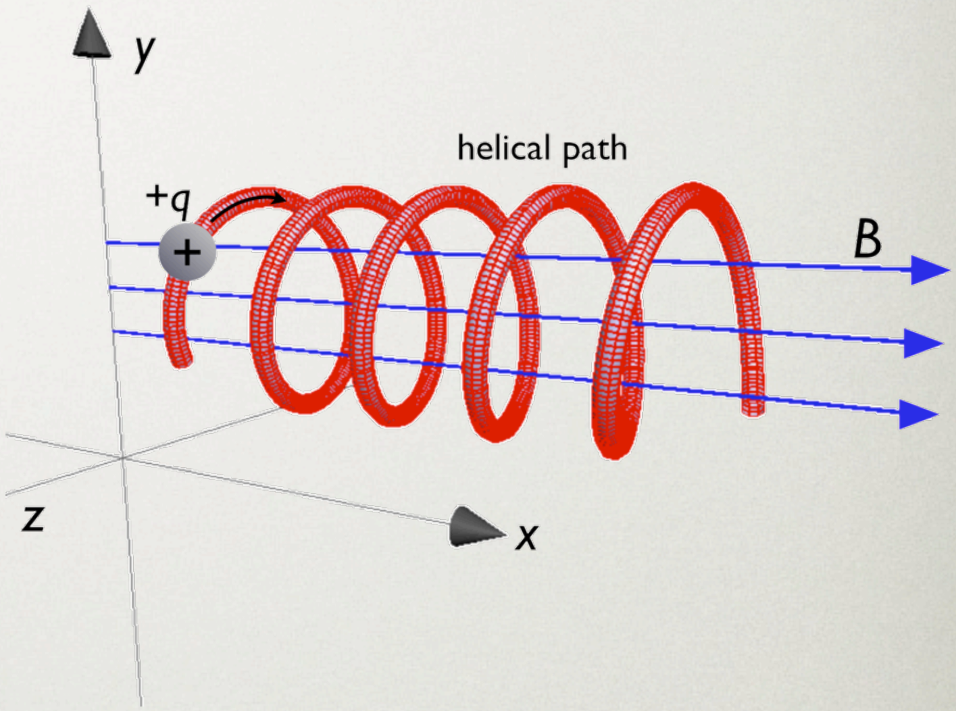
Physics 102

Dr. LeClair

Official things

Lecture:

- 203 Gallalee
- every day!



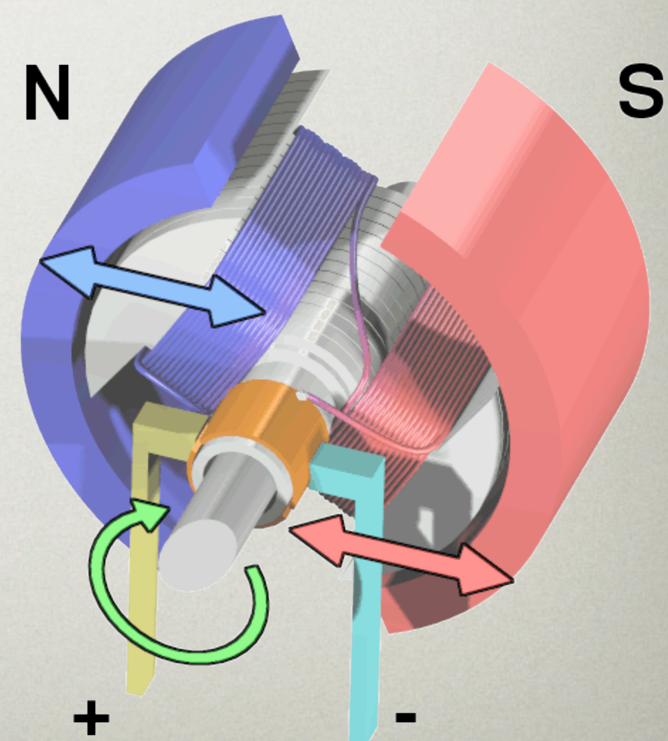
Lab:

- 329 Gallalee
- M-W-Th **~3 hr block**
- will not usually need whole 3 hours

NO lab today

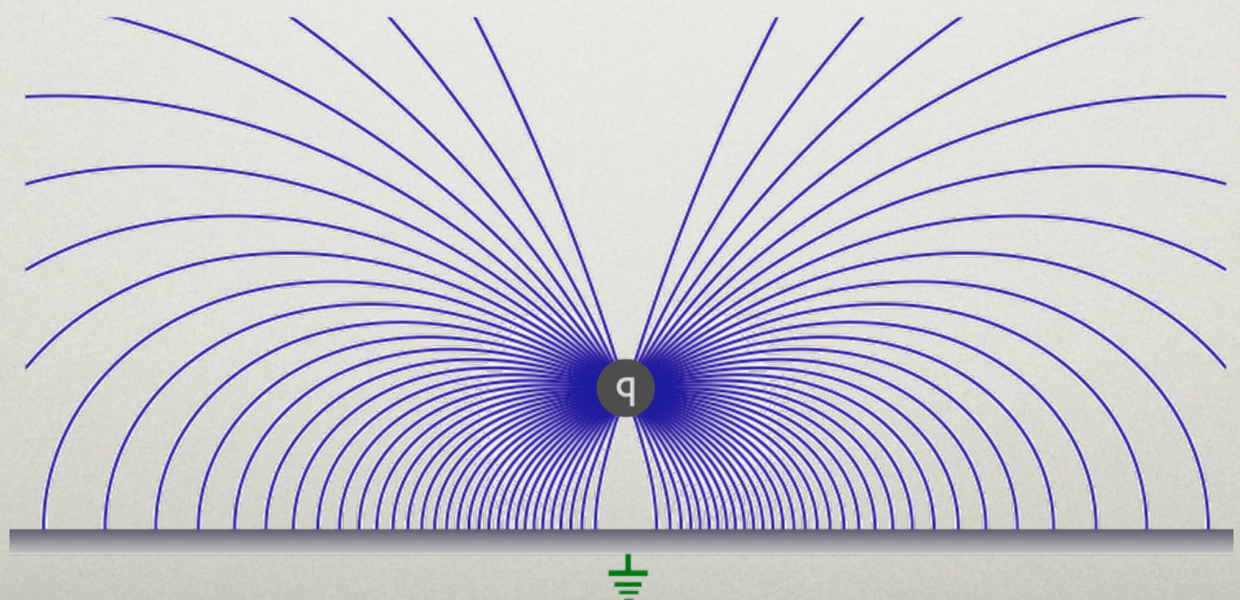
OFFICIAL THINGS

- Dr. Patrick LeClair
  - leclair.homework@gmail.com
  - office: 323 Gallalee / 2050 Bevill
  - lab: 1053 Bevill
- Office hours:
  - *1-1:30pm in Gallalee*
  - *4:30-5:30pm in Bevill*
- *other times by appointment*



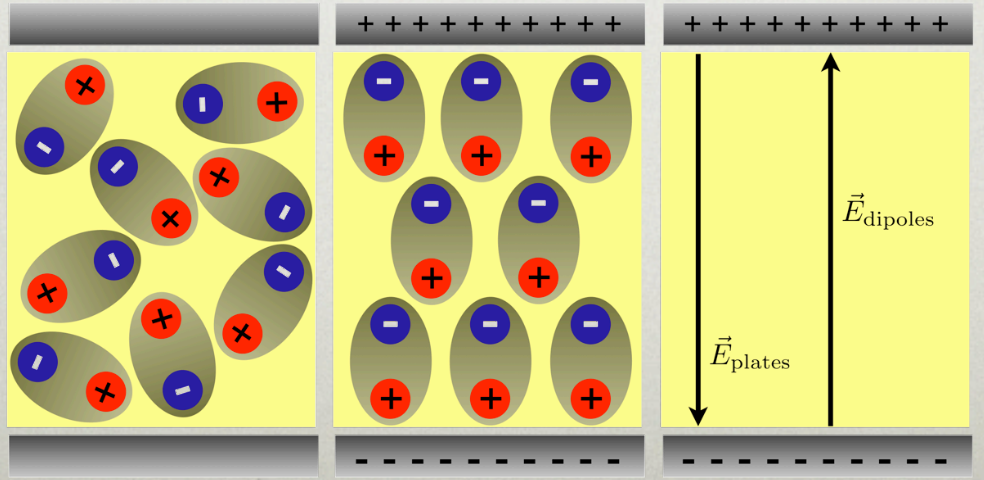
Misc. Format Issues

- we will take a break during lectures ...
- lecture and labs will try to stay linked
- learn a concept, then demonstrate it
- working in groups is encouraged *for homework*



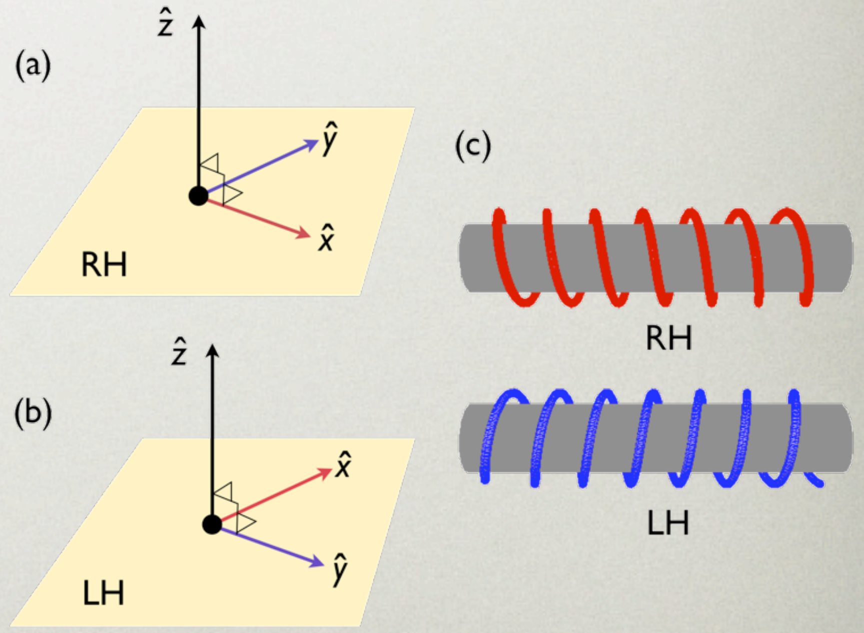
SOCIAL INTERACTION

- we need you in groups of 3-4 for labs
- groups are not assigned ...
  - ... so long as they remain functional relationships
  - even distribution of workload



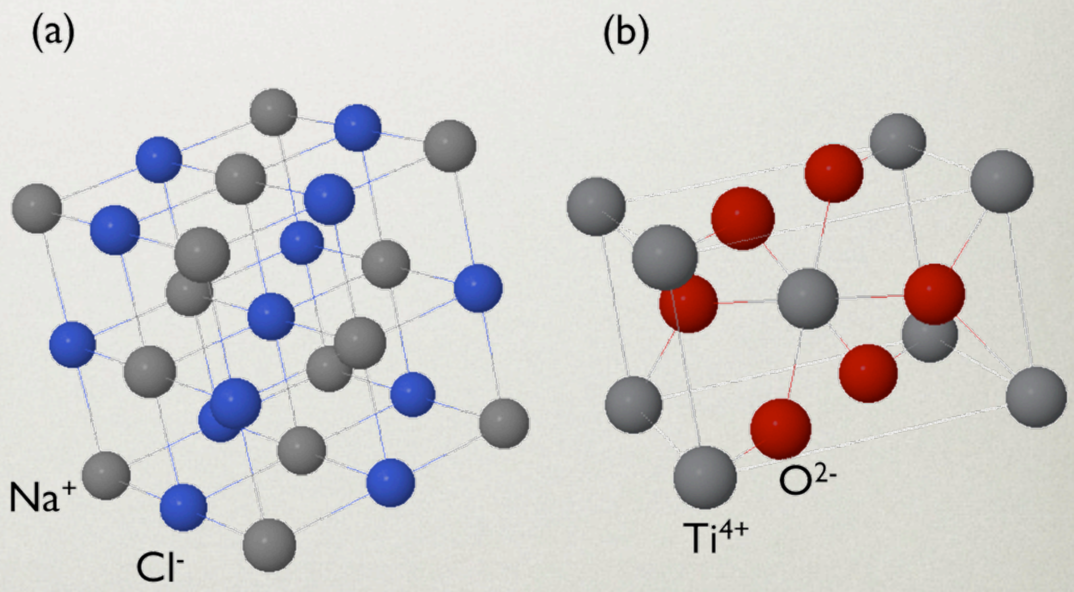
What will we cover?

- relativity
- electric forces & fields
- electrical energy & capacitance
- current & resistance
- dc circuits
- magnetism
- electromagnetic induction
- ac circuits & EM waves



WHAT WILL WE COVER (CONT.)

- reflection and refraction
- mirrors & lenses
- wave optics
- quantum physics
- atomic physics
- nuclear physics



Grading and so forth

- labs/exercises 10%
- quizzes 10%
- homework 20%
- exams: 3 of them, 20% each

  last one during final exam period, not cumulative

Homework

- Posted on web page, turn in hard copy or by email
- due date/time is rigid. drop lowest score.
- can collaborate, BUT turn in your own
- will go over @ start of lab sessions

QUIZZES

- sometimes. during most lab periods.
- only a few questions!
- previous day's work mostly
- 10-15 min anticipated

LABS / EXERCISES

- try to be on time ...
- something due every day lab is held
- if not a “real” lab:

  in-class exercises or simulations
- drop 1 lab

- USUALLY will not take 3 hours

STUFF YOU NEED

- textbook

  which one makes little difference

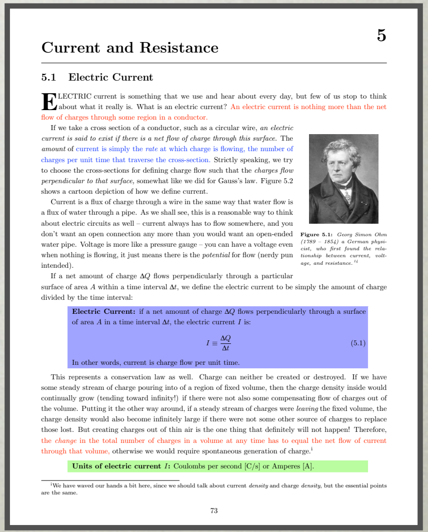
- course notes (optional)

  PDF online (do not print it here)

- calculator

  basic with trig/log

- notebook



Current and Resistance 5

5.1 Electric Current

ELECTRIC current is something that we use and hear about every day, but few of us stop to think about what it really is. What is an electric current? An electric current is nothing more than the net flow of charges through some region in a conductor.

If we take a cross section of a conductor, such as a circular wire, *an electric current is said to exist if there is a net flow of charge through this surface.* The *amount* of current is simply the *rate* at which charge is flowing, the number of charges per unit time that traverse the cross-section. Strictly speaking, we try to choose the cross-sections for defining charge flow such that the *charges flow perpendicular to that surface,* somewhat like we did for Gauss's law. Figure 5.2 shows a cartoon depiction of how we define current.

Current is a flux of charge through a wire in the same way that water flow is a flux of water through a pipe. As we shall see, this is a reasonable way to think about electric circuits as well – current always has to flow somewhere, and you don't want an open connection any more than you would want an open-ended water pipe. Voltage is more like a pressure gauge – you can have a voltage even when nothing is flowing, it just means there is the *potential* for flow (nerdy pun intended).

Figure 5.1: *Georg Simon Ohm (1789 – 1854) a German physicist, who first found the relationship between current, voltage, and resistance.*[14]

If a net amount of charge ΔQ flows perpendicularly through a particular surface of area A within a time interval Δt, we define the electric current to be simply the amount of charge divided by the time interval:

Electric Current: if a net amount of charge ΔQ flows perpendicularly through a surface of area A in a time interval Δt, the electric current I is:

$$I \equiv \frac{\Delta Q}{\Delta t} \tag{5.1}$$

In other words, current is charge flow per unit time.

This represents a conservation law as well. Charge can neither be created or destroyed. If we have some steady stream of charge pouring into of a region of fixed volume, then the charge density inside would continually grow (tending toward infinity!) if there were not also some compensating flow of charges out of the volume. Putting it the other way around, if a steady stream of charges were *leaving* the fixed volume, the charge density would also become infinitely large if there were not some other source of charges to replace those lost. But creating charges out of thin air is the one thing that definitely will not happen! Therefore, the *change* in the total number of charges in a volume at any time has to equal the net flow of current through that volume, otherwise we would require spontaneous generation of charge.[i]

Units of electric current I: Coulombs per second [C/s] or Amperes [A].

[i] We have waved our hands a bit here, since we should talk about current *density* and charge *density*, but the essential points are the same.

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SHOWING UP

- no make-up of in-class work

  "acceptable" + documented gets you a BYE

- missing an exam is seriously bad.

  acceptable reason - makeup or weight final

- lowest lab is dropped. I don't want to know.

DISTRACTIONS

- cell phones
  - keep it on a quiet mode.
  - take the call outside if it is urgent
- "no food/drink"
- at least one break during each lecture

OTHER

Academic misconduct

- do your own work on quizzes & exams
- suspected violations referred to A & S
- teamwork encouraged on labs/homework

Accessibility/disability accommodations

- for a request - 348-4285 Disabilities services
- after initial arrangements, contact me

INTERNETS

- we have our own intertubes:
  - http://ph102.blogspot.com
  - updated very frequently. often at odd hours.
  - comments (anonymous even) allowed
  - rss / twitter feeds of posts
- google calendar
- can add RSS feed of blog to facebook
- check blog & calendar before class

LET'S GET AT IT

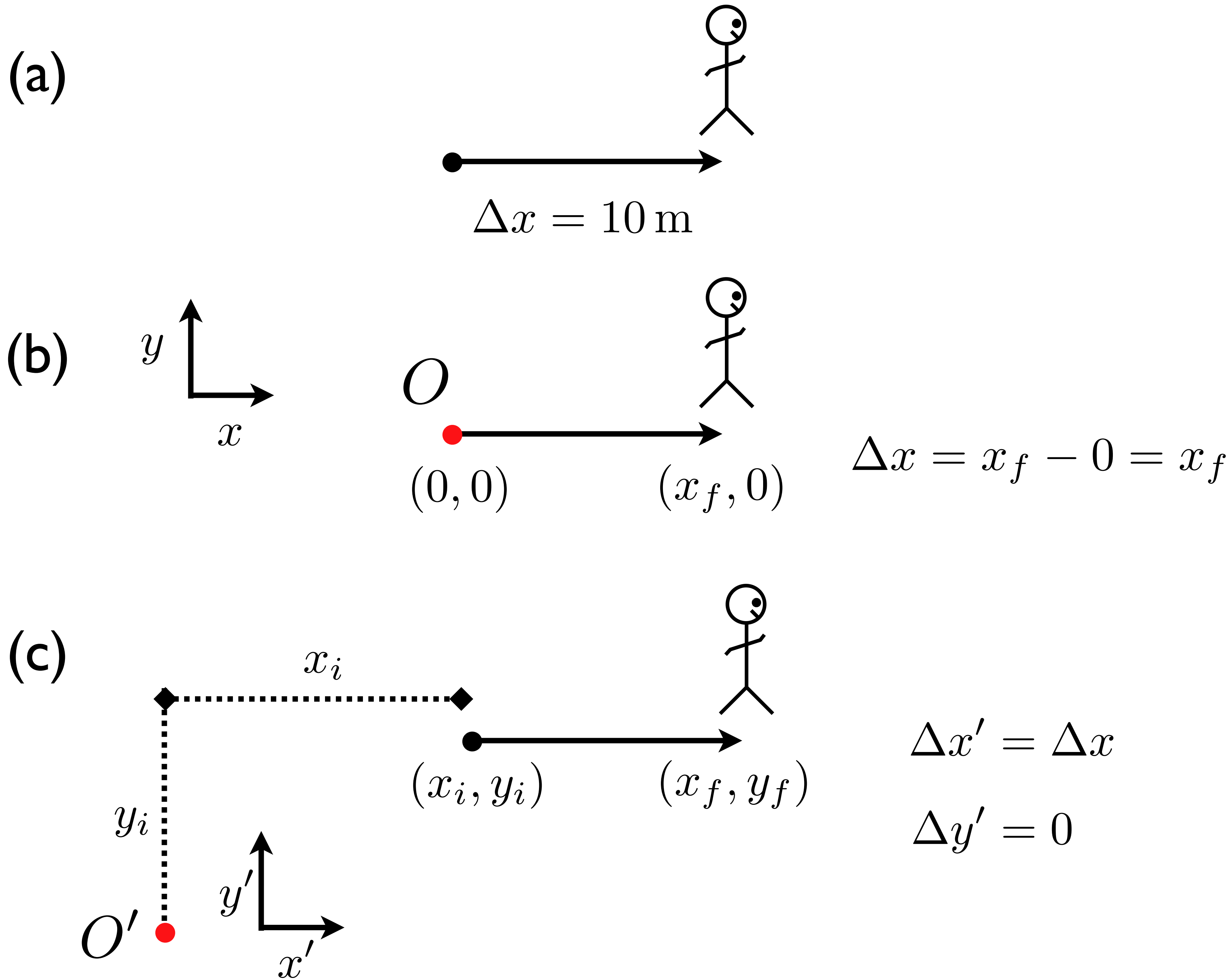
The pace will have to be brutal.

Today & tomorrow

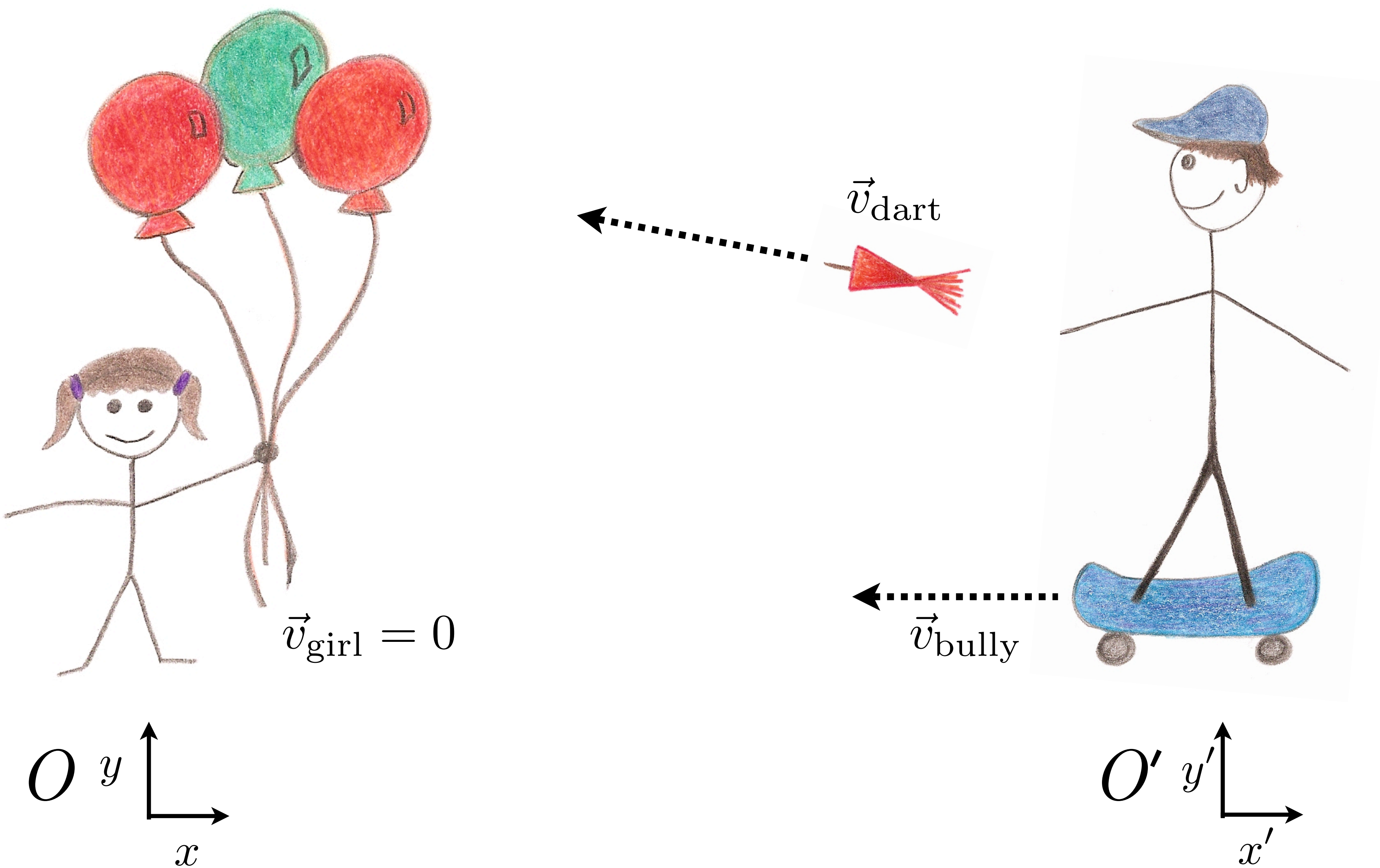
- Relativity (notes Ch. 1)
- no lab today

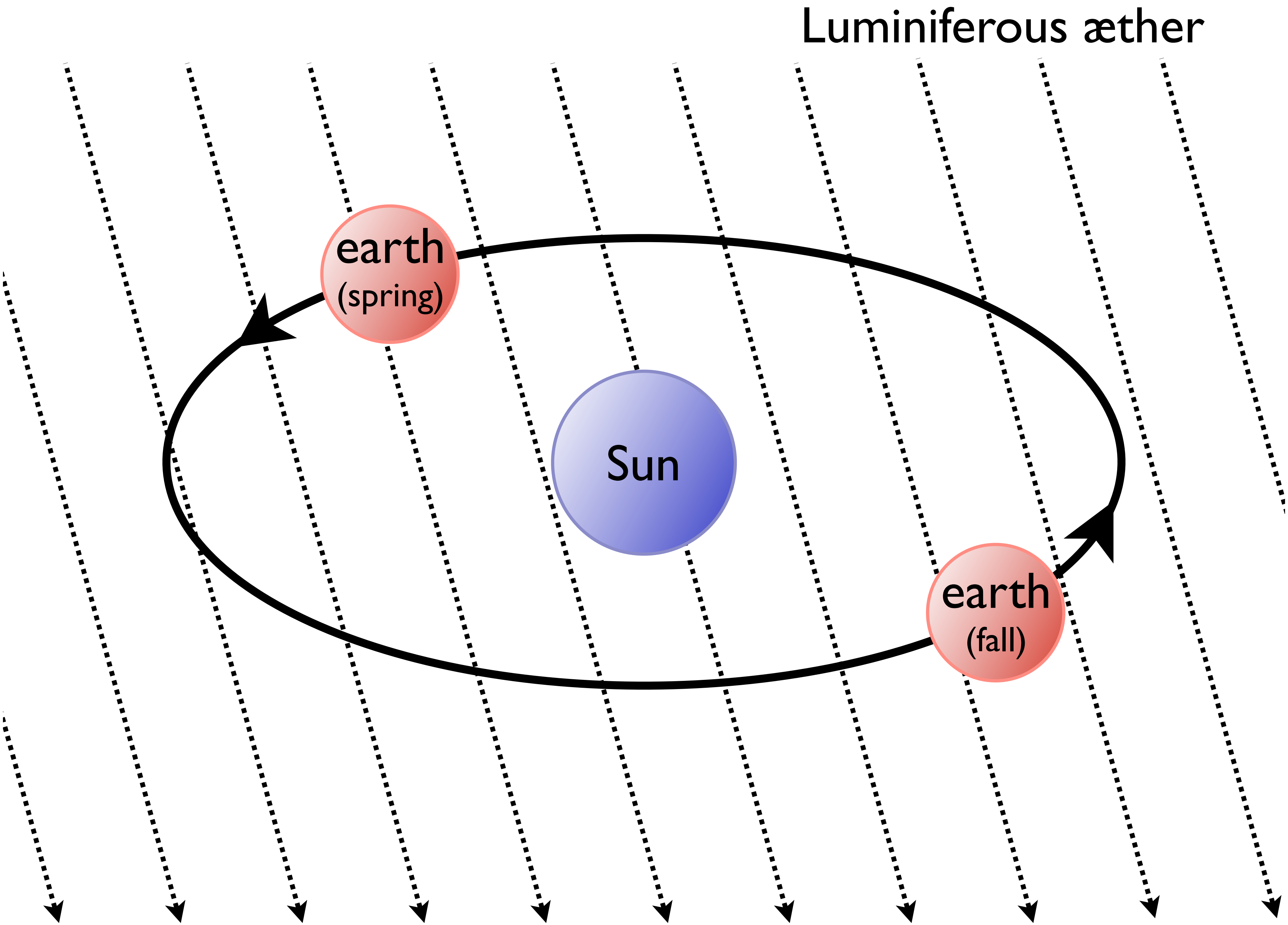
Monday

- electric fields & forces

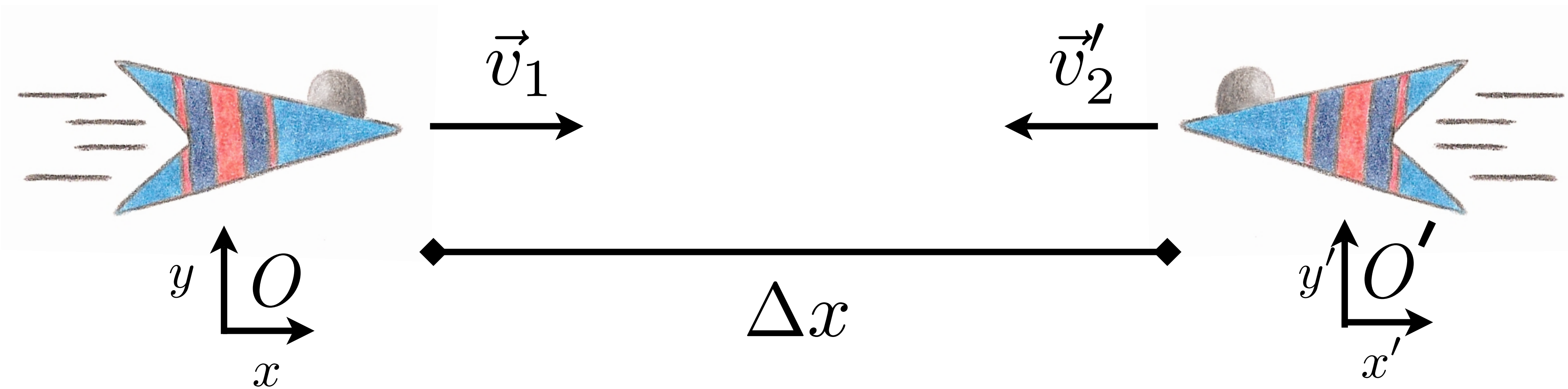


(a)
$\Delta x = 10\,\mathrm{m}$
(b)
y
x
O
$(0,0)$
$(x_f, 0)$
$\Delta x = x_f - 0 = x_f$
(c)
x_i
y_i
(x_i, y_i)
(x_f, y_f)
O'
y'
x'
$\Delta x' = \Delta x$
$\Delta y' = 0$

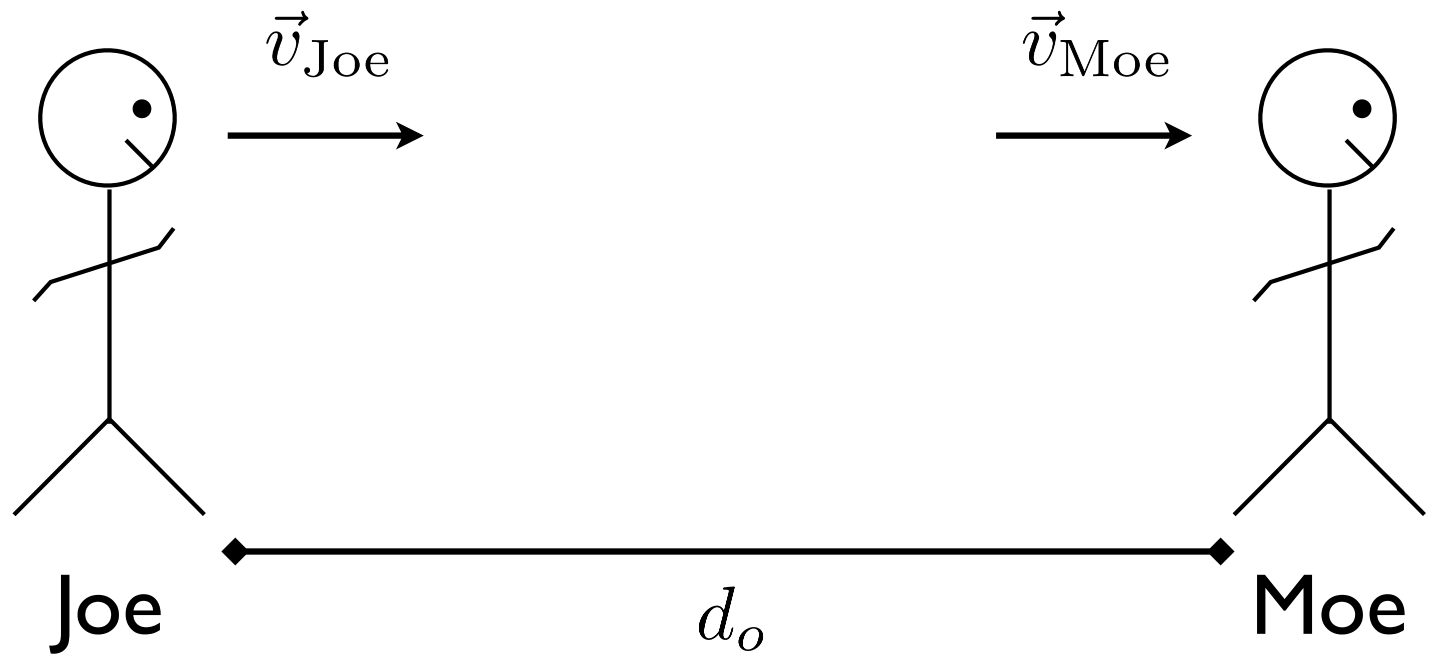

$\vec{v}_{\text{dart}}$
$\vec{v}_{\text{girl}} = 0$
$\vec{v}_{\text{bully}}$
O
y
x
O'
y'
x'



Luminiferous æther
earth
(spring)
Sun
earth
(fall)

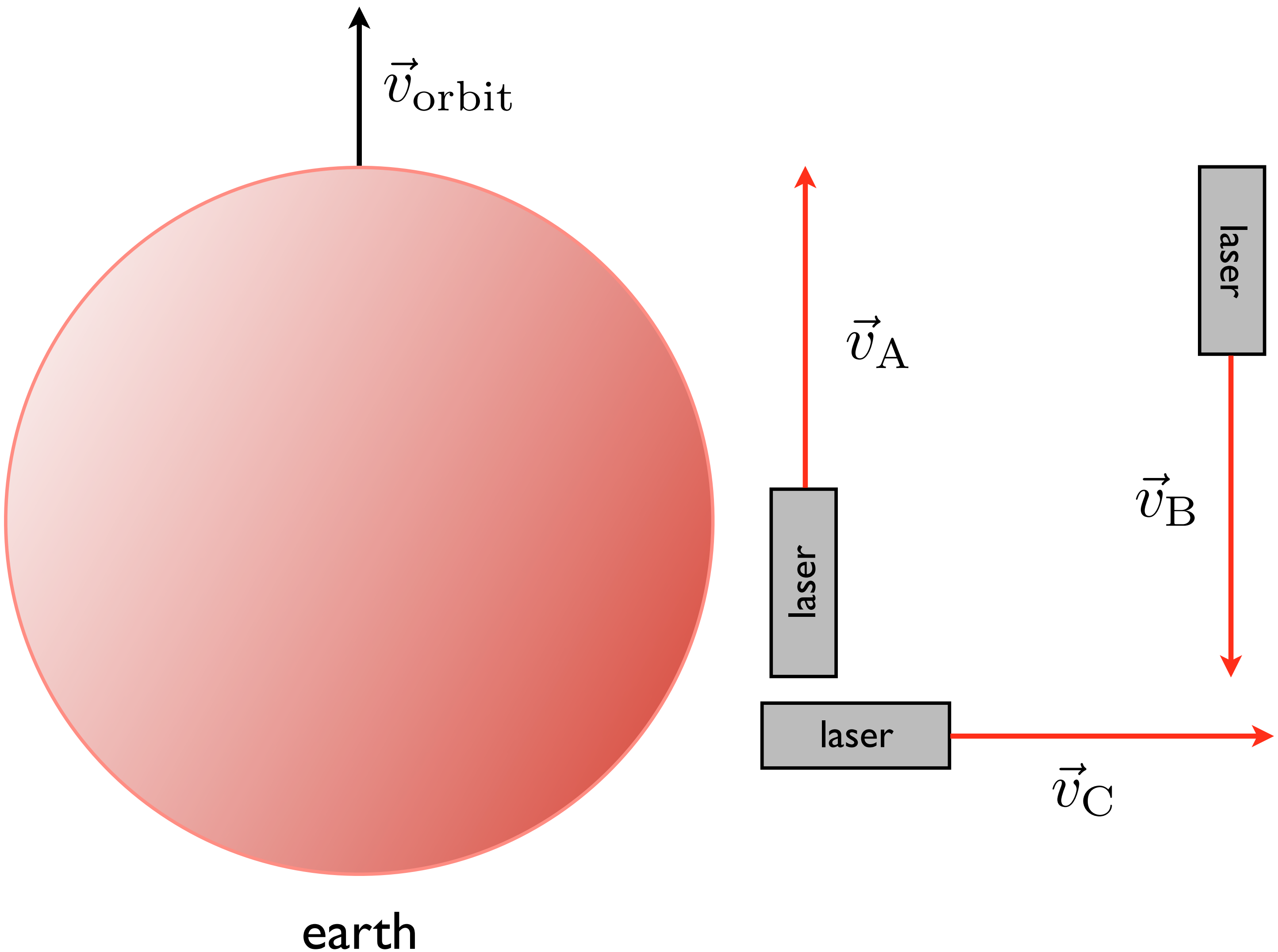


$\vec{v}_1$
$\vec{v}_2'$
y
O
x
Δx
y'
O'
x'


$\vec{v}_{\text{Joe}}$
$\vec{v}_{\text{Moe}}$
Joe
d_o
Moe

Choosing a coordinate system:

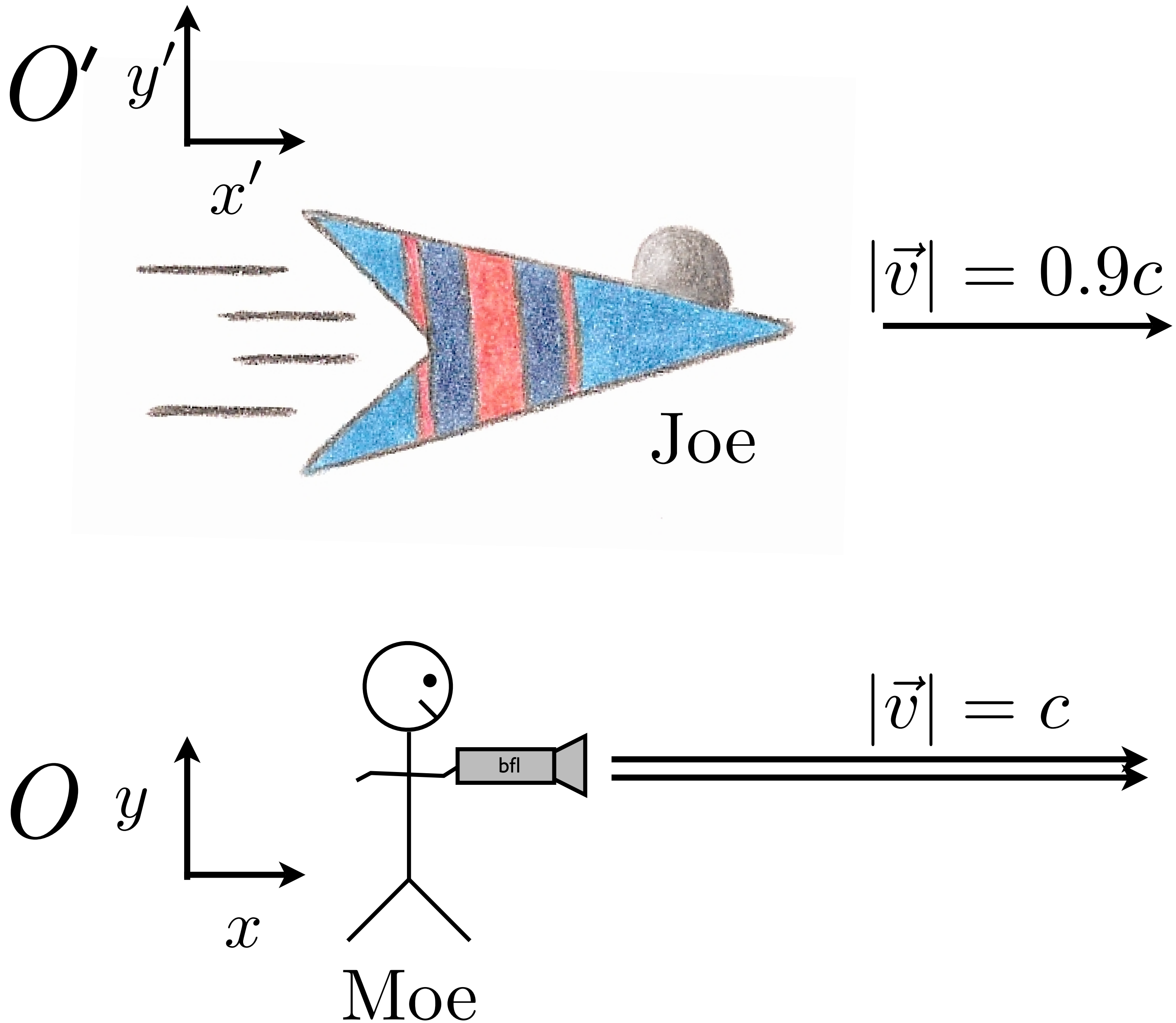
1. Choose an origin. This may coincide with a special point or object given in the problem - for instance, right at an observer's position, or halfway between two observers. Make it convenient!
2. Choose a set of axes, such as rectangular or polar. The simplest are usually rectangular or *Cartesian* x-y-z, though your choice should fit the symmetry of the problem given - if your problem has circular symmetry, rectangular coordinates may make life difficult.
3. Align the axes. Again, make it convenient - for instance, align your x axis along a line connecting two special points in the problem. Sometimes a thoughtful but less obvious choice may save you a lot of math!
4. Choose which directions are positive and negative. This choice is arbitrary, in the end, so choose the least confusing convention.



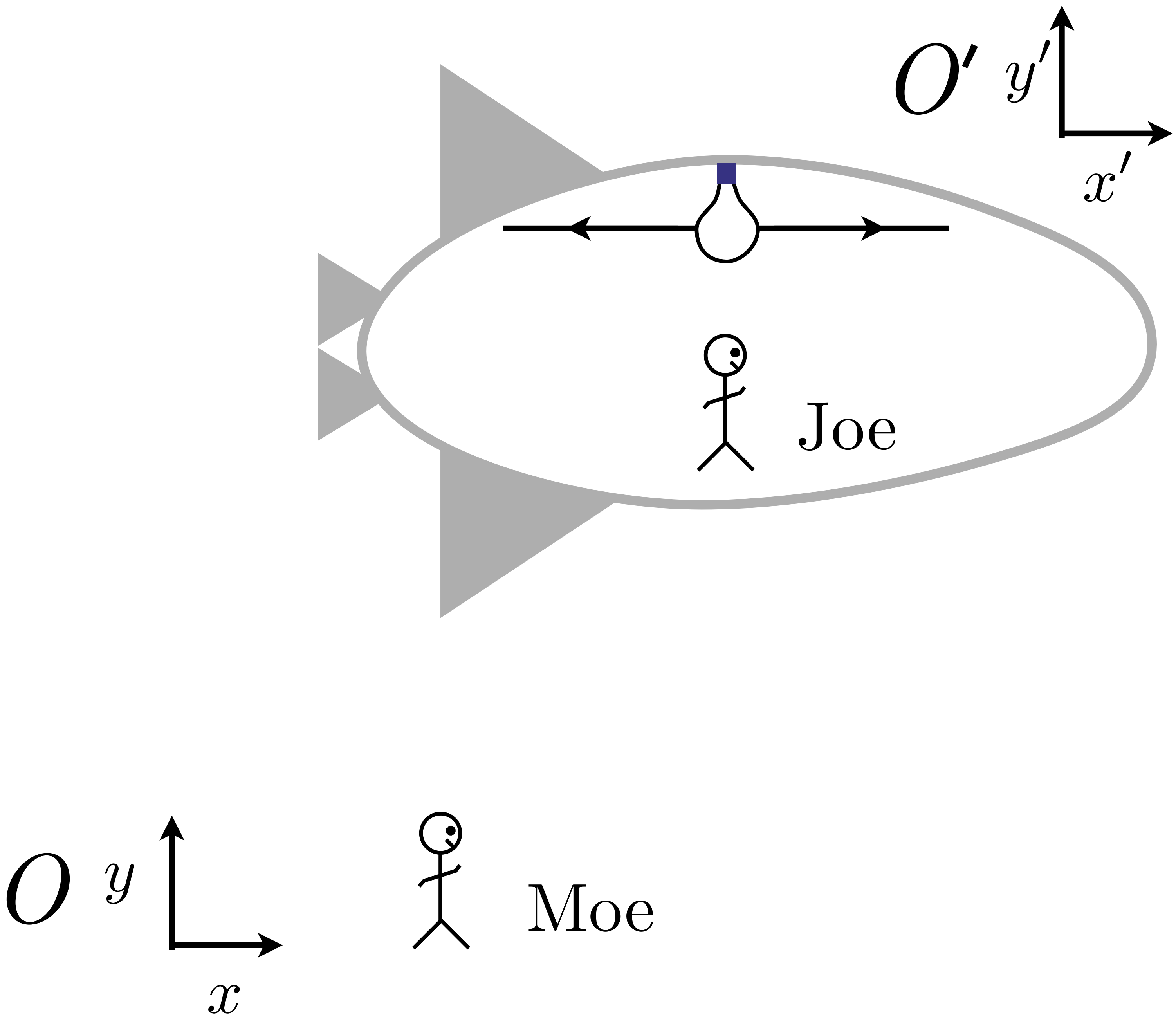
no difference

can't measure earth's velocity

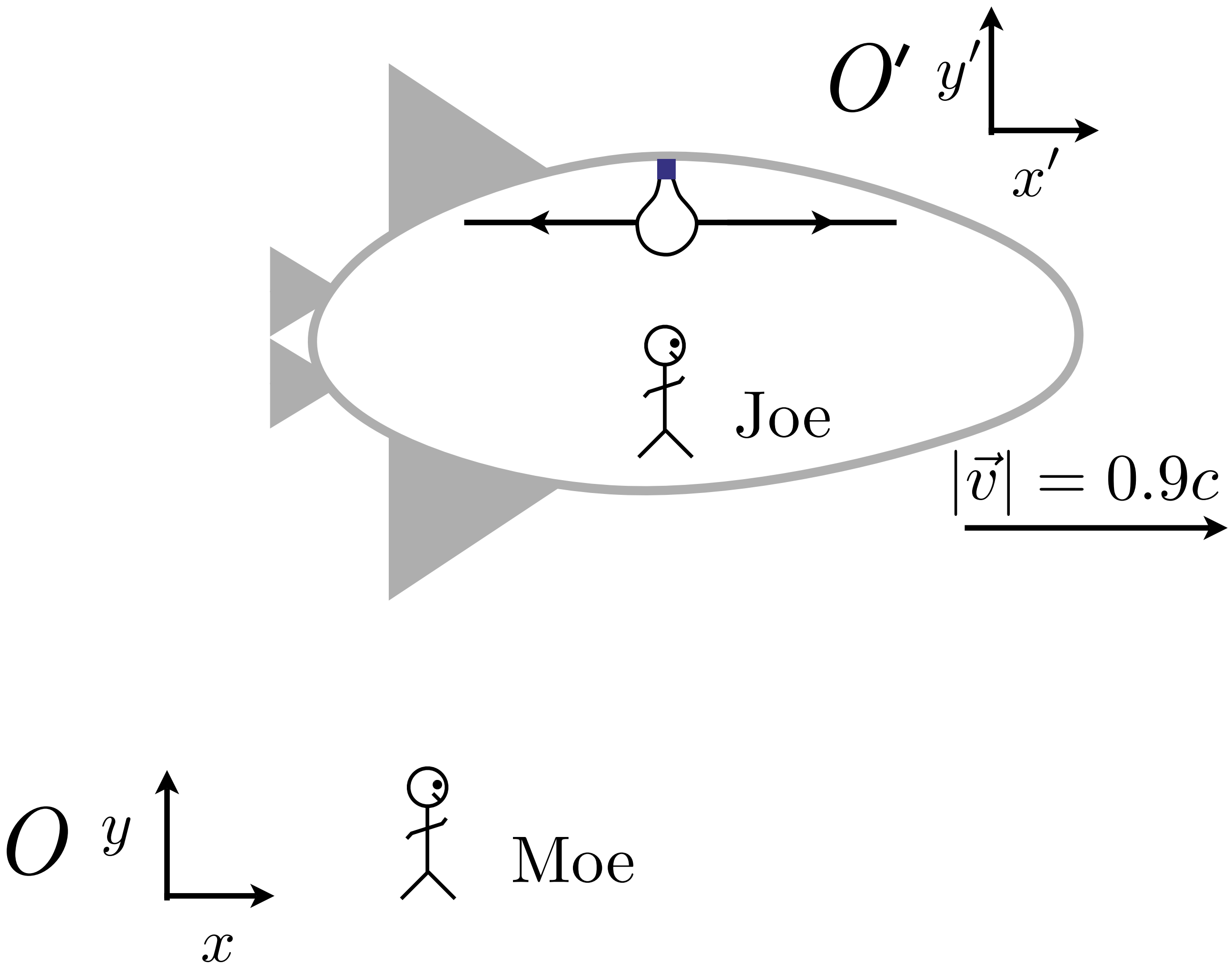
relative to empty space



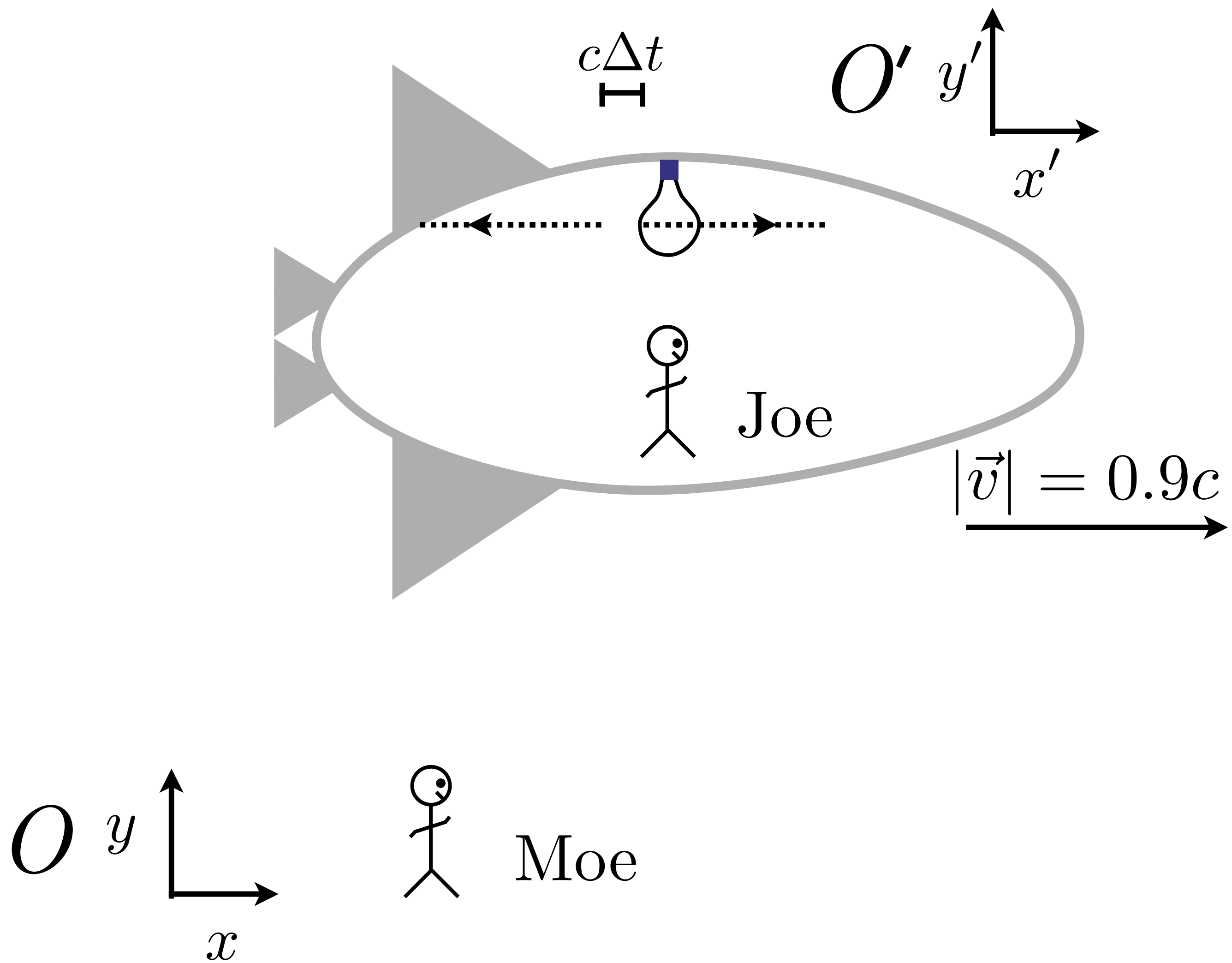
O'
y'
x'
Joe
$|\vec{v}| = 0.9c$
O
y
x
bfl
Moe
$|\vec{v}| = c$



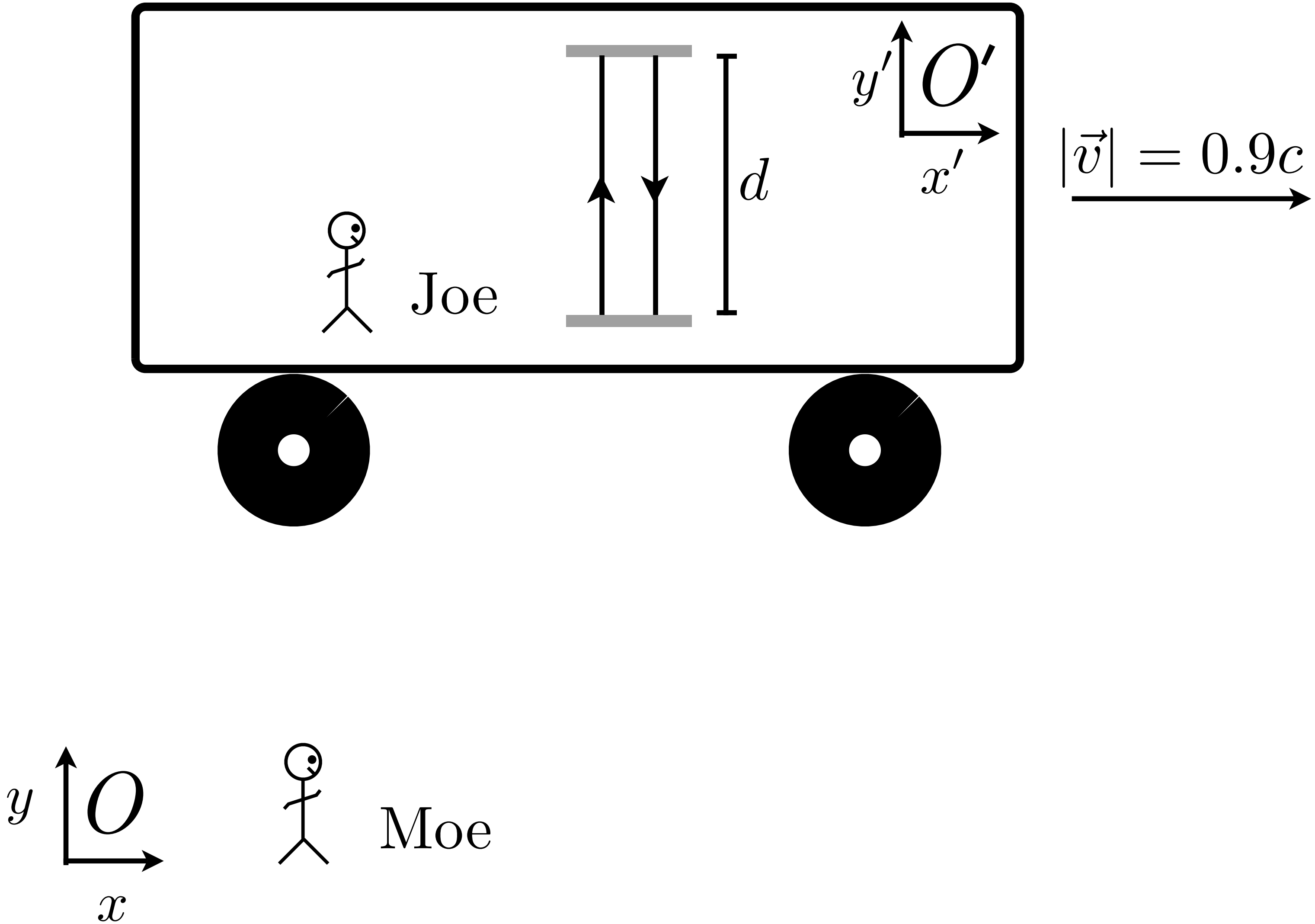
O′
y′
x′
Joe
O
y
x
Moe



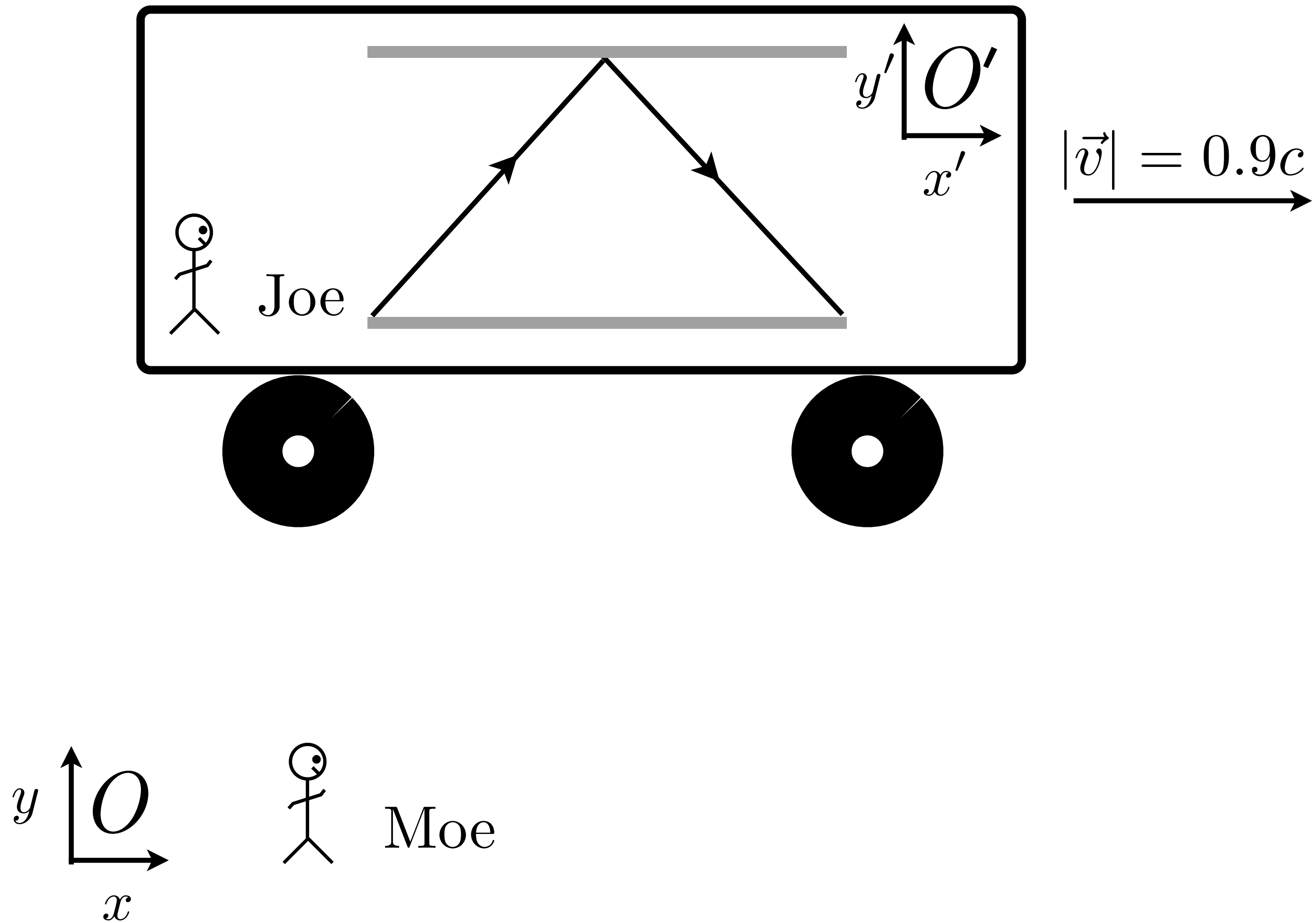
Joe flips on the light
he sees the light hit
the walls at the same time



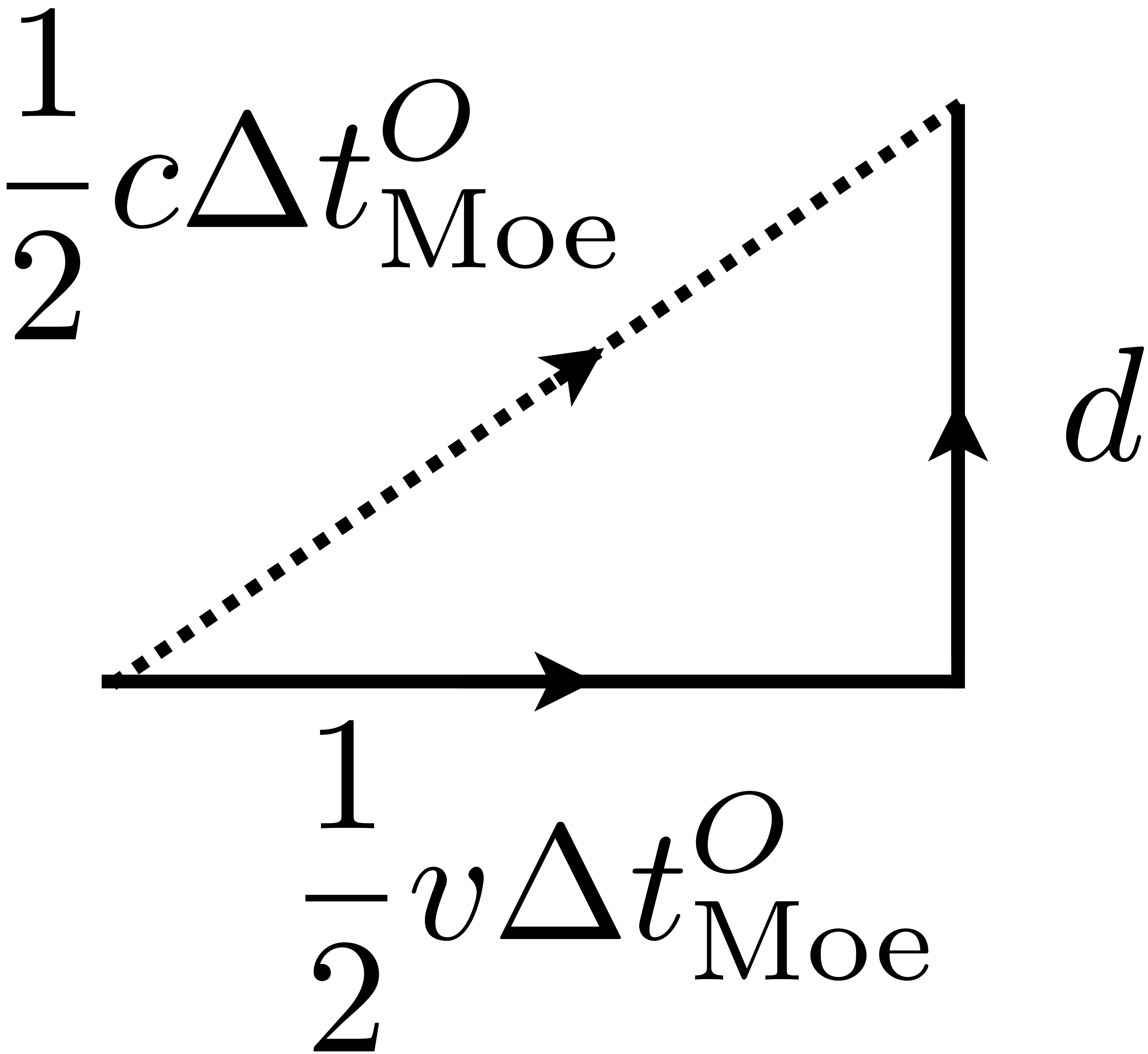
What does Moe see?
the ship moved;
the origin of the light did not



Joe bounces a laser off of some mirrors
he counts the round trips
this measures distance

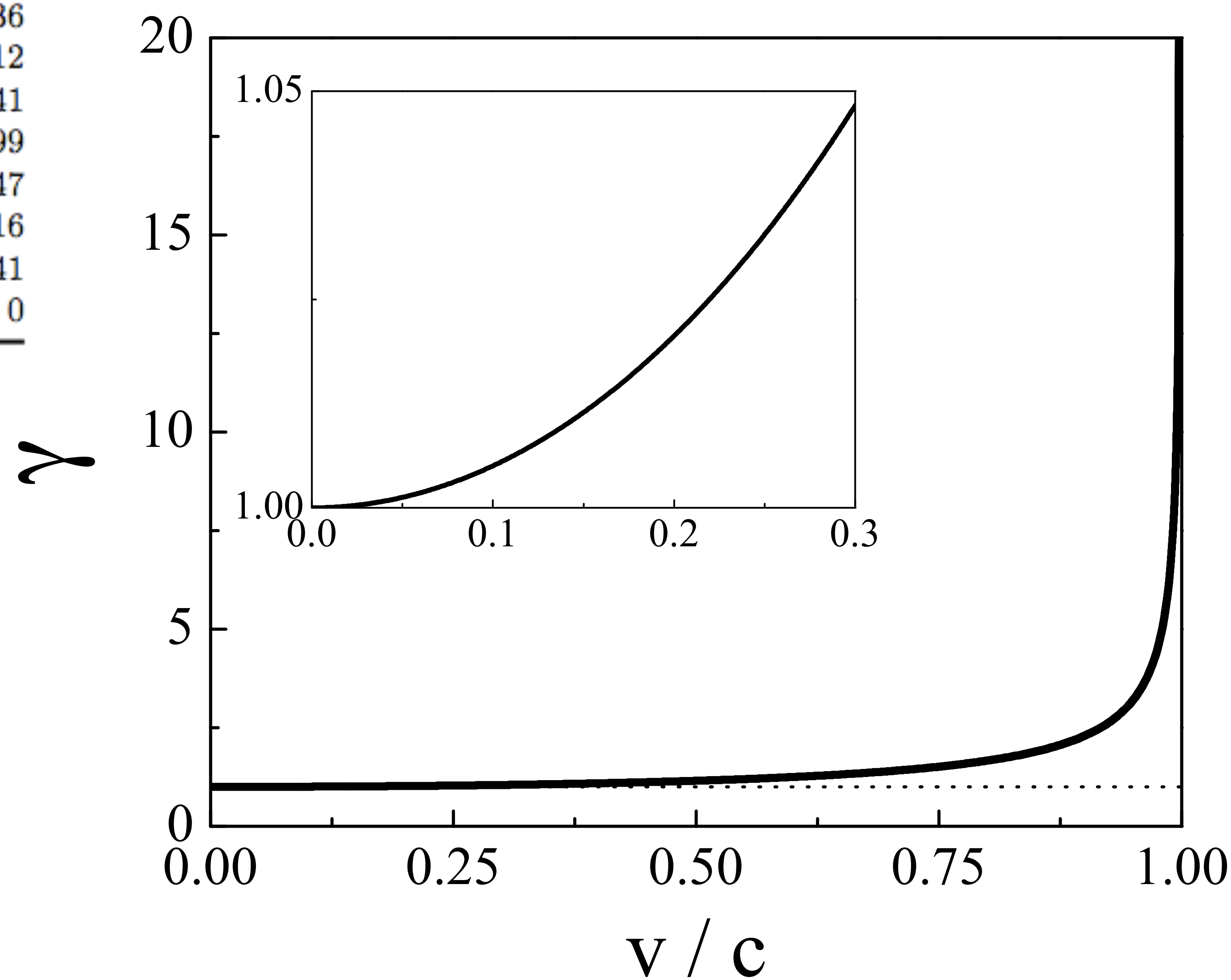


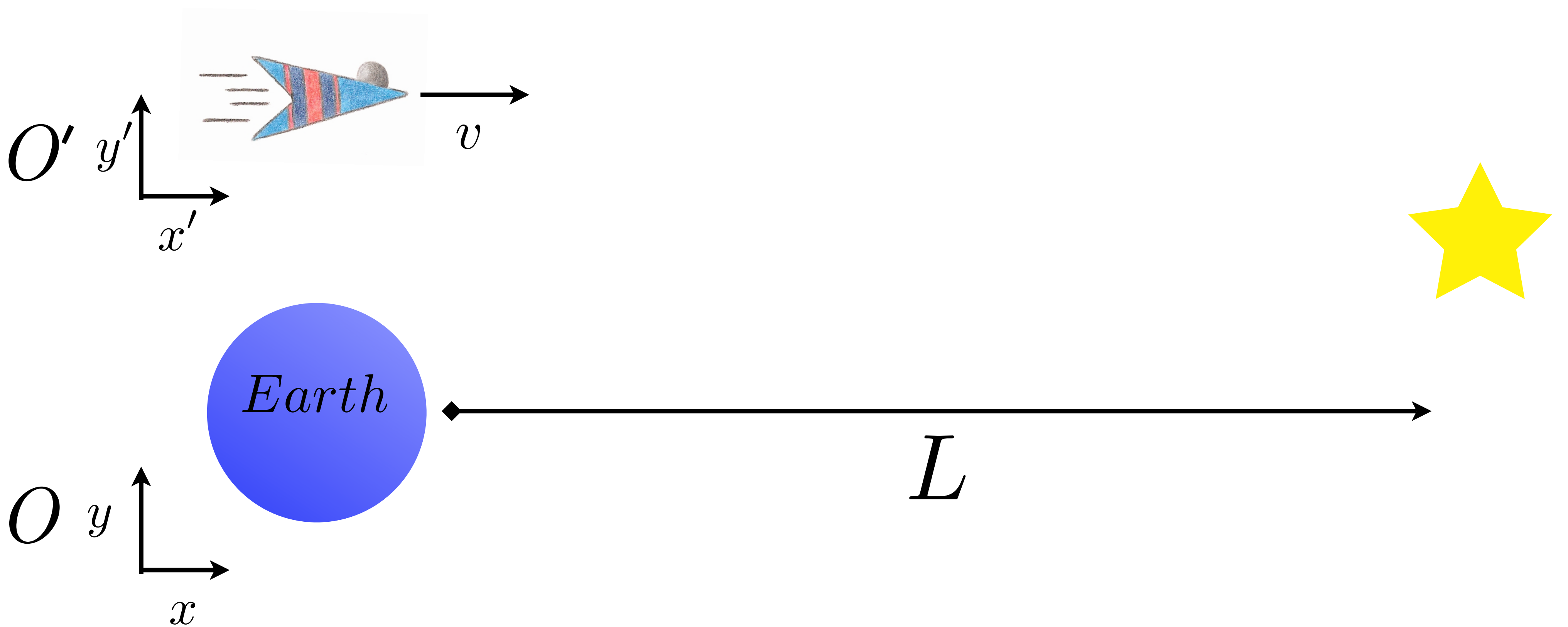
Moe sees the boxcar move;
once the light is created, it does not.
Moe sees a triangle wave



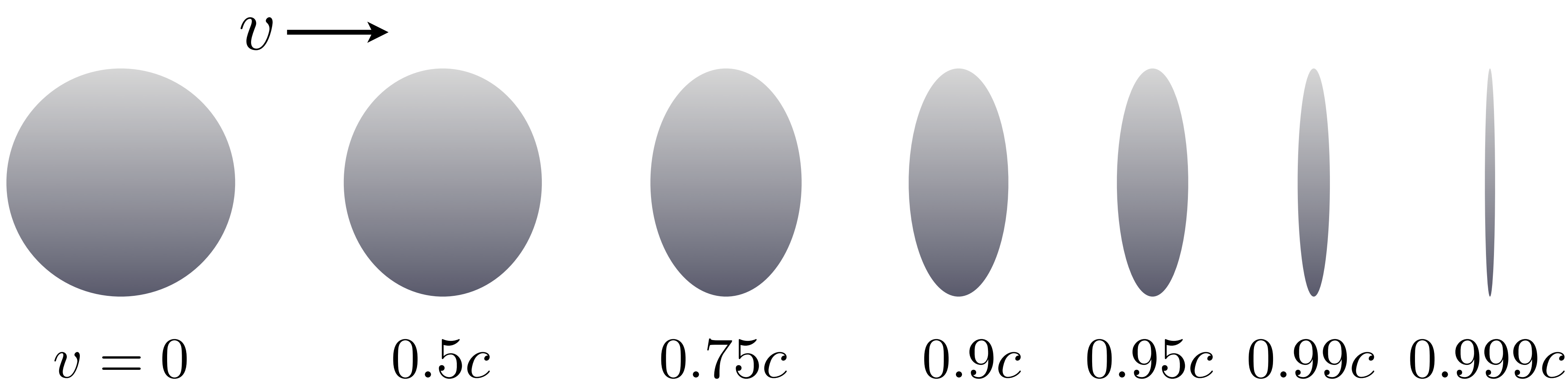
$\frac{1}{2}c\Delta t^{O}_{\text{Moe}}$
d
$\frac{1}{2}v\Delta t^{O}_{\text{Moe}}$

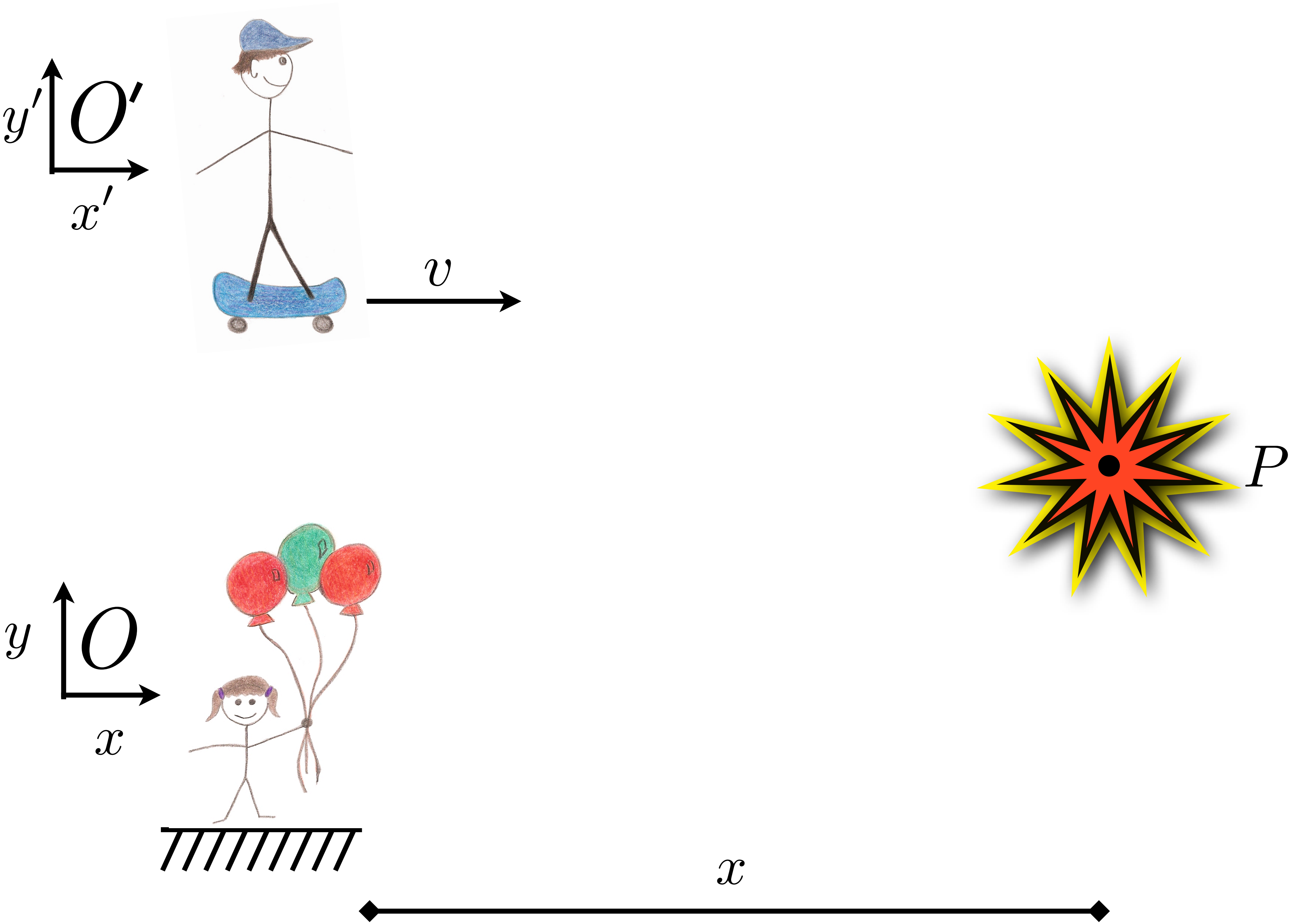
v [m/s]	$\frac{v}{c}$	γ	$1/\gamma$
0	0	0	∞
3×10^6	0.01	1.00005	0.99995
3×10^7	0.1	1.005	0.995
6×10^7	0.2	1.02	0.980
1.5×10^8	0.5	1.16	0.866
2.25×10^8	0.75	1.51	0.661
2.7×10^8	0.9	2.29	0.436
2.85×10^8	0.95	3.20	0.312
2.97×10^8	0.99	7.09	0.141
2.983×10^8	0.995	10.0	0.0999
2.995×10^8	0.999	22.4	0.0447
2.996×10^8	0.9995	31.6	0.0316
2.998×10^8	0.9999	70.7	0.0141
c	1	∞	0





O′
y′
x′
v
Earth
L
O
y
x


v
$v = 0$
$0.5c$
$0.75c$
$0.9c$
$0.95c$
$0.99c$
$0.999c$



y'
O'
x'
v
P
y
O
x
x

Transformation of distance between reference frames:

$$x' = \gamma(x - vt) \tag{1.37}$$

$$x = \gamma\left(x' + vt'\right) \tag{1.3}$$

Here (x,t) is the position and time of an event as measured by an observer in O stationary it. A second observer in O', moving at velocity v, measures the same event to be at positic and time (x',t').

Time measurements in different non-accelerating reference frames:

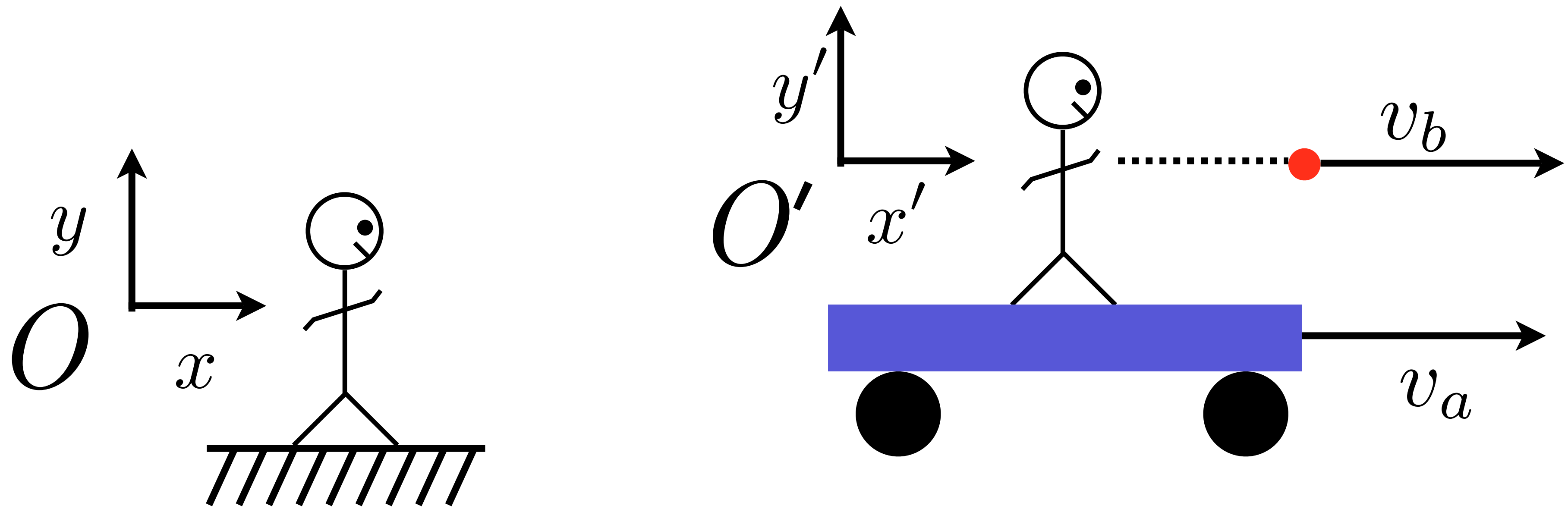
$$t' = \gamma\left(t - \frac{vx}{c^2}\right) \tag{1.46}$$

$$t = \gamma\left(t' + \frac{vx'}{c^2}\right) \tag{1.47}$$

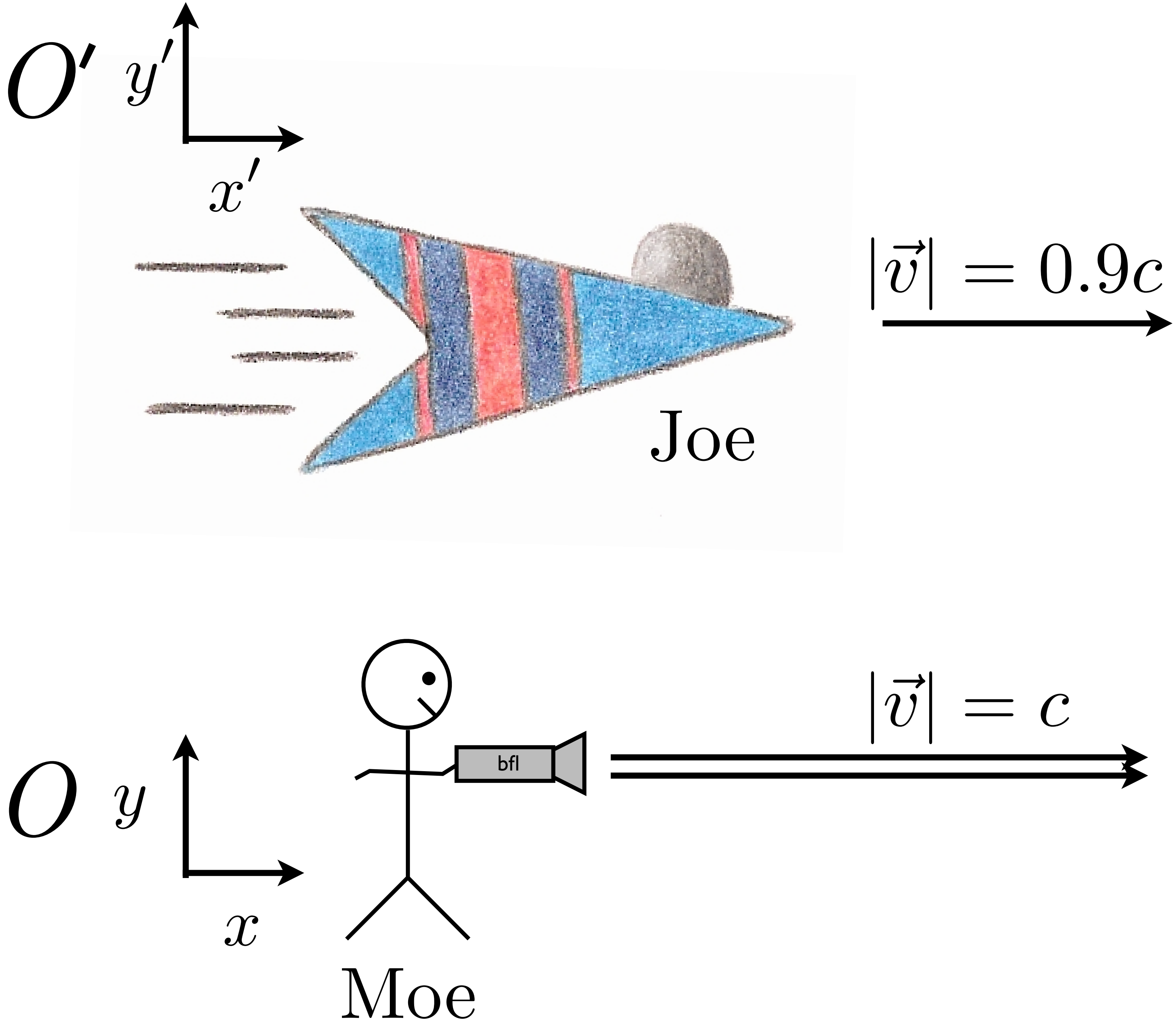
Here (x,t) is the position and time of an event as measured by an observer in O stationary to it. A second observer in O', moving at velocity v, measures the same event to be at position and time (x',t').

Elapsed times between events in non-accelerating reference frames:

$$\Delta t' = t_1' - t_2' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right) \quad (1.4$$



y
O
x
y'
O'
x'
v_b
v_a



O'
y'
x'
$|\vec{v}| = 0.9c$
Joe
O
y
x
bfl
$|\vec{v}| = c$
Moe

let’s work out some problems

1. An astronaut traveling at $v = 0.80c$ taps her foot 3.0 times per second. What is the frequency of taps determined by an observer on earth? (*Hint: be careful about the difference between time and frequency!*)

- ◯ 5.0 taps/sec
- ◯ 6.7 taps/sec
- ◯ 1.8 taps/sec
- ◯ 3.0 taps/sec

2. A spaceship moves away from earth at high speed. How do experimenters on earth measure a clock in the spaceship to be running? How do those in the spaceship measure a clock on earth to be running?

- ◯ slow; fast
- ◯ slow; slow
- ◯ fast; slow
- ◯ fast; fast

3. If you are moving in a spaceship at high speed relative to the earth, would you notice a difference in your pulse rate? In the pulse rate of the people back on earth?

- ◯ no; yes
- ◯ no; no
- ◯ yes; no
- ◯ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of $0.950c$ with respect to the pendulum?

- ◯ 6.00 sec
- ◯ 13.4 sec
- ◯ 0.938 sec
- ◯ 9.61 sec

1. 1.8 **taps/sec.** The 'proper time' Δt_p is that measured by the astronaut herself, which is 1/3 of a second between taps (so that there are 3 taps per second). The time interval *between taps* measured on earth is dilated (longer), so there are *less* taps per second. For the astronaut:

$$\Delta t_p = \frac{1\,\text{s}}{3\,\text{taps}}$$

On earth, we measure the dilated time:

$$\Delta t' = \gamma \Delta t_p = \frac{1}{\sqrt{1 - \frac{0.8^2 c^2}{c^2}}} \cdot \left(\frac{1\,\text{s}}{3\,\text{taps}}\right) = \frac{1}{\sqrt{1 - 0.8^2}} \cdot \left(\frac{1\,\text{s}}{3\,\text{taps}}\right) \approx \frac{0.56\,\text{s}}{\text{tap}} = \frac{1\,\text{s}}{1.8\,\text{taps}}$$

1. An astronaut traveling at $v = 0.80c$ taps her foot 3.0 times per second. What is the frequency of taps determined by an observer on earth? (*Hint: be careful about the difference between time and frequency!*)

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- ○ fast; slow
- ○ fast; fast

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- ○ no; yes
- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of $0.950c$ with respect to the pendulum?

- ○ 6.00 sec
- ○ 13.4 sec
- ○ 0.938 sec
- ○ 9.61 sec

2. slow; slow. The time-dilation effect is symmetric, so observers in each frame measure a clock in the other to be running slow. Put another way, the *relative* velocity of the earth and the ship is the same no matter who you ask – each says the other is moving with some speed v, and they are sitting still. Therefore, the dilation effect is the same in both cases.

1. An astronaut traveling at $v = 0.80c$ taps her foot 3.0 times per second. What is the frequency of taps determined by an observer on earth? (*Hint: be careful about the difference between time and frequency!*)

- ○ 5.0 taps/sec
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- ☆ 1.8 taps/sec
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2. A spaceship moves away from earth at high speed. How do experimenters on earth measure a clock in the spaceship to be running? How do those in the spaceship measure a clock on earth to be running?

- ○ slow; fast
- ☆ slow; slow
- ○ fast; slow
- ○ fast; fast

3. If you are moving in a spaceship at high speed relative to the earth, would you notice a difference in your pulse rate? In the pulse rate of the people back on earth?

- ○ no; yes
- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of 0.950c with respect to the pendulum?

- ○ 6.00 sec
- ○ 13.4 sec
- ○ 0.938 sec
- ○ 9.61 sec

3. no; yes. There is no relative speed between you and your own pulse, since you are in the same reference frame, so there is no difference in your pulse rate (possible space-travel-related anxieties aside). There is a relative velocity between you and the people back on earth, however, so you would find their pulse rate *slower* than normal. Similarly, they would find *your* pulse rate slower than normal, since you are moving relative to them. Relativistic effects are always attributed to the other party – you are always at rest in your own reference frame.

1. An astronaut traveling at $v = 0.80c$ taps her foot 3.0 times per second. What is the frequency of taps determined by an observer on earth? (*Hint: be careful about the difference between time and frequency!*)

- ○ 5.0 taps/sec
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- ○ slow; fast
- ★ slow; slow
- ○ fast; slow
- ○ fast; fast

3. If you are moving in a spaceship at high speed relative to the earth, would you notice a difference in your pulse rate? In the pulse rate of the people back on earth?

- ★ no; yes
- ○ no; no
- ○ yes; no
- ○ yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of $0.950c$ with respect to the pendulum?

- ○ 6.00 sec
- ○ 13.4 sec
- ○ 0.938 sec
- ○ 9.61 sec

4. 9.61 **sec.** The proper time is that measured by in the reference frame of the pendulum itself, $\Delta t_p = 3.00\,\text{sec}$. The moving observer has to observe a *longer* period for the pendulum, since from the observer's point of view, the pendulum is moving relative to it. Observers always perceive clocks moving relative to them as running slow. The factor between the two times is just γ:

$$\Delta t' = \gamma \Delta t_p = \frac{3.0\,\text{sec}}{\sqrt{1 - \frac{0.95^2 c^2}{c^2}}} = \frac{3.0\,\text{sec}}{\sqrt{1 - 0.95^2}} \approx 9.61\,\text{sec}$$

1. An astronaut traveling at $v = 0.80c$ taps her foot 3.0 times per second. What is the frequency of taps determined by an observer on earth? (*Hint: be careful about the difference between time and frequency!*)

- 5.0 taps/sec
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- slow; fast
- slow; slow
- fast; slow
- fast; fast

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- no; yes
- no; no
- yes; no
- yes; yes

4. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of $0.950c$ with respect to the pendulum?

- 6.00 sec
- 13.4 sec
- 0.938 sec
- 9.61 sec

6. You are packing for a trip to another star, and on your journey you will travel at $0.99c$. Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain your answer.

7. A deep-space probe moves away from Earth with a speed of $0.88c$. An antenna on the probe requires 4.0 s, in probe time, to rotate through 1.0 rev. How much time is required for 1.0 rev according to an observer on Earth?

8. A friend in a spaceship travels past you at a high speed. He tells you that his ship is 24 m long and that the identical ship you are sitting in is 18 m long.

(a) According to your observations, how long is your ship?
(b) According to your observations, how long is his ship?
(c) According to your observations, what is the speed of your friend's ship?

6. No. There is no relative speed between you and your cabin, since you are in the same reference frame. You and your bed will remain at the same lengths relative to each other.

6. You are packing for a trip to another star, and on your journey you will travel at $0.99c$. Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain your answer.

7. A deep-space probe moves away from Earth with a speed of $0.88c$. An antenna on the probe requires $4.0\,\mathrm{s}$, in probe time, to rotate through $1.0\,\mathrm{rev}$. How much time is required for $1.0\,\mathrm{rev}$ according to an observer on Earth?

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(c) According to your observations, what is the speed of your friend's ship?

7. 8.42 s. The time interval in the probe's reference frame is the proper one Δt_p ... which makes sense, since the antenna is part of the probe itself! The probe and antenna are moving relative to the earth, and therefore the earthbound observer measures a longer, dilated time interval $\Delta t'$:

$$\begin{aligned} \text{probe} &= \Delta t_p \\ \text{earth} &= \Delta t' \\ \Delta t' &= \gamma \Delta t_p \end{aligned}$$

As usual, we first need to calculate γ. No problem, given the probe's velocity of $0.88c$ relative

to earth:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{1}{\sqrt{1 - \frac{(0.88c)^2}{c^2}}} = \frac{1}{\sqrt{1 - 0.88^2}} = 2.11$$

The proper time interval for one revolution Δt_p in the probe's reference frame is 4.0 s, so we can readily calculate the time interval observed by the earthbound observer:

$$\Delta t' = \gamma \Delta t_p = 2.11 \cdot (4.0\,\text{s}) = 8.42\,\text{s}$$

6. You are packing for a trip to another star, and on your journey you will travel at $0.99c$. Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain your answer.

7. A deep-space probe moves away from Earth with a speed of $0.88c$. An antenna on the probe requires 4.0 s, in probe time, to rotate through 1.0 rev. How much time is required for 1.0 rev according to an observer on Earth?

8. A friend in a spaceship travels past you at a high speed. He tells you that his ship is 24 m long and that the identical ship you are sitting in is 18 m long.

(a) According to your observations, how long is your ship?
(b) According to your observations, how long is his ship?
(c) According to your observations, what is the speed of your friend's ship?

8. 24 m; 18 m; 0.661c. Once again: if you are observing something in your own reference frame, there is no length contraction or time dilation. You always observe your own ship to be the same length. If your friend's ship is 24 m long, and yours is identical, you will measure it to be 24 m.

On the other hand, you are moving relative to his ship, so you would observe his ship to be length contracted, and measure a shorter length. Your friend, on the other hand, will observe *exactly the same thing* - he will see *your* ship contracted, by precisely the same amount. Your observation of his ship has to be the same as his observation of his ship - since you are only the two observers, and you both have the same *relative* velocity, you must observe the same length contraction. If he sees your ship as 18 m long, then you would also see his (identical) ship as 18 m long.

Given the relationship between the contracted and proper length, we can find the relative velocity easily. Your measurement of your own ship is the proper length L_p, while your measurement of your friend's ship is the contracted length L':

$$\begin{aligned}
L_p &= \gamma L' \\
\implies \gamma &= \frac{L_p}{L'} = \frac{24}{18} = \frac{4}{3} \\
\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} &= \frac{4}{3} \\
1-\frac{v^2}{c^2} &= \frac{3^2}{4^2} = \frac{9}{16} \\
\frac{v^2}{c^2} &= 1-\frac{9}{16} = \frac{7}{16} \\
v &= \sqrt{\frac{7}{16}}c = \frac{\sqrt{7}}{4}c \approx 0.661c
\end{aligned}$$