TIME AND LENGTH

The Universe, Life and Light 14
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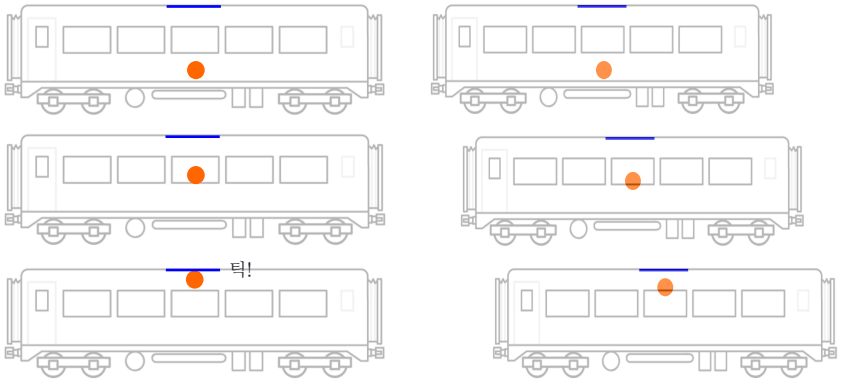
참조: 최강신. (2016). 빛보다 느린 세상

Speed of light is the same

- Two trains: the left is at rest and the right is moving



- Simultaneity broken.
- Regardless of the motion of constant velocity.
- That on the right has not arrived yet.

Two principles

Einstein, A. (1905). Zur elektrodynamik bewegter körper. *Annalen der physik*, *322*(10), 891-921.

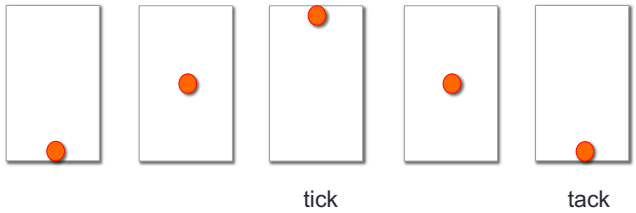
1. The speed of light is constant, regardless of the observer.
2. Observers moving relatively at constant velocity are equal.

We have no way to tell which is better.

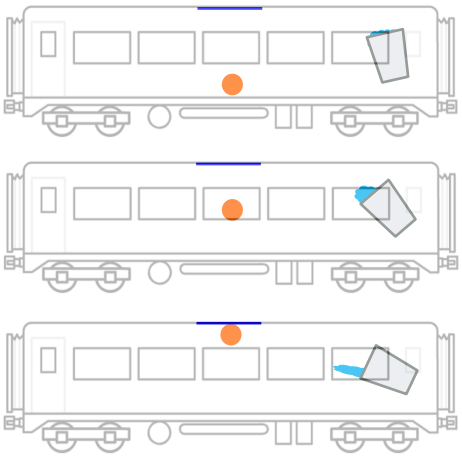
- Tacit assumption: Length and time is absolute.
  - The length and time of a moving body is the same as that at rest.
- We should reconsider the notion of space and time.

Agreeing on time

- Alice and bob prepares the same clock.
- Using light.
- Event: collision of two.
  - ex. Light and detector. It happens or not to both observers.



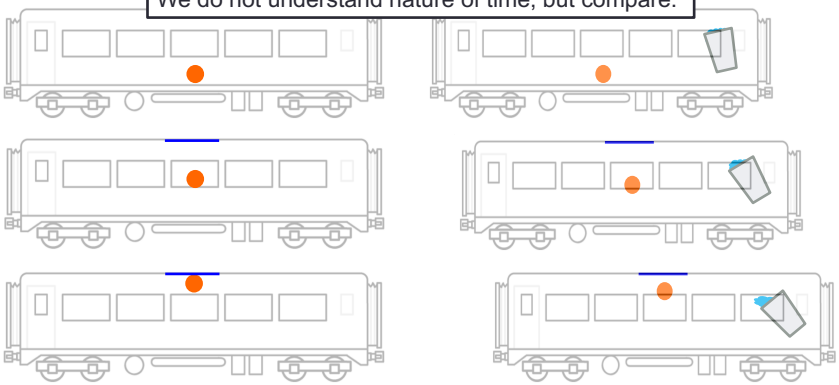
Time between events



t_{rest} = height / c

Time dilation 팽창, 늘어짐

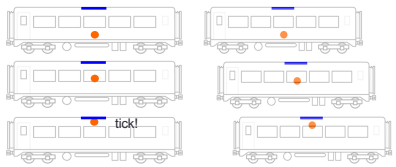
We do not understand nature of time, but compare.

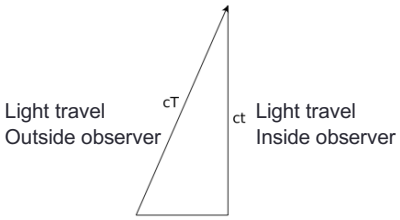


- Already one tick on the left, not yet on the right.
- The right is a slow-motion of the left. T_{moving} is longer than not height / c

Time dilation

- Speed = distance / time





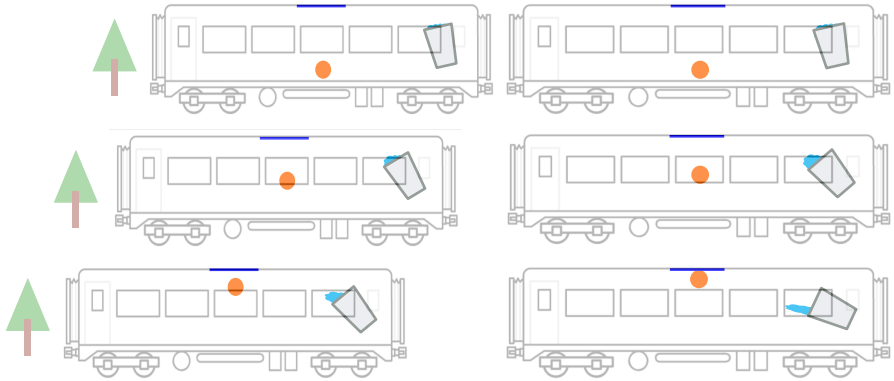
- Using Pythagoras' theorem,

$$(cT)^2 = (vT)^2 + (ct)^2$$

$$T = \frac{t}{\sqrt{1-(v/c)^2}}$$

- To outside observer, the time interval inside T is longer than her own t: moving time flows slower than her own.

Relativity

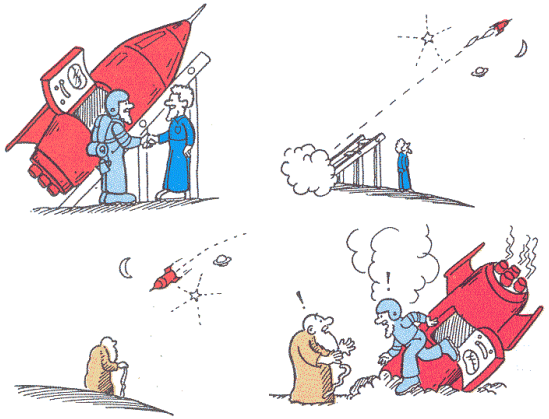


- From the moving observer's viewpoint, the left train is moving.
- Whose clock is slower?

Twin paradox

Langevin (1911)

- If we the moving train is observed short,
  what happens my rest train seen from the moving train?



Test

- Hafele and Keating (1979)

Constant *c*

- From various experiments, we found that the speed of light is always same regardless of observer.

- $u + v$ is modified to

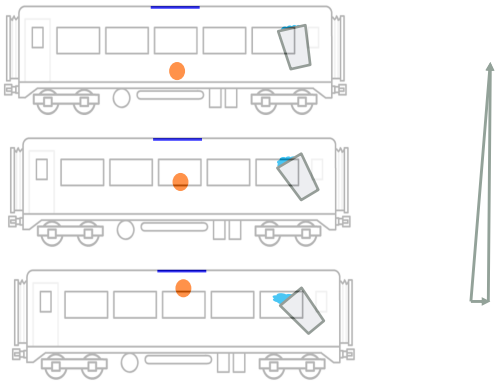
$$\frac{u+v}{1+\frac{uv}{c^2}}$$

- Addition of $c + \frac{1}{2}c$: not 3/2 c but…
- For large c it is practically $u + v$.
- Time change; length change cancelled.

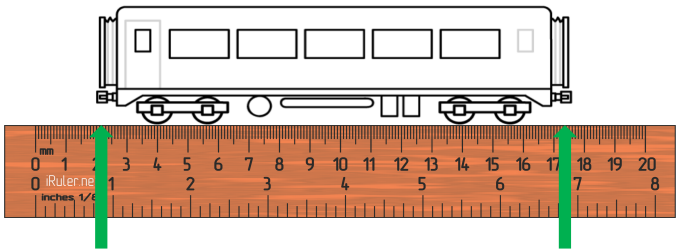
This addition rule is the most general addition rule for ‘uniform space’.

Why we don’t see it?

- Usually, the train speed $v \sim 60$km/h is much less then the speed of light $c \sim 940000000$ km/h.



Measuring length

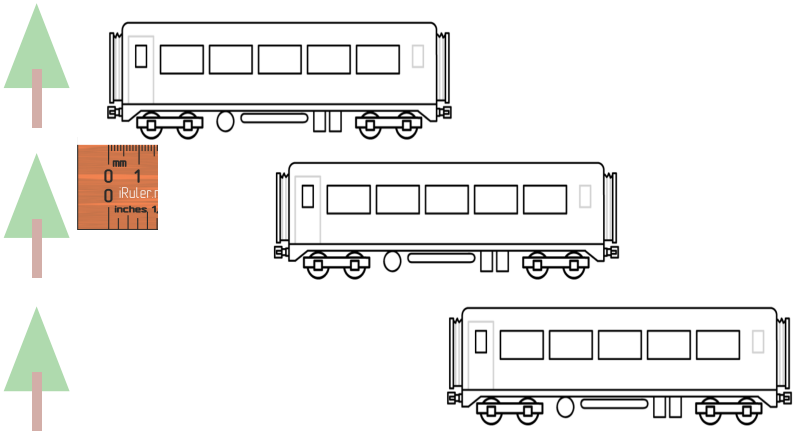


- Problems

1. Only with meter stick we can measure relative length.
2. Only one part we can observe at each moment.
3. Finite speed of light.

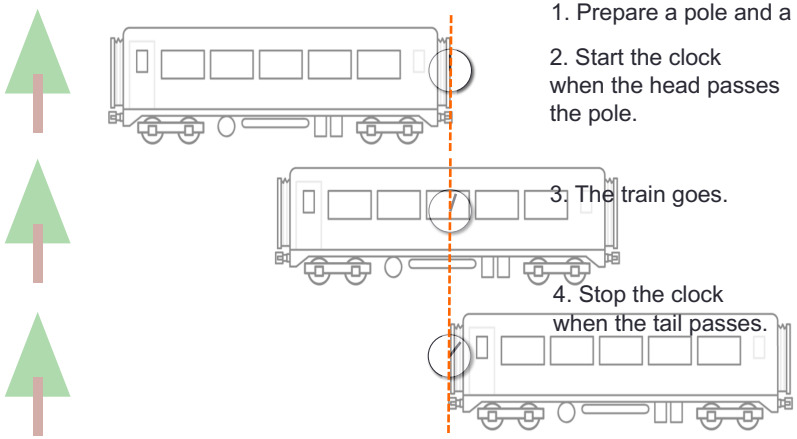
Difference of the numbers
at the same moment.

The moving length



We cannot do it to the moving train.

The moving length



1. Prepare a pole and a clock.
2. Start the clock when the head passes the pole.
3. The train goes.
4. Stop the clock when the tail passes.

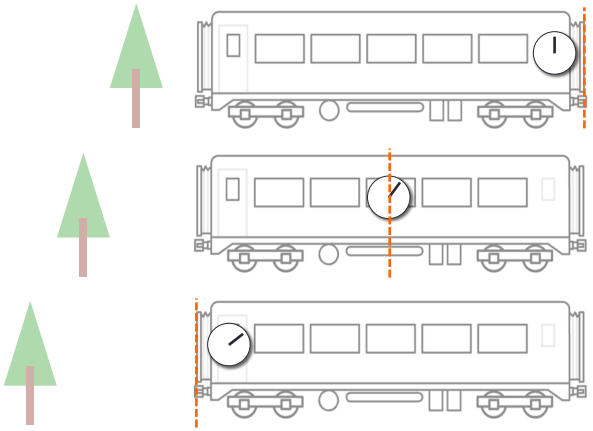
The moving length observed at the station

$$L_{moving} = v\ t$$

The clock runs at the normal rate.

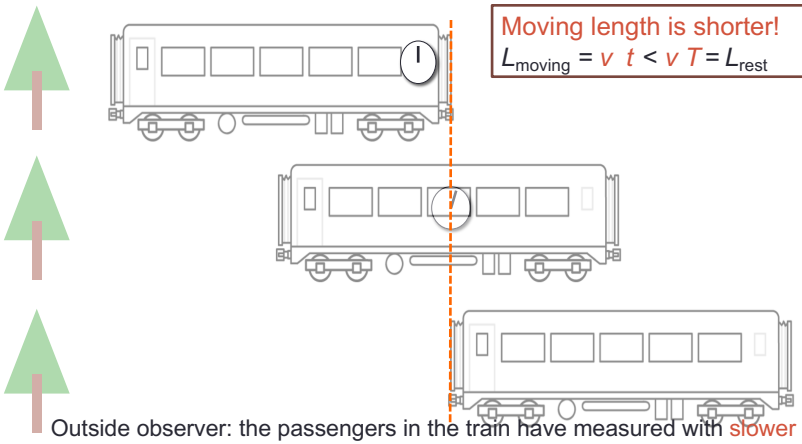
The rest length

Passengers: “we are measuring the length of the train at rest.”



$$v\ T = L_{rest}$$

The rest length, clocks, seen from outside

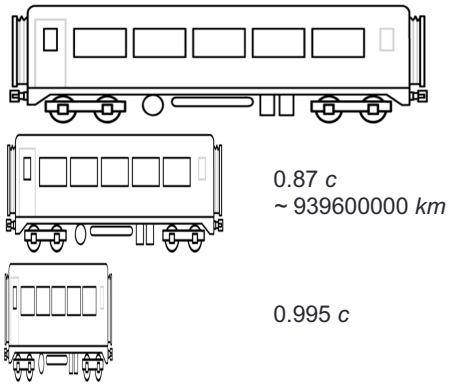


Moving length is shorter!
$L_{moving} = v\ t < v\ T = L_{rest}$

Outside observer: the passengers in the train have measured with slower clock.
$T > t$

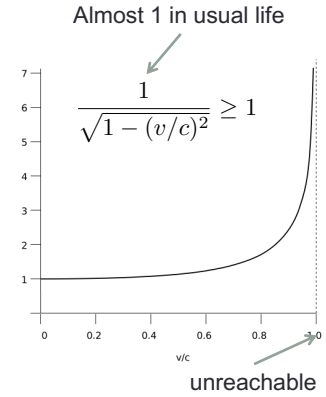
Length contraction

- The faster the vehicle, the shorter the length.



0.87 *c*
~ 939600000 *km / h*

0.995 *c*



Summary

- Two principles
  - Principle of relativity: The experiments should be the same for every constantly moving observers
  - Invariance of speed of light.
- Explained by introducing relative length and time.
  - Length and time are to be compared with others.
  - No absolute length and time.
- Moving object
  - Slower time flow
  - Length contraction