

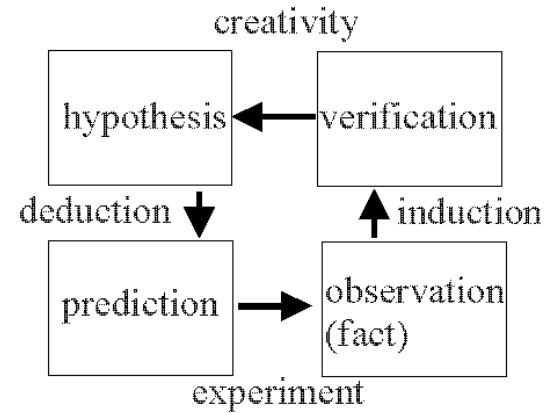


Today

- 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



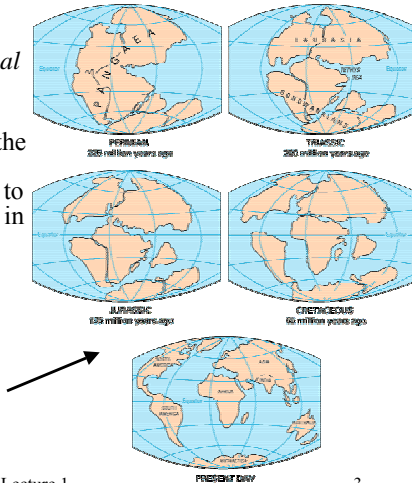
The goal is to find theories that work better (no theory is ever proven true)

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- People who do pseudoscience usually do not publish in normal **peer-reviewed** scientific journals.



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.



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.



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...



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](#)



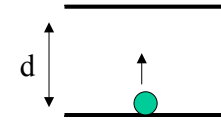
What is time?

- 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:

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

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

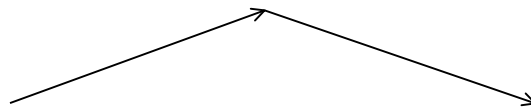
$$\text{click} = \frac{2 \times 1m}{2m/s} = 1s$$



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?

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

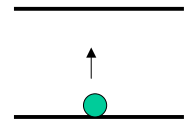
What is the average acceleration at 4 s?

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



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 with 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: $\beta = v/c$ $t = \gamma t_0$ $\gamma = \frac{1}{\sqrt{1 - \left(\frac{v^2}{c^2}\right)}} = \sqrt{\frac{1}{1 - \beta^2}}$
 - 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
 - l_0 is the “proper” length $l = \frac{l_0}{\gamma}$ $\gamma = \frac{1}{\sqrt{1 - \left(\frac{v^2}{c^2}\right)}} = \sqrt{\frac{1}{1 - \beta^2}}$
- 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



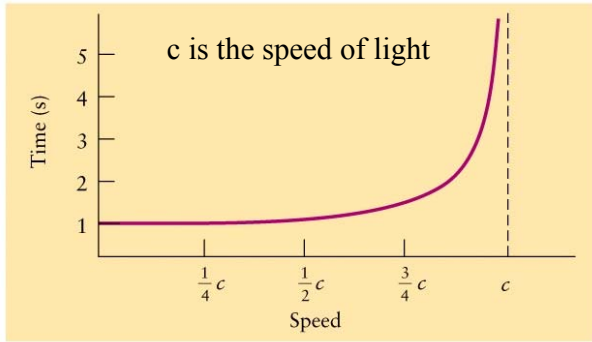
What does this mean?

- **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



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)



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?



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.



Time Travel -- A Teaser

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