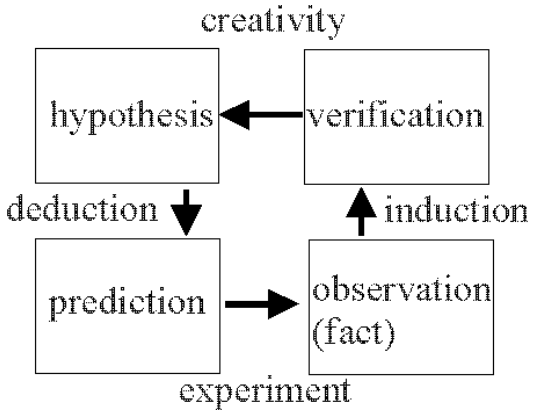
Today

- Announcements:
  - HW#1 is due Wednesday (Jan 16) by 8:00 am
- What is science (cont'd)?
- What it time?
- Motion – rates of change
- Special Relativity
- Time Travel – Introduction

The Scientific Method

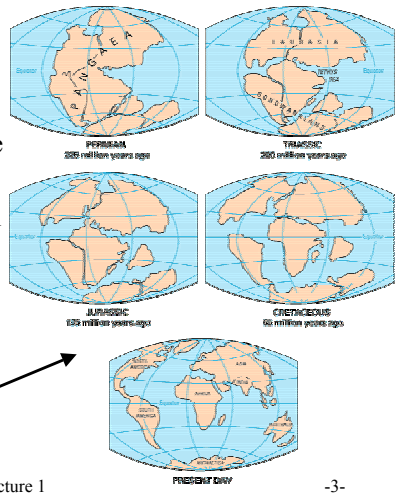


The goal is to find theories that work better (no theory is ever proven true)

Example: Gravity
Aristotle – Newton – Einstein – String Theory?

Keep an open mind

- "Heavier-than-air flying machines are impossible." (*Lord Kelvin, president, Royal Society, 1895*)
- "Professor Goddard does not know the relation between action and reaction and the need to have something better than a vacuum against which to react. He seems to lack the basic knowledge ladled out daily in high schools." (*New York Times editorial about Robert Goddard's revolutionary rocket work, 1921*)
- In 1912 Alfred Wegener (1880-1930) proposed that the continents were once compressed into a single protocontinent which he called Pangaea (meaning "all lands"), and over time they have drifted apart into their current distribution.



Pseudoscience

(not bad, just not science)

- The hypothesis is not at risk. If data does not agree with the hypothesis, then the data is assumed to be wrong. Some facts are ignored.
- Exploit the controversies and inadequacies in a competing theory.
- Portrayed as an underdog being punished by the scientific establishment.
- Reliance on fear and other emotions, or reliance on a lack of knowledge
- People who do pseudoscience usually do not publish in normal peer-reviewed scientific journals.

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Some Pseudoscience Examples

- Intelligent Design/Creationism
  - See here and here for an interesting debate btw. Darwinists and ID'ers
- Cold Fusion
- Mercury in vaccines "causes" autism
- Homeopathy
- Parapsychology (ESP and such)
- And many more at http://skepdic.com/pseudosc.html

NOTE: Pseudoscience does not always have a "crackpot" or negative ring to it! Some very smart physicists might be doing it.

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Is **String Theory** Pseudoscience?

PHILIP W. ANDERSON
Physicist and Nobel laureate, Princeton University

Is string theory a futile exercise as physics, as I believe it to be? My belief is based on the fact that **string theory is the first science in hundreds of years to be pursued in pre-Baconian fashion, without any adequate experimental guidance. It proposes that Nature is the way we would like it to be rather than the way we see it to be**; and it is improbable that Nature thinks the same way we do.

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Significant Figures

- In science numerical values as a result of experiments or models are only known to a certain number of digits, which are called significant figures.
- If a numerical answer is required for the homework normally you should use 3 significant figures (actually the system is not supposed to care).
- To reduce the number of SF round up or down
  - 5.67898 given to 3 SF is 5.68
  - 3.34997×10^{-2} given to 3 SF is 3.35×10^{-2} or (3.35E-2) Examples
- 3.2 means the real number is between 3.15 and 3.24999…
- Don't sweat the details. The important thing is to know that when you hear a scientist say "the Earth is 4.5 billion years old", that means the age is between 4.45 and 4.549999…

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What is time?

"If nobody asks me, I know; but if I were desirous to explain it to one that should ask me, plainly I know not." - Augustine of Hippo

"I confess I do not believe in time." - Vladimir Nabokov

"Time is the accident of accidents." - Epicurus

"Time is nature's way of keeping everything from happening at once" - Woody Allen

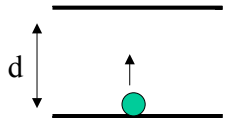
"Time is a #&$@." – Tupac Shakur

What is time?

- Time is the thing that is measured by clocks.
- What is a clock?
- We can describe how to make a clock.
- Disclaimer: Don't sweat it if the rest of today's lecture is over your head! The main point is to show "things aren't always as they seem!"

A simple clock

- A perfectly elastic ball bouncing between two fixed walls:



- One click:

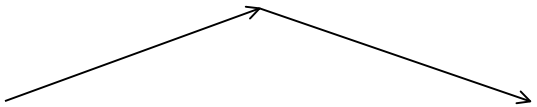
$$\text{time} = \frac{\text{distance}}{\text{speed}} \quad or \quad \text{distance} = \text{speed} \cdot \text{time}$$

$$\text{time for a click} = \frac{2 \times \text{d}}{\text{speed}}$$

$$click = \frac{2 \times 1m}{2m/s} = 1s$$

What happens if the clock is moving?

Path moving:



Path not moving:

(Show movie…)

Clicker Question #1

If a clock is moving at a modest speed of 1 m/s, what can we say about the length of a click for a clock in motion relative to one at rest? Choose the best answer:

A). They are the same.

B). A click in the moving clock takes longer because the distance traveled is longer.

C). A click in the moving clock is faster because the velocity of the ball is greater.

(Hint: This question is ambiguous as we shall see. Pretend I'm asking this in an ISP209 class 200 years ago, well before Einstein came along.)

Motion

- **Position** – location in space relative to an origin.
- **Velocity** – rate of change of position

$$v = \frac{\text{change in position}}{\text{corresponding change in time}} = \frac{x_f - x_i}{t_f - t_i} = \frac{\Delta x}{\Delta t}$$

- **Acceleration** – rate of change of velocity

$$a = \frac{\text{change in velocity}}{\text{corresponding change in time}}$$

Example – Position of a ball at different times

x (m)	t (s)
0	0
1	1
2	2
2.5	2.5
3.0	3
3.0	4
2.0	5

What is the average velocity between 1 and 2 s?

$$v = \frac{\Delta x}{\Delta t} = \frac{2m - 1m}{2s - 1s} = \frac{1m}{1s} = 1\,m/s$$

What is the average velocity between 2 and 2.5 s?

$$v = \frac{\Delta x}{\Delta t} = \frac{0.5\,m}{0.5\,s} = 1\,m/s$$

Example

x (m)	t (s)
0	0
1	1
2	2
2.5	2.5
3.0	3
3.0	4
2.0	5

v (*m/s*)
1
1
1
1
0
-1

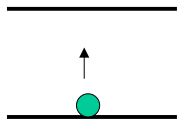
What is the average acceleration at 1 s?

$$a = \frac{\Delta v}{\Delta t} = \frac{1m/s - 1m/s}{1s} = 0\,m/s^2$$

What is the average acceleration at 4 s?

$$a = \frac{\Delta v}{\Delta t} = \frac{-1m/s - 0m/s}{1s} = -1\,m/s^2$$

Special Relativity



- Suppose we use a photon of light as the "ball" in our clock.
- The laws of electromagnetism require that the speed of light be a constant, **independent of the motion of the clock.**
- Einstein's two postulates of special relativity: **1). The speed of light is a constant in all inertial reference frames. 2). The laws of physics are the same in all inertial reference frames**
- Special relativity deals with non-accelerating frames of reference (General Relativity deals will all cases)

Clicker Question #2

If a **photon clock** is moving to the right at **half the speed of light**, what can we say about the length of a click for the clock in motion relative to one at rest? Choose the best answer:

A). They are the same.

B). A click in the moving clock takes longer because the distance traveled is longer.

C). A click in the moving clock is faster because the velocity of the ball is greater.

Consequences of Special Relativity

- Clocks in moving systems run more slowly.
  - Equations: β = v/c

$$t = \gamma\, t_0 \quad \gamma = \sqrt{\frac{1}{1-\left(\frac{v^2}{c^2}\right)}} = \sqrt{\frac{1}{1-\beta^2}}$$

  - t_0 is called the "proper" time it is the time measure in the inertial reference frame.
  - c = speed of light = 299 792 458 m / s
- The length of moving objects is smaller
  - 1_0 is the "proper" length

$$l = \frac{l_0}{\gamma} \quad \gamma = \sqrt{\frac{1}{1-\left(\frac{v^2}{c^2}\right)}} = \sqrt{\frac{1}{1-\beta^2}}$$

- How do we know?
  - Clock in airplanes
  - Lifetime of fundamental particles

Clicker Question #3

Now imagine you are riding along with a **photon clock** moving to the right at **half the speed of light**, while your friend on the ground has her own photon clock. How will your friend's clock on the ground tick **according to you** ? Choose the best answer:

A). They are the same.

B). Your friend's clock ticks slower than yours.

C). Your friend's clock ticks faster than yours.

HINT: Don't be afraid of something that seems paradoxical

What does this mean?

- **Time is relative**. It depends on the reference frame of the observer, i.e., whether the clock is at rest or in motion relative to the observer.
- If a person were to travel at near the speed of light (at a speed corresponding to γ) for 2 years (Δt), when they came back to Earth, they would aged by only a few moments.

Age (according for moving person) = $t_0 + \Delta t/\gamma$

Age (according to person on Earth) = t_0 + 2 years

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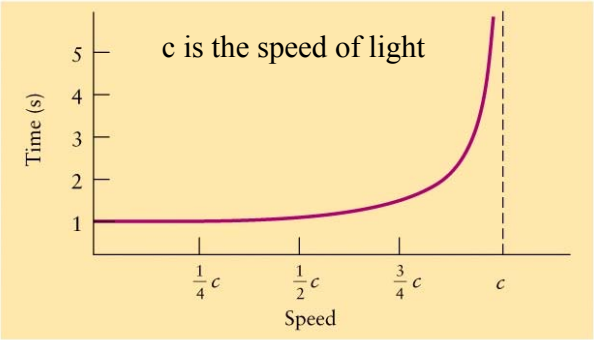
Time Dilation



v/c	γ
.1	1.00504
.2	1.02062
.3	1.04828
.4	1.09109
.5	1.1547
.6	1.25
.7	1.40028
.8	1.6667
.9	2.29416
1	∞

Time on Earth for 1s on the spaceship.
The world record v/c (for electrons) is from SLAC in California: 0.999999875
$\gamma = 20{,}000$ (can NEVER reach v = c for things with mass)

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What is time?

- Time is the thing that is measured by clocks.
- The more modern view is that time is one of the dimensions in space time (general relativity – much more about this later).
- If time is a dimension, is it possible to move back and forth in time, much like we move around in space?

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Clicker Question #4

What do you think: Is time travel permitted by the weirdness of time dilation and special relativity?

A). Yes. We can go forward and backwards.

B). Sort of. We can travel forward in time but not backwards.

C). Sort of. We can travel backwards but not forwards.

D) Nope.

NOTE: This is just a survey question. I.e., all answers get full points.

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Time Travel -- A Teaser

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.