

# Physics 253

P. LeClair




## OFFICIAL THINGS

 Dr. Patrick LeClair

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- facebook / twitter (@pleclair)

 Office hours:

- MWF 1-2 in Bevill
- Tu, Th 11-12 in Gallalee
- *(email/txt ahead is best MWF)*

 *other times by appointment*



# OFFICIAL THINGS

## Lecture:

☀ 200 Gallalee

☀ TuTh 9:30-10:45

- we'll need most of this time
- will go over problems, but only so many
- a big part of learning is solving on your own ...

☀ some notes provided (scanned or otherwise)

☀ no attendance policy, I will make it worth your time



# WHAT WILL WE COVER?

- ☀ Relativity
- ☀ Thermal radiation & Planck's hypothesis; photons
- ☀ Wave mechanics & matter waves
- ☀ Schrödinger's equation
- ☀ Atomic structure; quantum model of the atom
- ☀ multi-electron atoms & molecules
- ☀ periodic solids, band theory
- ☀ Spin, Fermi-Dirac statistics
- ☀ applications, such as:
  - semiconductors
  - lasers
  - magnetic resonance



# GRADING AND SO FORTH

☀ homework (25%)

- drop lowest; weekly
- PDF Posted on Blackboard

☀ exams (two @ 25%)

☀ comprehensive final (25%)



# HOMWORK

☀ new set every week on Blackboard [pdf]

☀ due about a week later mostly

☀ hard copy or Blackboard submission

hard copies: my mailbox, start of class

electronic: type / scan / pics OK

☀ can collaborate - BUT turn in your own

☀ have to show your work to get credit



## QUIZZES

- ☀ rare. may take the form of group activities
- ☀ previous lecture's material (review)
- ☀ 5-10 min anticipated. spontaneous.
- ☀ will count the same as a homework set
- ☀ do the homework & reading, and it will be trivial



# STUFF YOU NEED

☀ textbook

Krane 3rd edition

Amazon has it

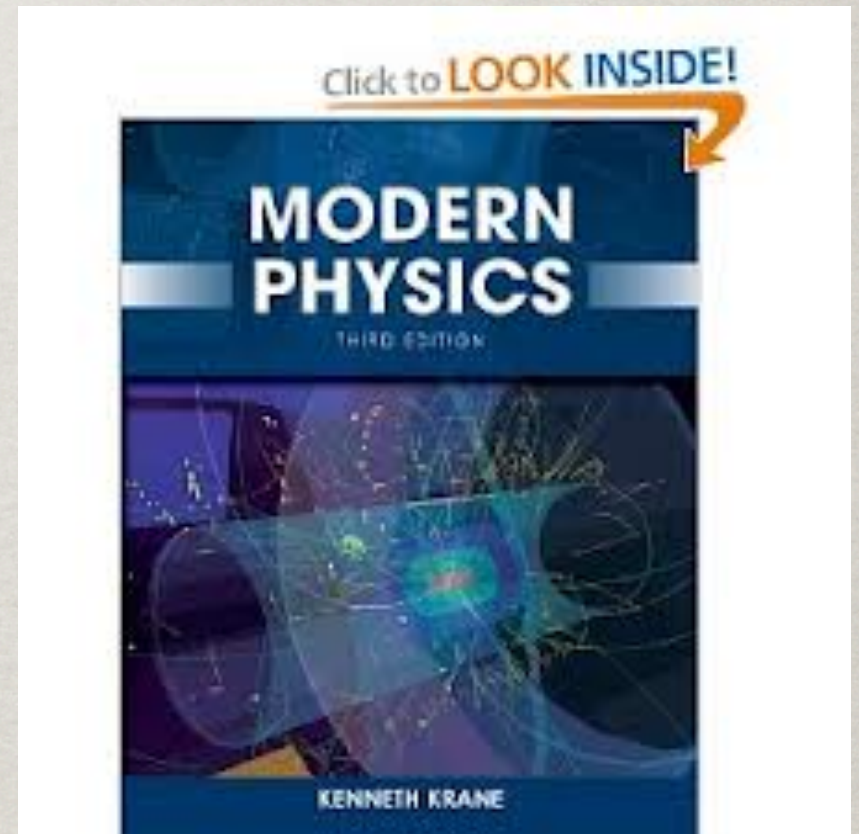
used / older edition OK

☀ calculator

basic with trig/log

graphing unnecessary

☀ paper & writing implement





# USEFUL THINGS

Purcell, Edward M. *Electricity and Magnetism*. In Berkeley Physics Course. 2nd ed. Vol. 2. New York, NY: McGraw-Hill, 1984. ISBN: 9780070049086. (E&M review, higher level than Serway)

Feynman, Richard P., Robert B. Leighton, and Matthew Sands. *The Feynman Lectures on Physics*. 2nd ed. Vol. 2. Reading, MA: Addison-Wesley, 2005. ISBN: 9780805390452. (General goodness)


For some material (e.g., optics and circuits) we will make use of supplemental online notes from PH102, which you can find there:


<http://faculty.mint.ua.edu/~pleclair/ph102/Notes/>

(also: online notes of some kind posted for many lectures)



# SHOWING UP

 we hope you will find some utility in the class

 homework / exams may rely on stuff I say in class

 missing an exam is seriously bad.

acceptable reason ... makeup or weight final



# BLACKBOARD

☀ posting of HW, notes, grades

☀ course calendar

☀ that's probably about all we'll do with it

☀ if you are not on the roster, see me after class



# SCHEDULE

- ☀ Online calendar ... will try to keep up the pace
- ☀ Spreadsheet of dates / topics / reading also posted
- ☀ For Tuesday:
  - read Ch. 1, and Ch. 2 at least through 2.4
  - or- read online notes from PH102



# QUICK ADVERTISEMENTS:

## PHY-EE DOUBLE MAJOR

- ✻ Electrical and Computer Engineering majors need ~ 4 additional hours to complete a second major in Physics.
- ✻ This combination of fundamental and applied physics can be highly advantageous when the graduate enters the job market.



# TODAY

- ✻ “Review” of classical physics

- ✻ Relativity

  - ✻ why do we need it?

  - ✻ what are the basic principles?

  - ✻ how can we find a model consistent with them?



# OTHER

- ✻ Parking tickets start at \$25
- ✻ Calculus fluency *assumed* (through Cal II)



# The laws of classical physics, in brief

## I. Motion

$$\frac{d\vec{p}}{dt} = \vec{F} \quad \text{where} \quad \vec{p} = \frac{m\vec{v}}{\sqrt{1 - v^2/c^2}}$$

Newton, with Einstein's modification

## 2. Gravitation

$$\vec{F} = -G \frac{m_1 m_2}{r^2} \hat{r}_{12}$$



### 3. Conservation of charge

$$\vec{\nabla} \cdot \vec{j} = -\frac{d\rho}{dt}$$

(flux of current through closed surface) = - (rate of change of charge inside)

any conservation of stuff:

(net flow of stuff out of a region) =  
(rate at which amount of stuff inside region changes)



## 4. Maxwell's equations

$$\vec{\nabla} \cdot \vec{\mathbf{E}} = \frac{\rho}{\epsilon_r \epsilon_0} \quad (\text{flux of E thru closed surface}) = (\text{charge inside})$$

$$\vec{\nabla} \cdot \vec{\mathbf{B}} = 0 \quad (\text{flux of B thru closed surface}) = 0$$

$$\vec{\nabla} \times \vec{\mathbf{E}} = -\frac{\partial \vec{\mathbf{B}}}{\partial t} \quad \begin{array}{l} (\text{circulating E}) = (\text{time varying B}) \\ (\text{line integral of E around loop}) = -(\text{change of B flux through loop}) \end{array}$$

$$\epsilon_0 c^2 \vec{\nabla} \times \vec{\mathbf{B}} = \vec{\mathbf{j}} + \epsilon_r \frac{\partial \vec{\mathbf{E}}}{\partial t}$$

$$\begin{array}{l} (\text{circulating B}) = (\text{time varying E}) \\ (\text{integral of B around loop}) = (\text{current through loop}) + (\text{change of E flux through loop}) \end{array}$$



## 4. Maxwell's equations (alt)

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_r \epsilon_0}$$

Gauss: electric charge = source of electric fields

$$\vec{\nabla} \cdot \vec{B} = 0$$

There are no magnetic charges

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

Faraday: time-varying B makes a circulating E

$$\epsilon_0 c^2 \vec{\nabla} \times \vec{B} = \vec{j} + \epsilon_r \frac{\partial \vec{E}}{\partial t}$$

Ampere: currents and time-varying E make B

## 5. Force law

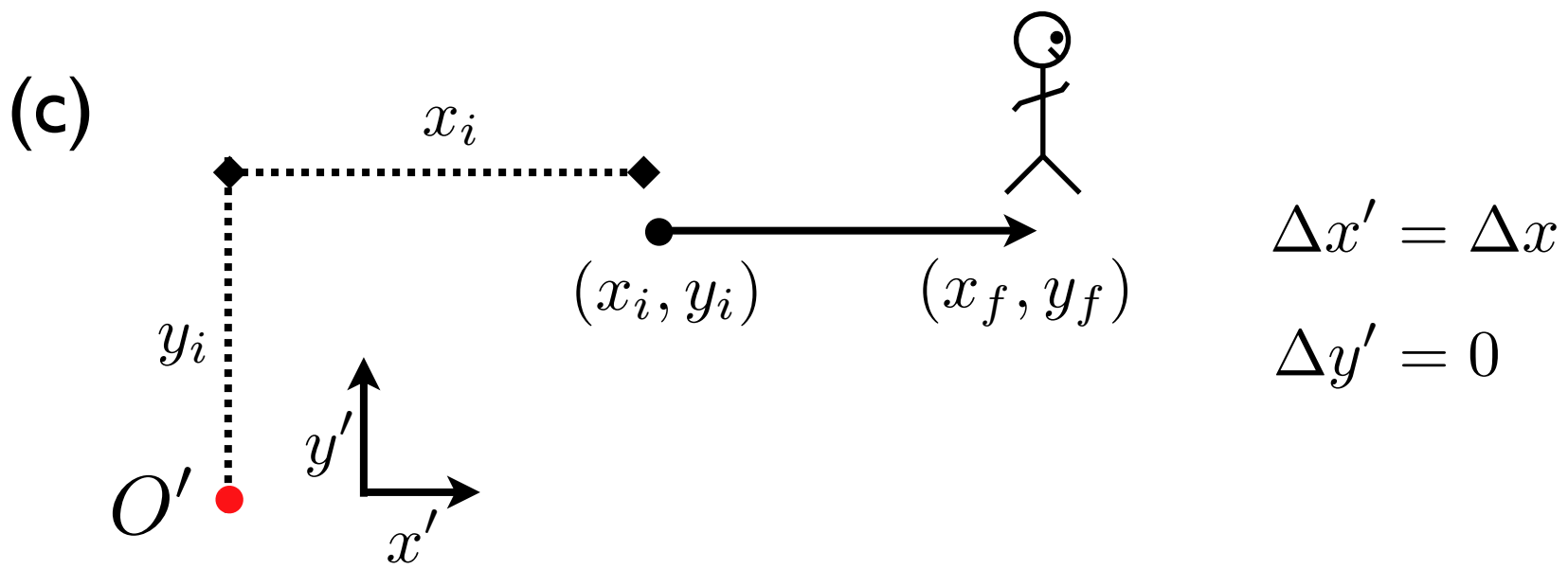
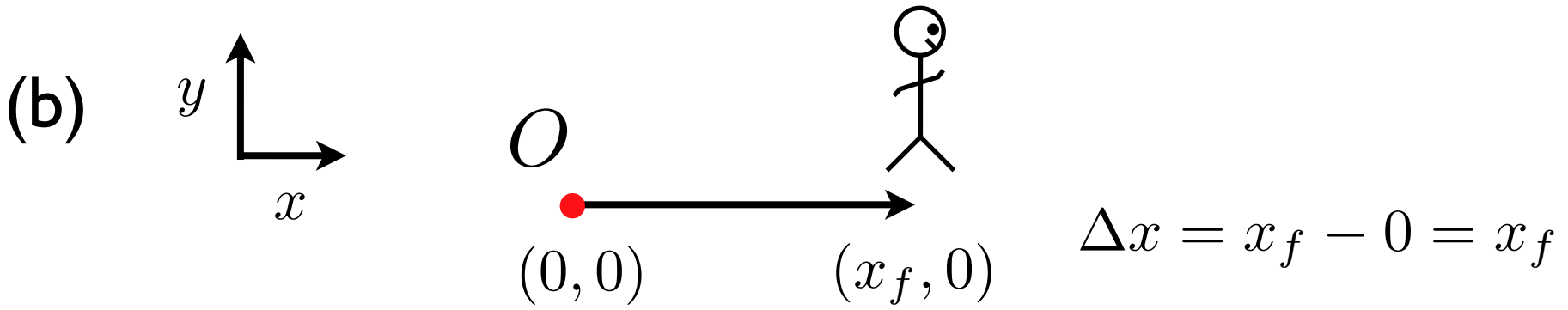
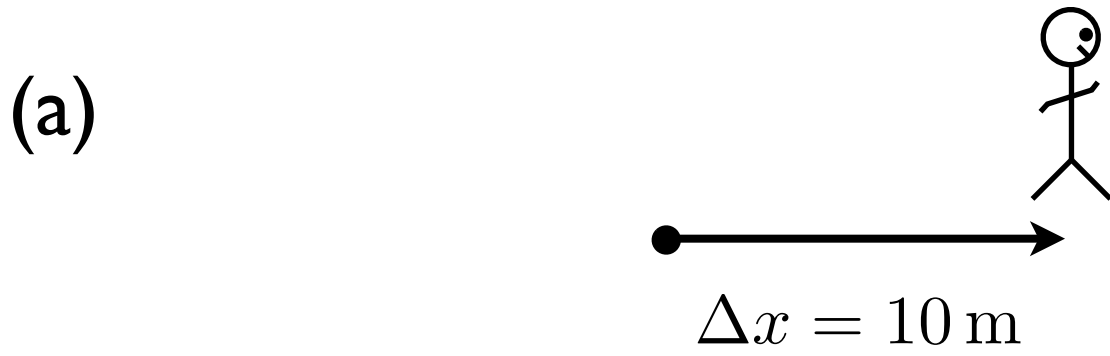
$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$



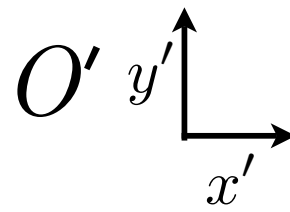
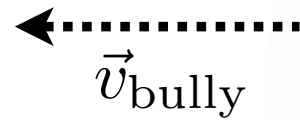
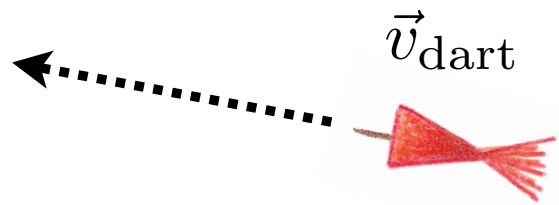
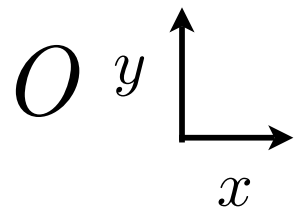
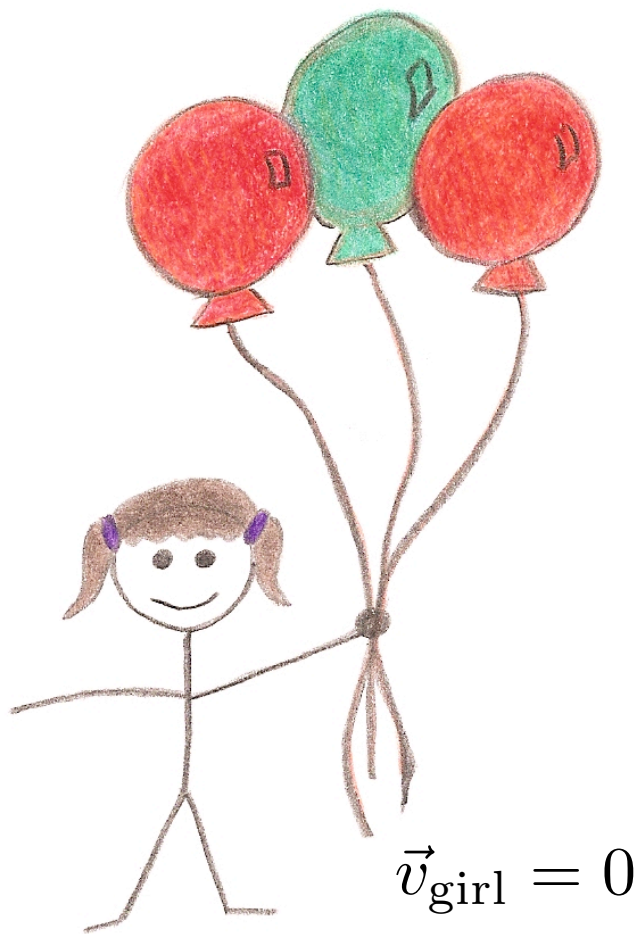
**And that's all of it!**

**Of course, the solutions are tougher ...**



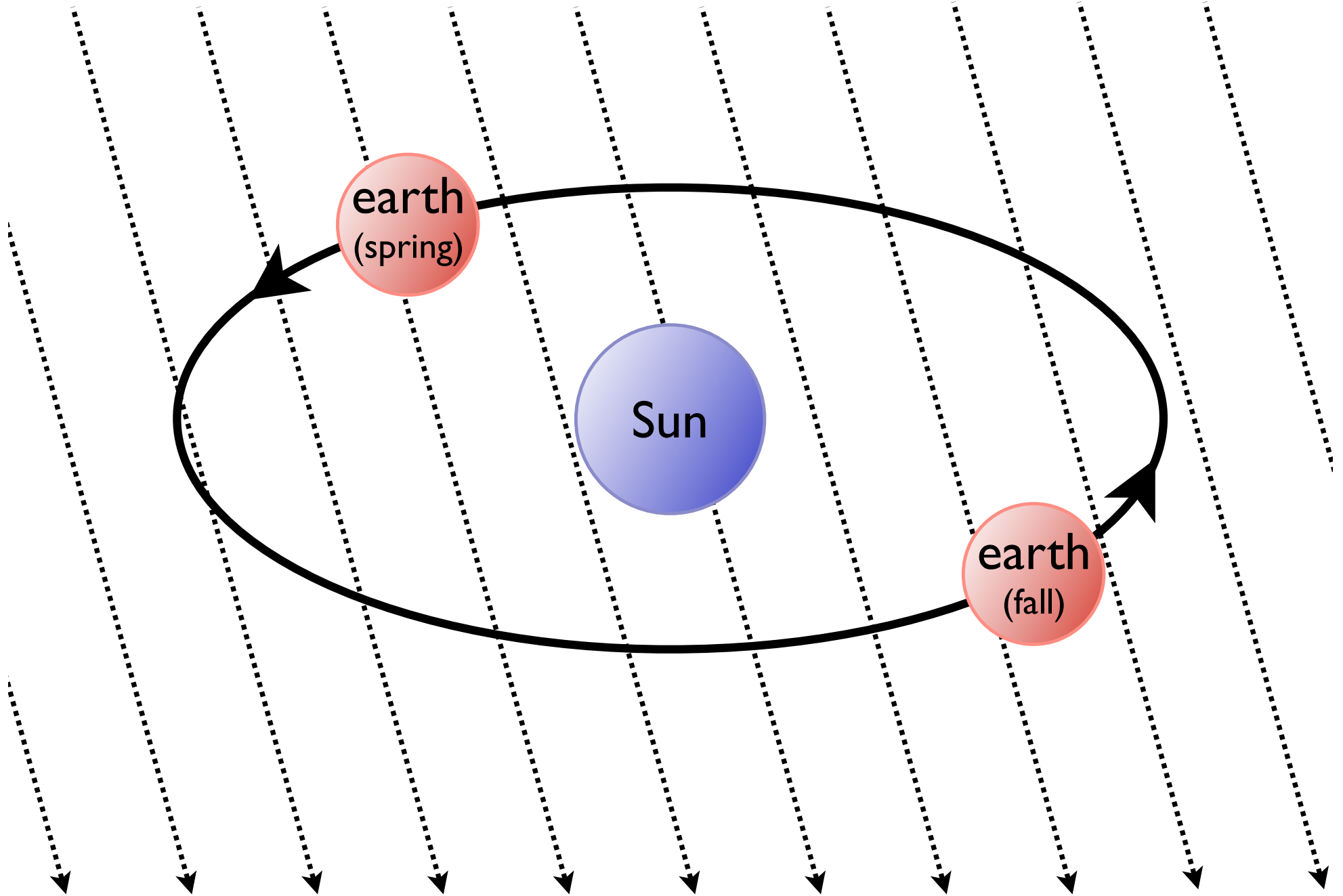




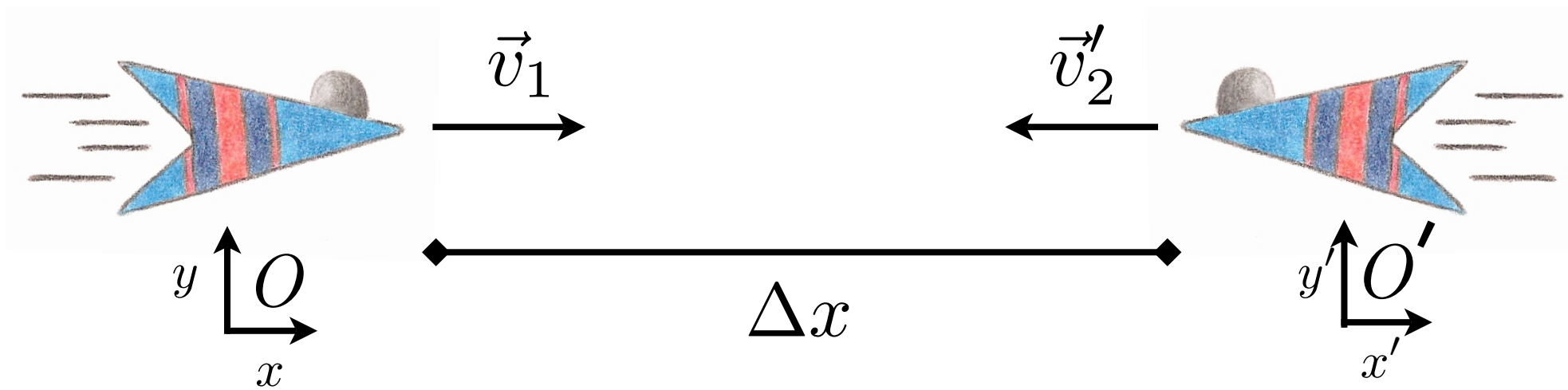




Luminiferous æther

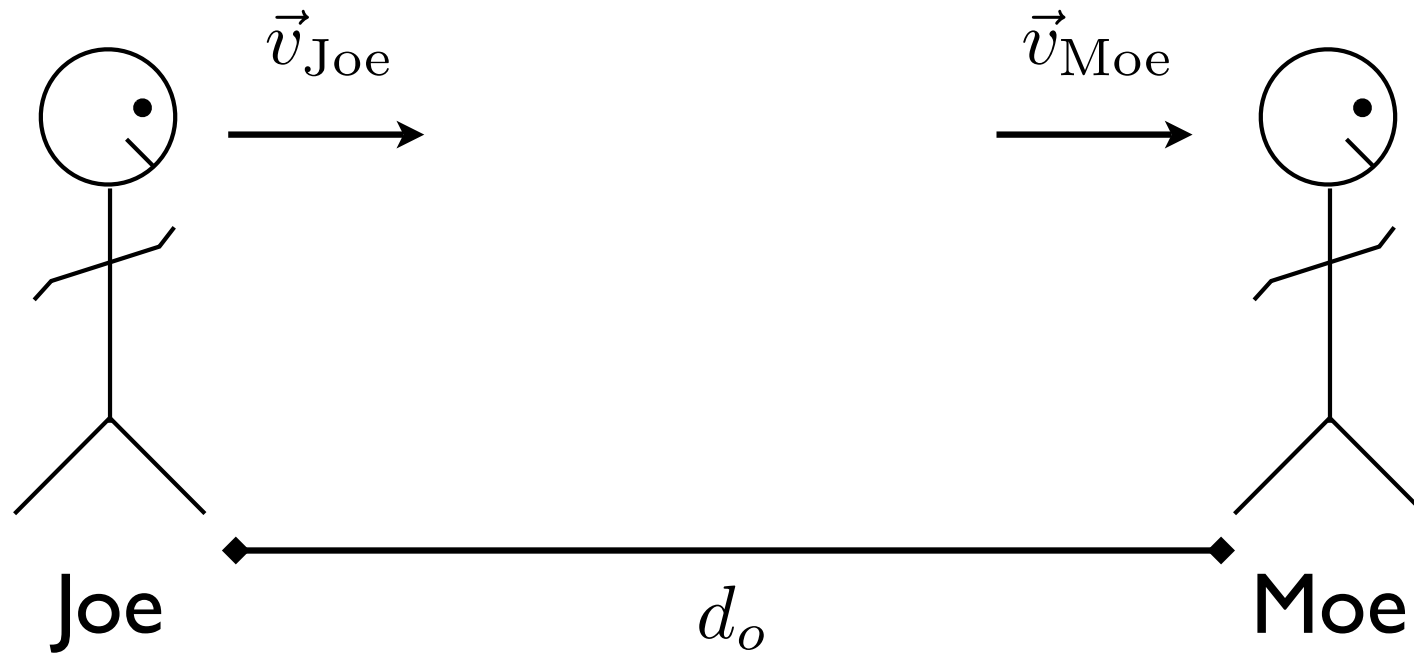








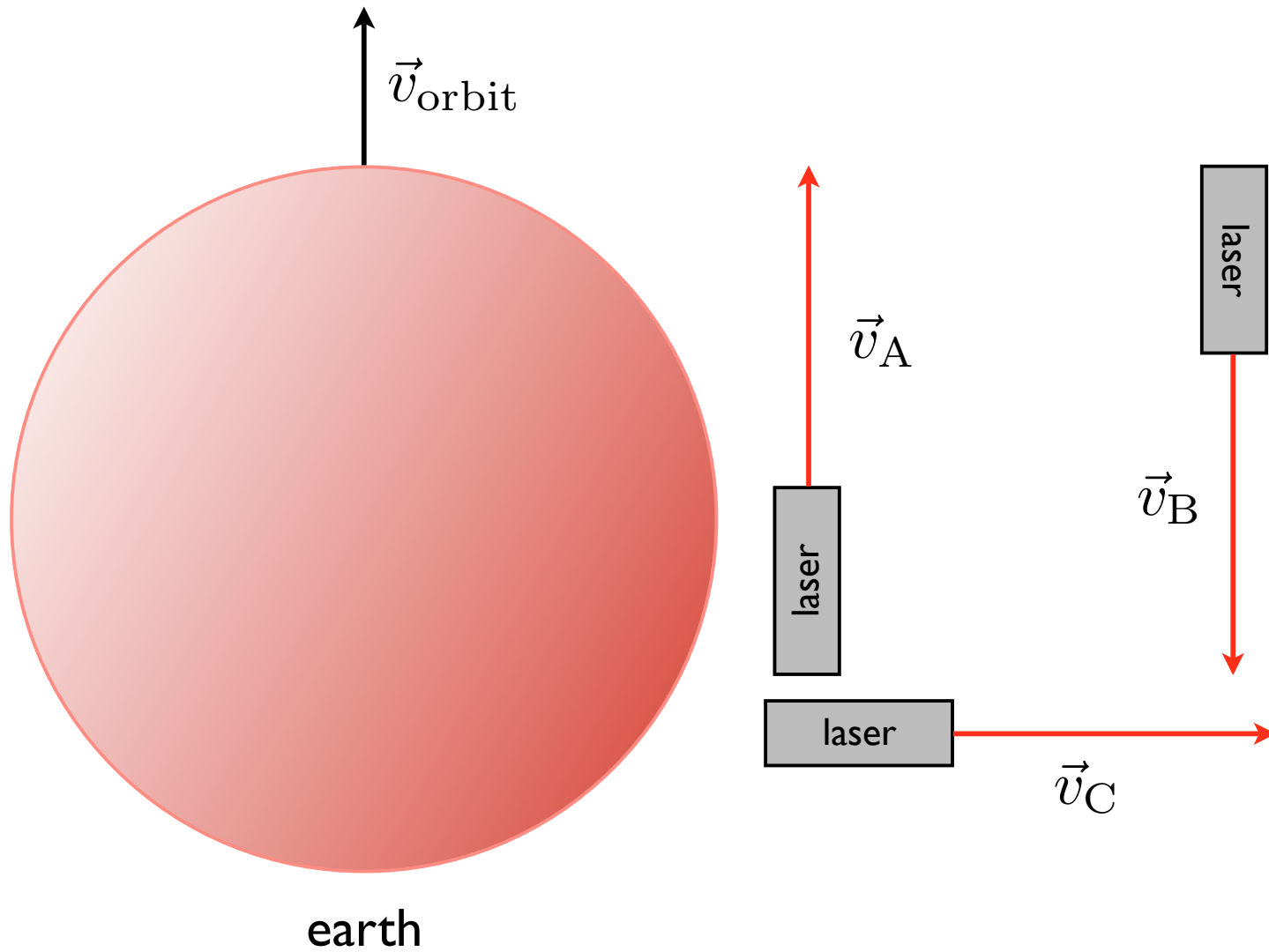
really the same situation - we just  
assume the ground is 'special'



## Choosing a coordinate system:

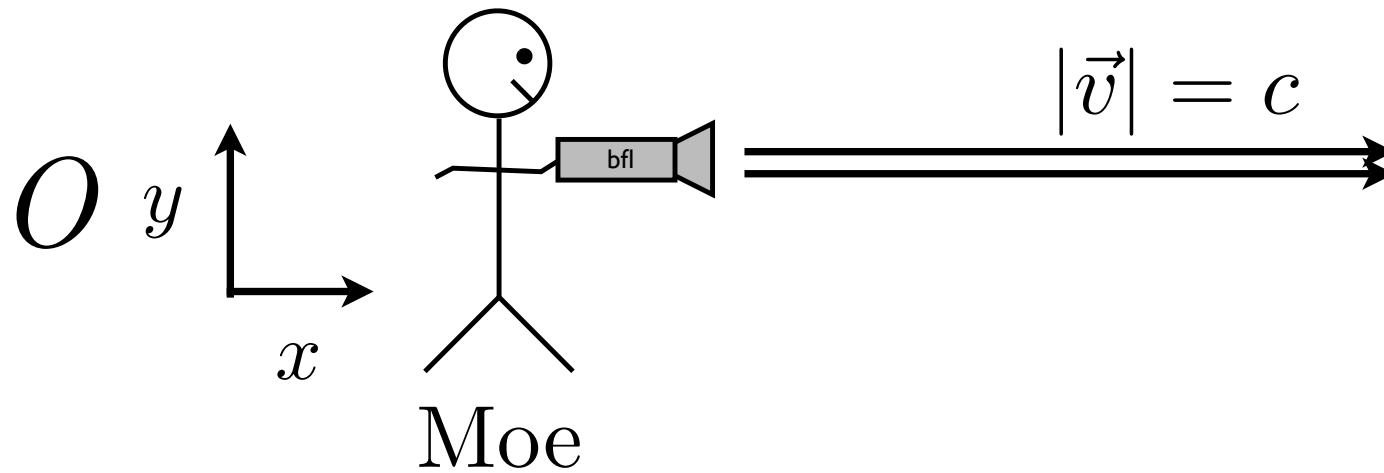
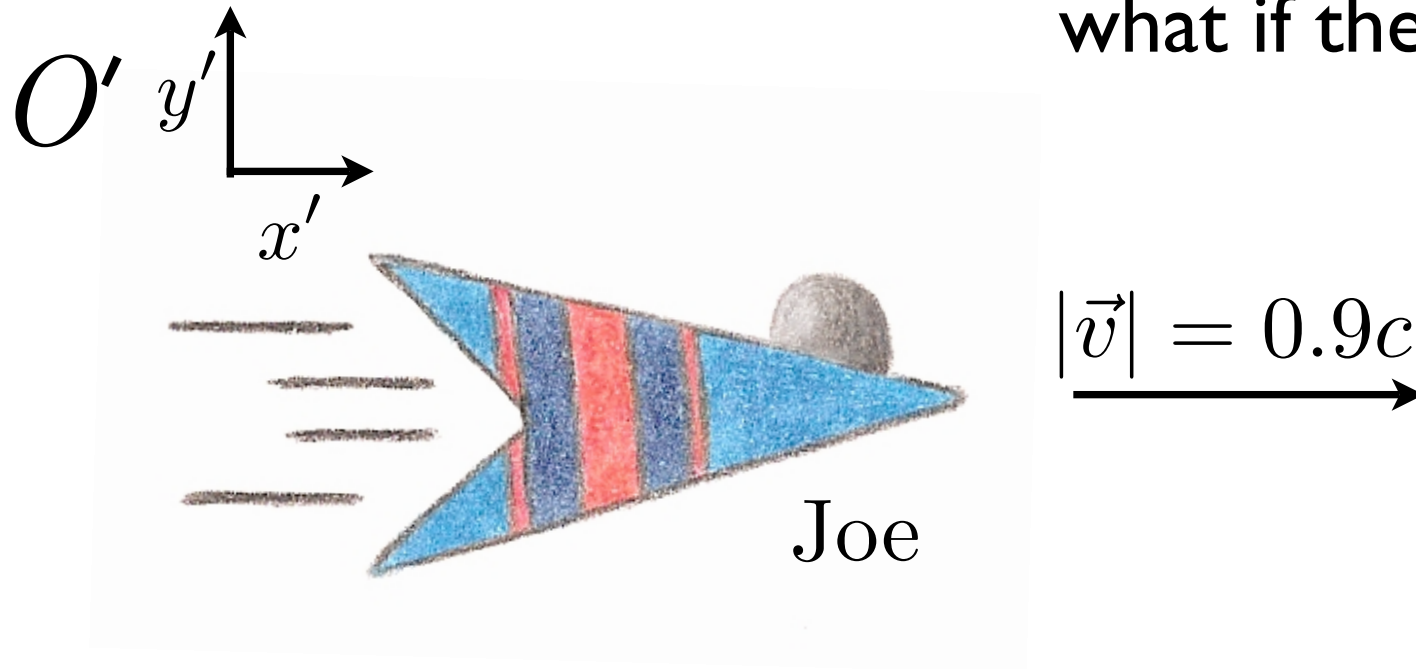
1. Choose an origin. This may coincide with a special point or object given in the problem - for instance, right at an observer's position, or halfway between two observers. Make it convenient!
2. Choose a set of axes, such as rectangular or polar. The simplest are usually rectangular or *Cartesian*  $x$ - $y$ - $z$ , 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.



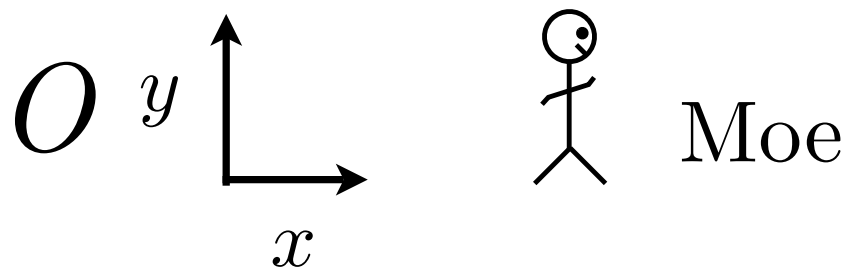
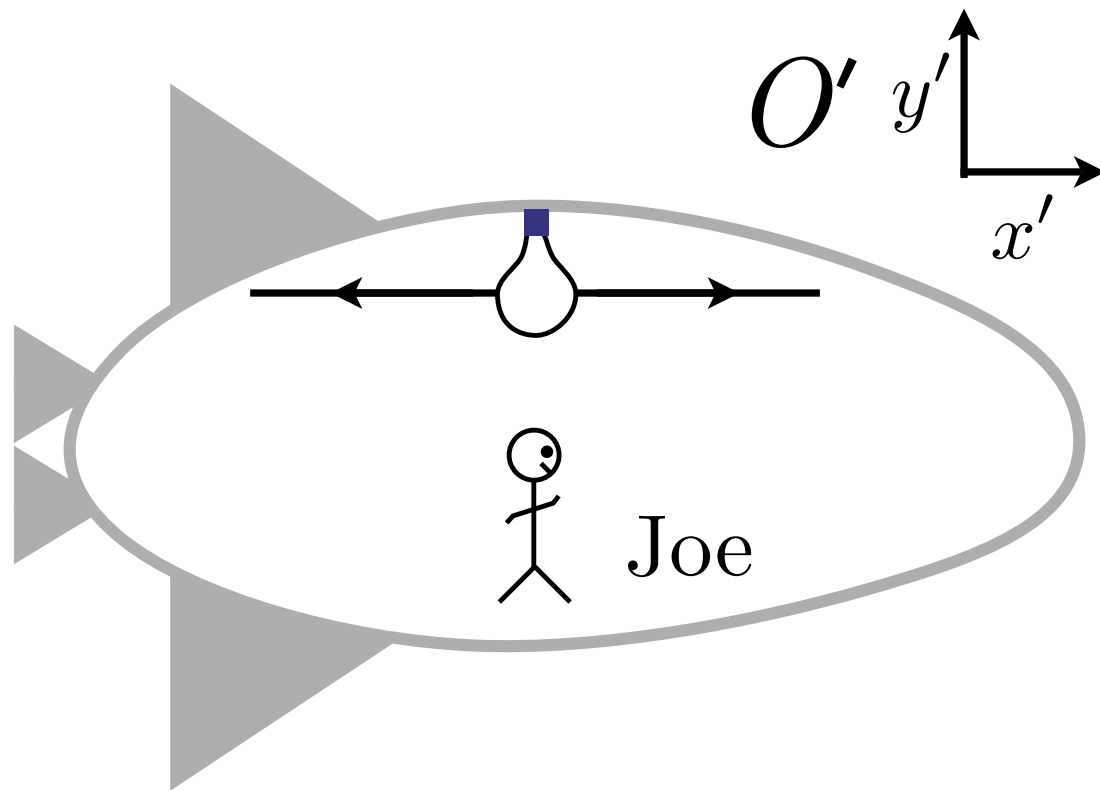


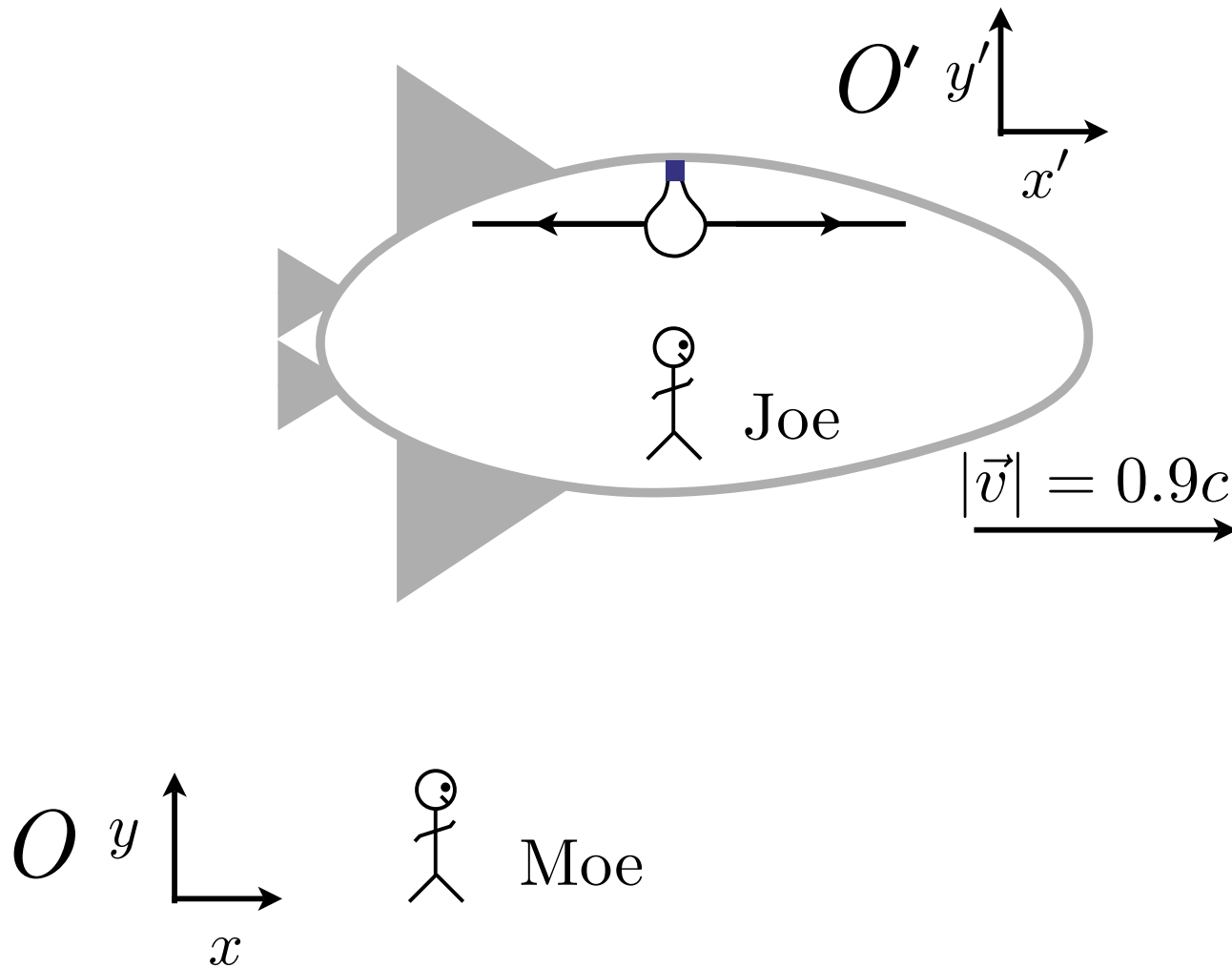
no difference  
can't measure earth's velocity  
relative to empty space

do they agree on speed of light?  
what if they don't?



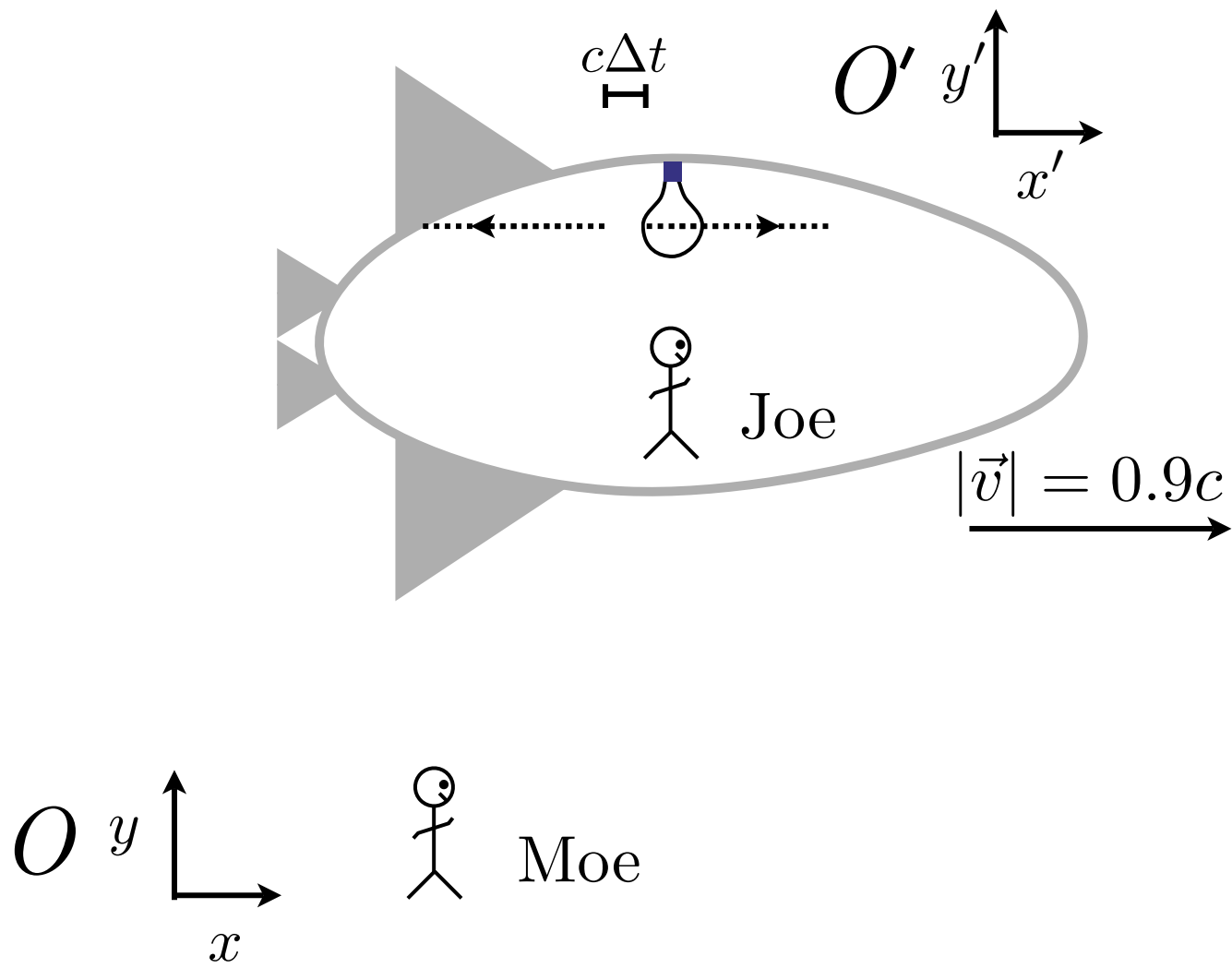




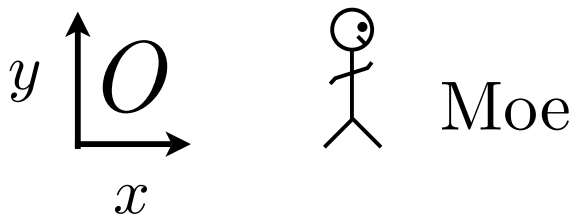
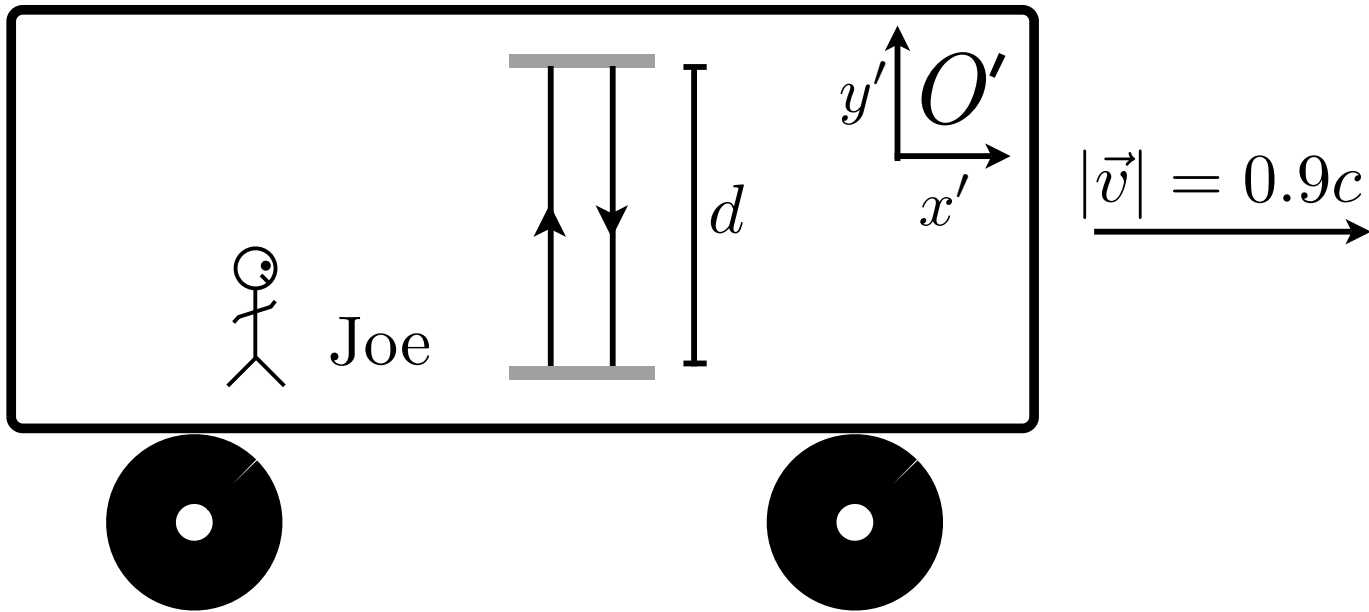


Joe flips on the light  
he sees the light hit  
the walls at the same time



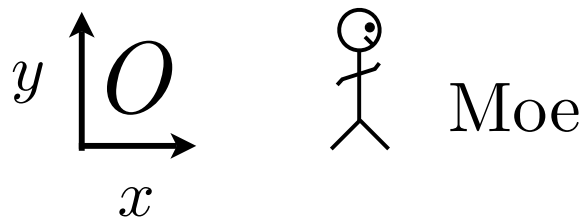
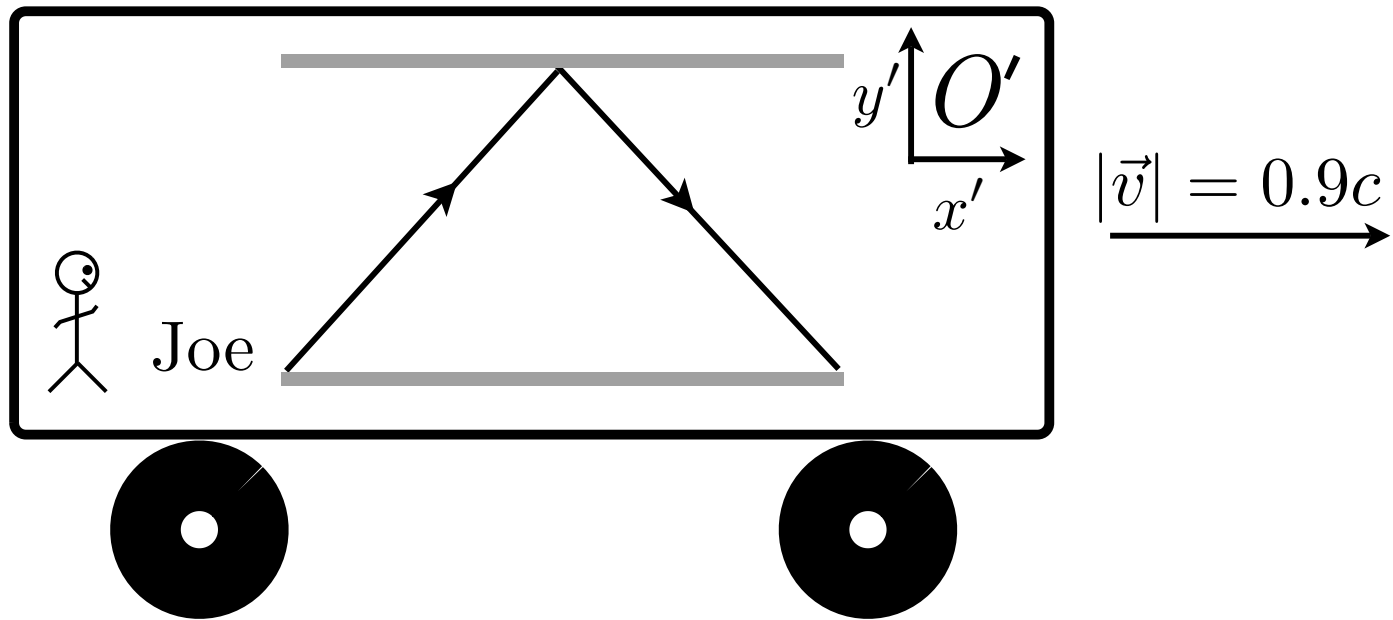


What does Moe see?  
 the ship moved;  
 the origin of the light did not

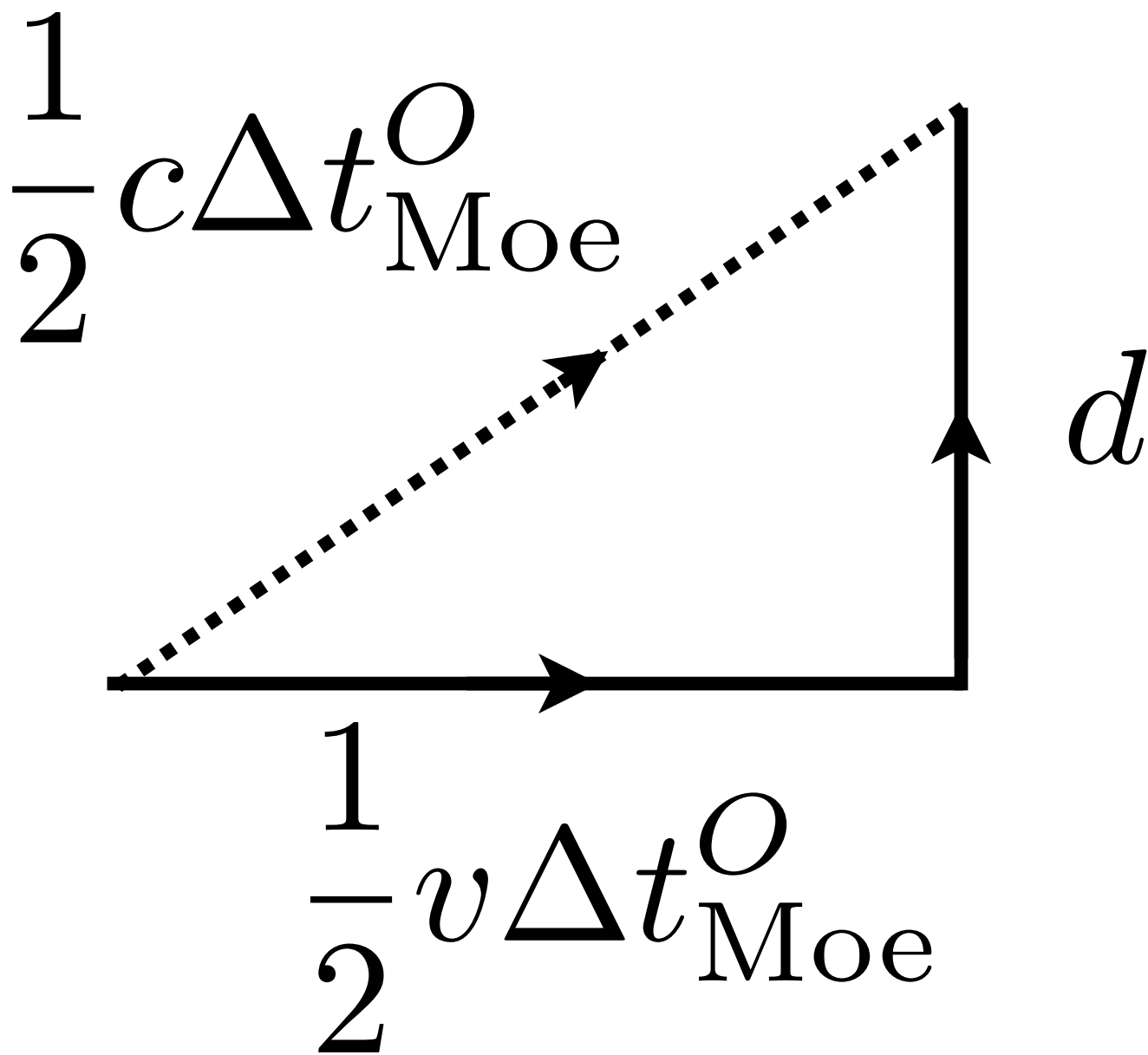


Joe bounces a laser off of some mirrors  
he counts the round trips  
this measures distance





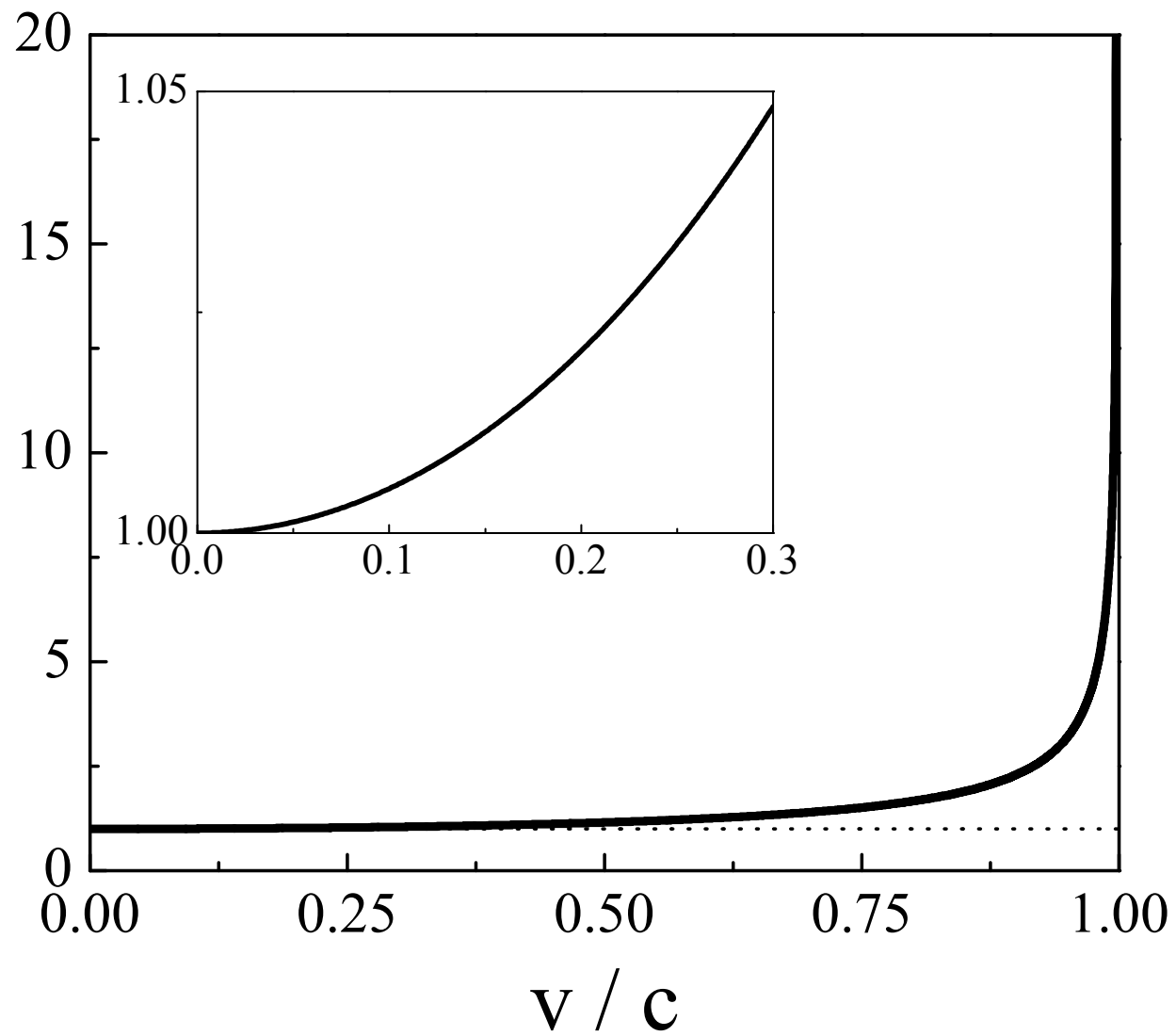
Moe sees the boxcar move;  
 once the light is created, it does not.  
 Moe sees a triangle wave

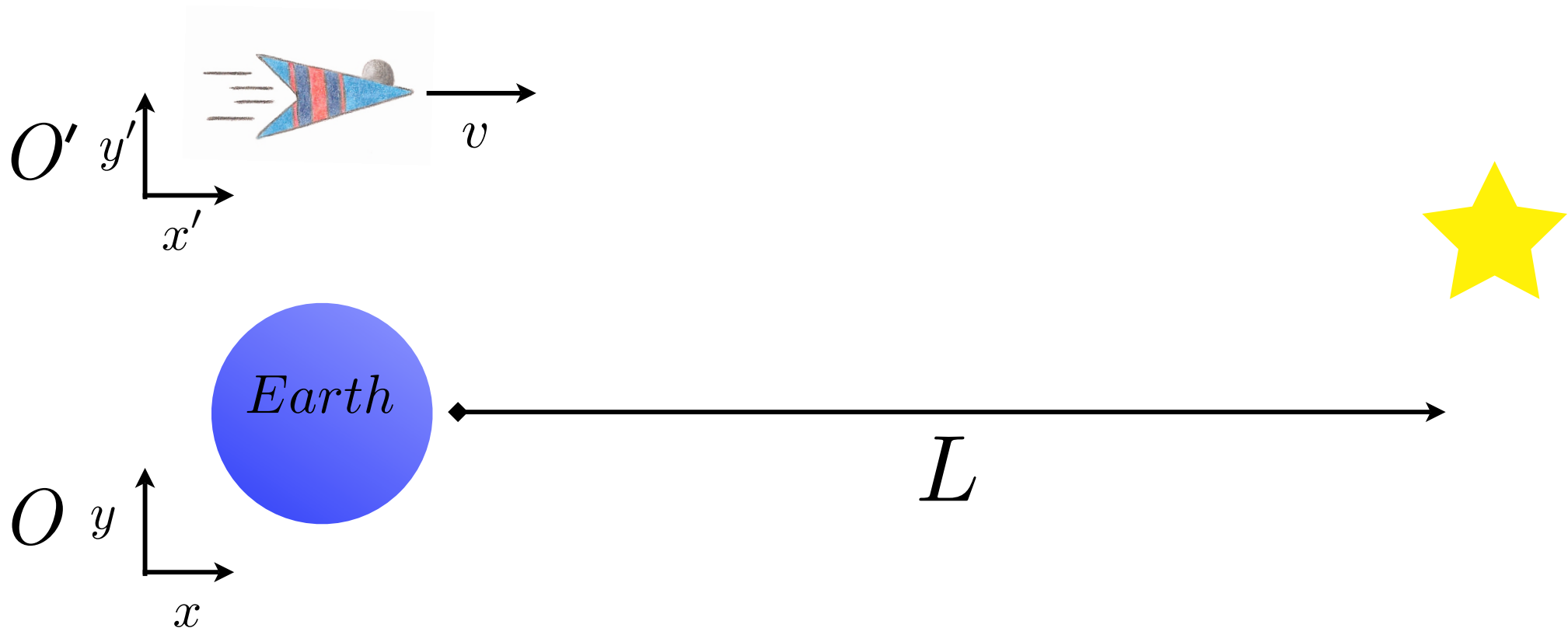




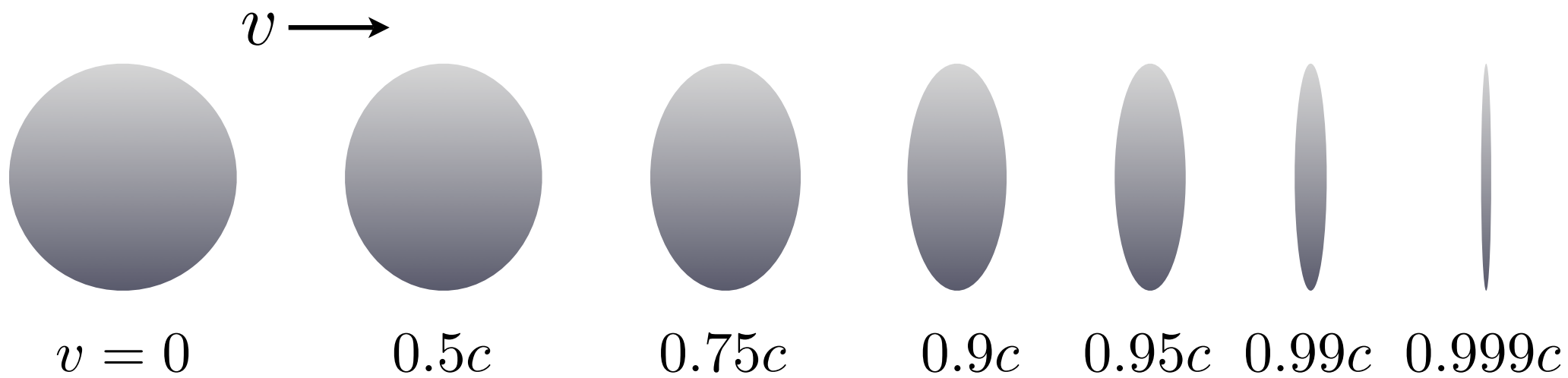
$v$ [m/s]	$\frac{v}{c}$	$\gamma$	$1/\gamma$
0	0	0	$\infty$
$3 \times 10^6$	0.01	1.00005	0.99995
$3 \times 10^7$	0.1	1.005	0.995
$6 \times 10^7$	0.2	1.02	0.980
$1.5 \times 10^8$	0.5	1.16	0.866
$2.25 \times 10^8$	0.75	1.51	0.661
$2.7 \times 10^8$	0.9	2.29	0.436
$2.85 \times 10^8$	0.95	3.20	0.312
$2.97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

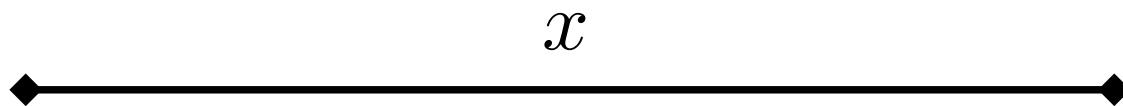
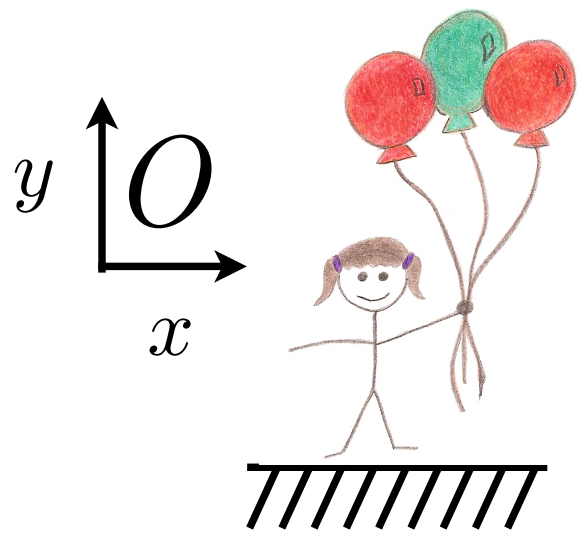
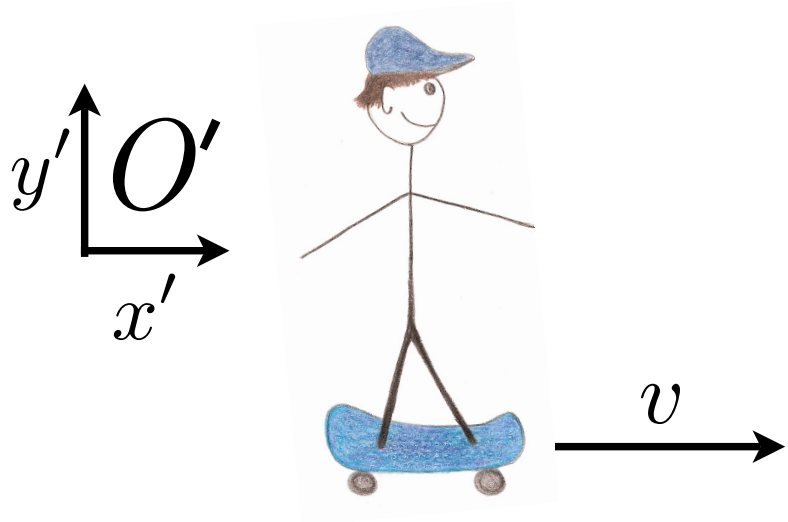
$\gamma$











## Transformation of distance between reference frames:

$$x' = \gamma(x - vt) \quad (1.3)$$

$$x = \gamma(x' + vt') \quad (1.3)$$

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  $x'$  and time  $(x', t')$ .

## Time measurements in different non-accelerating reference frames:

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

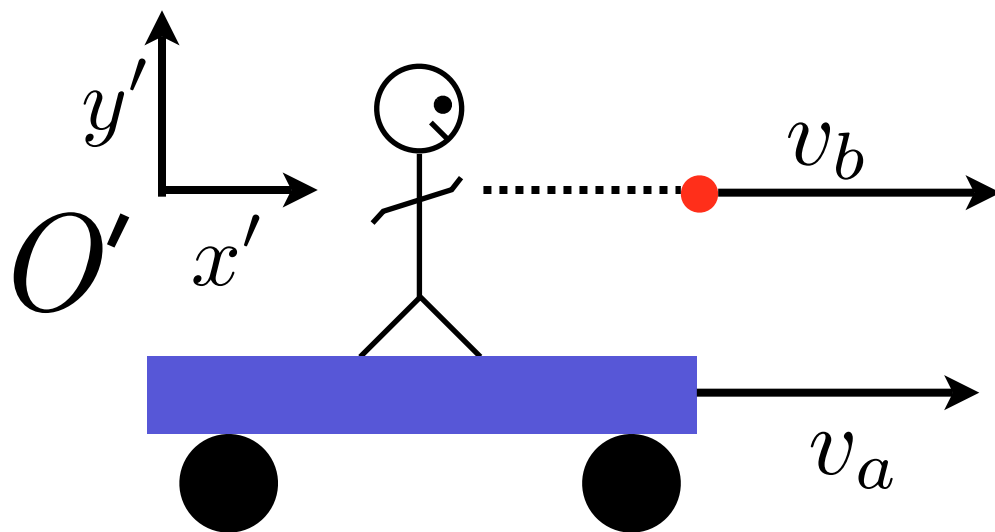
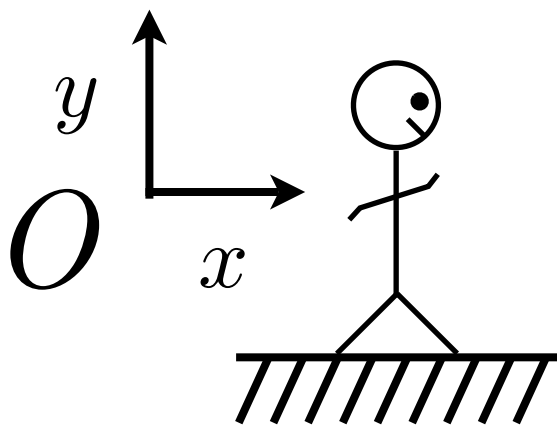
$$t = \gamma\left(t' + \frac{vx'}{c^2}\right) \quad (1.47)$$

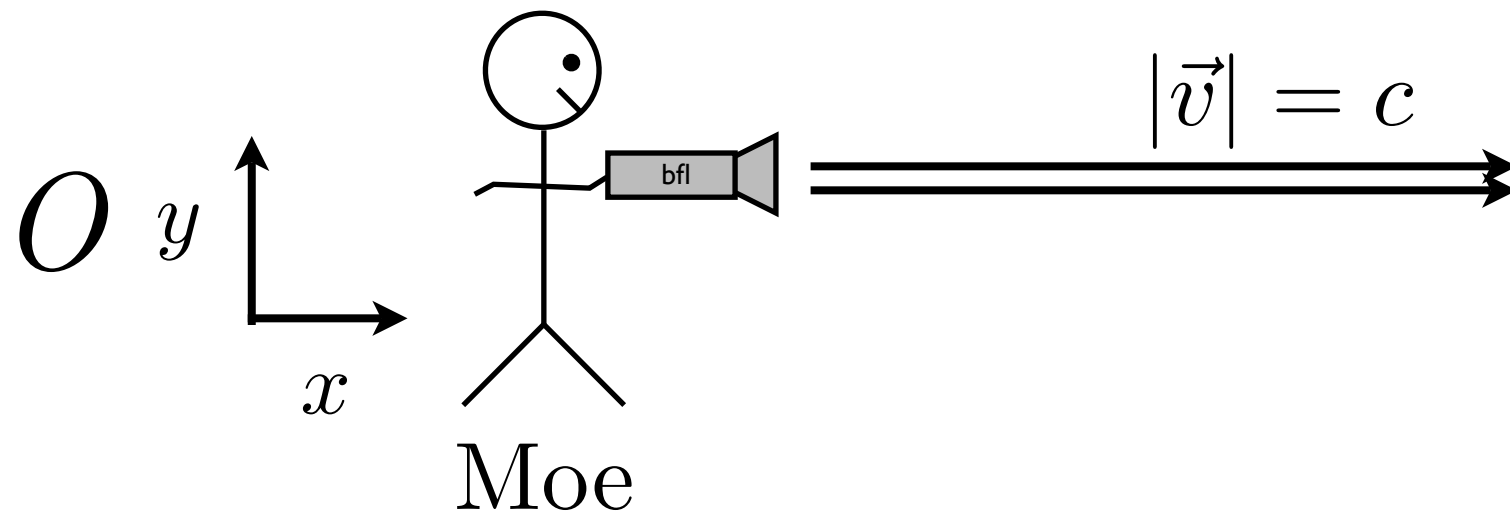
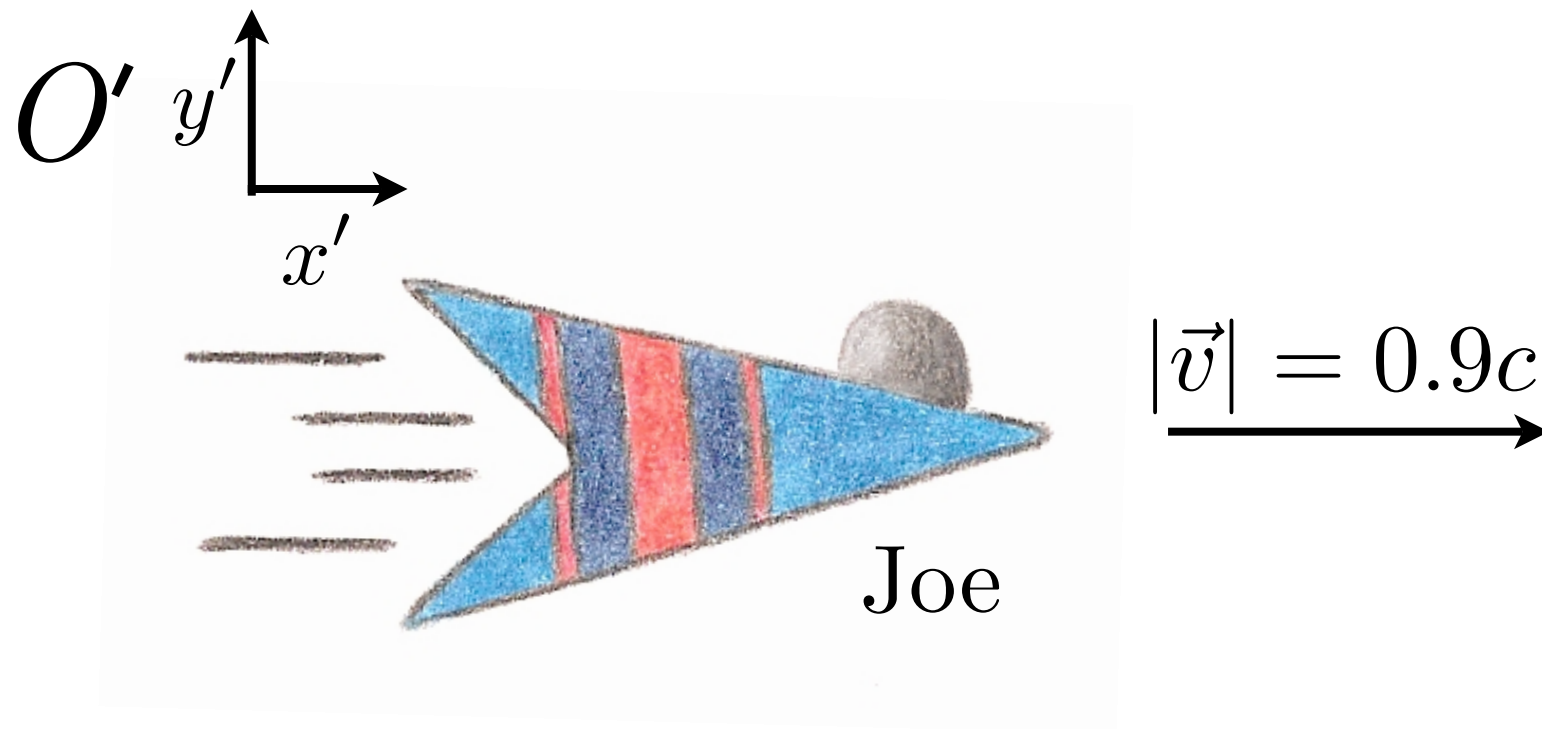
Here  $(x, t)$  is the position and time of an event as measured by an observer in  $O$  stationary to it. A second observer in  $O'$ , moving at velocity  $v$ , measures the same event to be at position  $x'$  and time  $(x', t')$ .

## Elapsed times between events in non-accelerating reference frames:

$$\Delta t' = t'_1 - t'_2 = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right) \quad (1.4)$$







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'  $\Delta t_p$  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:

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

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**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.

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



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- no; yes
- no; no
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- 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,  $\Delta t_p = 3.00$  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  $\gamma$ :

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

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!*)

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

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- 6.00 sec
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- 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  $4.0\text{ s}$ , in probe time, to rotate through  $1.0\text{ rev}$ . How much time is required for  $1.0\text{ rev}$  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  $24\text{ m}$  long and that the identical ship you are sitting in is  $18\text{ m}$  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.

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**7. 8.42 s.** The time interval in the probe's reference frame is the proper one  $\Delta t_p$  ... 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  $\gamma$ . 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  $\Delta t_p$  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  $4.0\text{ s}$ , in probe time, to rotate through  $1.0\text{ rev}$ . How much time is required for  $1.0\text{ rev}$  according to an observer on Earth?

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(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  $L'$ :

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