trade

Particle Detectors

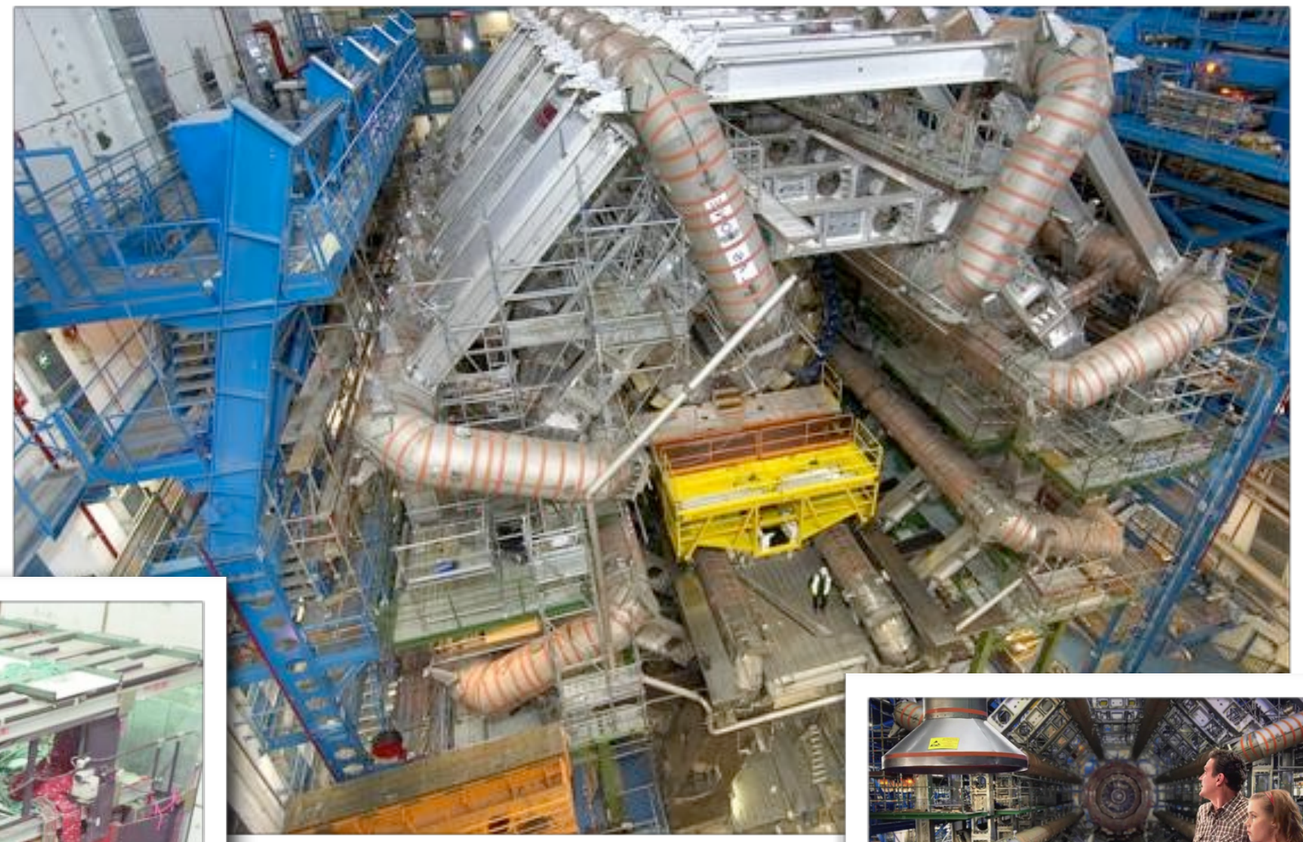


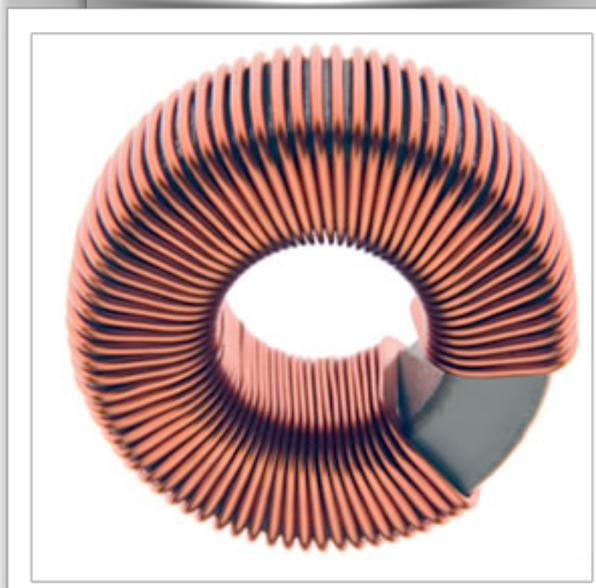






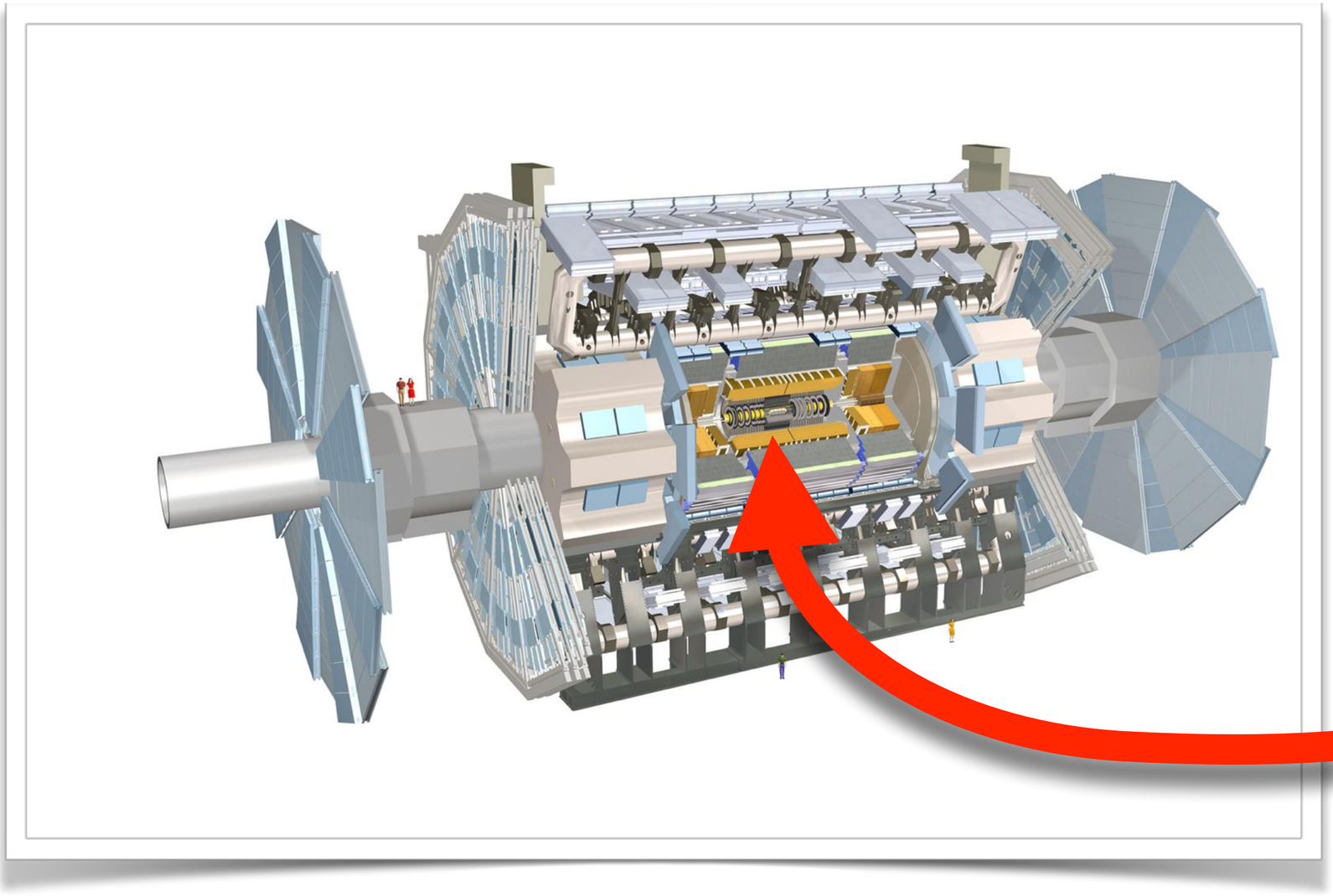
our experiment at Fermilab and CERN



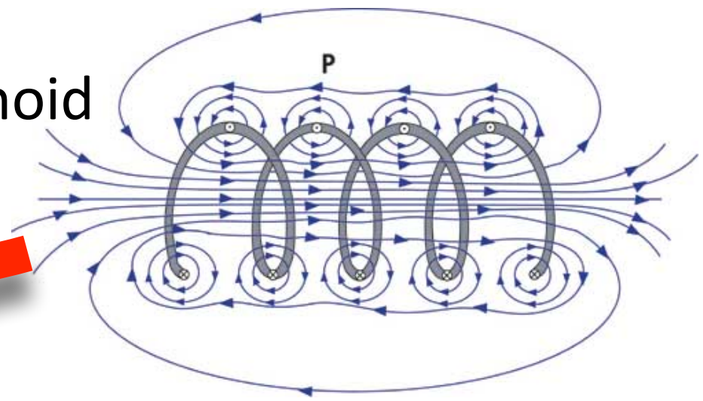


a toroid

ATLAS central detector



a solenoid



back to the weird

0

1887

Albert Michelson (1852-1931)

and

Edward Morley

The Nobel Prize in Physics 1907
Albert A. Michelson

Share this:

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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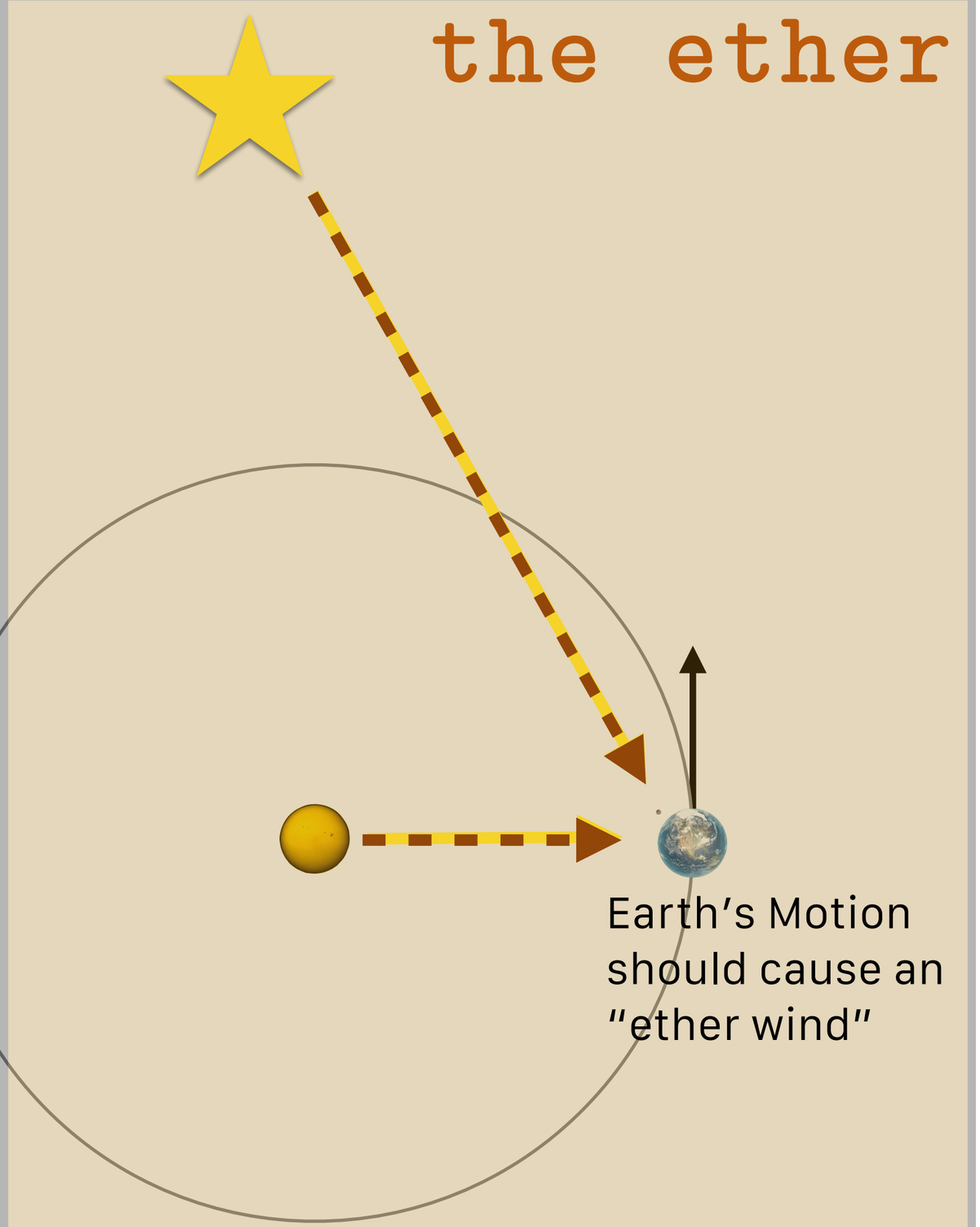
style: "The Nobel Prize in Physics 1907". *Nobelprize.org.* Nobel Media AB 2014. Web. 28
<http://www.nobelprize.org/nobel_prizes/physics/laureates/1907/>

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



Ether functioned as a 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 times depending on direction...upstream? downstream? across?

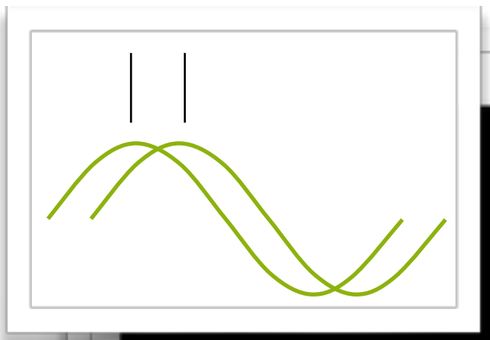
‘‘Michelson Morley Experiments’’

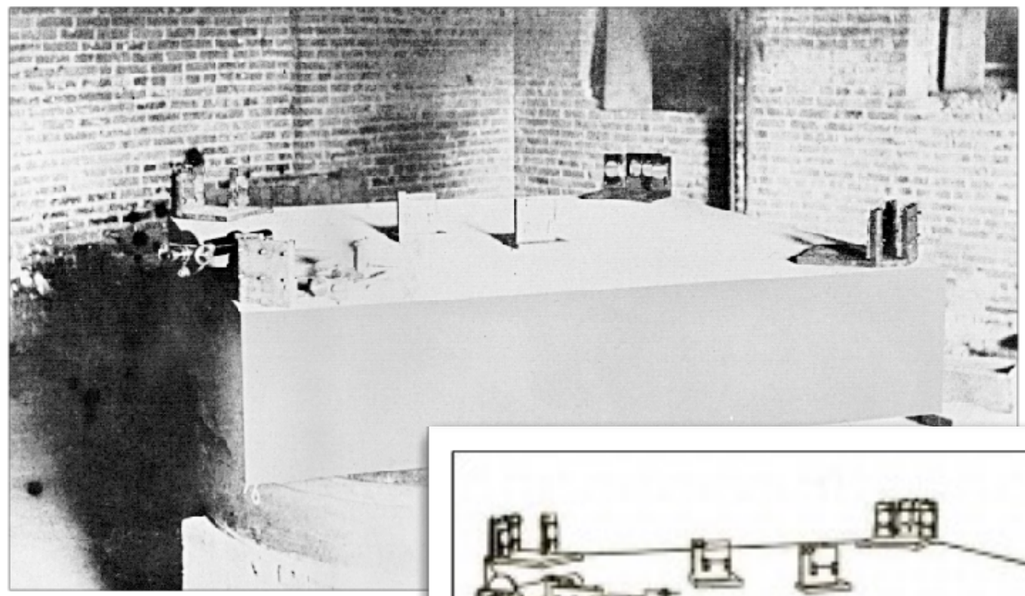
trying to measure the speed of Earth relative to Ether

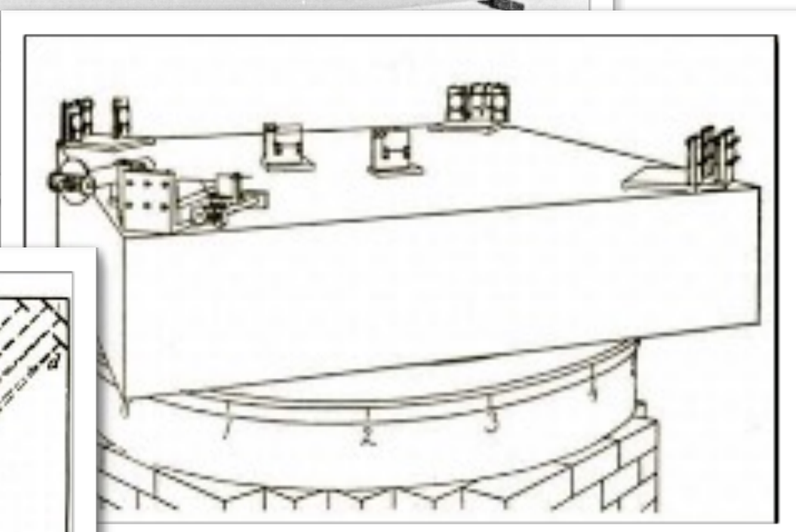
This technique was perfected by cowboy, Albert Michelson and eventually his sidekick, Edward Morley at Case Western Reserve in Cleveland between 1880 and 1888

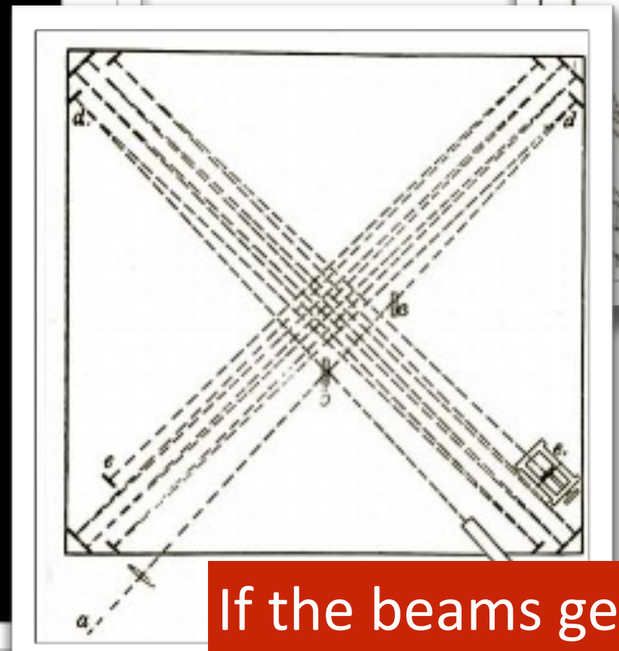
measure the fringes in light interfering from the two paths...then rotate the instrument 90 degrees - and do it again.

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





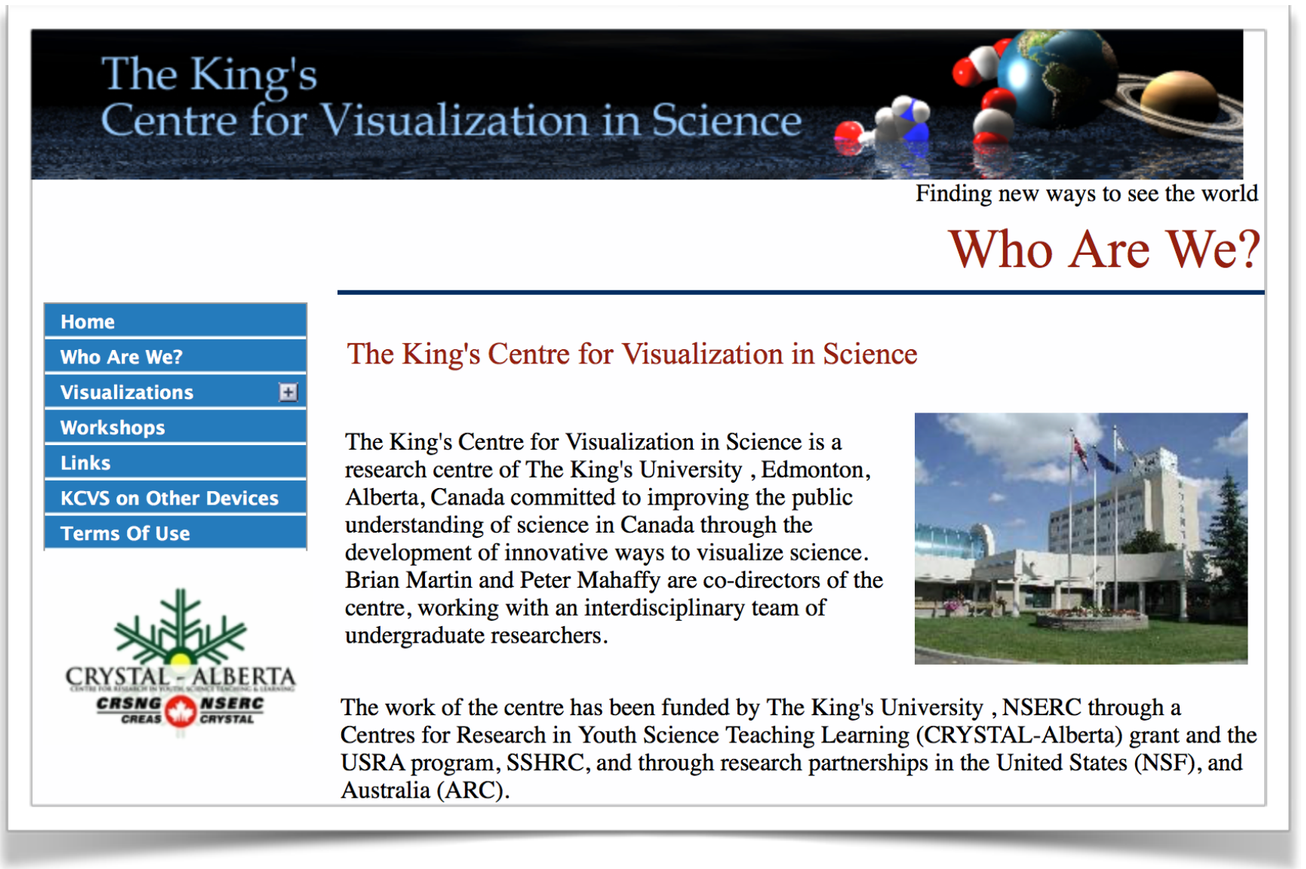




If the beams get back out of phase...one traveled through the ether differently from the other.

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.

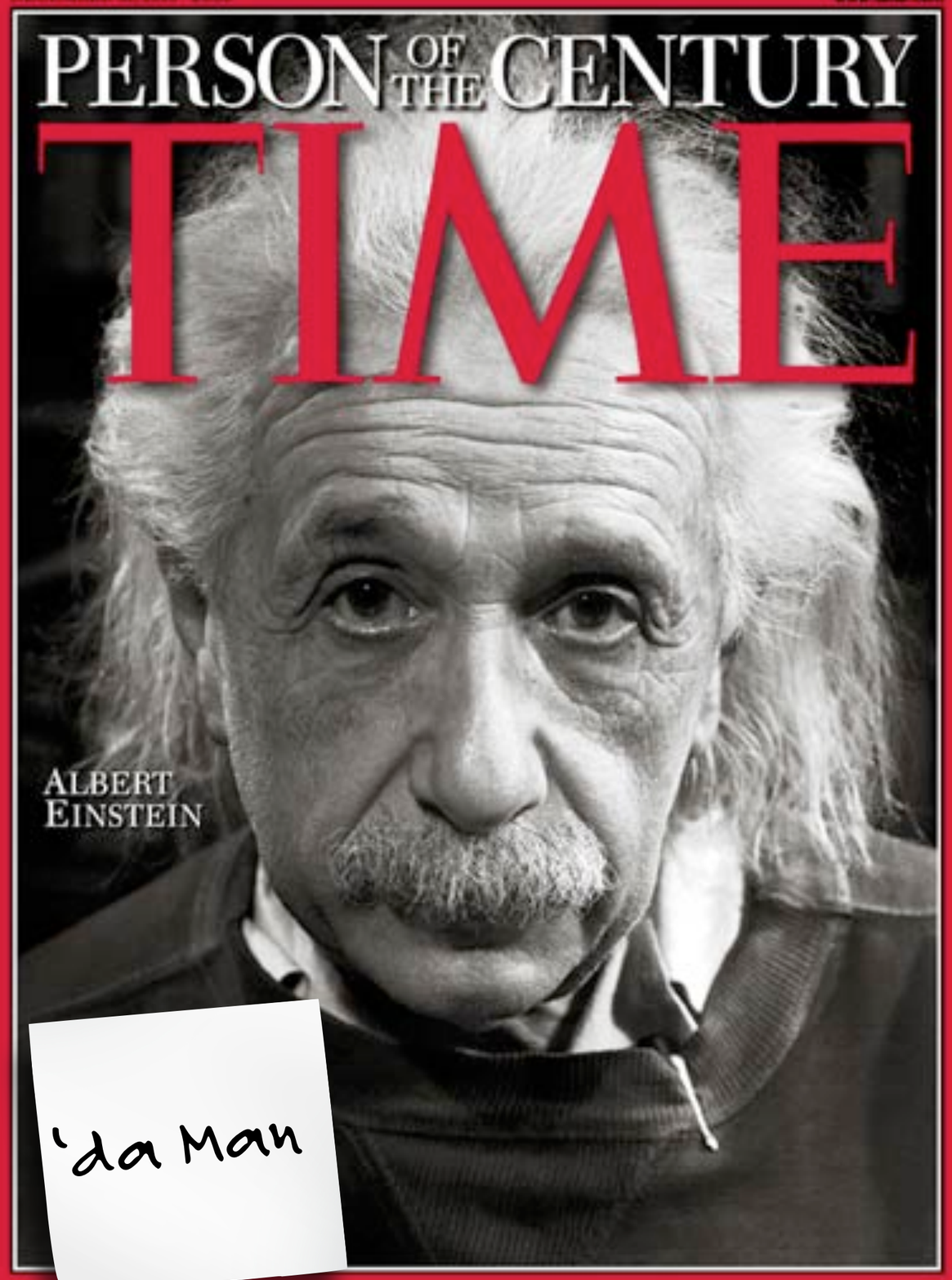
The earth did not appear to be moving through an Ether.
The question: did Einstein know of the MM experiment?
He always said “no.”

DECEMBER 31, 1999 $4.95

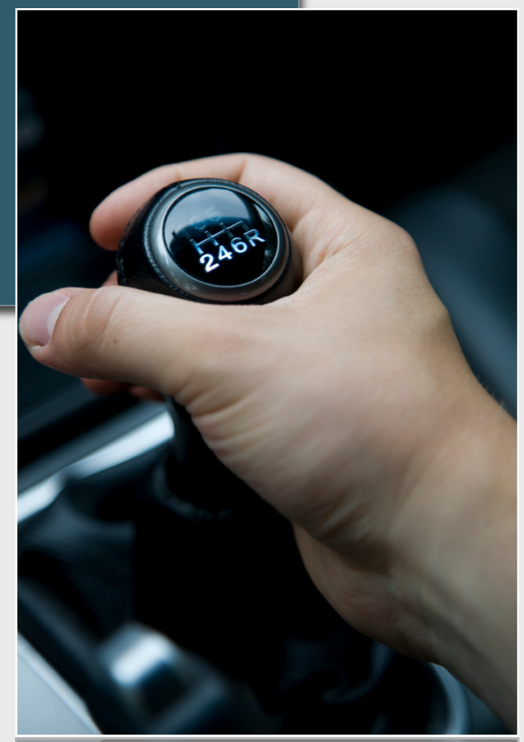
www.time.com

PERSON OF THE CENTURY

TIME



Special Relativity



In the lecture slides directory:

Hobson10_Relativity.pdf is a good introduction

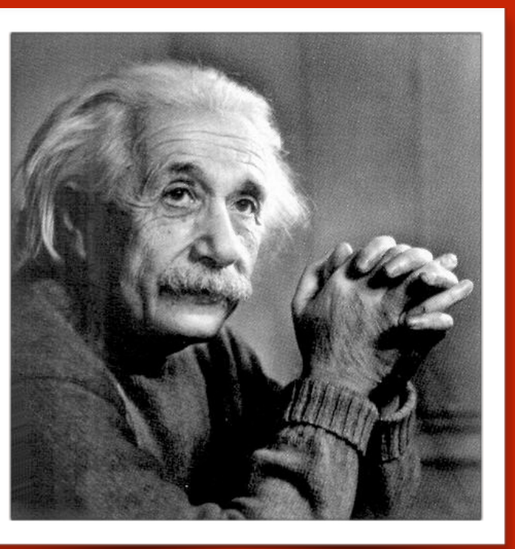
Also, chapter 2 in Oerter is good.


WHAT DO WE WANT?
TIME TRAVEL
WHEN DO WE WANT IT ?
IT'S IRRELEVANT!

1905

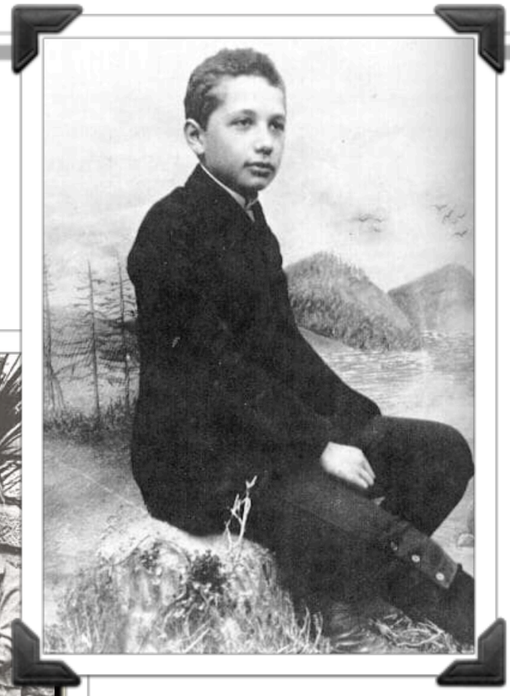
Albert Einstein

1879 – 1955



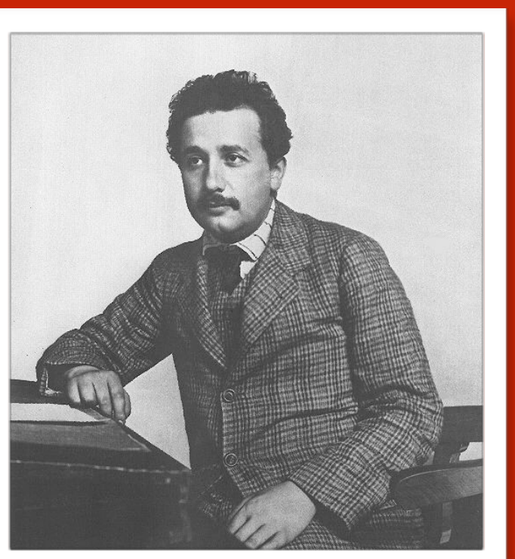
> Oh, that Einstein, always skipping lectures... I certainly never would have thought he could do it.

former professor
Hermann Minkowski



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

} next week

This? ...a pretty good year.

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

General Relativistic Cosmology

} just before break, and forever after!

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

1902: 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

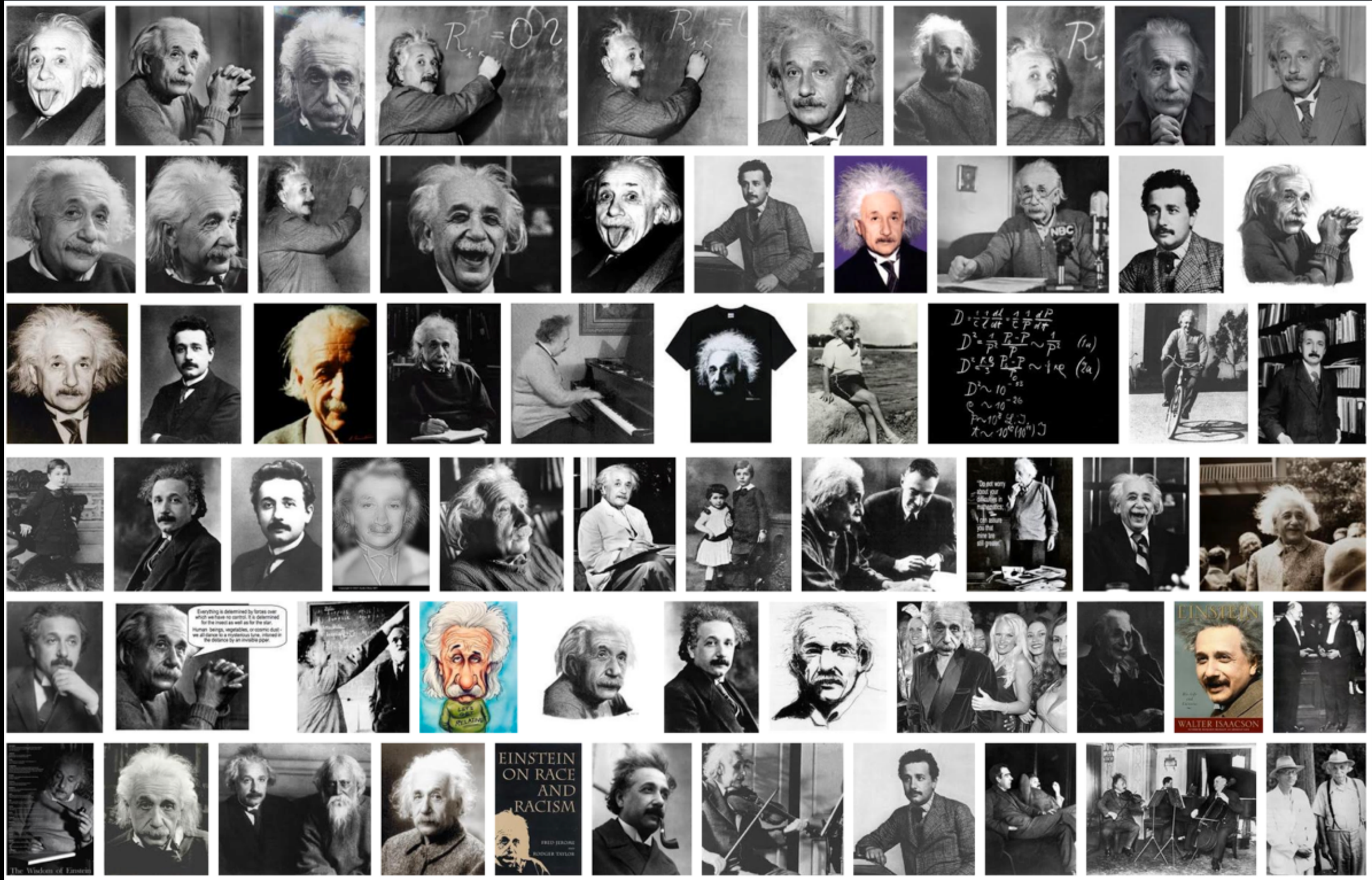
1907 University Bern? nope

1906 Doctorate

1909 Professor

1912 Professor
work with Grossman

1913 1st GR paper

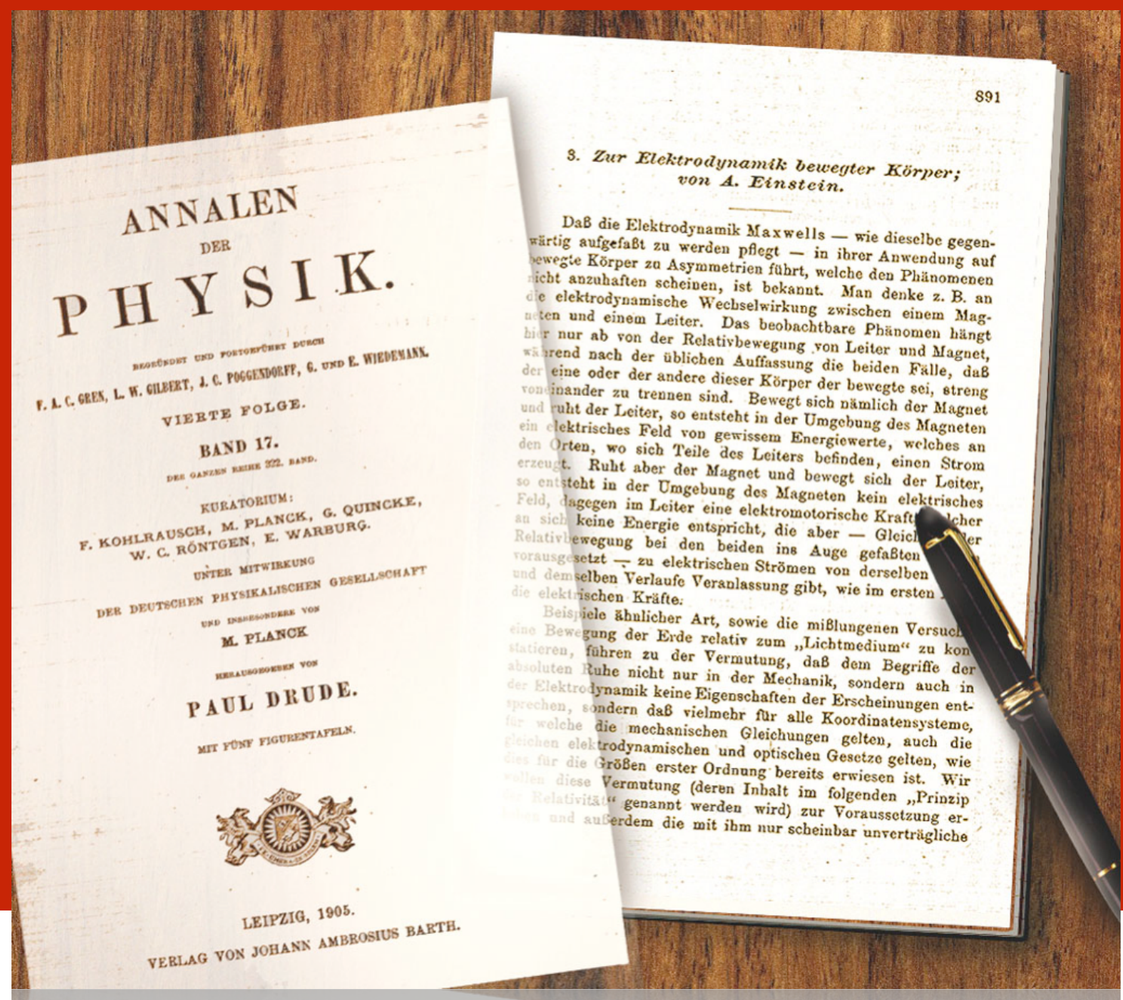

Everything is determined by forces over which we have no control. It is determined for the insect as well as for the star.
Human beings, vegetables, or cosmic dust - we all dance to a mysterious tune, intoned in the distance by an invisible piper.
EINSTEIN ON RACE AND RACISM
FRED JEROME
ROGER TAYLOR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

https://www.youtube.com/watch?v=0amFZCFfQkg

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?

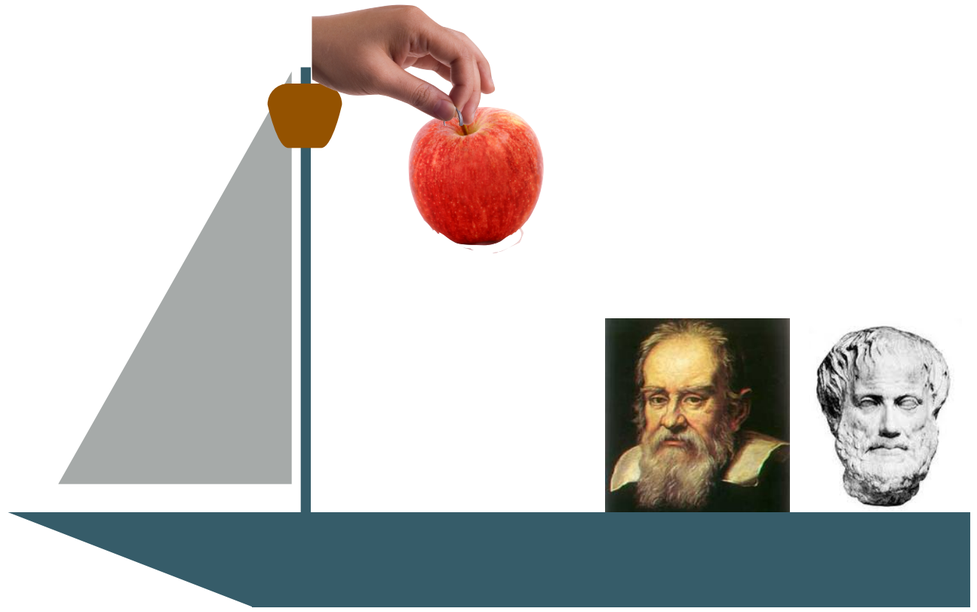
frames of reference

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
Same on shore

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."

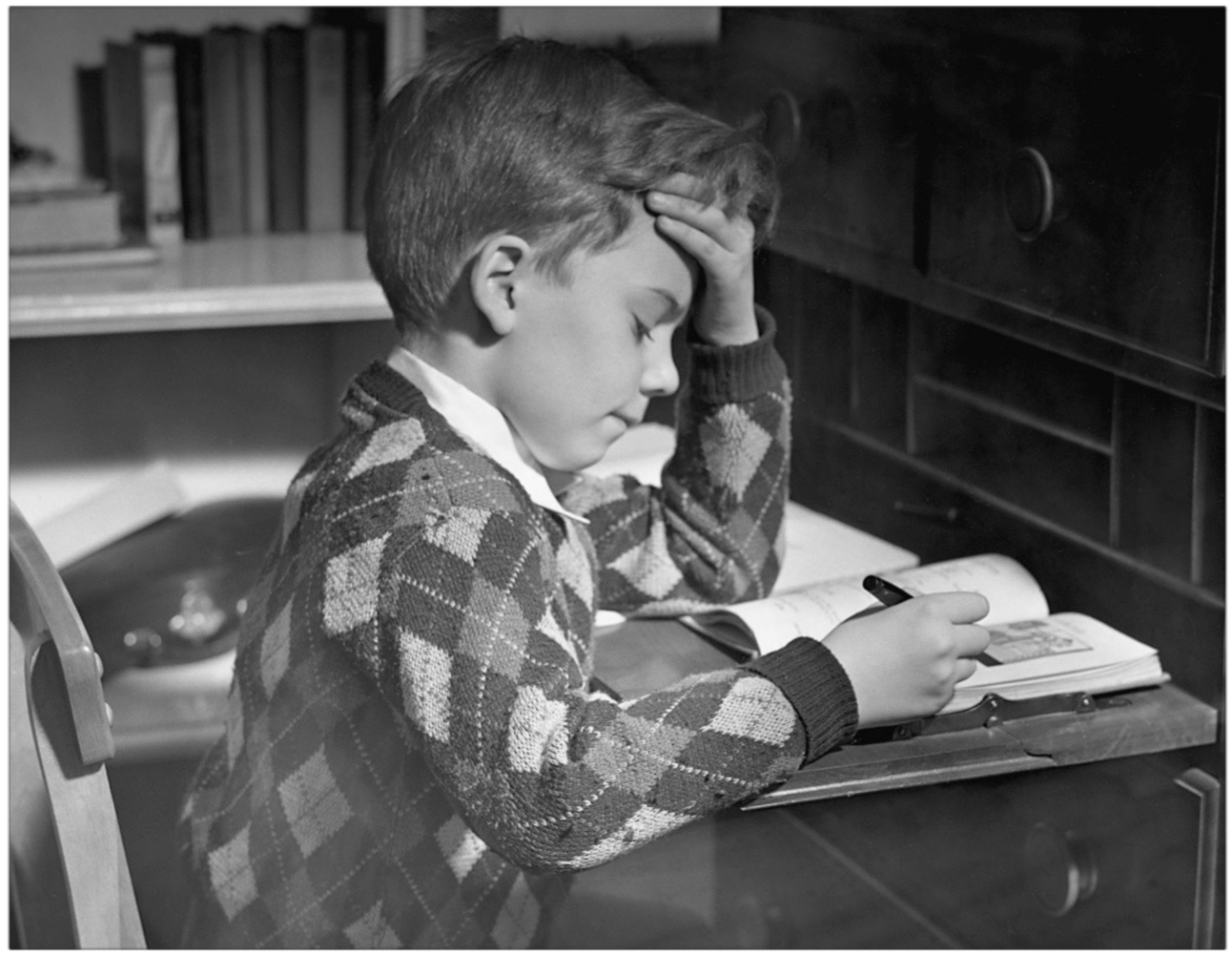
let’s think

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 – the "proper 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

likewise, a non-inertial frame is

um…a frame that's not inertial?

Yes, where constant motion is not observed – acceleration is at work

….and where there is acceleration there is a _____force_____

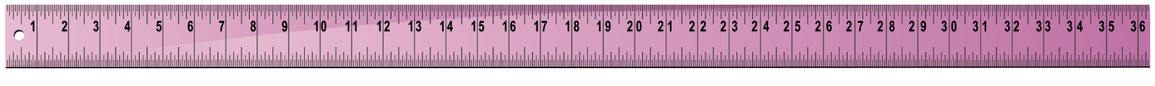
for measurement of motion, all you need are

clocks and rulers.

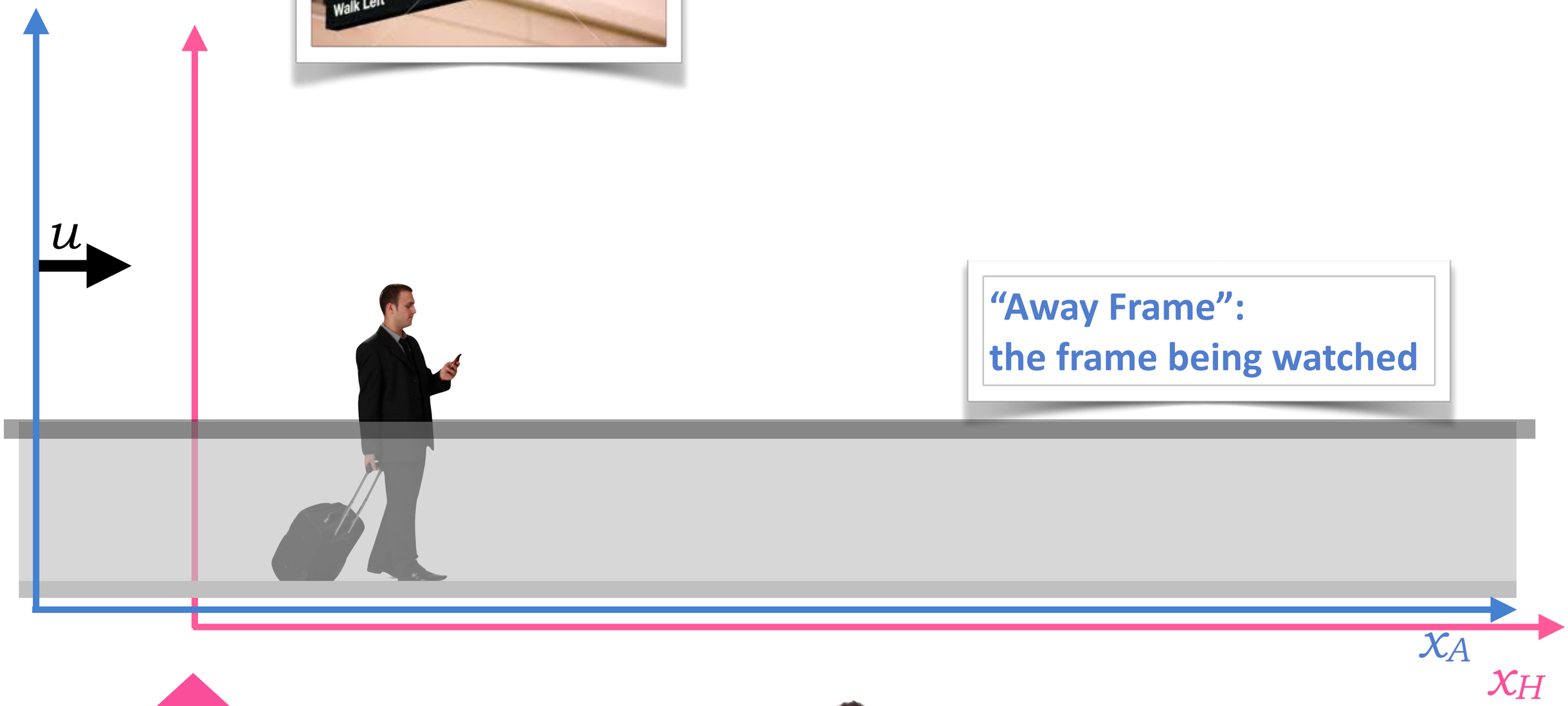
that might move relative to one another

AWAY frame

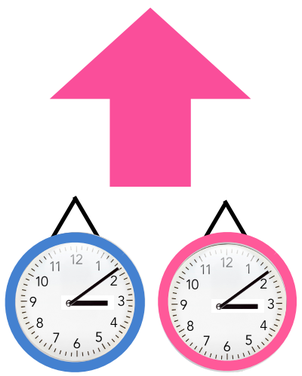
HOME frame



the airport



"Away Frame":
the frame being watched



= 0

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

"Home Frame":
watching a moving frame

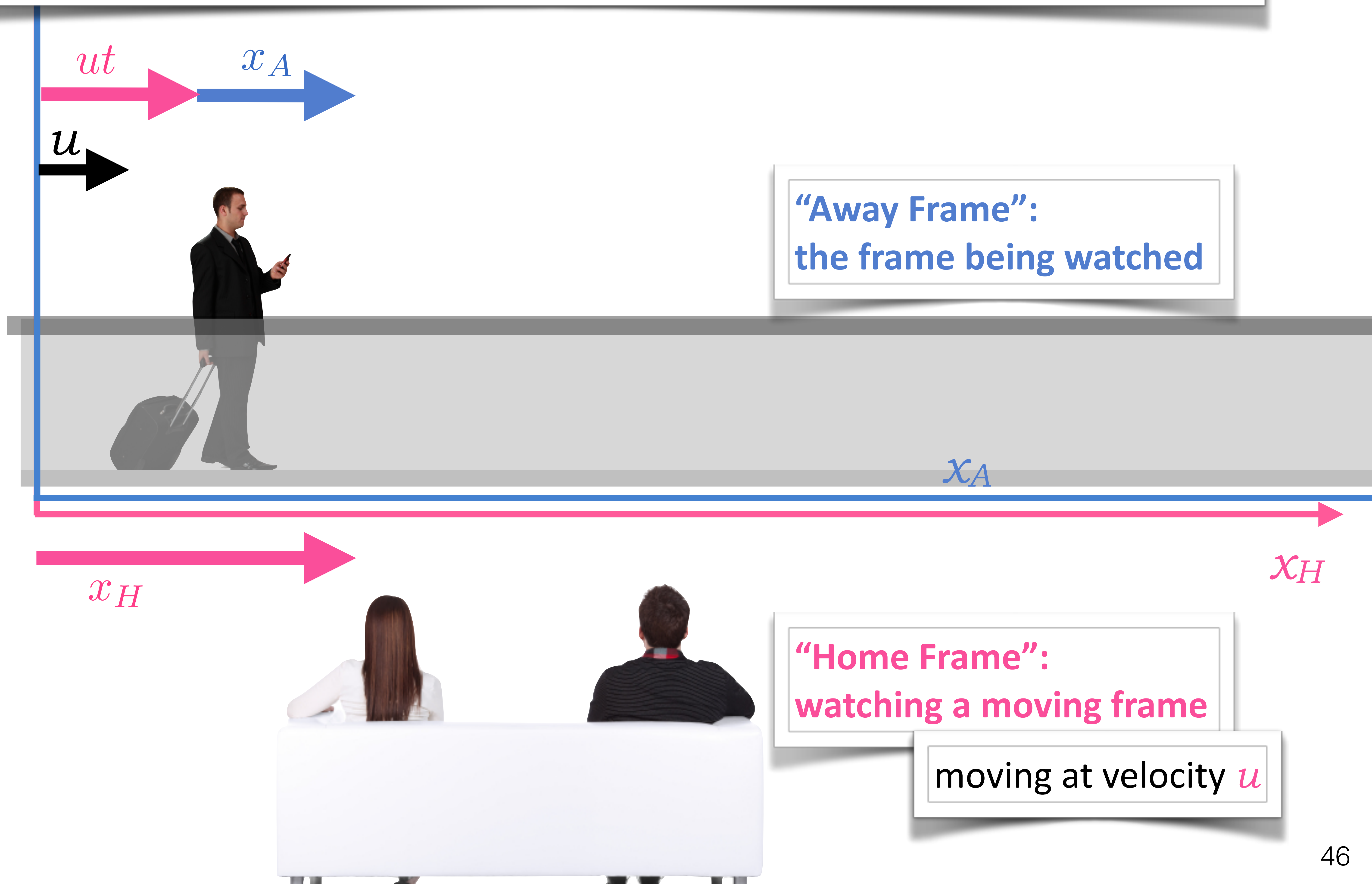
moving at velocity u

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

$d(t)_H$

AIRPORT="Home"

x_A

=

u

SIDEWALK="Away"

move the sidewalk
paper edge to here

x_A

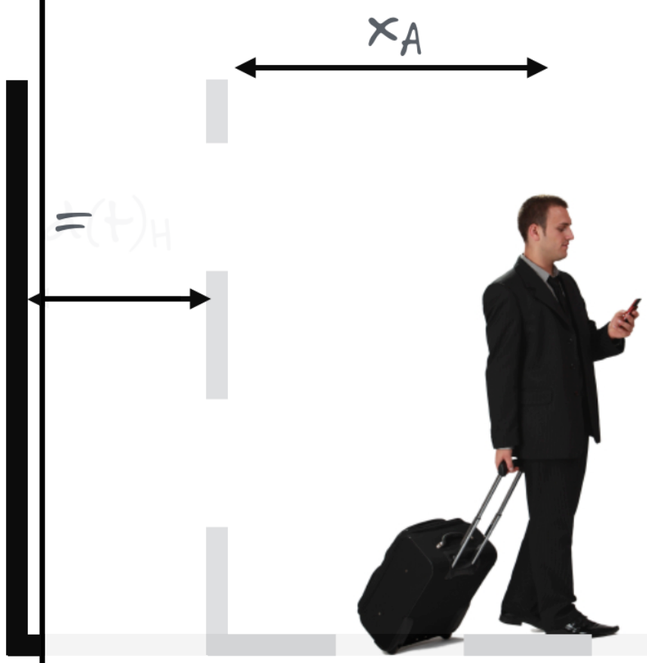
$=$ $d(t)_H$

u

SIDEWALK="Away"

AIRPORT="Home"

move the sidewalk
paper edge to here



SIDEWALK="Away"
AIRPORT="Home"

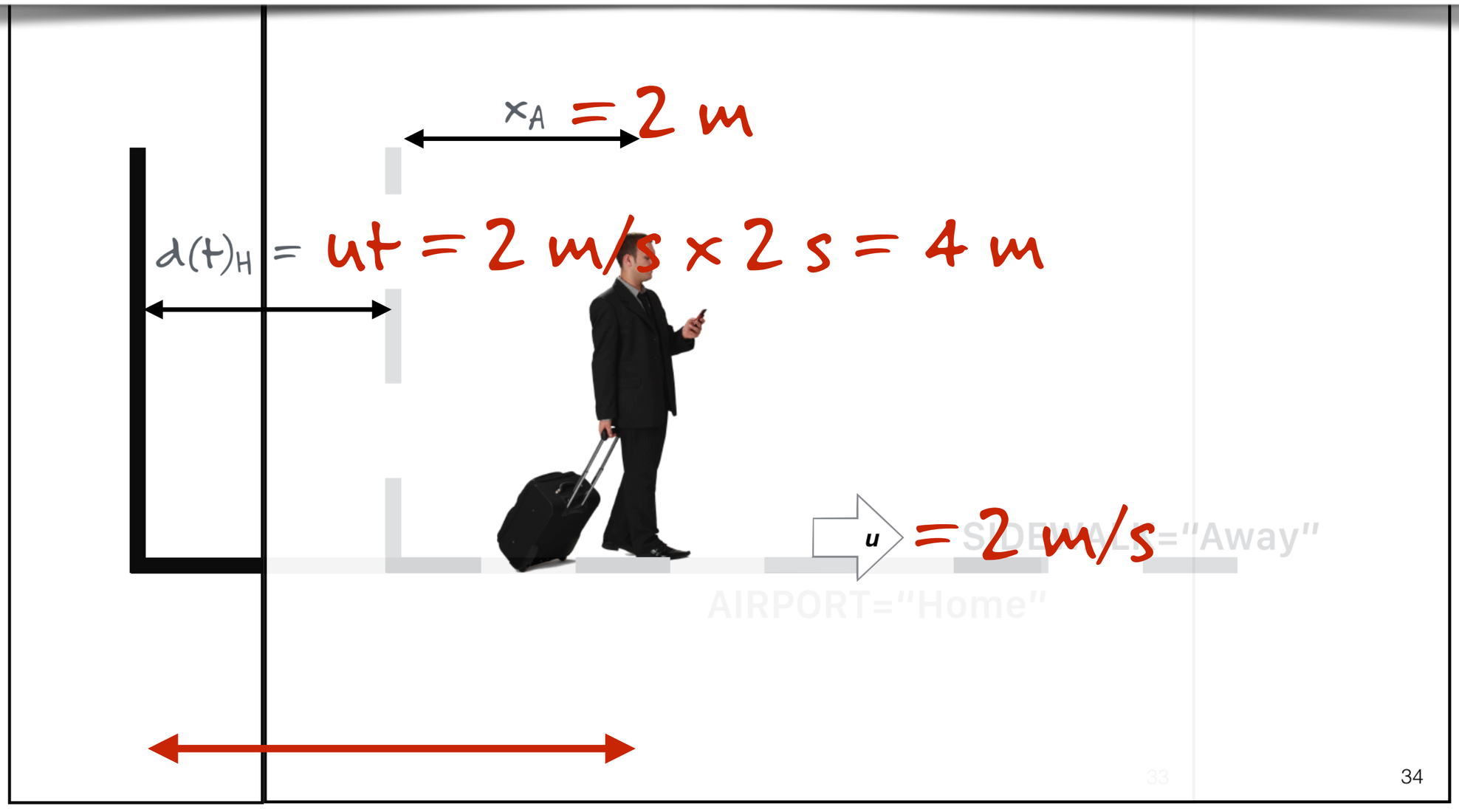
sidewalk velocity relative to concourse: $u = 2\ \mathrm{m/s}$

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?

6 m



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

‘‘coordinate transformation’’

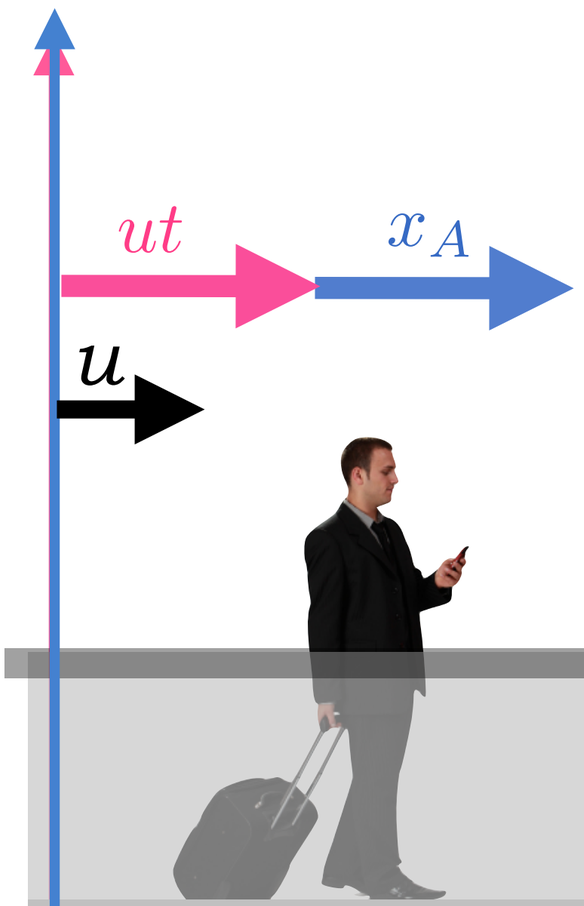
take the coordinates in one Frame and
write them in a different Frame

here: Home and Away

the airport

"Galilean Transformation"

$$x_H = x_A + ut$$



"Away Frame":
the frame being watched

"Home Frame":
watching a moving frame

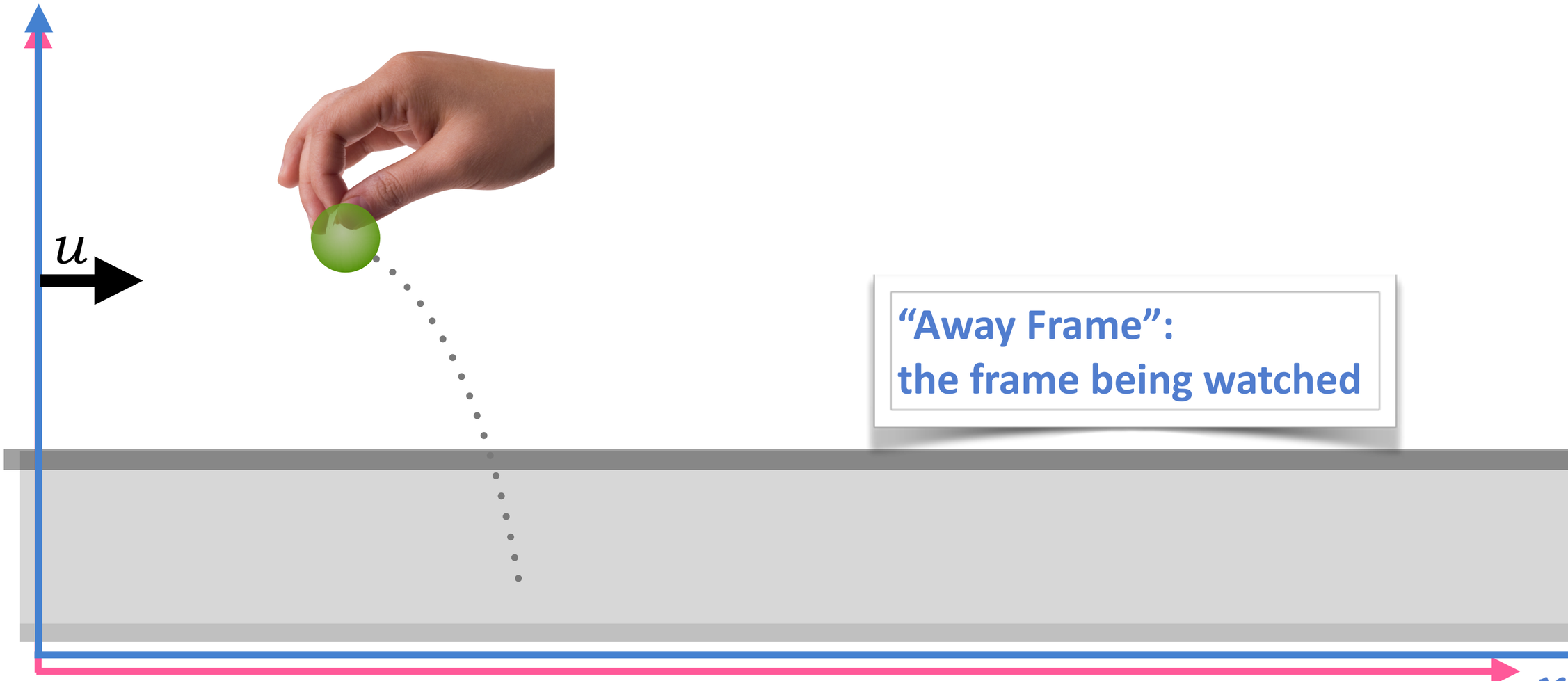
moving at velocity u

Remember, what Galileo said was:

the physics doesn’t care

about constant-velocity motion

view from the concourse:



"Away Frame":
the frame being watched

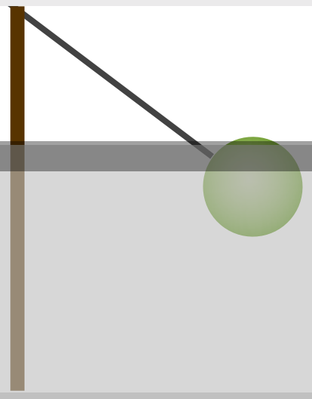
"Home Frame":
watching a moving frame

moving at velocity u

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

Says:



u

x_H

“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 $t_H \rightarrow t_A$

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

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?

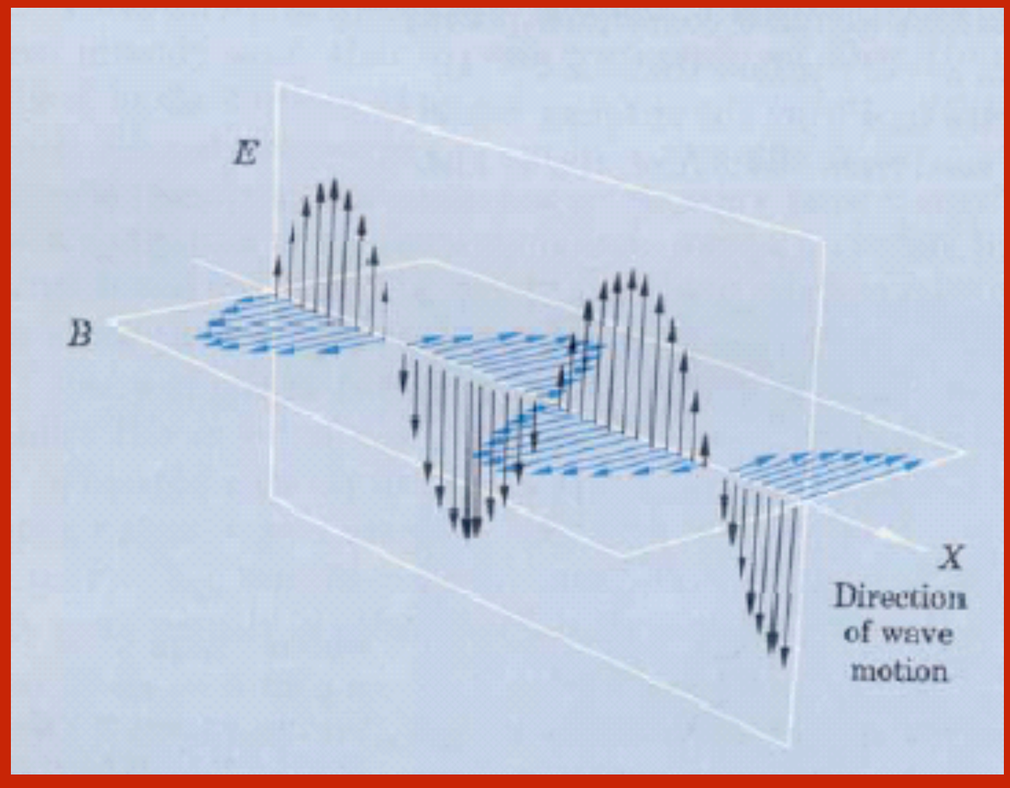
Einstein always asked

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”…can there be light?

in fact

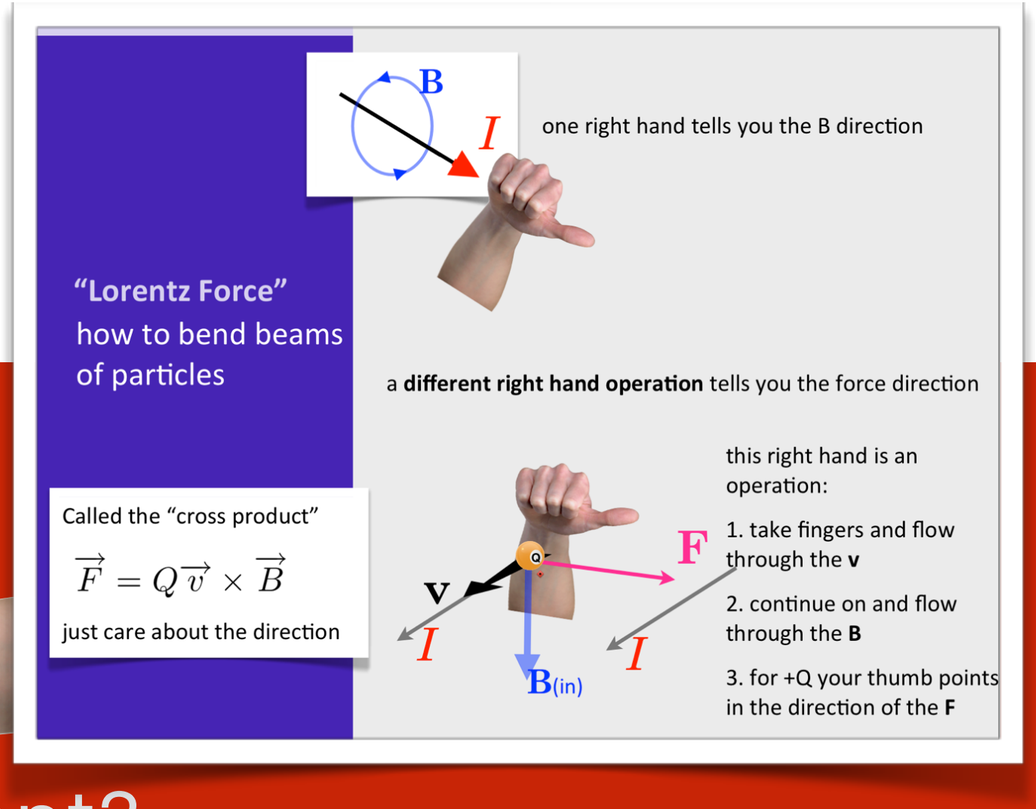
the faster in space you would travel

time would appear to stop

a light beam from the clock could not keep up

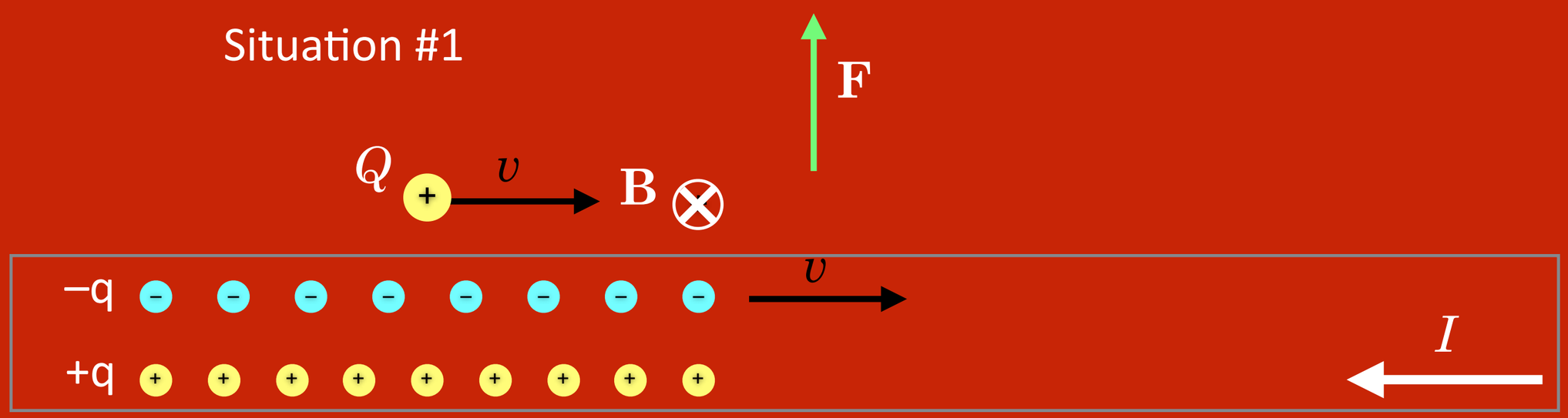
The famous clock tower in Bern (Zytglogge), Switzerland that Einstein mused about

a simple question

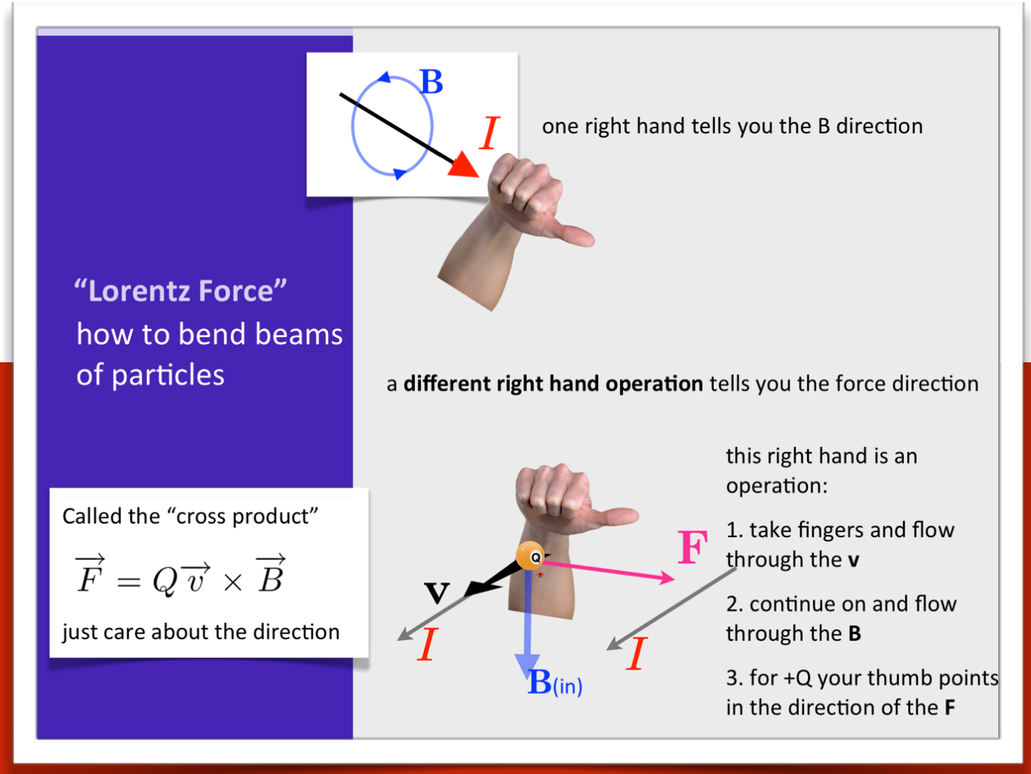


how about a charge next to a current?

Situation #1

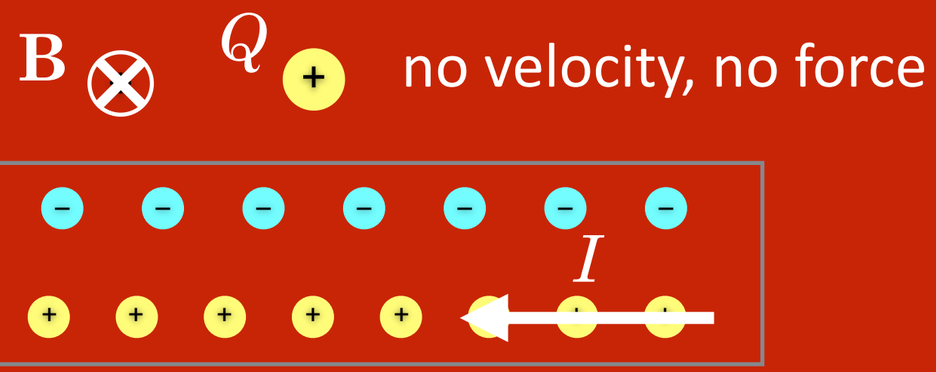


a simple question



how about a charge next to a current?

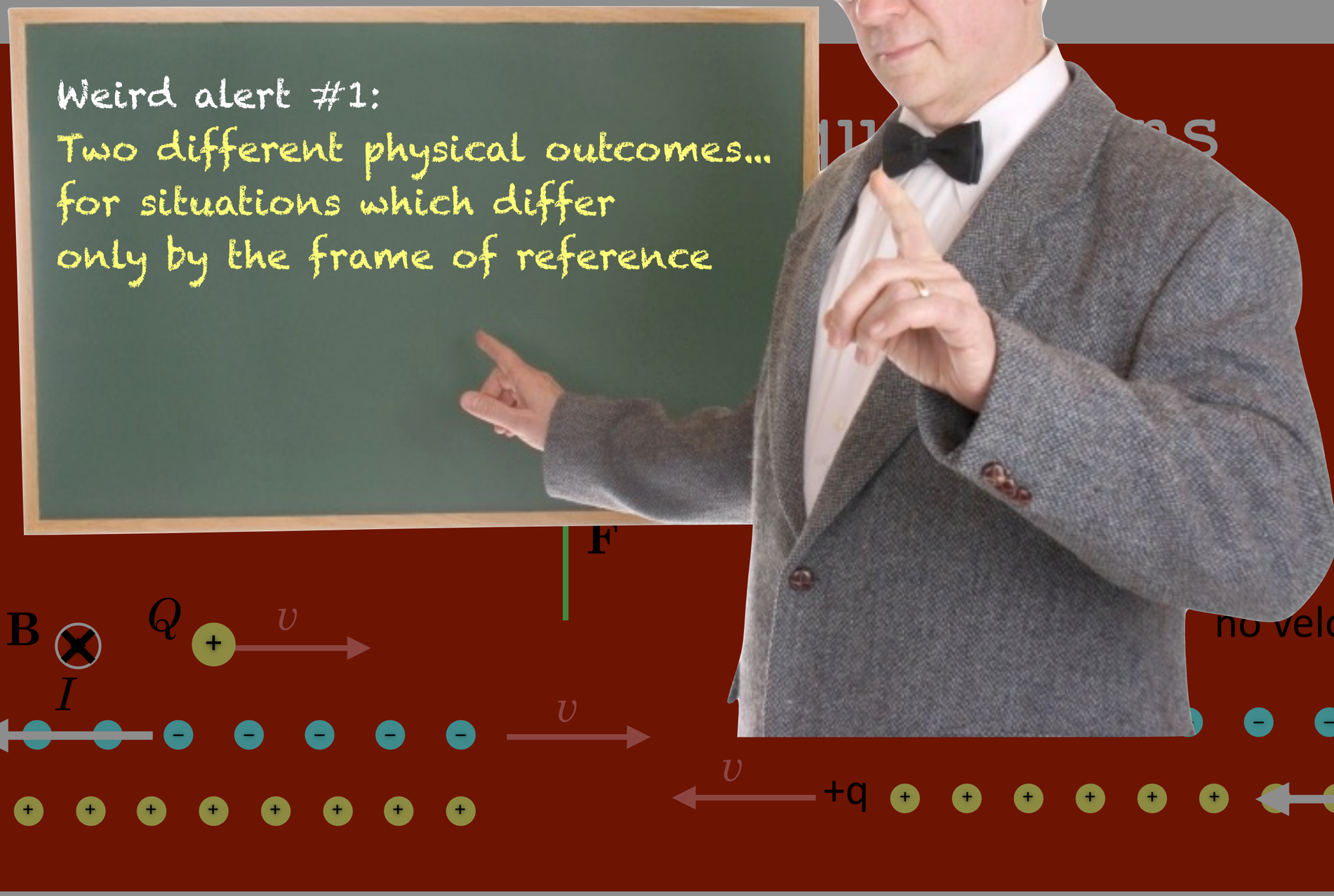
Situation #2



These situations differ only in the reference frame...

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

hold the phone.



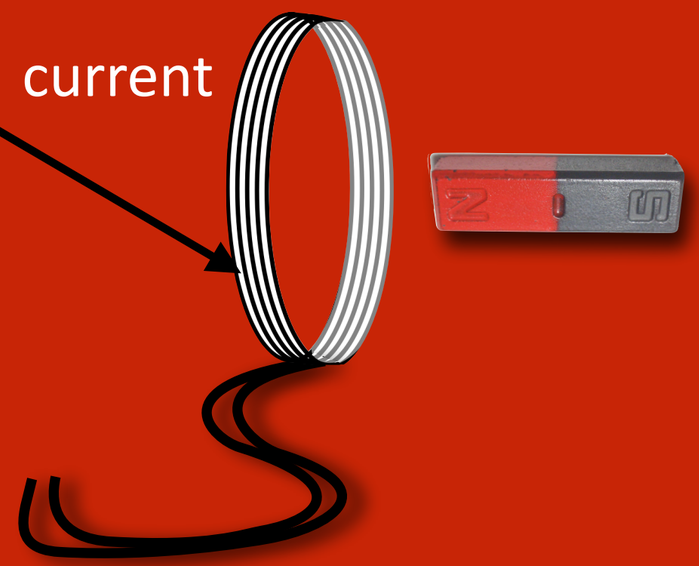
These situations differ only in the reference frame...

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

The changing magnetic field creates an electric field in wire

That produces a force on electrons

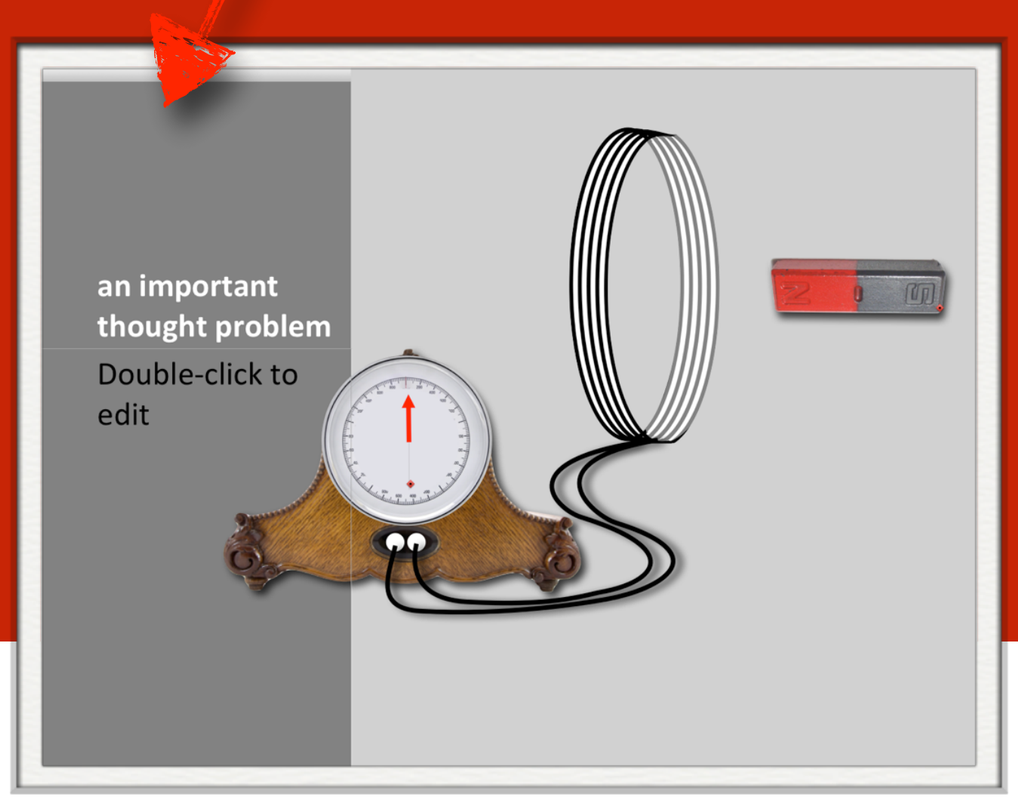
which moves them in the wire – **which is a current**

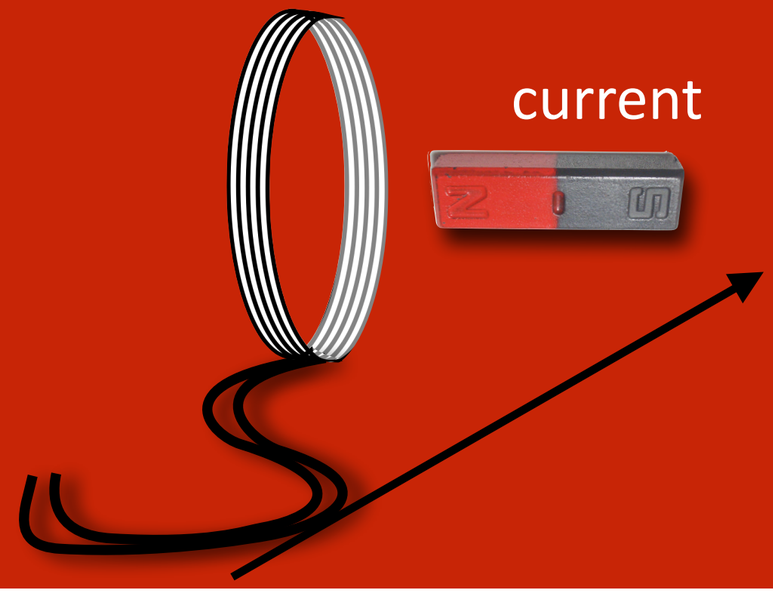


REMEMBER?

here's another one

my favorite coil-magnet





Magnetic field is constant – no electric fields

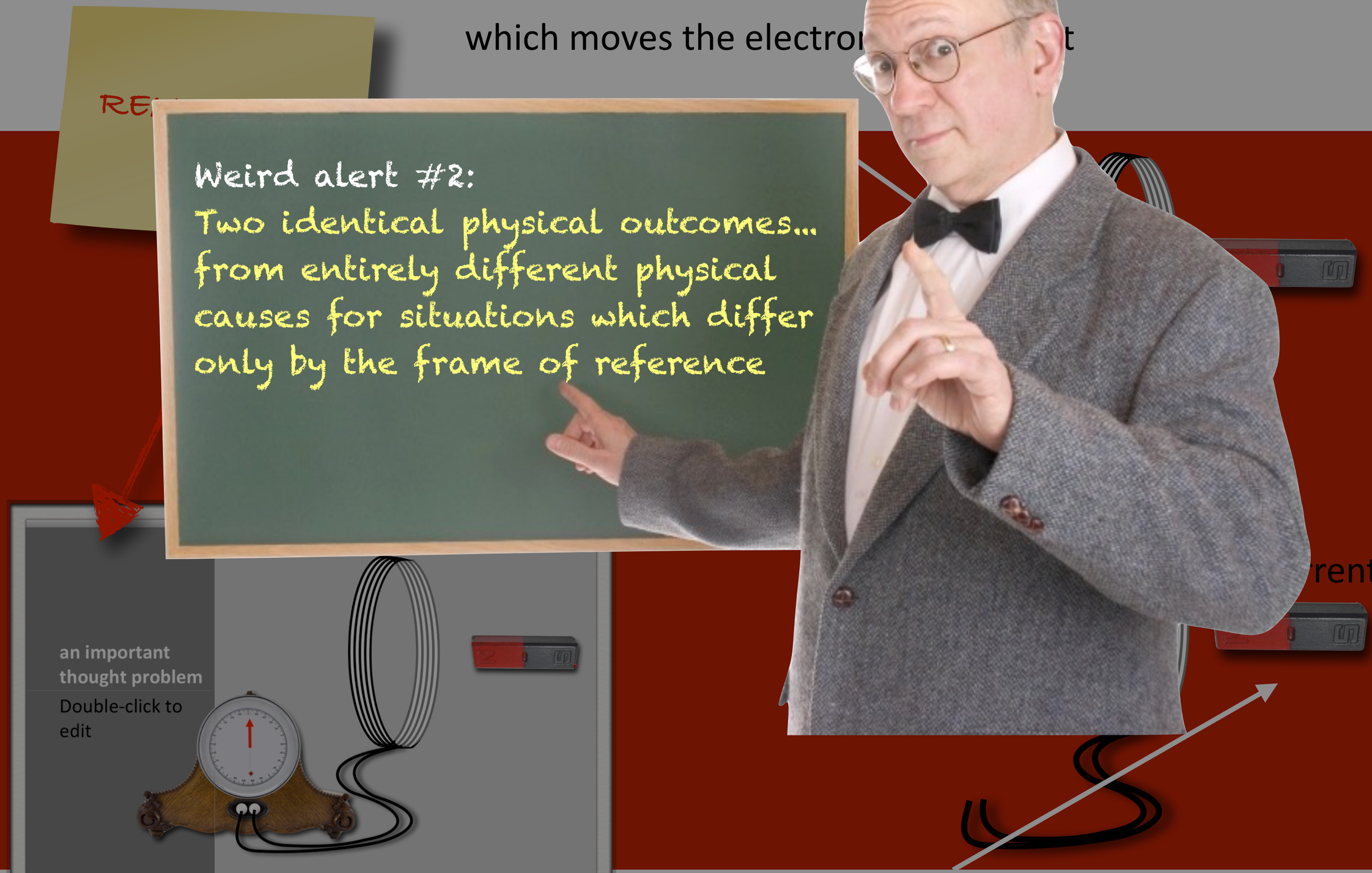
The electrons in the wire have a velocity

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



rent

Magnetic field is constant – no electric fields

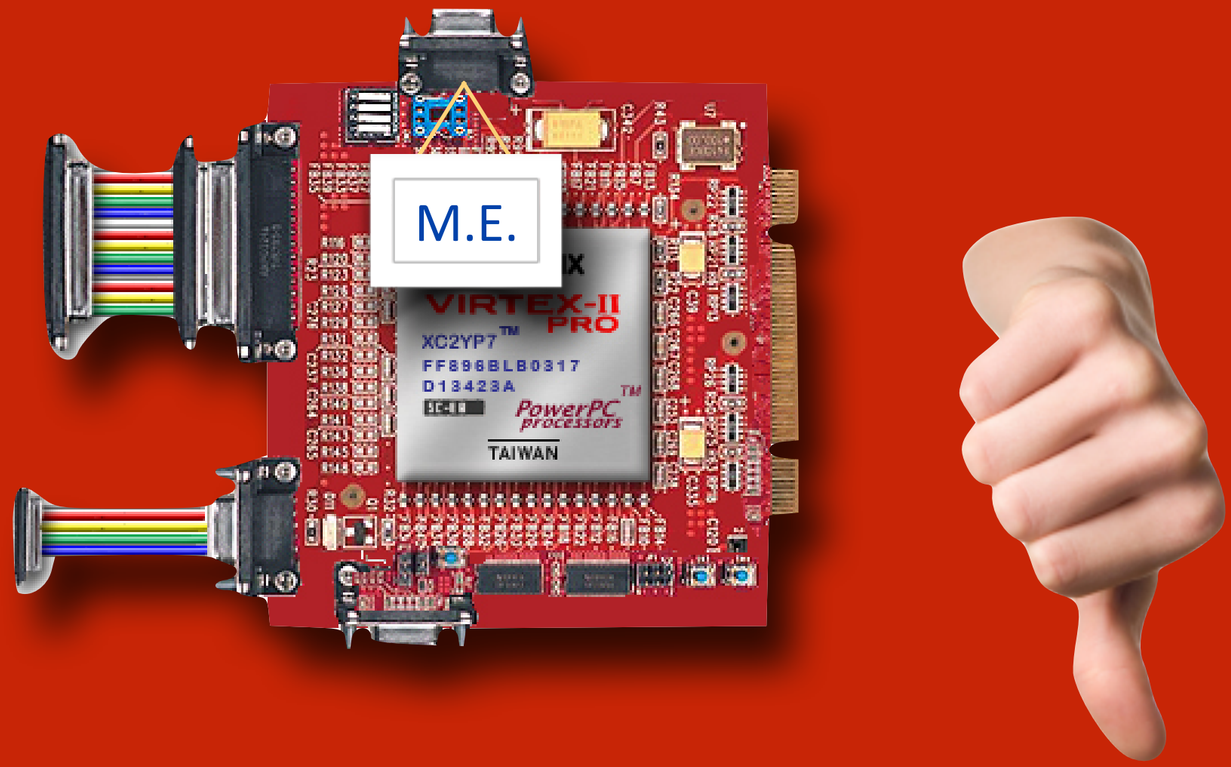
The electrons in the wire have a velocity

That produces a force on them – a current

so Maxwell's Equations

seem to fail between

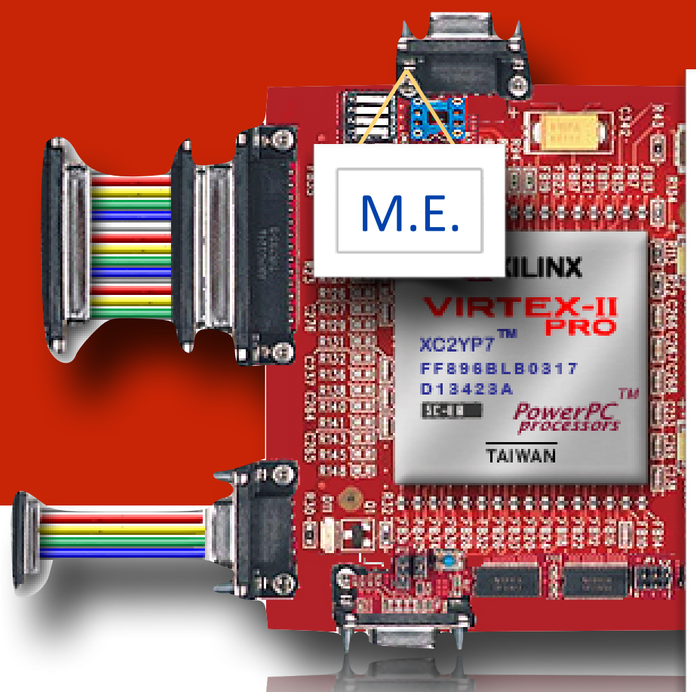
relatively moving inertial frames



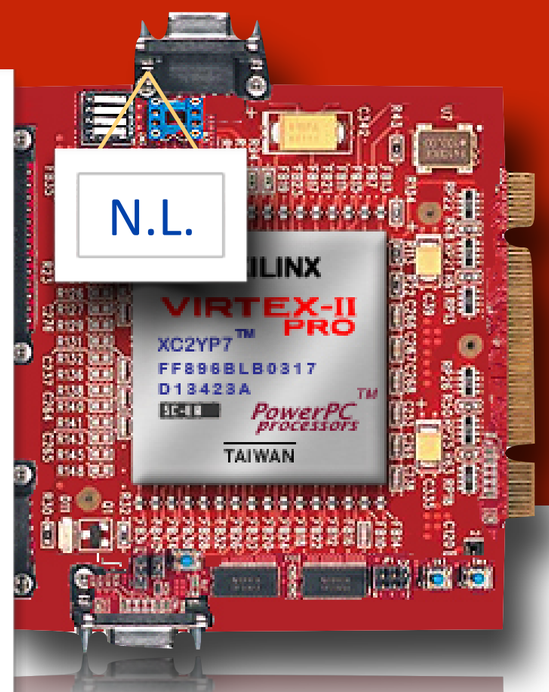
this is crazy! the two models of the world differ

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

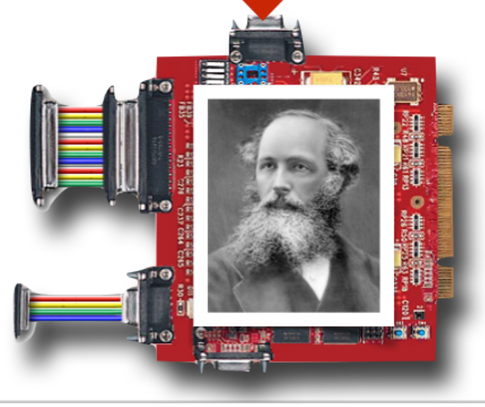
Look how the equations are symmetric: E ↔ B

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

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

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

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



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

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

in 1905 he proposed that c is special

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

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