

## Michelson (1899)

“The more important fundamental laws and facts of physical reality have all been discovered and they are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote .... Our future discoveries must be looked for in the 6th place of decimals.”

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## Announcements

- Problem Set 9 (Relativity 2) is released
  - Due by 11:59 PM on Friday April 3
  - This is the final Problem Set of the term
- Pre-Class Quiz 11 (Relativity 3) is released
  - Due by 10 AM on Monday April 6
  - This is the final Pre-Class Quiz of the term

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## Announcements 2

- New Sub-Section of the **SCN**: §C.6: **Addition of Velocities**
  - Added Sunday March 29 at 5:00 PM
- Reading Assignment for this week: **SCN** §B, §37.7, **SCN** §C, §37.9, § 37.10
- Suggested Problems for this week: Chapter 37: 57, 63, 75. **SCN** 2, 3, 4 (Parts 1 and 2 only), 5
- Reading Assignment for next week: **SCN** §D, the **Equivalence Principle** sub-section of §13.3
- Suggested Problems for next week: none
  - This section is purely qualitative

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## Last Time

- Events and Measurements
  - Reference frame: a lattice of meter sticks and synchronised clocks
  - An event occurs: *where* by the lattice of meter sticks; *when* by the time of the nearest clock
- Time Dilation
  - A consequence of the speed of light being  $c$  for all observers
  - Cosmic Ray muons
  - Twin “Paradox”

$$\beta \equiv \frac{v}{c} \quad \gamma \equiv \frac{1}{\sqrt{1 - \beta^2}}$$

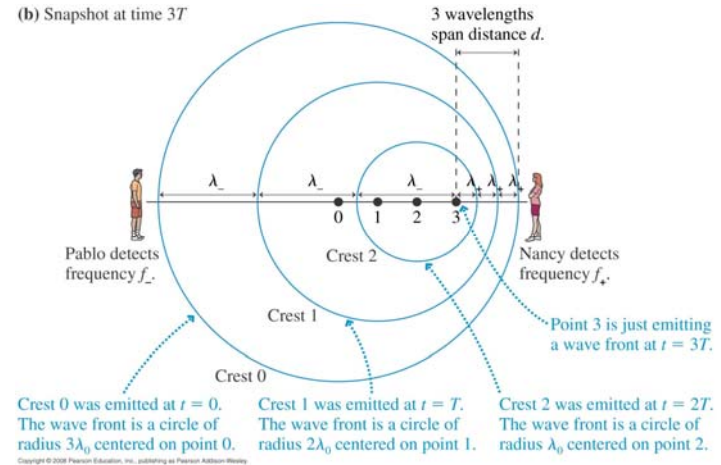
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## Today

- A loose end: Doppler Effect for light
- Length Contraction
- Simultaneity
- The Dimensions of Spacetime
- Spacetime Diagrams

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**Figure 20.26 (b):  
Wave source moving to the right**



Formed Here

Rest lifetime: 2.196  $\mu\text{s}$   
Speed: 0.999653  $c$   
Lifetime: 83.37  $\mu\text{s}$

$L_0 = 25 \text{ km}$

Decays at  
Earth's  
surface

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## The Chain of Reasoning so Far

Einstein: the speed of light is the same for all observers

**THEREFORE**

Moving clocks run slowly (experimentally confirmed)

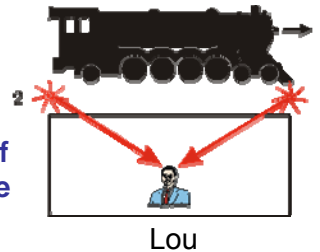
**THEREFORE**

Object lengths are contracted along their direction of motion (not tested)

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Event 1: When the right side of the locomotive passes the right side of the platform a flash of light is emitted.

Event 2: When the left side of the locomotive passes the left side of the platform a flash of light is emitted.

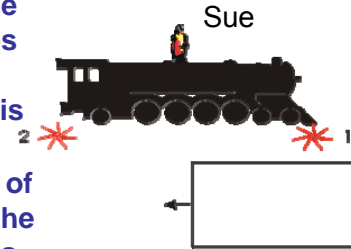


Lou is in the middle of the platform. For him the length of the locomotive is equal the width of the platform. The two events were simultaneous for Lou, and he sees the two flashes of light simultaneously.

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Event 1: When the right side of the locomotive passes the right side of the platform a flash of light is emitted.

Event 2: When the left side of the locomotive passes the left side of the platform a flash of light is emitted.



Sue is in the middle of the locomotive. For her the length of the locomotive is greater than the width of the platform. For Sue, which event occurs first?

- A. Event 1 B. Event 2 C. They were simultaneous

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### The Chain of Reasoning so Far

Einstein: the speed of light is the same for all observers

**THEREFORE**

Moving clocks run slowly (experimentally confirmed)

**THEREFORE**

Object lengths are contracted along their direction of motion (not tested)

**THEREFORE**

Simultaneity of 2 events is reference frame dependent (not tested)

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### Relativity

- Time between two events:  $\Delta t$
- Distance between two events:  $\Delta x$
- $s^2 = (c \Delta t)^2 - (\Delta x)^2$  the same value for all observers
  - $s \equiv$  interval

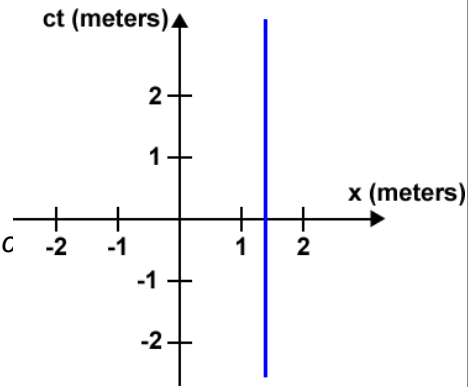
### Surveyors

- North position (feet):  $\Delta N$
- East position (meters):  $\Delta E$
- $d^2 = (k \Delta N)^2 + (\Delta E)^2$  the same value for both schools of surveying
  - $d \equiv$  distance

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The worldline represents an object moving relative to us at:

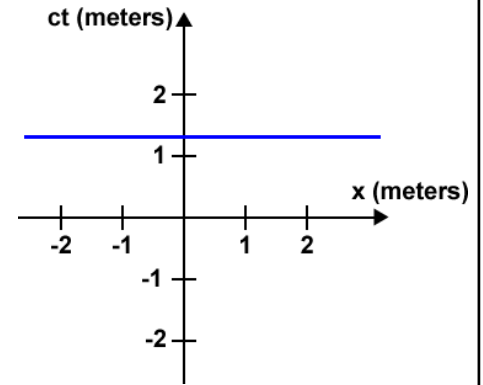
- A. Stationary
- B. Less than  $c$
- C. Equal to  $c$
- D. Greater than  $c$
- E. Infinitely fast



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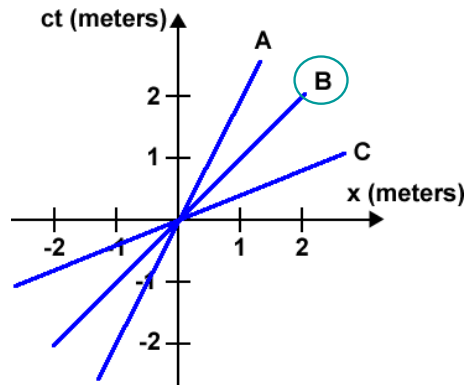
The worldline represents an object moving relative to us at:

- A. Stationary
- B. Less than  $c$
- C. Equal to  $c$
- D. Greater than  $c$
- E. Infinitely fast



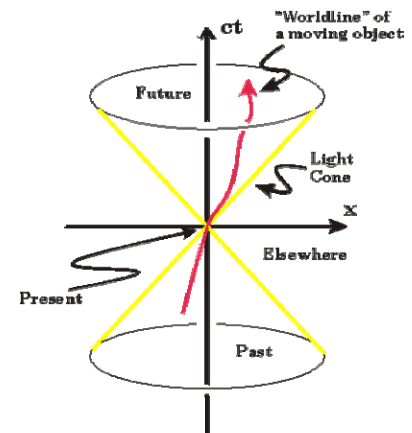
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Which worldline is closest to representing an object moving at  $c$  relative to us?



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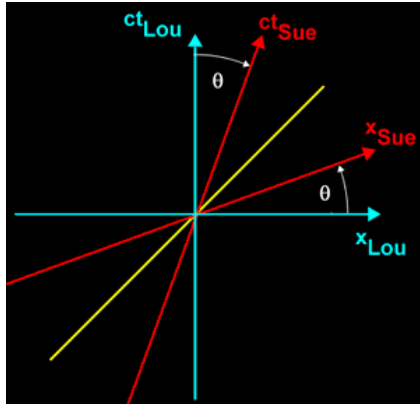
### Spacetime Diagram



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### Recall

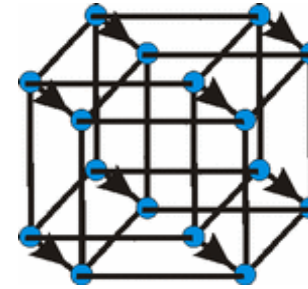
- $s^2 = (c \Delta t)^2 - (\Delta x)^2$  the same value for all observers



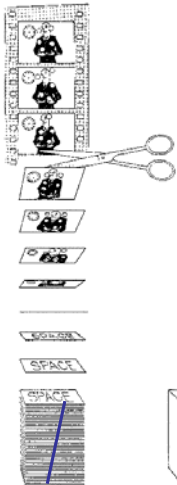
$$\tanh(\theta) = \frac{v}{c}$$

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### “Tesseract” – a representation of a 4 dimensional object:



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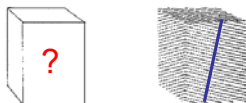


“In spacetime, everything which for us constitutes the past, the present, and the future is given in block ...”

-- de Broglie

“Our consciousness crawls along our worldline as a spark burns along a fuse.”

-- Park



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### Einstein:

- “For us believing physicists the distinction between past, present, and future is illusion, however persistent.”

-- on the death of his friend Besso

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