INTRODUCTION TO MODERN PHYSICS

Welcome to Phy 3305

5th Solvay Conference on electrons and photons

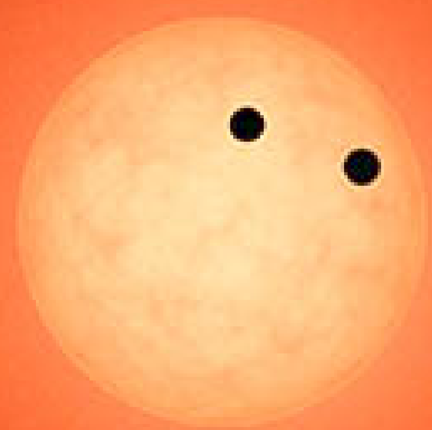
<u>**17 Nobel prize**</u> winners in the photo

Professor Jodi Cooley

SMU Honors Physics (PHYS 1010)

Prof. Stephen Sekula ♦ Christopher Milke

Let us take a trip to an alien world



First Meeting: Aug. 22, 6:15pm, FOSC 60

Free Food!

PHYS 1010 ♦ **www.physics.smu.edu/sekula/honors**

- Zero-credit-hour add-on to introductory physics sequence
- Meets once per week (6:15pm – 7:30pm)
- 1 team-based semester-long project
- Earn "Honors" designation on transcript
- Learn physics by subject immersion

ANNOUNCEMENTS

- Reading Assignments:
  Chapter 1 (all) and Chapter 2.1 - 2.3
- First homework assignment was given out today and is due Tuesday, August 29th.
- Read the homework policy!
- Read the syllabus!
- Read the hand out on sig figs!

COURSE INSTRUCTOR

Professor Jodi Cooley

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Mr. James Thomas
jamesthomas@smu.edu

COURSE INSTRUCTOR

Professor Jodi Cooley

Office: 151 Fondren Science

cooley@physics.smu.edu

AVAILABILITY

Course: Tues & Thurs. 12:30 - 1:50 pm

Office Hours:

TBD

Fill out doodle poll by NOON on Wednesday (Aug. 22).

http://doodle.com/poll/72sm895av3wk2gpn

NOTE: This course does not use blackboard.

COURSE WEBSITE

http://www.physics.smu.edu/cooley/phy3305/

TEXTBOOK

Modern Physics by Randy Harris (2nd Edition)

I also recommend that you consider purchasing a mathematical handbook (i.e. Schaum's Outline Series: Mathematical Handbook of Formulas and Tables by Murray R. Spiegel, 3rd. edition)

EXTRA CREDIT - SEE HANDOUT

Free one-year membership to APS gives subscription to Physics Today!

https://www.aps.org/membership/student.cfm

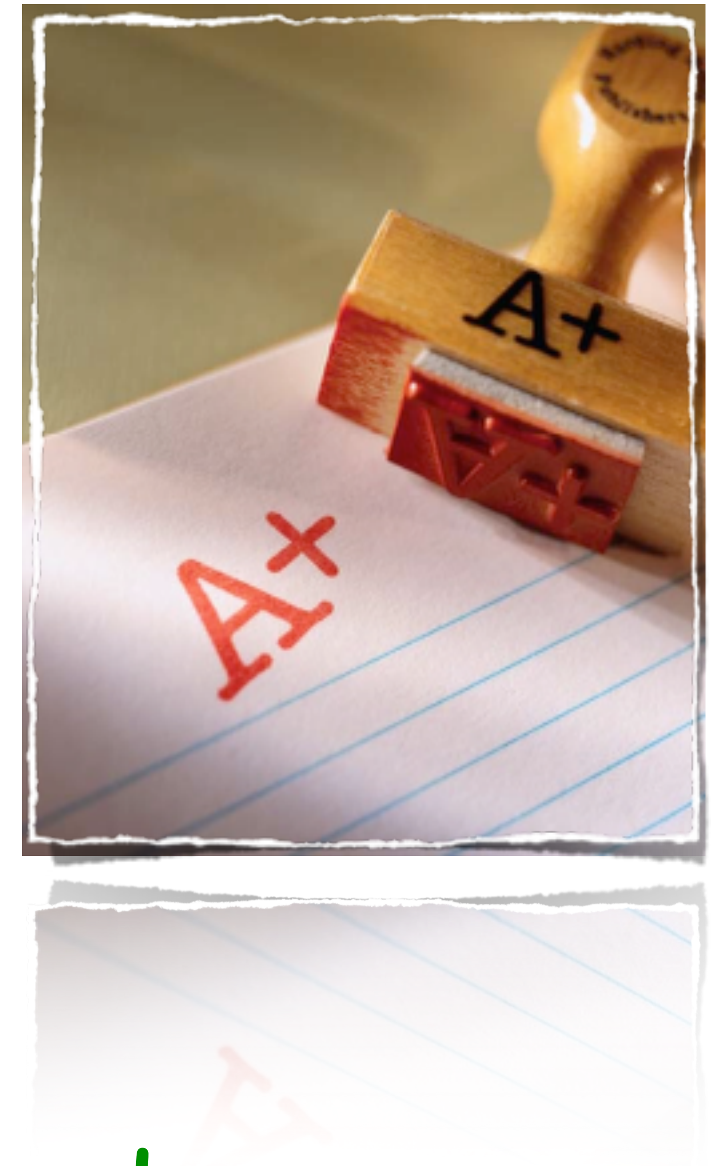
SURGEON GENERAL'S WARNING

a)Too much exposure to Modern Physics may cause severe headaches,

... ok not true, but:

- You have **ALL** been learning and doing classical physics for about 20 years
- **NONE** of you have had any first hand experience with modern physics
- Will be introduced to some counter-intuitive concepts
  - Do not expect to be able to do the problems on the very first try. Give it 3-4 legitimate tries before seeking help.
- Collaborating with classmates on solving problems is acceptable (in fact, it is encouraged!), but the solutions you hand in MUST be your own (see SMU Honor Code)
- **No credit for late homework.**
- ***Attendance:*** Judge for your self, ... how many SMU courses were you able to master by just staying at home and reading the book
- **Corollary:** Don't expect to be able to brush off the course for a whole semester and learn everything by cramming for a whole day prior to the exam, it also doesn't work to eat burgers all semester expect to lose 10 lbs by going to the gym for 24 hrs straight?

HOW TO DO WELL IN THE COURSE



a) Do all the homework sets!

b) Study in small groups (make sure you're contributing to the group as much as your absorbing from it)

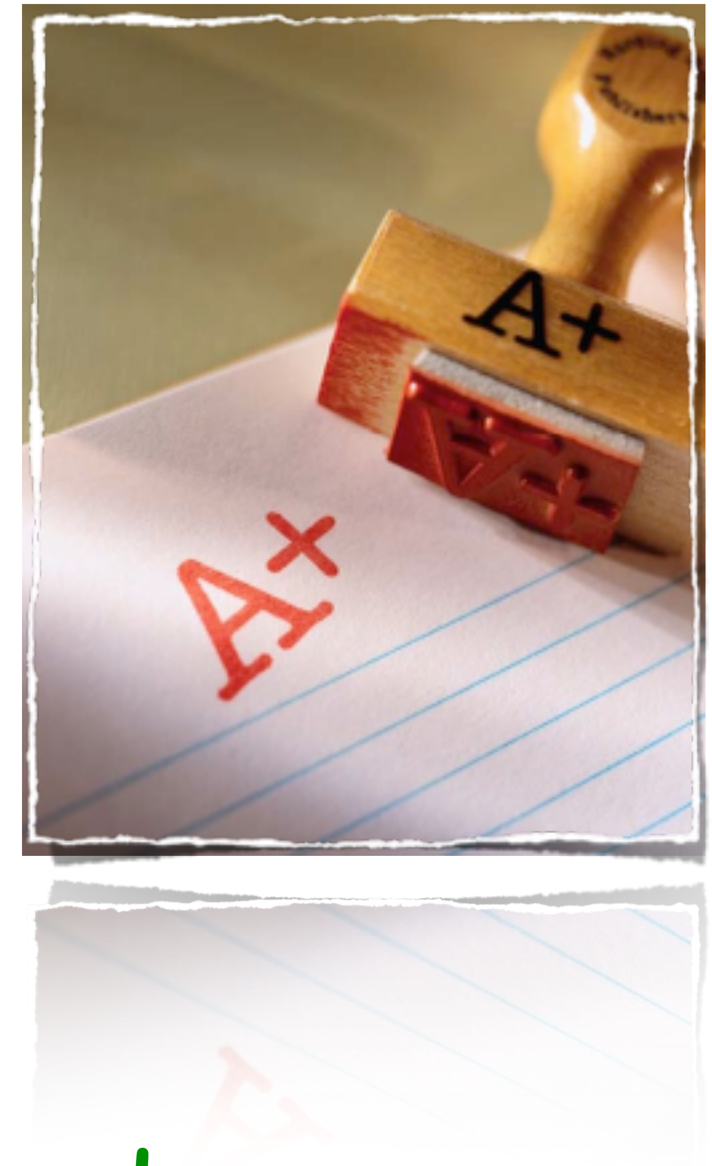
c) Come to class

d) Don't waste time on last minute all-nighters

Your Grade:

15% Homework
5% Quizzes
40% Midterm exams
20 % Presentation
20 % Final Exam

HOW TO DO WELL IN THE COURSE



Everyone has a chance to earn an A in this class. There is no 'curve'.

93%: A
85%: A-
80%: B+
75%: B
70%: B-
65%: C+
60%: C
55%: C-

Your Grade:

15% Homework
5% Quizzes
40% Midterm exams
20 % Presentation
20 % Final Exam

EXPECTATIONS

What to expect from me

- An interesting and thought provoking course
- Consideration and fairness (this does not mean easy!)
- Availability & approachability to talk to about any difficulties & questions
- Punctuality

What I expect from you

- Sincere effort
- Honesty
- Homework should follow the **homework guidelines** on the course website.
- Punctuality

TOPICS

- Special Relativity (ch 2)
- The Nature of Particles (ch 3 - 4)
- Quantum Mechanics (5 - 7)
- Atomic Physics & Spin (ch 8)
- Statistical Physics * (ch 9)
- Other Topics (student presentations)

* Time permitting

What is Plagiarism?

http://www.smu.edu/StudentAffairs/StudentLife/StudentHandbook/HonorCode

PLAGIARISM5 Intentionally or knowingly representing the words or ideas of another as one's own in any academic exercise.

5 In regards to cases of plagiarism, ignorance of the rules is not an excuse. The University subscribes to the statement on plagiarism which appears on page six of William Watt's An American Rhetoric (1955).S

PLAGIARISM

a)It is plagiarism to copy your homework from the Instructor Solution Manuel.

b)It is plagiarism to copy the homework from another student (current or previous).

c)It is plagiarism to copy the solutions to your homework from google.

d)Academic honesty means that you acknowledge your sources! This includes people in your study group.

I will report future incidents of plagiarism to the Honor Council. If you have any questions about academic honesty in this class, please feel free to talk to me during office hours.

THE CONSTITUTION OF THE HONOR COUNCIL OF SMU

PREAMBLE AND DEFINITIONS We, the students of Southern Methodist University, with the approval of the Provost and the Dean of Student Life, establish the Honor Council to uphold the standards of academic integrity set forth in the Honor Code. Acts punishable under the code include, but are not limited to the following:

ACADEMIC SABOTAGE Intentionally taking any action which negatively affects the academic work of another student.

CHEATING Intentionally[1] using or attempting to use unauthorized materials, information, or study aids in any academic exercise[2].

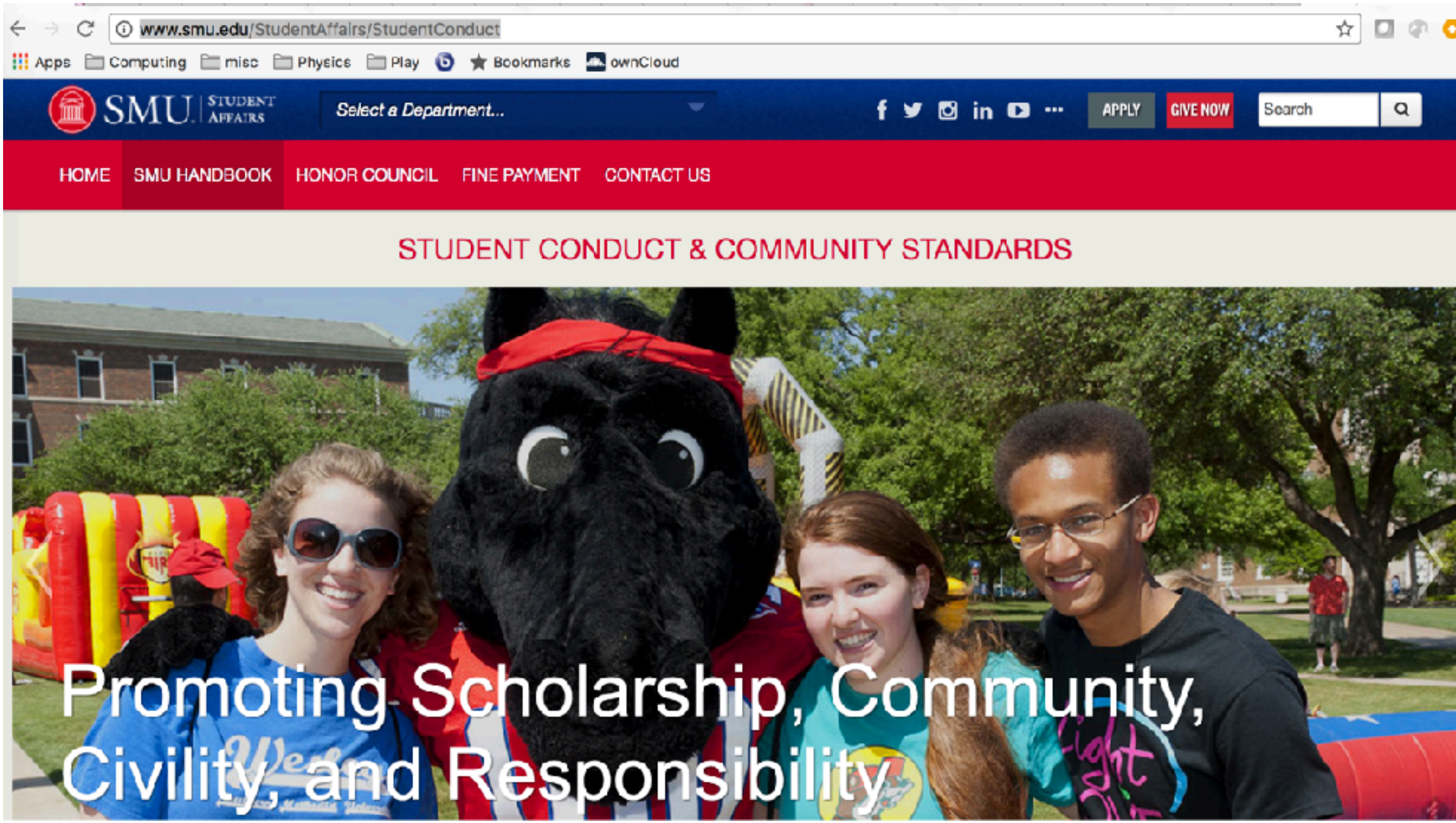
FABRICATION Intentional and unauthorized falsification or invention of any information or citation in an academic exercise[3].

FACILITATING ACADEMIC DISHONESTY Intentionally or knowingly helping or attempting to help another to violate any provision of the Honor Code[4].

PLAGIARISM[5] Intentionally or knowingly representing the words or ideas of another as one's own in any academic exercise.

STUDENT RESOURCES

http://www.smu.edu/StudentAffairs/StudentConduct



DETAILS

**In general you can expect the following schedule for assignments. However, you must pay attention as exam weeks and weeks when there are vacation days, assignment due dates may change.

Tuesdays:

- Homework is due.
- Homework is assigned for the following week.
- Regrade requests are due from assignment handed back on previous Thursday.

Thursdays:

- Graded homework is returned.
- Regraded homework is returned.

Note: In order for a problem to qualify for a regrade, you must have made an honest attempt of the problem on the original problem. Abuse of the regrade system will result in *NO* regrades for the entire class.

This semester in a classroom very close...

NEWTONIAN PHYSICS

Developed in the 1800's, extended forward 200 years. Force and acceleration are related to each other through inertial mass.

- Kepler's laws (accurate for many objects)
- Energy is a fundamental quantity that can not be created or destroyed, only transferred.
- Mass was recognized as a body's tendency to resist changes in motion (inertia).
- Light identified as a wave phenomenon.
- Electricity and magnetism were revealed as two faces of the same underlying phenomenon - Electromagnetism. All electric and magnetic phenomenon could be described as waves.

NEWTONIAN PHYSICS

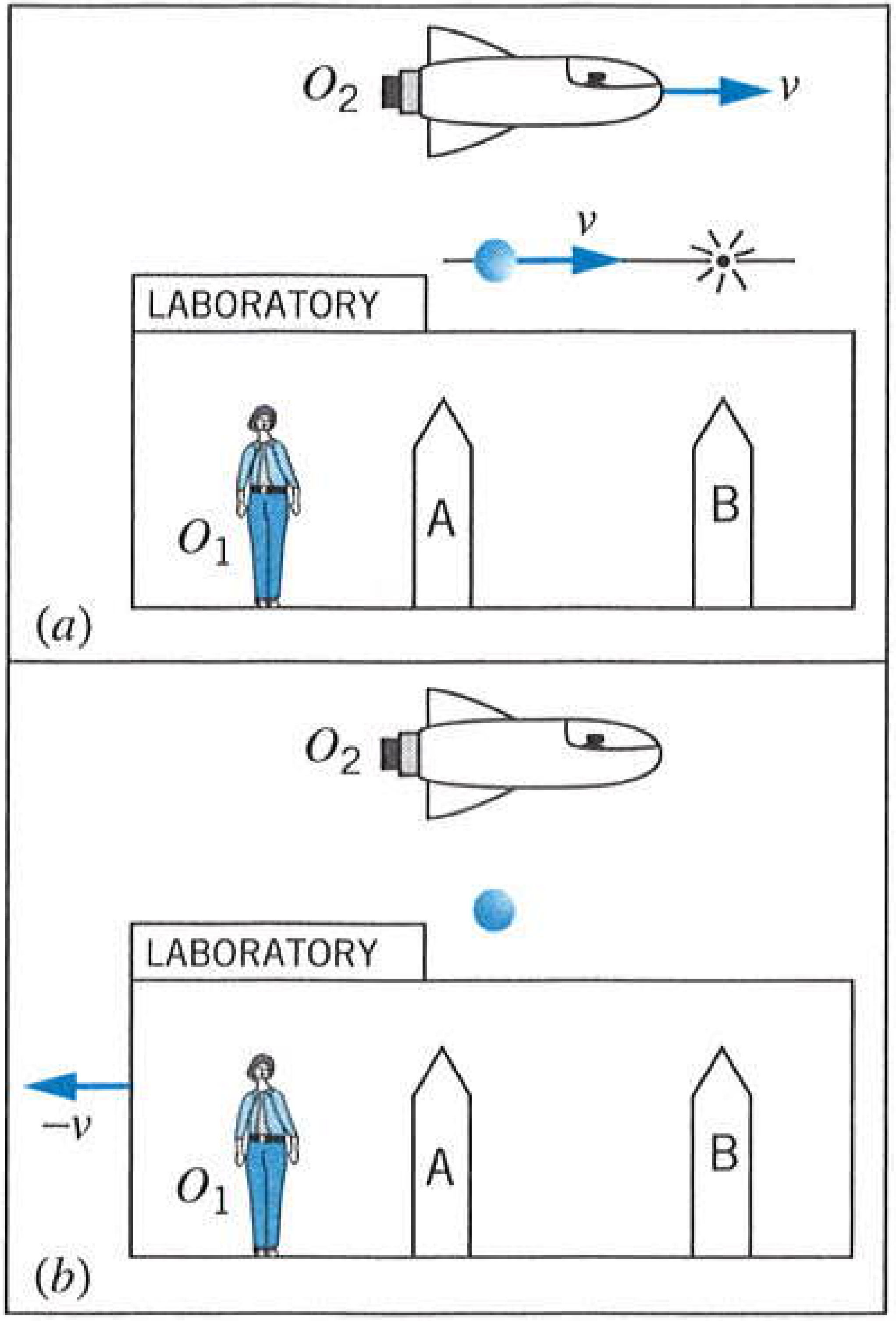
a) This view of the universe suggested that space and time are the same for all observers, regardless of their state of motion.

b) Energy is different from mass and both came in continuous units.

c) All things could be predicted..

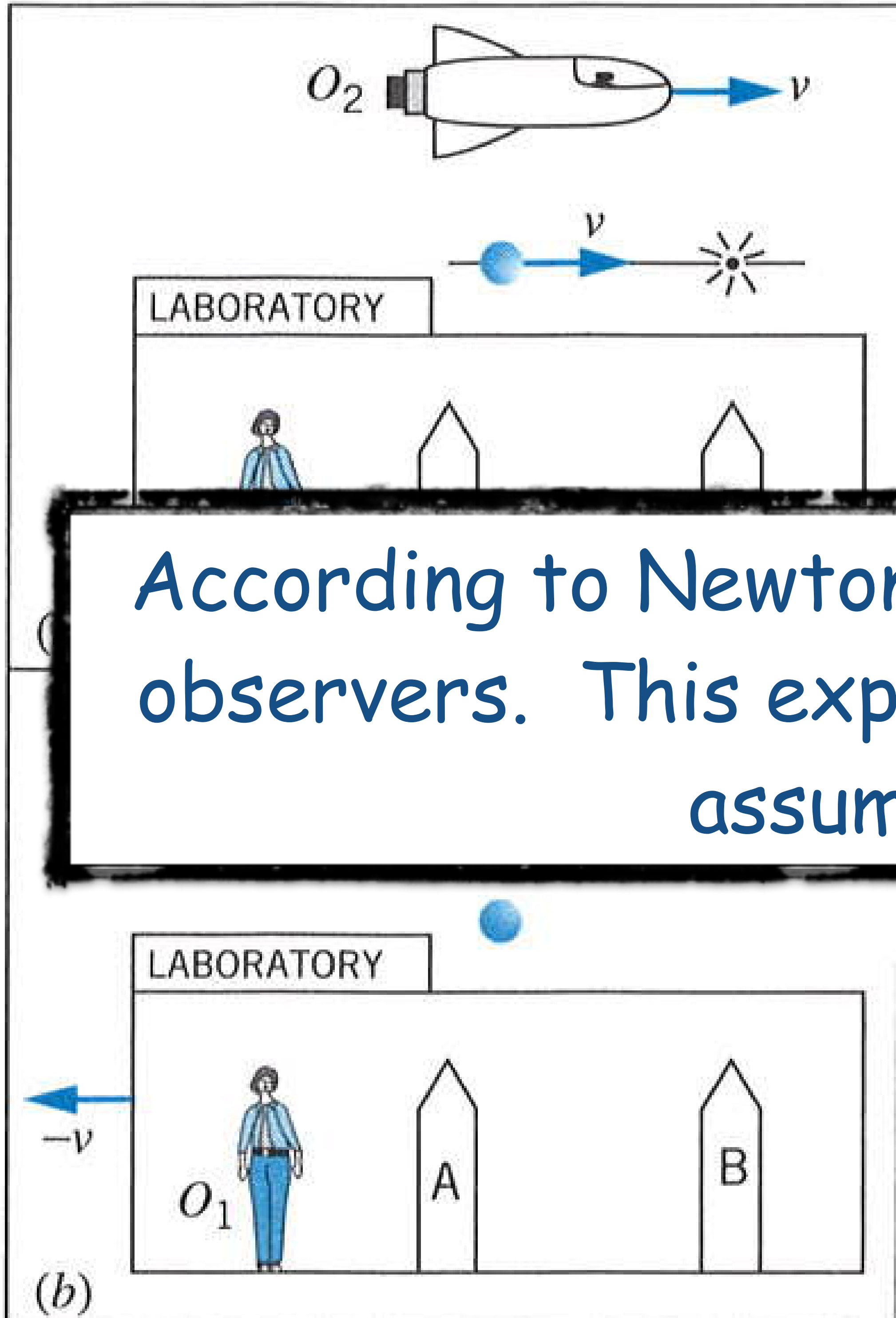
- Light was identified as alternating electric and magnetic waves traveling at $c = 2.995 \times 10^8$ m/s. It was assumed that light (as all EM waves) propagated in medium (the ether) and was affected by the motion of that substance.

FAILURES OF CLASSICAL CONCEPTS



- Pions are created in high energy collisions of two protons. They eventually decay to muons.
- **Situation (a):** Pions produced at rest in the laboratory are observed to have an average lifetime of 26.0 ns. (observer 1)
- **Situation (b):** Pions moving at 2.737×10^8 m/s (0.913 c) have an observed lifetime of 63.7 ns. (observer 2)

FAILURES OF CLASSICAL CONCEPTS

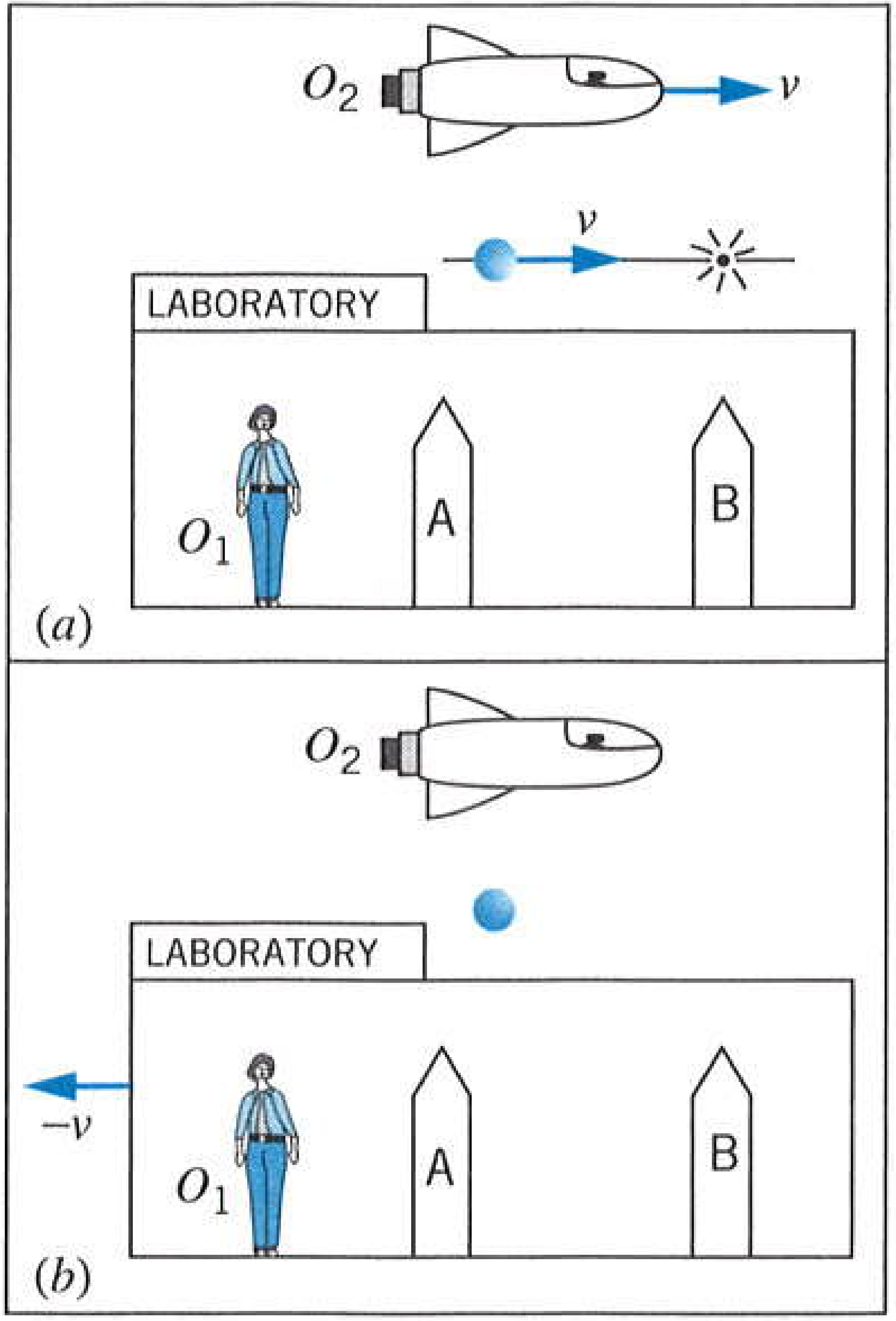


- Pions are created in high energy collisions of two protons. They eventually decay to muons.
- **Situation (a):** Pions produced

According to Newton's Laws, time is the same for all observers. This experiment demonstrates that this assumption is not true!

- **Situation (b):** Pions moving at 2.737×10^8 m/s (0.913 c) have an observed lifetime of 63.7 ns. (observer 2)

FAILURES OF CLASSICAL CONCEPTS



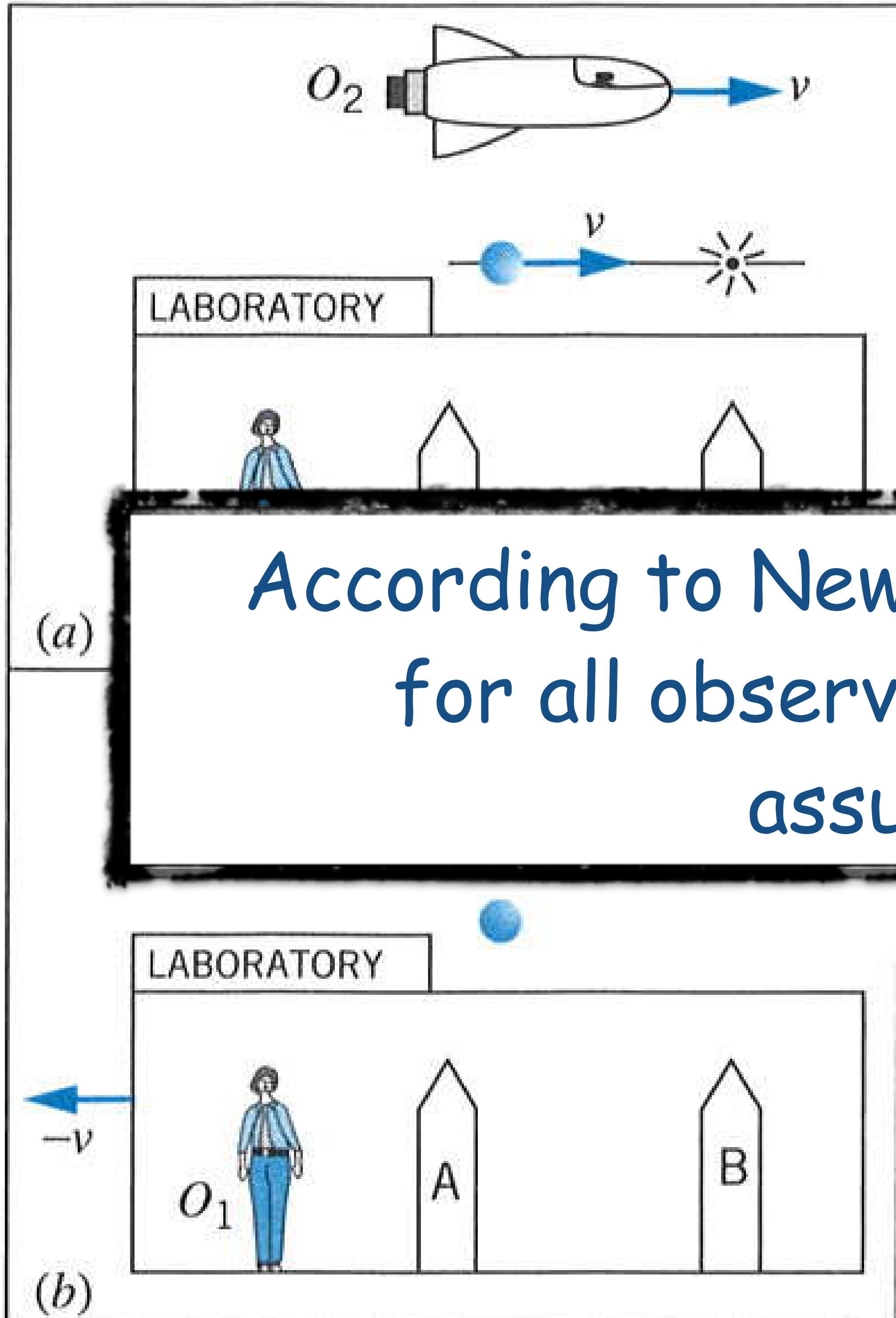
- Pions are created in high energy collisions of two protons. They eventually decay to muons.
- **Situation (a):** Distance between the two markers is

$$D_1 = (2.737 \times 10^8 \frac{m}{s})(63.7 \times 10^{-9}\, s) = 17.4\, m$$

- **Situation (b):** Distance between the markers is

$$D_1 = (2.737 \times 10^8 \frac{m}{s})(26.0 \times 10^{-9}\, s) = 7.11\, m$$

FAILURES OF CLASSICAL CONCEPTS



- Pions are created in high energy collisions of two protons. They eventually decay to muons.
- **Situation (a):** Distance

According to Newton's Laws, distance is the same for all observers. Again we find that this assumption is not true!

- **Situation (b):** Distance between the markers is

$$D_1 = (2.737 \times 10^8 \frac{m}{s})(26.0 \times 10^{-9}\, s) = 7.11\, m$$

FAILURES OF NEWTONIAN PHYSICS

a) Michelson and Morley Experiments: Light was unaffected by the motion of the observer. (Next class period).

b) The laws of E&M appeared 'special' in that their form changed depending on the state of motion of the observer (hwk 4c).

c) Theory of heat failed to predict the energy emitted by a blackbody. (Chapter 3)

- Heat is the thermal motion of atoms in a body. Consider heat trapped in a cavity (blackbody). The emitted spectrum of energy becomes infinite as the energy of radiation increases. This would cause the destruction of the universe if even one blackbody were in existence.
- Measured spectrums of real blackbodies show an increase and then cut-off.

MODERN PHYSICS

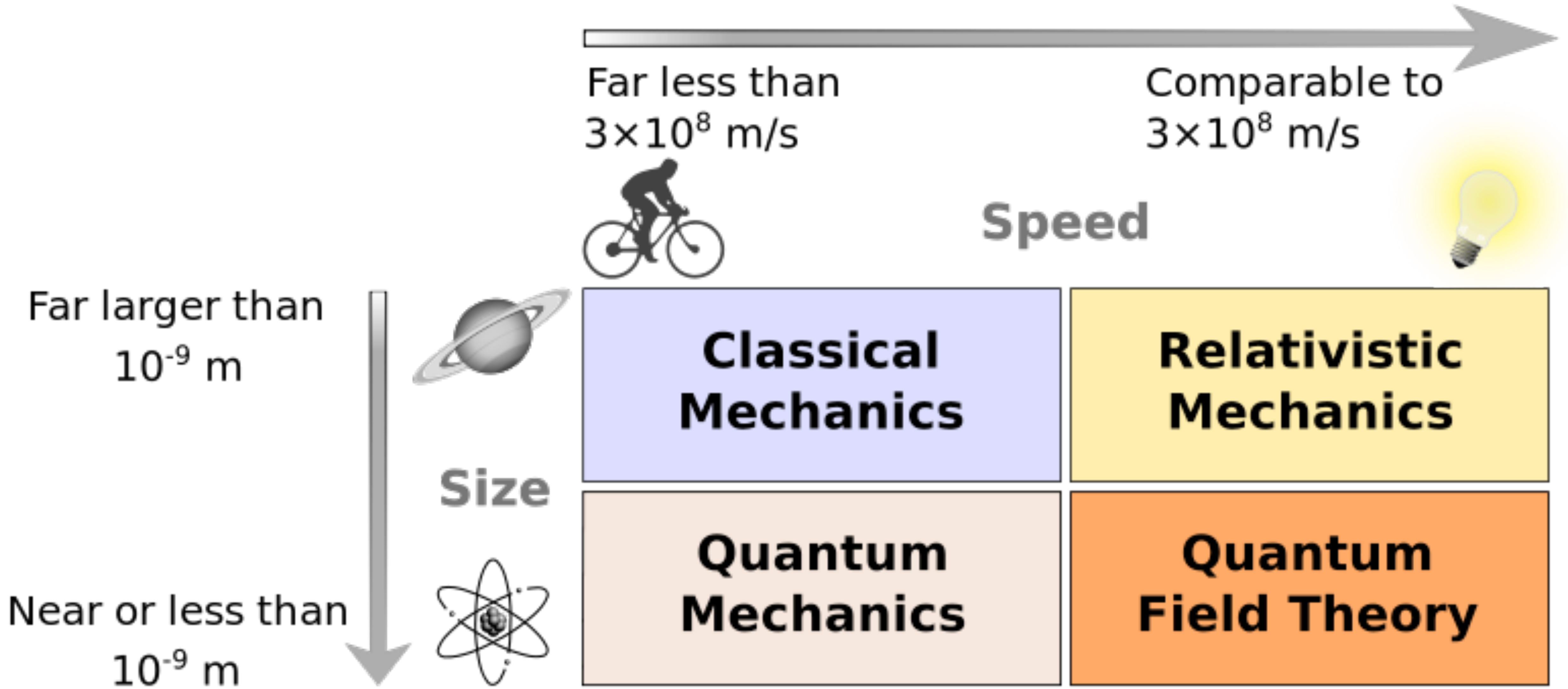
a) Two Basic Ideas:

- Time and space are not absolutes.
- Particles behave like waves and waves behave like particles.

b) Two Branches:

- Special Relativity
- Quantum Mechanics

c) With an understanding of these branches, we can then explore areas of modern physics such as superconductivity, modern optics, nuclear physics, particle physics and cosmology - along with a host of other areas of science.


Far less than
3×10^8 m/s
Comparable to
3×10^8 m/s
Speed
Far larger than
10^{-9} m
Size
Near or less than
10^{-9} m
Classical Mechanics
Relativistic Mechanics
Quantum Mechanics
Quantum Field Theory

SPEED OF LIGHT

walking	~1 m/s
running	~2-3 m/s
driving	~25 m/s (highway)
flying	~225 m/s
sound	~300 m/s
navigational satellite	~1000 m/s
light	~3 x 10^8 m/s

SYNCHRONIZING A SYMPHONY

A conductor is not just part of the social construct of an orchestra. He is required by the speed of sound and speed of light.

The distance between our ears is ~22 cm. The human auditory system is capable of discerning sounds that are no more than 0.660 ms apart (Duplex theory). This means that sounds arriving within 0.660 ms of each other sound as if they arrive at the same time.

Orchestra decides to toss the conductor.

SYNCHRONIZING A SYMPHONY

Does it make a difference?

Say, oboe at the center of the orchestra keeps the tempo.

How long does it take to reach the players at the edge of the pit which is 10 meters away?

10 m ÷ 300 m/s = 0.033 s or **33 ms**

Players at the edge are 33 ms late.

Since the human ear is capable of discerning the difference in sounds that are 0.66 ms apart, this is a problem. The whole orchestra will be out of sync.

SYNCHRONIZING A SYMPHONY

Why does the conductor fix this problem?

The conductor uses light, not sound, to synchronize the orchestra. Light travels at 3×10^8 m/s which means that it takes only 0.000067 ms for the players at the back of the pit to see the hand gesture. Hence, they are only 0.000067 ms out of sync with the players from the front of the orchestra.

The human ear is only able to discern a difference of 0.66 ms in sounds. So, the orchestra sounds in sync.

THUNDER AND LIGHTENING

Thunder and lightening during in a storm are generated at the same time. Assume that the distance between you and the source is d. Calculate the difference in time you observe between the lightening and thunder.

$$t_l = \frac{d}{c} \qquad \text{and} \qquad t_s = \frac{d}{v_s}$$

$$t_s - t_l = \frac{d}{v_s} - \frac{d}{c} = d(\frac{1}{v_s} - \frac{d}{c})$$

$$t_s - t_l = d(\frac{1}{300} - \frac{1}{300,000,000})$$

$$t_s - t_l = \frac{d}{300} \text{ [s]}$$

Next Time:

Michelson - Morley: The downfall of the ether!

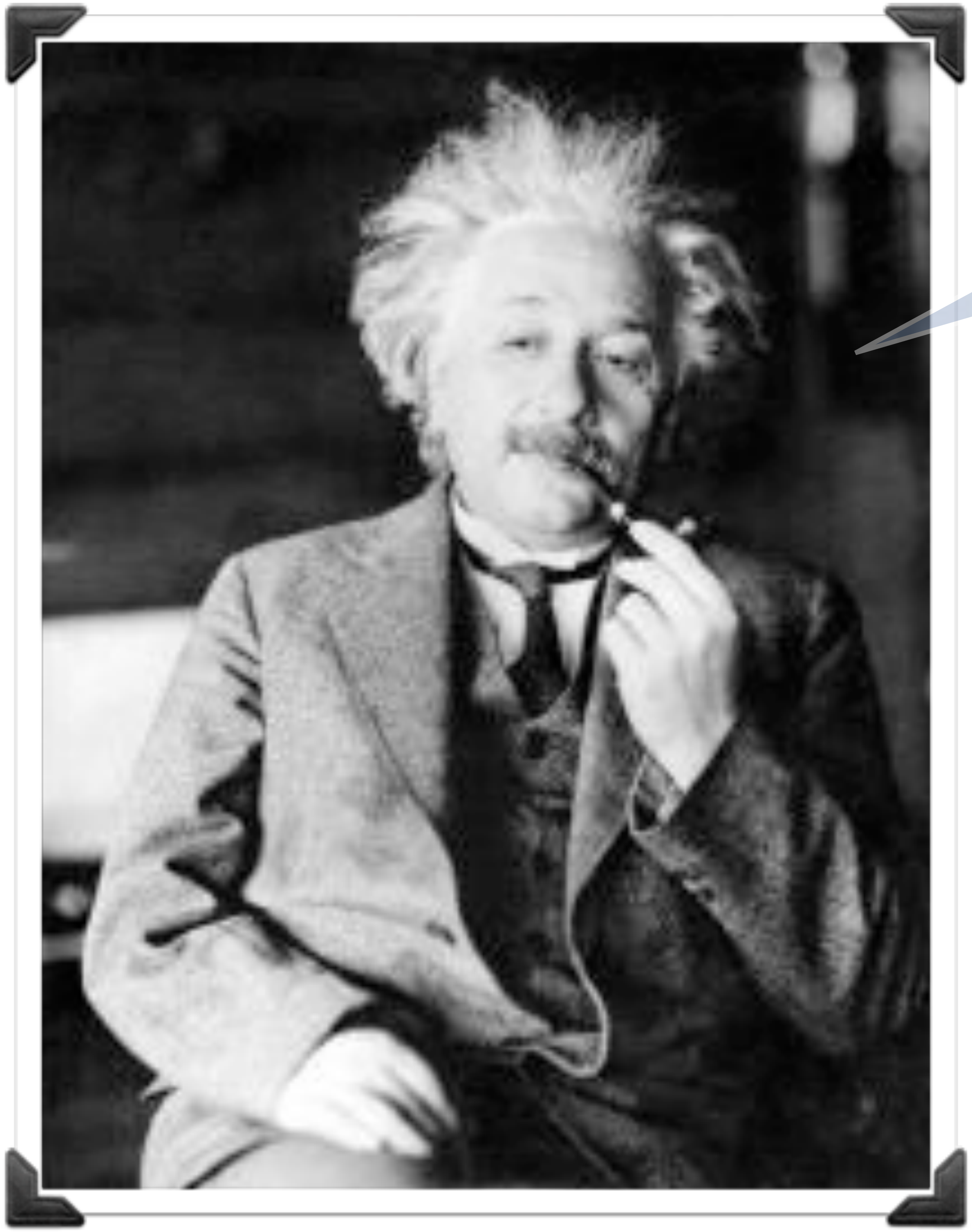
Simultaneity: Will two observers always agree that two events are simultaneous?

THE END (FOR TODAY)

"I hate to break it to you, but what people call 'love' (of majors other than physics) is just a chemical reaction that compels undergrads to worry about the wrong things. It hits hard, then slooooowly fades, leaving you stranded in an unhappy major. I did it, your friends are going to do it..."

"...BREAK THE CYCLE. RISE ABOVE. FOCUS ON PHYSICS."

Modified from "Rick and Morty," Season 1, Episode 6: "Rick Potion #9"



Welcome back to PHY 3305

Today's Lecture:

General Relativity

Albert Einstein
1879-1955

ANNOUNCEMENTS

- There will be no lecture video (and hence no quiz) on Tuesday, September 13th. We will be doing an in class activity that will count towards your homework grade. We will meet in FOSC 026 that day.

- No reading assignment for Tuesday, September 13th.

- Homework assignment 3 is due Tuesday, September 13th at the beginning of class.

- Regrades for assignment 2 are due Tuesday, September 13th at the beginning of class.

- Dr. Cooley will be out of town September 8-12th. Mr. Thomas will cover office hours that day.

- Extra Credit Opportunity 1 will be due Thursday, September 29th.

REVIEW QUESTION 1

An electron moves through the lab at 99% the speed of light. The lab reference frame is S and the electron's reference frame is S'. In which reference frame is the electron's rest mass larger?

A) In frame S, the lab frame.
B) In frame S', the electron's frame.
C) It is the same in both frames.

rest mass ~ stationary energy

$m = E/c^2$

REVIEW QUESTION 2

Are the (a) kinetic energy and (b) the total energy of a 1 GeV electron more than, less than or equal to those of a 1 GeV proton?

The total energy of a 1 GeV electron equals the total energy of a 1 GeV proton. However, the rest energy of an electron is less than the rest energy of a proton. Thus, the kinetic energy of a 1 GeV electron is greater than that of the kinetic energy of a 1 GeV proton.

Lecture Video:

THE PRINCIPLE OF EQUIVALENCE

Einstein postulated:

A homogenous gravitational field is completely equivalent to a uniformly accelerated reference frame.

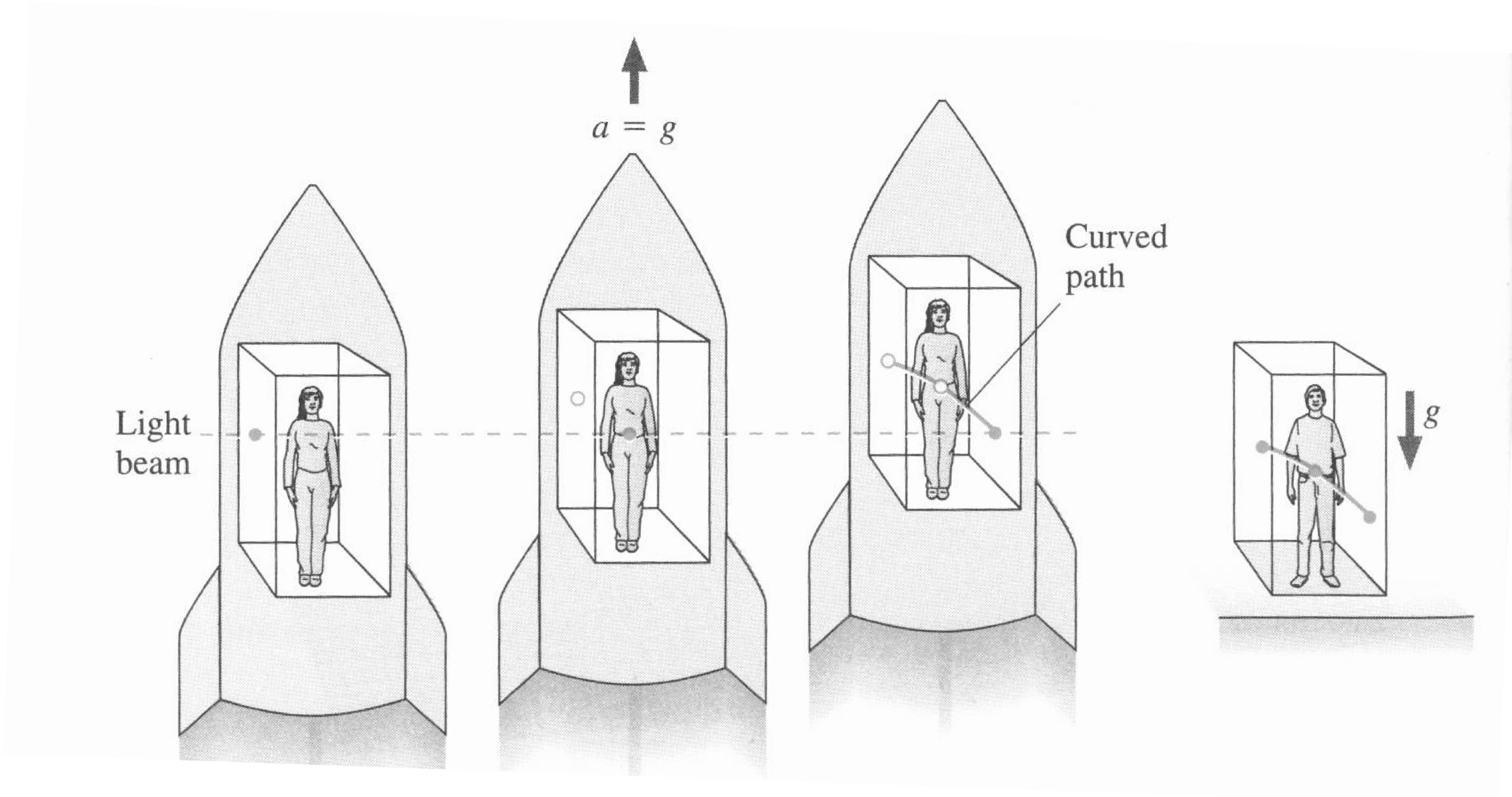
-or-

The form of each physical law is the same in all locally inertial frames.

Which of the following people will observe the same experimental results as someone who is standing on a solid lab floor on the moon?

a) An observer in a spaceship moving at constant velocity
b) An observer in an elevator on Earth moving upwards at constant velocity
c) An observer in an elevator on Earth with a broken cable (i.e. in free-fall)
d) An observer in an elevator on Earth moving downwards at constant velocity
e) An observer in a spaceship moving with constant acceleration

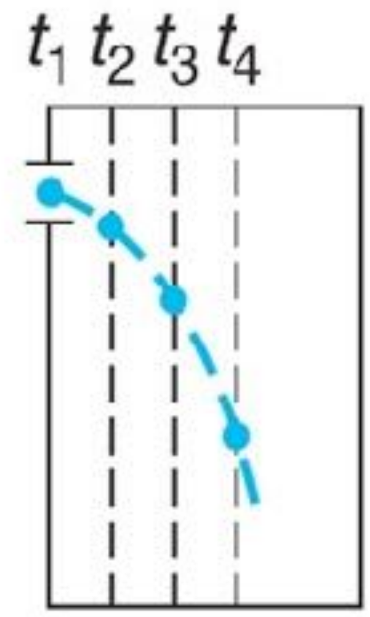
Deflection of Light in a Gravitational Field



Observing a beam of light in an accelerated reference frame.

DEFLECTION OF LIGHT IN A GRAVITATIONAL FIELD

- In an accelerating frame a light beams appears to be "falling down" in a parabolic arc

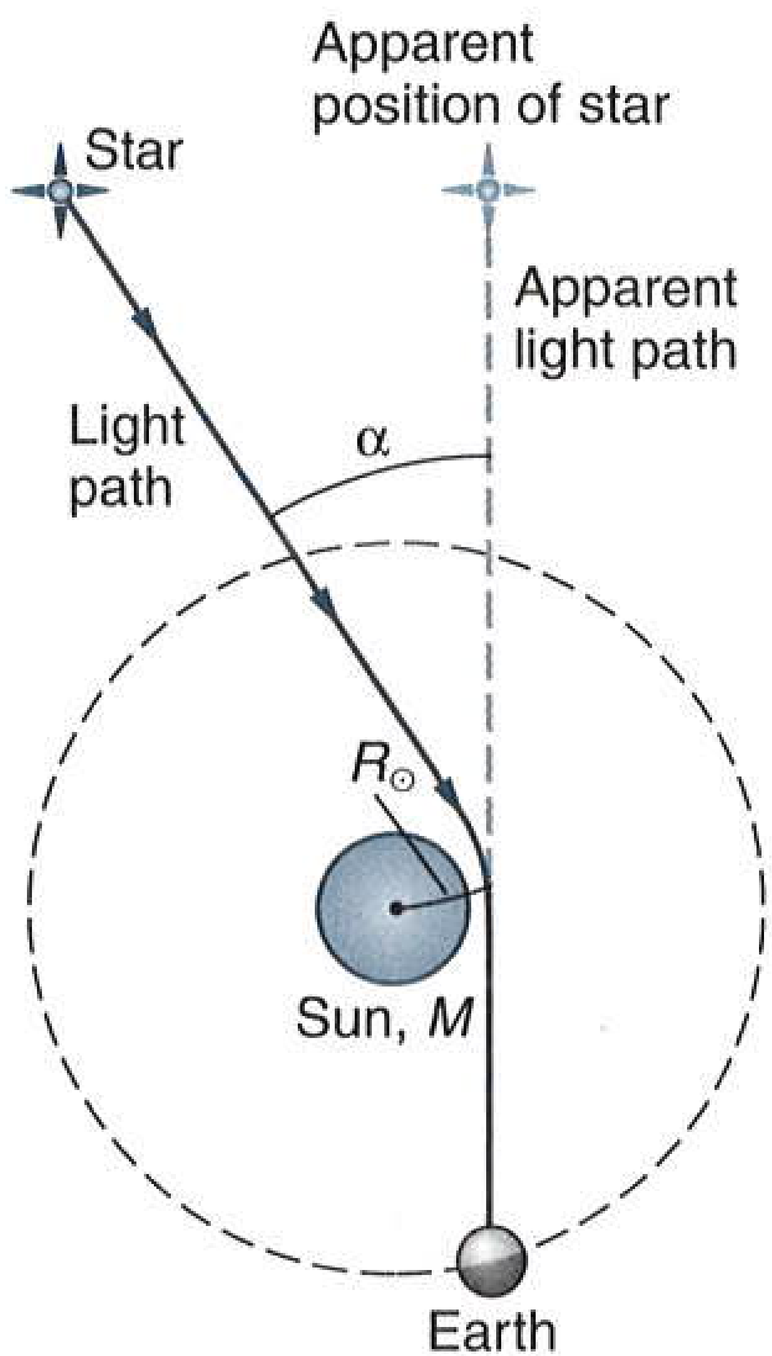


- According the the principle of equivalence: there is no physical difference between an accelerating frame and a gravitational field.

- Therefore a light beam will "fall down" in a gravitational field

Video Lecture:

Gravitational Lensing

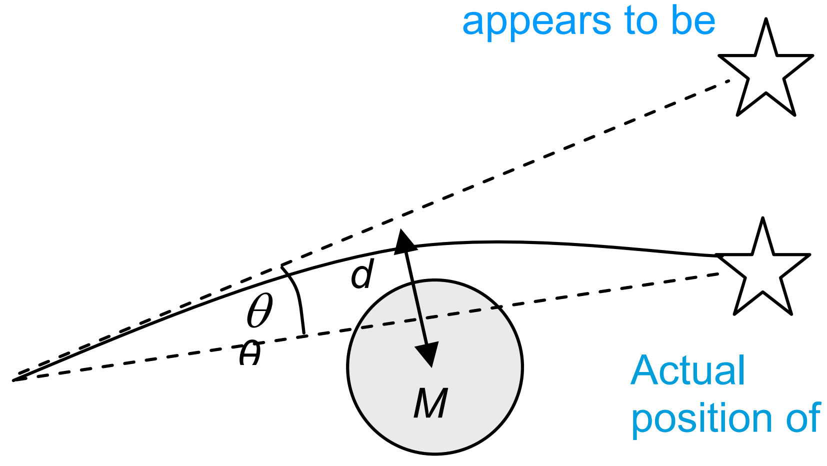


Note: This picture is an extreme exaggeration of the effect known as "Gravitational Lensing"

If you envision space-time as a fabric -- photons can not leave the fabric.

Demonstration!

Some of the best evidence that we have for the existence of dark matter comes from gravitational lensing.



$$\theta = \frac{4GM}{dc^2}$$

Calculate the deflection of light from a distant that approaches very close to the surface of the sun. The radius of the sun is 6.96 x 10^8 m.

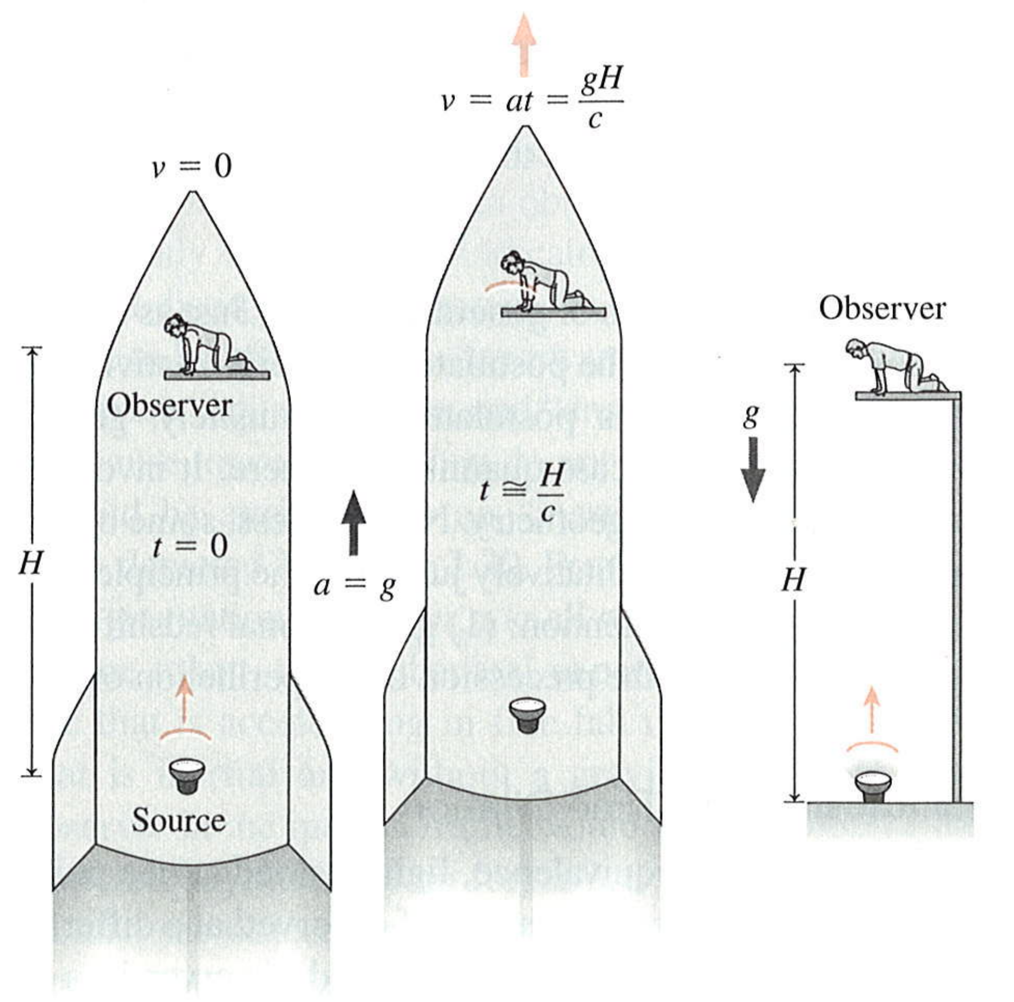
$$\theta = \frac{4(6.67 \times 10^{-11}\ N \cdot m^2/kg^2)(1.99 \times 10^{30}\ kg)}{(6.96 \times 10^8\ m)(3 \times 10^8\ m)^2} = 8.48 \times 10^{-6}\ rad$$

Convert to degrees:

$$= 4.86 \times 10^{-4}\ degrees$$

$$= 2.92 \times 10^{-2}\ arcmin$$

LAST TIME: Gravitational Redshift



(a) Accelerating frame (b) Equivalent frame

$$\Delta t_{lower} = \Delta t_{higher}(1 - \frac{gH}{c^2})$$

Relativity and GPS

$$\Delta t_{lower} = \Delta t_{higher}(1 - \frac{gH}{c^2})$$

General relativity tells us that a clock runs slower when it is deeper in a gravitational field (closer Earth). So, clocks on a satellite run faster than clocks at ground level. In Earth's non-uniform field ...

$$\Delta t_E = \Delta t_{sat}[1 - \frac{1}{c^2}(\frac{GM_E}{r_E} - \frac{GM_E}{r_{sat}})]$$

Apply the Physics

r = distance from center of Earth

A GPS satellite orbits at an altitude of 2.0×10^7 m and a speed of 3.0×10^3 m/s. The radius of Earth is 6.4×10^6 m.
a) By what fraction must the time be adjusted to account for both regular speed dependent and gravitational time dilation?

Speed dependent time dilation is given by

$$\Delta t_E = \Delta t_{sat}[1 - \frac{1}{c^2}(\frac{GM_E}{r_E} - \frac{GM_E}{r_{sat}})]$$

$$\Delta t = \gamma \Delta t_0 \longrightarrow \Delta t_E = \frac{\Delta t_{sat}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$\Delta t_E = \frac{\Delta t_{sat}}{\sqrt{1 - \frac{(3.9\times10^3 m/s)^2}{(3\times10^8 m/s)^2}}} = (1 - 1.7 \times 10^{-10})^{-\frac{1}{2}} \Delta t_{sat}$$

Use Binomial Expansion: $$\Delta t_E \approx (1 + 8.5 \times 10^{-11})\Delta t_{sat}$$

Gravitational time dilation of the satellite is given by

$$\Delta t_E = \Delta t_{sat}[1 - \frac{1}{(3 \times 10^8 m/s)^2}(\frac{(6.67 \times 10^{14} \frac{m^3}{s^2})5.98 \times 10^{24} kg}{6.4 \times 10^6 m} - \frac{(6.67 \times 10^{14} \frac{m^3}{s^2})5.98 \times 10^{24} kg}{2.64 \times 10^7 m})]$$

$$\Delta t_E = (1 - 5.26 \times 10^{-10})\Delta t_{sat}$$

The gravitational effect makes the satellite's time larger. Its clock runs faster.
The speed-dependent effect makes the satellite's time smaller. Its clock run slower.

The fractional change is then:

$$\frac{\Delta t_E - \Delta t_{sat}}{\Delta t_{sat}} = (8.5 \times 10^{-11}) - (5.26 \times 10^{10})$$

$$\frac{\Delta t_E - \Delta t_{sat}}{\Delta t_{sat}} = -4.4 \times 10^{-10}$$

If this effect was not accounted for, how soon would the time be in error be 10 ns?

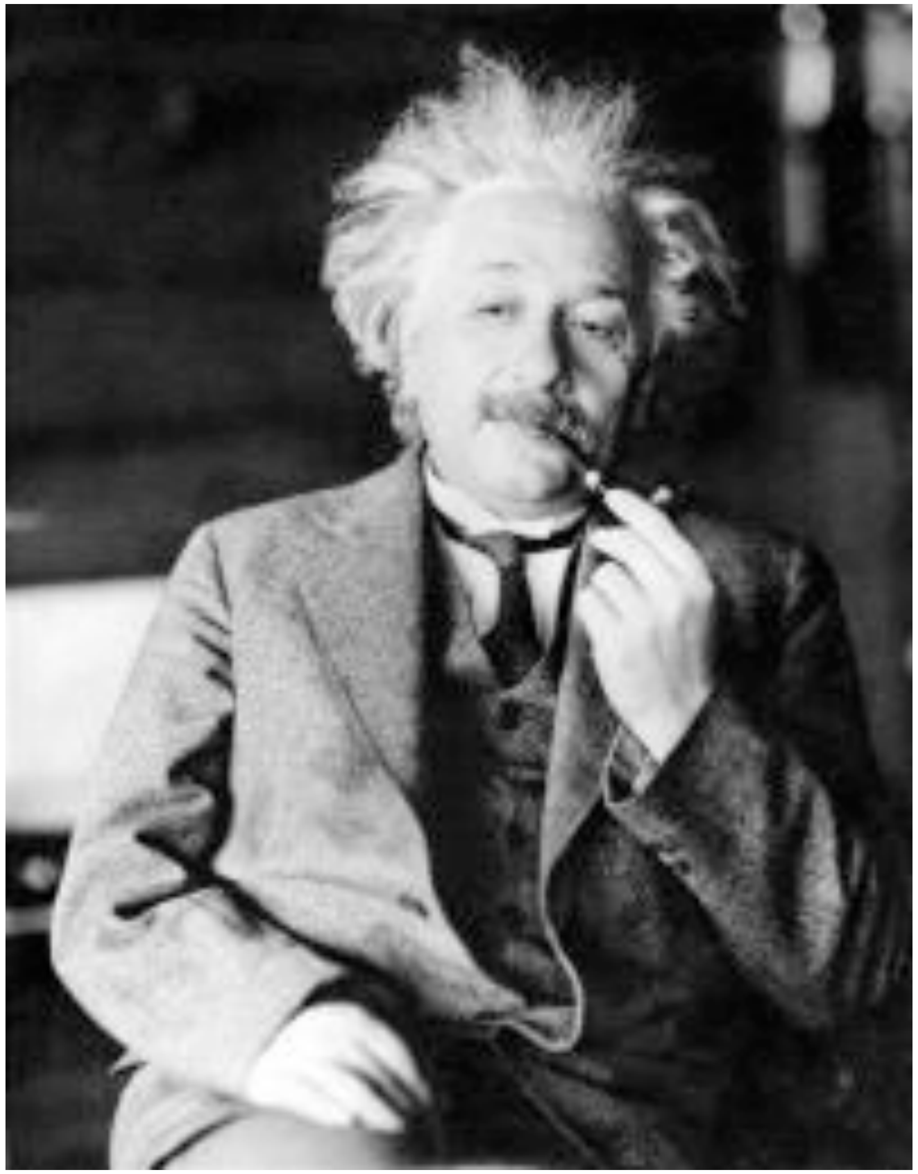
$$\frac{10 \times 10^{-9} s}{\Delta t_{sat}} = 4.4 \times 10^{-10}$$

$$\Delta t_{sat} = 23\ s$$

Clocks aboard GPS satellites account for the gravitational effect. Velocities and elevations of the receiver units are calculated in the receiving units.

Einstein's Postulates:

1. The laws of physics are invariant to observers in different inertial reference frames.
2. The speed of light is the same to all observers, regardless of their motion relative to the light source.



As a consequence of Einstein's Postulates, <u>no information travels faster than the speed of light</u>.

This claim is supported by the Lorentz Equations!

Events simultaneous in one reference frame occur in different orders in another reference frame.

Is it possible that the effect can precede the cause?

NO!

The Lorentz transformations forbid it! Events can only be reversed if they are not causally related.

Event A occurs at space time coordinates (300 m, 2μs).

A) Event B occurs at spacetime coordinates (1200 m, 6 μs). Could A possible be the cause of B?

Yes

$$v = \frac{1200 - 300\ m}{6 \times 10^{-6} - 2 \times 10^{-6}\ s} = 2.3 \times 10^{-6}\ m/s$$

Intuitive example, think of how a shadow moves.

Project a shadow of your finger on a wall & wiggle it. The shadow travels faster than your finger. If you wiggle your finger at c, the shadow's speed will appear greater than c.

Is this a violation of cause and effect?

SHADOWS

Shadows on a wall.

The misconception is that the edge of a shadow "moves" along a wall, when in actuality the change in a shadow's motion is part of a new projection, which will propagate at the speed of light from the object of interference.

TELEVISION IN THE 'OLDEN' DAYS

In the 'olden' days televisions contained a picture tube, a beam of electrons sent from the back to the front (screen) by an electron gun. When the electrons strike the screen, it causes a phosphor to glow briefly. To produce an image across the entire screen, the glowing beam is electrically deflected up and down and right and left.

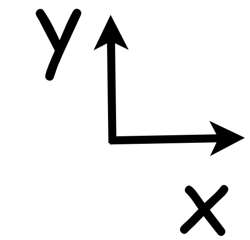
The beam may sweep from left to right at a speed greater than c. Why is this not a violation of the claim that no information may travel faster than the speed of light?

LIGHTSPOTS

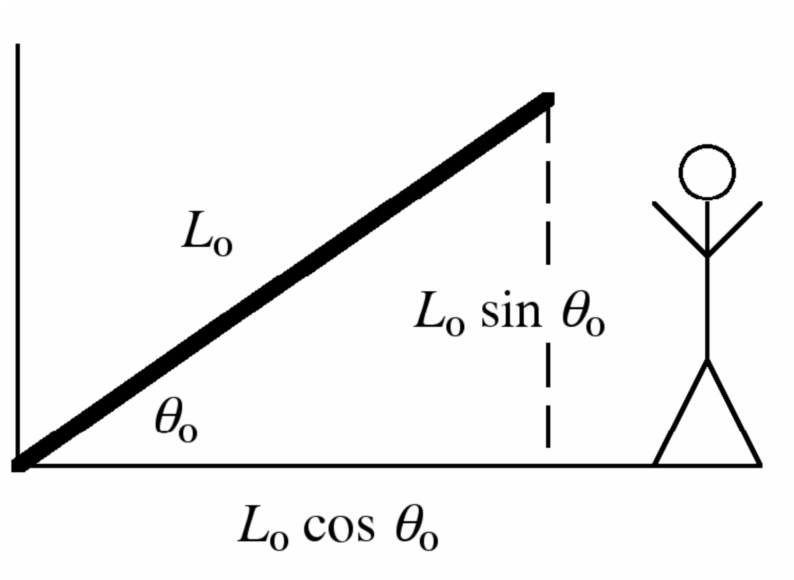
The light spots are caused by electrons hitting the phosphors, not the electrons themselves. No electron travels from one side of the screen to the other. Nothing that can have information about the left-hand side of the screen moves to the right-hand side of the screen. The events (electrons hitting phosphors) are all planned ahead of time and have no effect upon on another. Thus, no information travels faster than c.

REVIEW PROBLEM

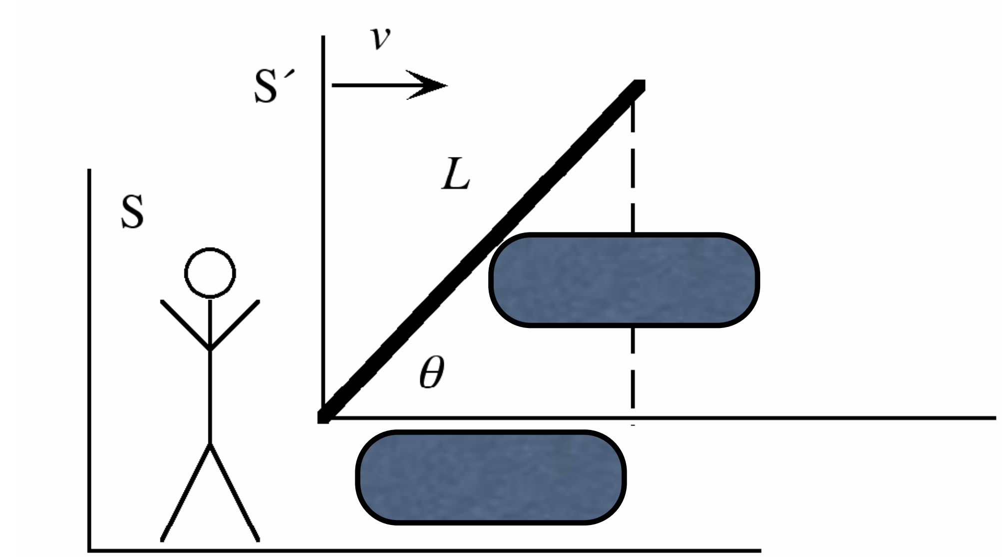
A plank, fixed to a sled at rest in frame S, is of length L_0 and makes an angle Θ_0 with the x-axis. Later, the sled zooms through frame S at a constant speed v parallel to the x-axis. Derive an expression for the length of the plank and the angle it makes with the x-axis according to an observer who remains at rest in frame S. Simplify so that your final expression for L is in terms of $\cos\Theta_0$ and your final expression for Θ is in terms of $\tan\Theta_0$.



Original:



Later:



What is the observed length along the y-axis?

$$L'_y = L_0 \sin \theta_0$$

What is the observed length along the x-axis?

$$L'_x = \frac{L_0 \cos \theta_0}{\gamma_\mu} = \sqrt{1 - \frac{v^2}{c^2}}(L_0 \cos \theta_0)$$

Use geometry to find total length L.

$$L = \sqrt{L_x'^2 + L_y'^2}$$

$$L = (L_0^2 \sin^2\theta_0 + (1 - \frac{v^2}{c^2})L_0^2\cos^2\theta_0)^{\frac{1}{2}}$$

$$L = L_0(1 - \cos^2\theta_0 + \cos^2\theta_0 - \frac{v^2}{c^2}\cos^2\theta_0)^{\frac{1}{2}}$$

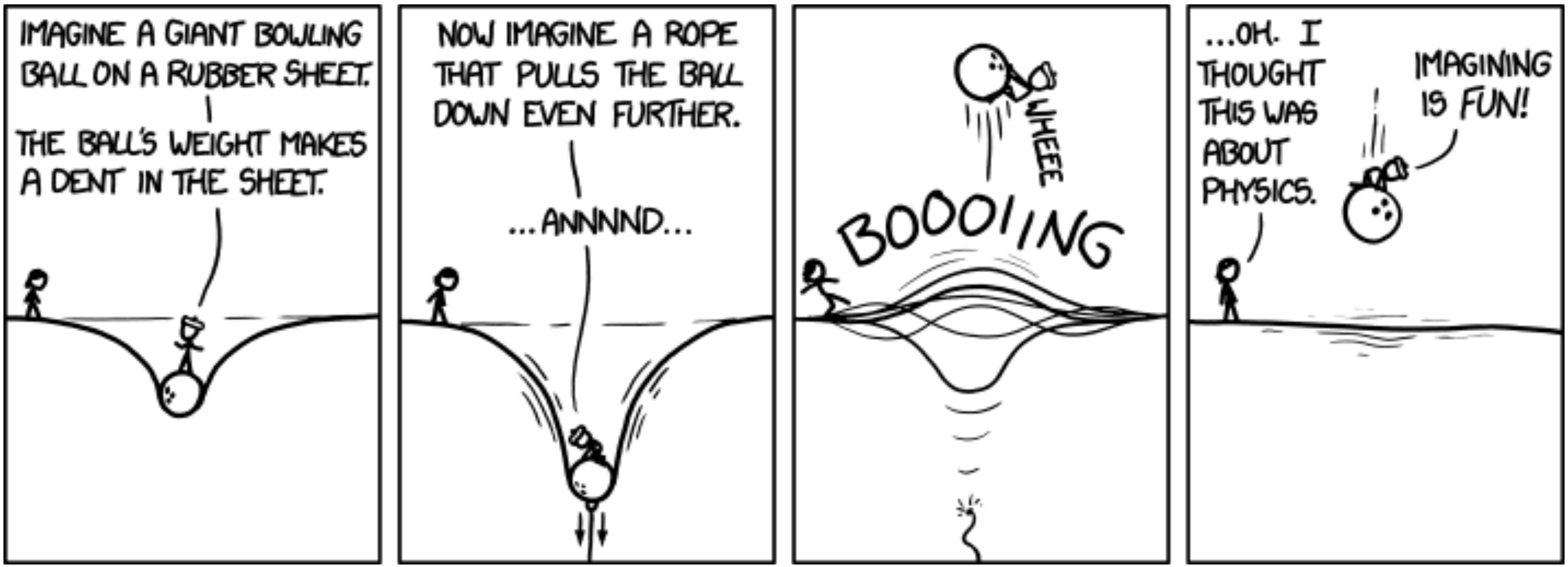
$$\boxed{L = L_0\sqrt{1 - \frac{v^2}{c^2}\cos^2\theta_0}}$$

Use geometry to find Θ.

$$\tan\theta = \frac{L_y'}{L_x'} = \frac{\gamma_\mu L_0 \sin\theta_0}{L_0\cos\theta_0}$$

$$\boxed{\theta = tan^{-1}(\gamma_\mu \tan\theta_0)}$$

THE END (FOR TODAY)



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