Relatively Speaking

Peter Watson

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1. Is time travel possible (for human beings)?

2. Why it's a good question: This question has peaked my curiosity for many years. If we do develop some sort of H.G. Wells' time machine...do we create another timeline? Isn't it really the 'present' for us even though we're going 'back into the past'? Therefore, are we really 'time traveling' since we are still in the present? Furthermore, to answer this question, I think that we would need to explore the basic concepts stated in Einstein's theory of relativity (time, length relativity, etc.) The time travel question can also lead us to explore the idea of worm holes.

Text

Statutory Warning

- This lecture is for mature audiences only
- Extreme violence may be caused to your pre-conceptions

Relative Motion

- Suppose a train is travelling at 5 m/s and a bandit is running towards the front at 2 m/s, relative to the train.

[redacted]

- How fast is he moving relative to the ground?

[redacted]

How fast is he moving relative to the train?

[redacted]

[redacted]

How fast is the ground moving relative to him?

[redacted]

[redacted]

Frames of Reference

The proper name for "point of view" is "frame of reference": a non-accelerating frame is an "inertial frame"

This is Galilean Relativity: All inertial frames are equivalent

Suppose we do experiment in two different frames:

1. Earth Frame: if we measure a distance(velocity) in this frame, we will call it x(v)
2. Train Frame: if we measure a distance(velocity) in this frame, we will call it x'(v')

e.g. just dropping a ball

- In the train frame

[redacted]

[redacted]

- In the earth frame

[redacted]

[redacted]

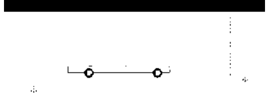
- Results of any experiment can be described in any frame: no frame is preferred.

Put differently: you cannot do an experiment to decide if you are moving, since one man's motion is another man's station!.

Inertial Frames

- An inertial frame is one that does not accelerate
- Stationary objects stay stationary

[redacted]



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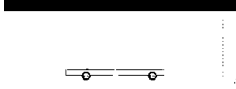
Non-inertial Frames

- An non-inertial frame does accelerate
- Stationary objects can accelerate without forces

[redacted]



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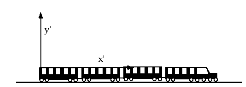
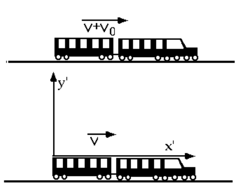
- Can transform the results of an experiment in any one frame to any other.



- Velocity in earth frame = Velocity of train frame + Velocity in train frame

and can compare them both



Have gone through this in (sordid) detail since it is wrong!

- We have assumed:

1. Laws of Physics are the same in all inertial frames,

2. Time is the same in all frames

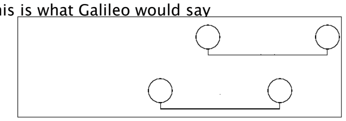
- 2. is a hidden assumption, that was never written down.
- The correct statement (Einstein) is

1. Laws of Physics are the same in all inertial frames,

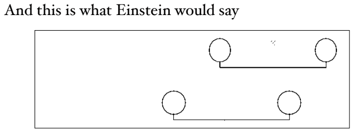
2. The speed of light is the same in all frames

This means that (since speed = distance/time) distance and/or time must change when we go from one frame to another.

- This is what Galileo would say



- And this is what Einstein would say

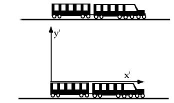


Means clocks must measure different times

Suppose we fire a beam of light from the front of a train.

- From the point of view of the earth we would expect

in fact



Note that this implies that nothing can go faster than the speed of light

Nick Toller

1. How is it possible that scientists recording neutrinos moving faster than the speed of light?
2. Why is this a good question? It deals with some of the most basic properties of the Universe (particles being unable to move faster than light) and is something topical that appears in news media. It could also lead into a discussion of other popular science fiction ideas of faster than light travel and time travel.
3. (4) Completely explaining this would require an understanding of general relativity.

Text

Oladunni Abiodun

1. Question: Why is faster-than-light travel seemingly possible?
2. It is a good question because the concept of teleportation seems to be based on our ability to move faster than light so if it was possible it would solve a lot of transportation and maybe even communication problems.
3. Seems like something that would have a pretty straightforward but difficult explanation

PW

Nothing can go faster than light

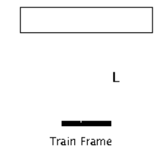
FASTER-THAN-LIGHT NEUTRINOS CAUSED BY LOOSE CABLE?

'FASTER-THAN-LIGHT' NEUTRINO TEAM LEADERS RESIGN

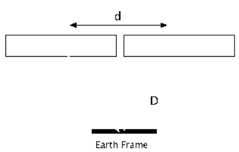
Discovery

Time Dilation

- To find out how the time changes from one frame to another, consider bouncing a light off a mirror as the train goes past.



- In the earth frame, the light has to travel further, since the train has moved.

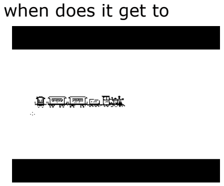


We can solve this giving

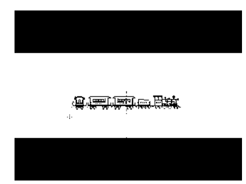
- so
  i.e. moving clocks run slow

Simultaneity

- Since time is not the same in two frames, events which are simultaneous in one frame are not in another
- e.g suppose a flash of light is emitted at the centre of a train: when does it get to the end?
- in the earth frame



- but in the train frame



The Twin Paradox

- How much does this slowing down of time matter?
- e.g. Suppose you are in an OC Transpo bus ($v_0 = 10ms^{-1}$):

how slow will your watch appear to run compared to your clock at home?

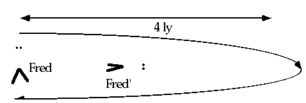
T = 1 hour at home

Corresponds to 1 hour - 1 picosecond on the bus

Note there are a lot of other consequences

- Length contraction (moving objects appear to be shorter)
- Increase of mass (objects get heavier the faster they go, so cannot go faster than light)
- and

Twin Paradox



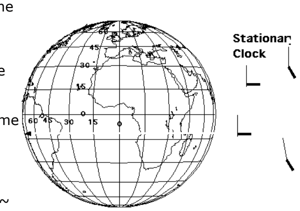
- The star α-Centauri is 4 light-years distant from earth.
- Fred and Fred' are both 20.
- Fred' leaves for α-Centauri at .9 c.
- How old is Fred when Fred' gets back?
- 28.89 yrs
- How old is Fred'?
- 23.87 yrs

Your reaction to all this should be:

- **"This is really stupid. What really happens?"**
- Answer: In physics you cannot ask
- "What really happens?"
- The best one can do is ask
- "What can I measure?"

So can we measure it?

- Hafele-Keating experiment done in 1980:
- atomic clock flown round the world (first-class!) and compared to time of atomic clock "at rest".
- Time lost by moving clocks ~ 190 ns



Vladimir: That passed the time
Estragon: It would have passed in any case.
Vladimir: Yes, but not so quickly.
Beckett: waiting for Godot.

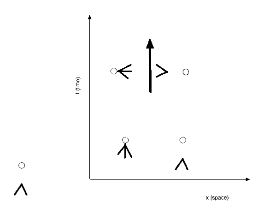
Time as a fourth dimension

The changes to space and time that Einstein found show that they are aspects of the same thing: space-time.

Galileo-Newton Space is 3-D, time is an independent quantity

Einstein-Minkowski, Space-time is 4-D, and motion mixes space and time in different ways

- Einstein's concept of time can be expressed graphically by "worldlines" in a space-time diagram.
- Reduced to 1 space and 1 time dimension, can describe interactions as events: e.g 2 men walk into each and fall over.



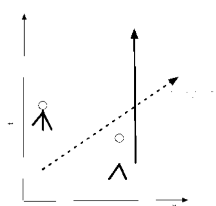
Following constraints must be satisfied by world-lines:

Must be oriented from past to future: "flow of time".

Static object remains at same x, but time still moves.

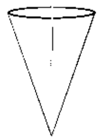
Moving objects have maximum slope corresponding to speed of light.

Events occur when worldlines intersect



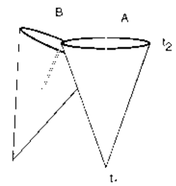
Light Cone

- Possible light paths are represented by "Light Cone".
- Cannot escape the light cone (it includes all possible futures for you!)

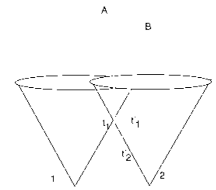


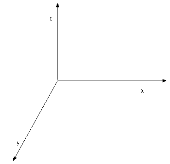
"Light Cone" represents possible paths of signals:

- i.e. interaction need not be direct, but can send (e.g.) phone message.
- Shows person A sending signal at time t_1 which is received by B at time t_2
- Note times are measured in A's frame



- Can see the violation of simultaneity:
- e.g. two flashes of light are seen as simultaneous by observer A but not by B



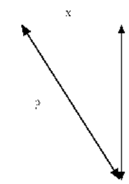


Some world-lines are more complex: e.g. a planet with 2 space dimensions

- e.g suppose we have an event now and one in the future at time t and position x: the distance is **not**

$s^2 = x^2 + t^2$

(in fact we can't even add space and time).
- We must use



- (note the minus sign)
- but even this needs careful interpretation.

e.g. Suppose we send a flash of light:

How does time move in the frame of the light?

Can we describe this in English?

Imagine you are a photon

You can't

How about a novel?

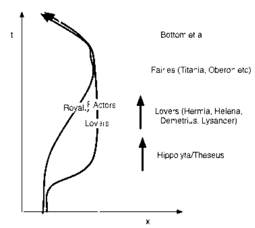
My Life as a Photon

By

Bit Delight

However this 4-D picture is useful. We can analyze the time in any creative work in the same way:

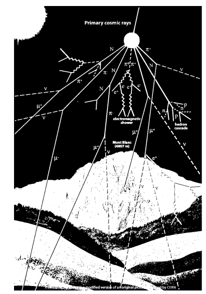
- e.g. Midsummer Nights Dream.
- Note this is a gross over-simplification:
- e.g the lovers + fairies + Bottom have very complex crossing world-lines
- I'll put a girdle round the earth in forty minutes (Puck)



The assertion: prior to 1900 the space-time diagram for any work satisfied the standard conditions: Aristotle's three unities become "space-time causality is preserved" or "special relativity is satisfied".

Time Dilation in practice

- Muons (μ) are particles like heavy electrons produced by cosmic rays
- One goes through you each minute on average)!
- Lifetime ~ 2 μs



How do they get to earth?

- If they are travelling at 0.9999 c should only go 600 m
- However, lifetime gets extended (clock runs slow!) to .45 ms
- Can travel 135 km in this time
- Most can get to earths surface

How do we explain this from pov of muon?

- **Lifetime** stays the same (2 μs)
- **Length** from top of atmosphere to ground gets contracted to 22 m