Class 2: Einstein's Postulate

In this class we will explore the remarkable consequences that follow if the speed of light is a constant, independent of the motion of source and observer

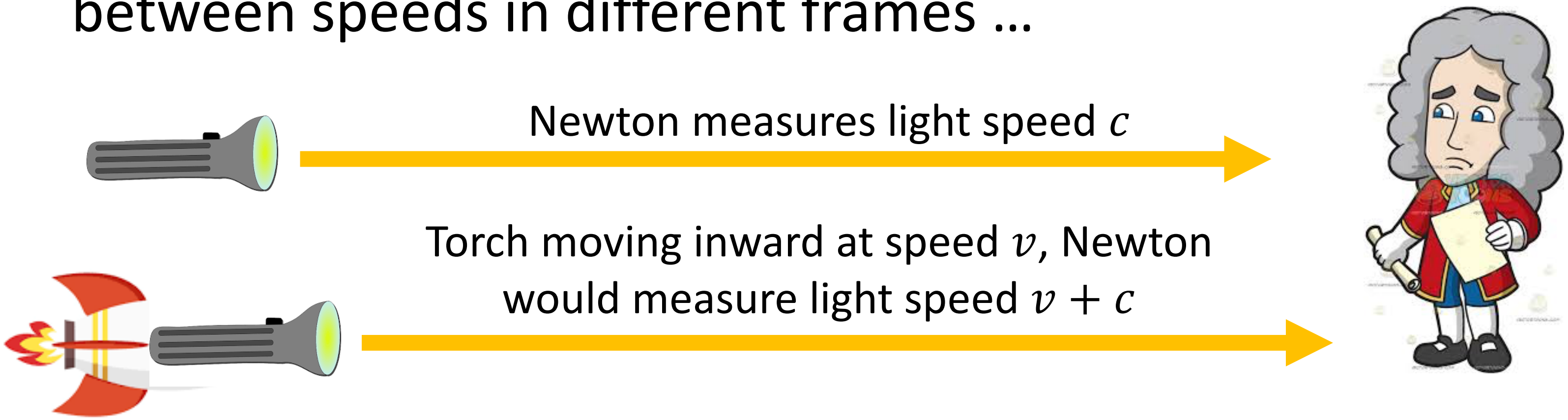
Class 2: Einstein's Postulate

At the end of this session you should be able to …

- … describe **Einstein's postulate** that the speed of light is the same in every inertial reference frame
- … recognize the **relativity of simultaneity**: events that are simultaneous in one frame, are not simultaneous in others
- … apply the concepts of **time dilation** and **length contraction**, which relate time and space intervals measured in different inertial reference frames
- … recall that the **proper time difference** between 2 events is measured in a frame where they occur at the same place

The speed of light

- Consider how classical physics would describe the relation between speeds in different frames …

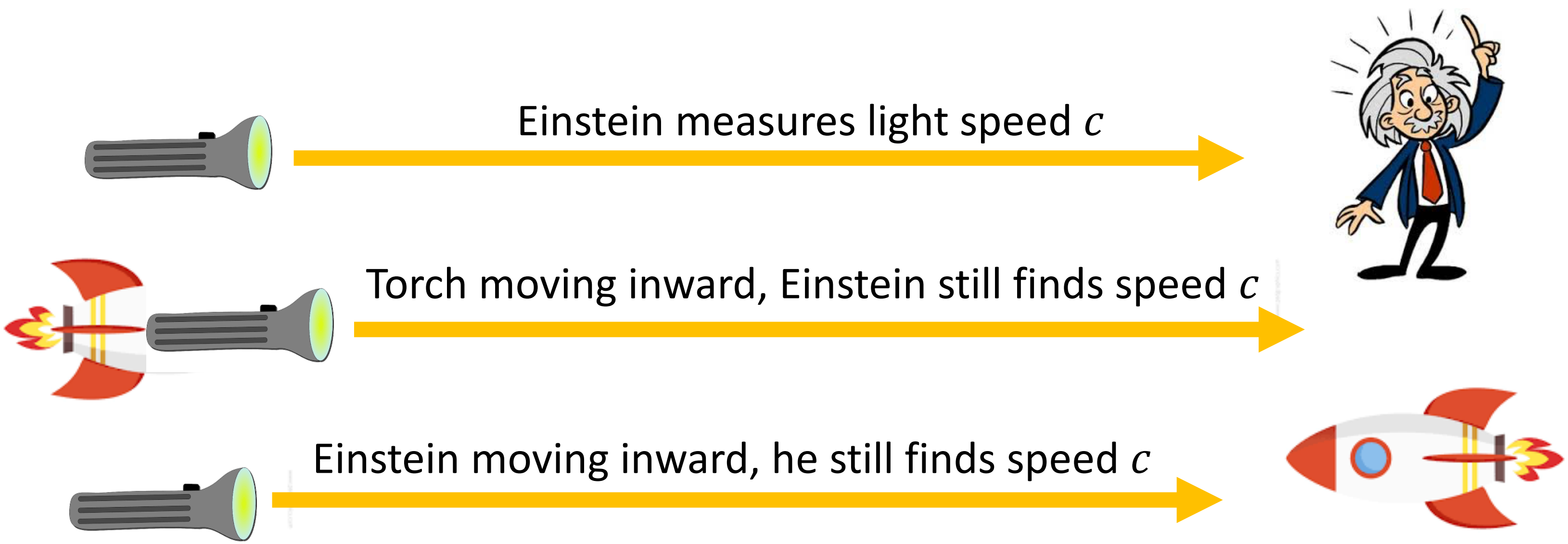


- This idea is rejected by relativity, which begins instead with **Einstein's postulate** (1905):

The speed of light is constant in all inertial reference frames, independent of the motion of the source and observer

The speed of light

The speed of light is constant in all inertial reference frames, independent of the motion of the source and observer *[Note this in the Workbook]*



- A simple idea, with some powerful and alarming consequences!

A few thought experiments

- It’s useful to explore these ideas by **thought experiments** – imagining situations which may not be precisely replicated in a laboratory, but which confront the logic of a theory*

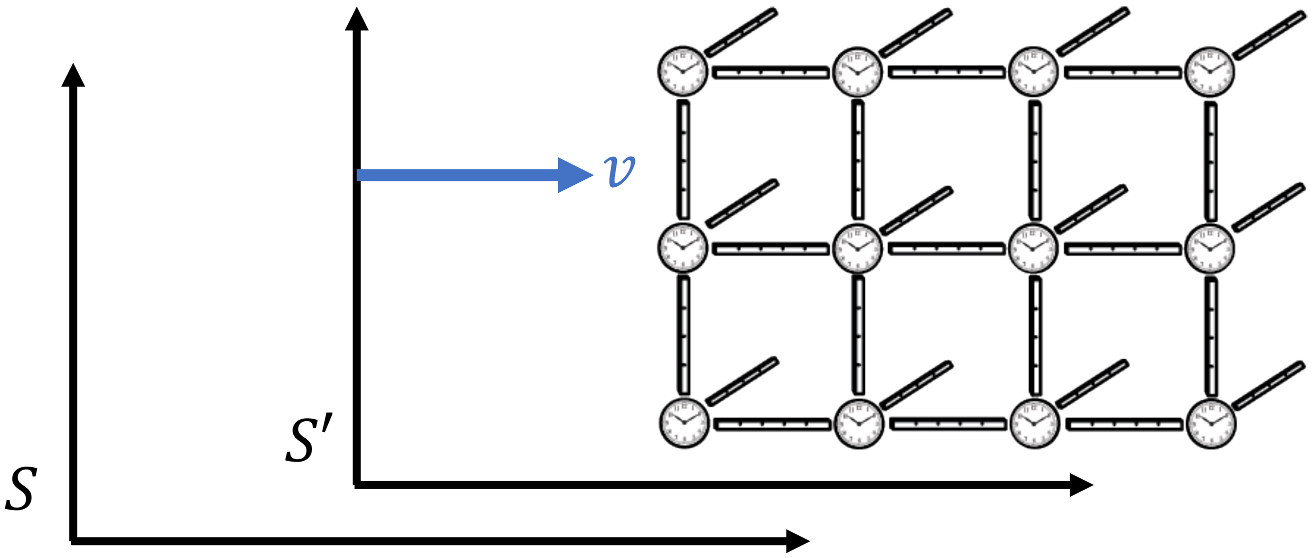
* And therefore usually give you a head-ache!

https://www.cartoonstock.com/directory/t/thought_experiment.asp

"SINCE YOU CONDUCT ONLY THOUGHT-EXPERIMENTS, WE WERE HOPING YOU WOULD, FROM TIME TO TIME, COME UP WITH SOME THOUGHT-RESULTS."

A few thought experiments

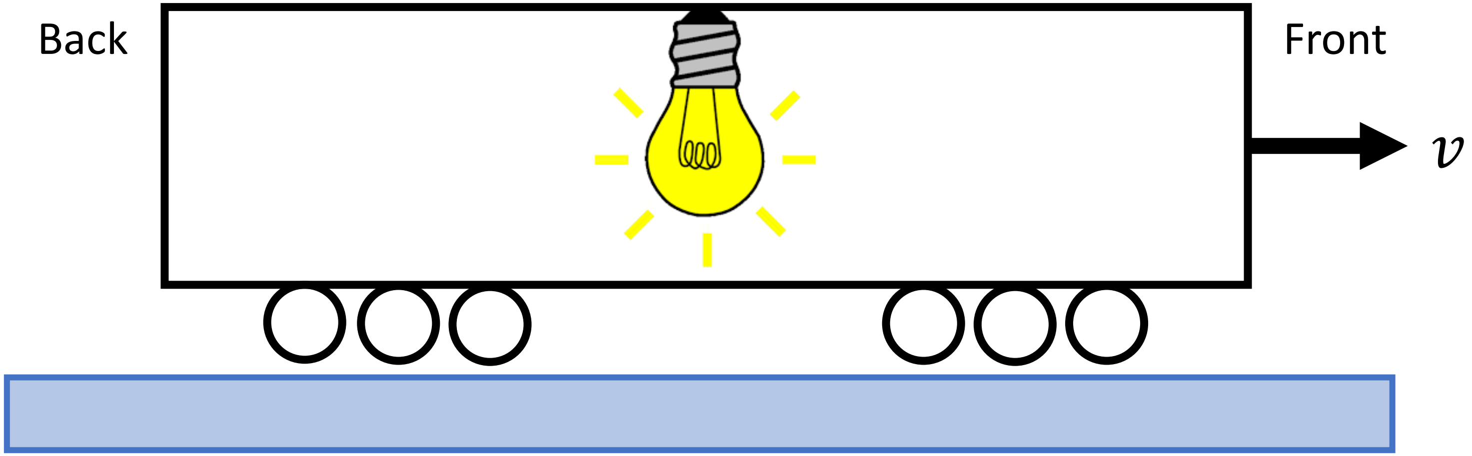
- We will often compare these thought experiments from the viewpoints of the **standard inertial frames**, S and S', moving with relative speed v



- These reference frames are each kitted out with the usual lattice of observers and synchronized clocks

Simultaneity

- A train (frame S') is travelling past a platform (frame S), and a light bulb in the middle of the carriage is switched on

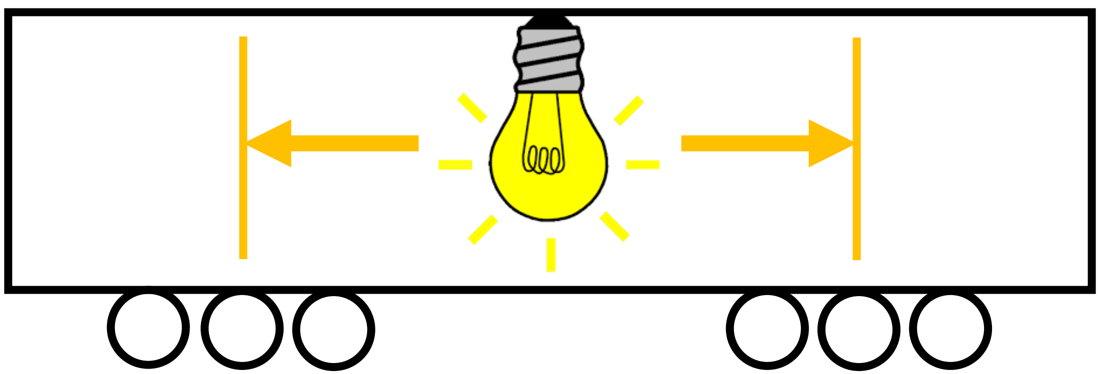


- The light pulse spreads out, and we'll compare when the light first hits the front, and back, of the carriage

- These occurrences are 2 events called E_F (front) and E_B (back)

Simultaneity

- We first consider the situation as viewed from **the reference frame of the train** (frame S')

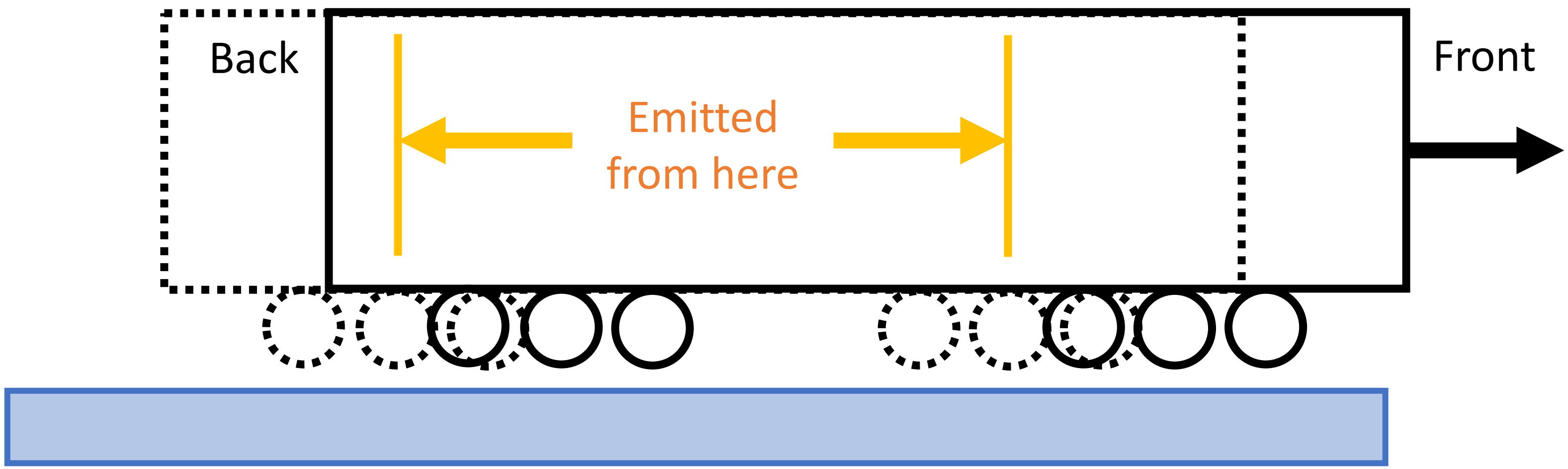


(Train is stationary in this frame)

- The light pulses, travelling at speed c, hit the front and back of the carriage at the same time
- The events E_F and E_B are **simultaneous** in frame S'

Simultaneity

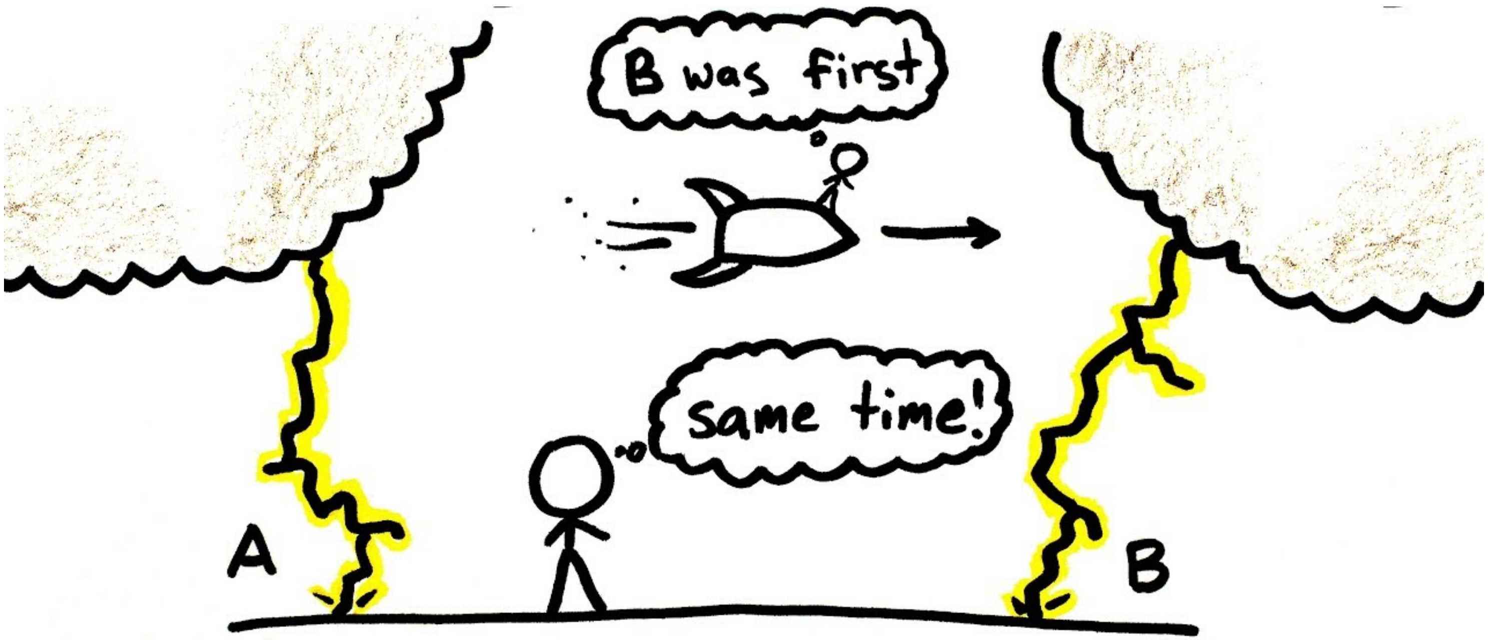
- Now consider the situation as viewed from **the platform** (frame S), through which the train is moving



- The light pulses are travelling at speed c, but the back of the carriage has moved closer, and the front has moved away – so **the light reaches the back first** (E_B happens before E_F)

Simultaneity

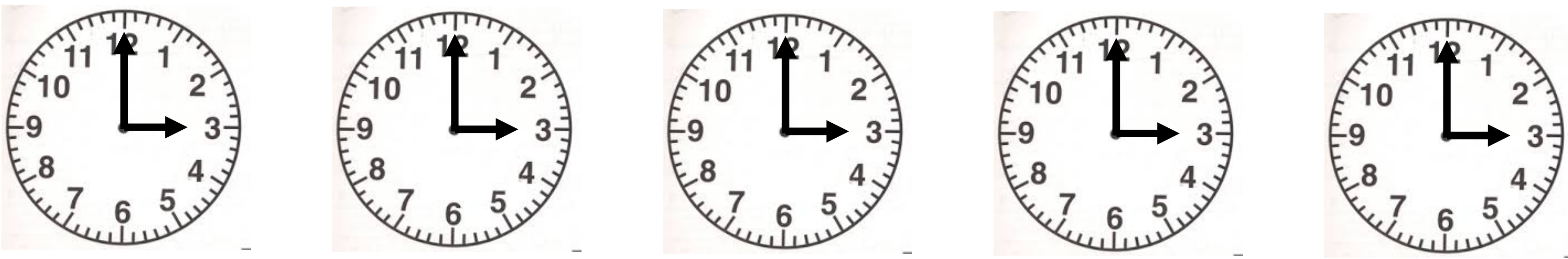
If two events are simultaneous in one frame, they are not simultaneous in another frame



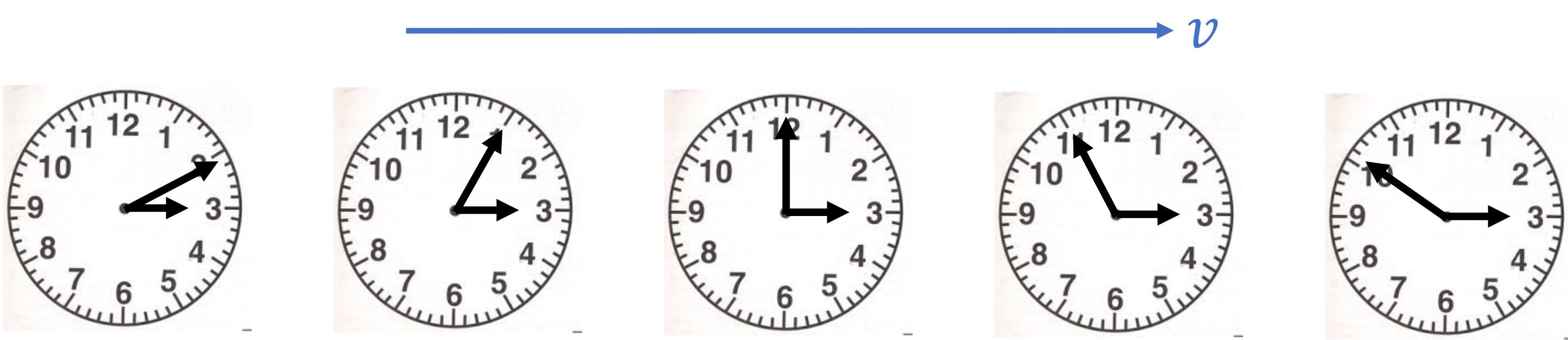
Minute Physics: https://www.youtube.com/watch?v=SrNVsfkGW-0

Simultaneity

- Consider the set of synchronized clocks in frame S', which are ticking simultaneously **as measured in that frame**

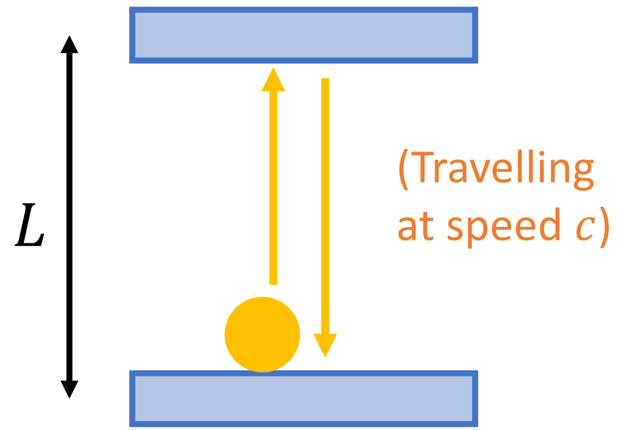


- These ticks **cannot be simultaneous** in another frame – so the clocks *are unsynchronized when measured in frame S !!*



Time Dilation

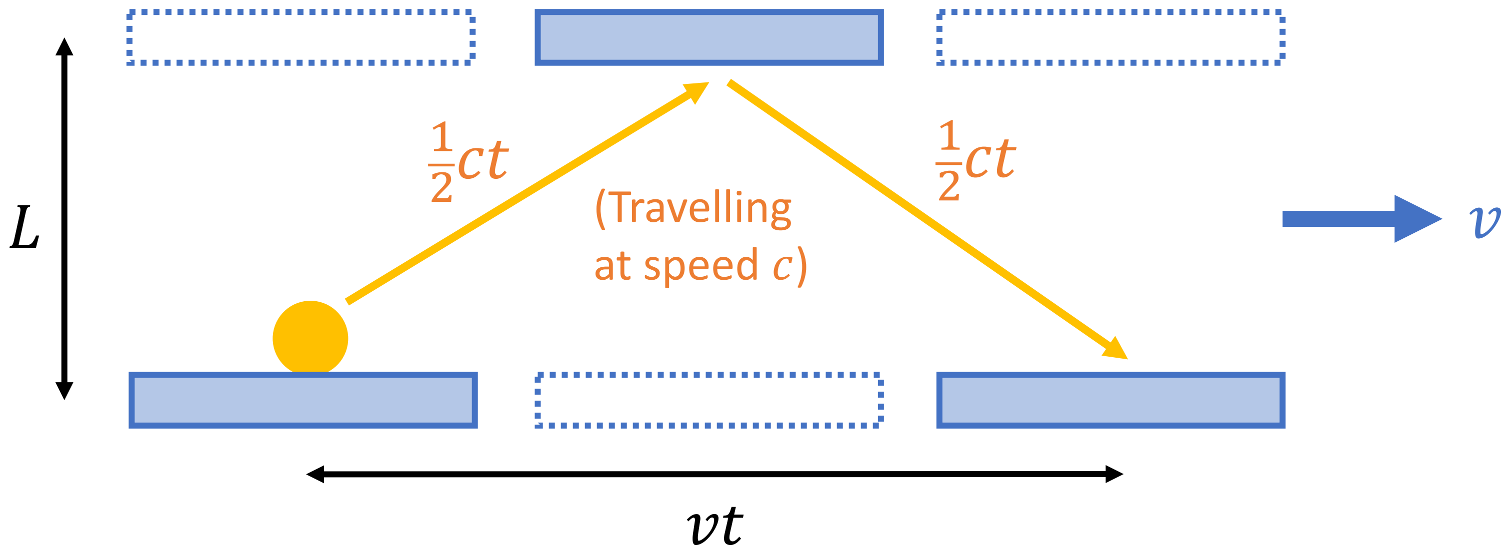
- For our next experiment, consider a simple "clock" in frame S' which consists of light bouncing between two mirrors



- Each tick of the clock is a complete oscillation of the light, which takes time $2L/c$ in this frame
- *(Yes, this is a strange way to make a clock, but the following logic applies equally well to the ticks of your wristwatch, or the beats of your heart)*

Time Dilation

- Let’s now put the clock in motion at speed v through frame S – what’s the time period t in this frame?



- **The light has to travel further, so the period is longer**
- We’ll show that $t = \frac{2L}{c} \times \frac{1}{\sqrt{1-v^2/c^2}}$

Time Dilation

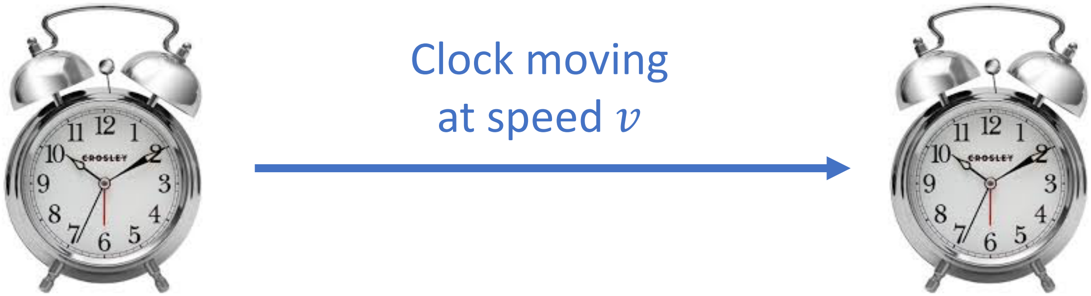
Clock ticks are further apart, if recorded in a frame through which the clock is moving

[Note this in the Workbook]

https://www.kanopy.com/product/escaping-contradiction-simultaneity-relati

Proper time

- We introduce here the **proper time difference**, which has the symbol $\Delta\tau$ ($\tau =$ the Greek letter "tau")
- A proper time difference between 2 events is **measured in a frame where the events occur at the same place**
  [Note this in the Workbook]

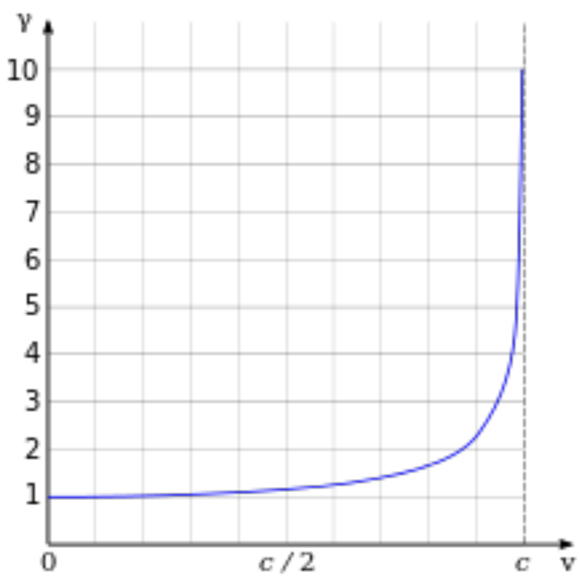


- In the clock frame, the ticks happen at the same place and are separated by a proper time difference – in the ground frame, the separation is always longer: $\Delta t = \Delta\tau/\sqrt{1 - v^2/c^2}$

Gamma factor

- The quantity $1/\sqrt{1-v^2/c^2}$ occurs throughout relativity and has the symbol γ (the Greek letter "gamma")

$$\boxed{\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}}$$

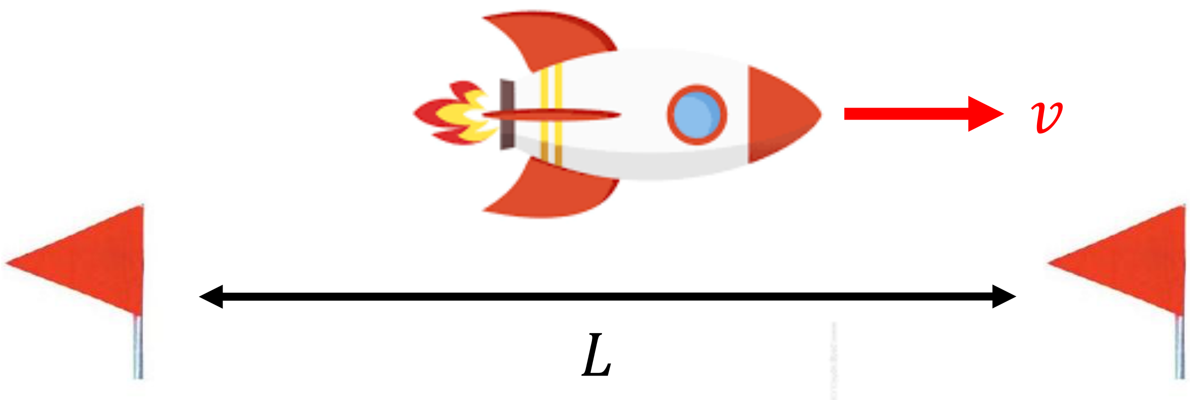


https://en.wikipedia.org/wiki/Lorentz_factor

- γ is a measure of "how relativistic" is the situation
- $\gamma = 1$ for $v = 0$, $\gamma \to \infty$ as $v \to c$
- γ is known as the **Lorentz factor**

Length contraction

- For our final thought experiment, consider a rocket ship (frame S') travelling with speed v between 2 points which are separated by distance L on the ground (frame S)
- First, consider the situation **as viewed in the ground frame S:**



- According to ground observers, the rocket ship takes time $\Delta t_{ground} = L/v$ to travel this distance

Length contraction

- *How long does this trip take in the rocket frame S'?*

- We can use the time dilation relation: $\Delta t = \frac{\Delta\tau}{\sqrt{1-v^2/c^2}}$
- The start and end of the trip occur **at the same place** in the rocket frame, so are separated by a proper time interval $\Delta\tau$
- In the ground frame, the time interval is $\Delta t_{ground} = \Delta t = \frac{L}{v}$
- So, time in rocket frame is $\Delta t_{rocket} = \Delta\tau = \frac{L}{v}\sqrt{1 - v^2/c^2}$

Length contraction

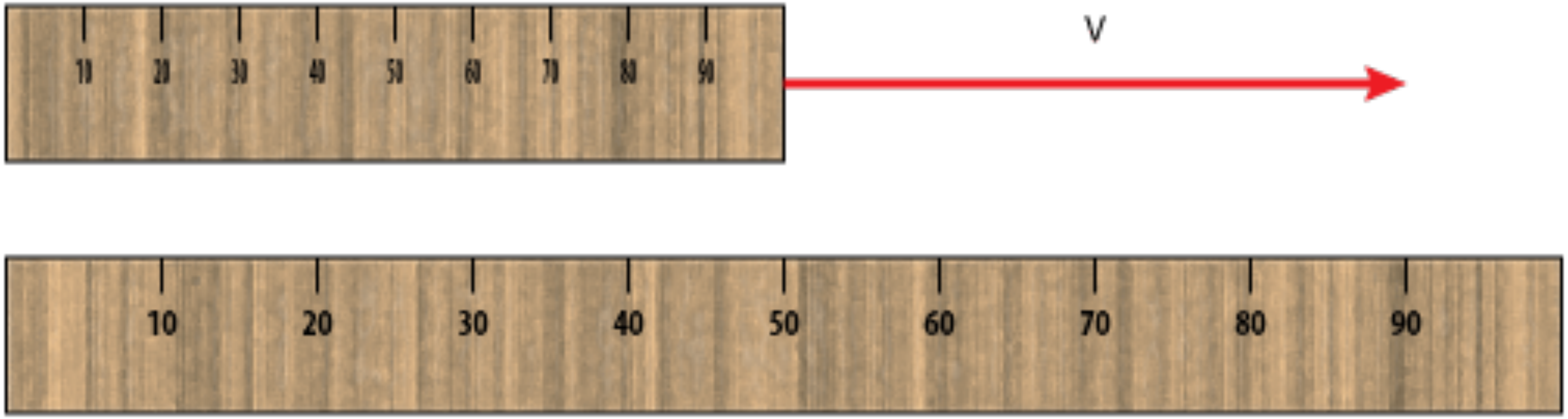
- *What is the distance travelled according to the rocket?*

- The ground is moving past the window at speed v, for time $\Delta t_{rocket} = \frac{L}{v}\sqrt{1 - v^2/c^2}$
- Rocket passengers measure that they have moved a distance $L_{rocket} = v\,\Delta t_{rocket} = L\,\sqrt{1 - v^2/c^2} = L/\gamma$
- *This distance is less than the separation on the ground, L !!*

Length contraction

The length of an object is measured to be shorter in a frame in which it is moving

[Note this in the Workbook]



https://sciencenotes.org/moving-rulers-shorter-length-contraction-example-problem/

Trip to the stars!

As part of Swinburne's Physics class in the year 2118, you suggest a rather ambitious 3rd year Grand Challenge project to visit the closest star Proxima Centauri, located 4.2 light years from the Sun.

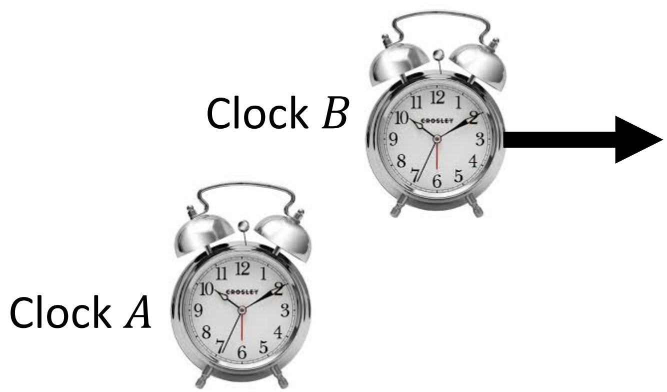
Your supervisor (who may or may not know any relativity) complains that it will take you at least 4.2 years to get there, since you cannot travel faster than light, but you only have 3 months to finish the project! However, having recently studied time dilation you know better …

- How fast would you need to travel to reach Proxima Centauri in 3 months, according to your own wristwatch?
- How can your rocket ship travel 4.2 light years in only 3 months – doesn't that involve faster-than-light travel??
- Is it possible to hand in your project back at Swinburne on time??

Paradoxical thinking

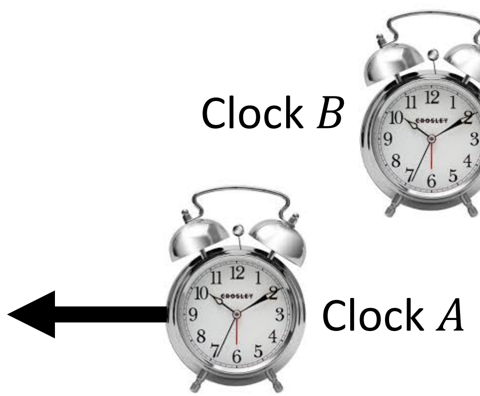
- We have learnt that "moving clocks run slow". Consider clocks A and B, at rest in frames S and S', respectively

View from S



Clock A at rest,
"Clock B runs slow"

View from S'



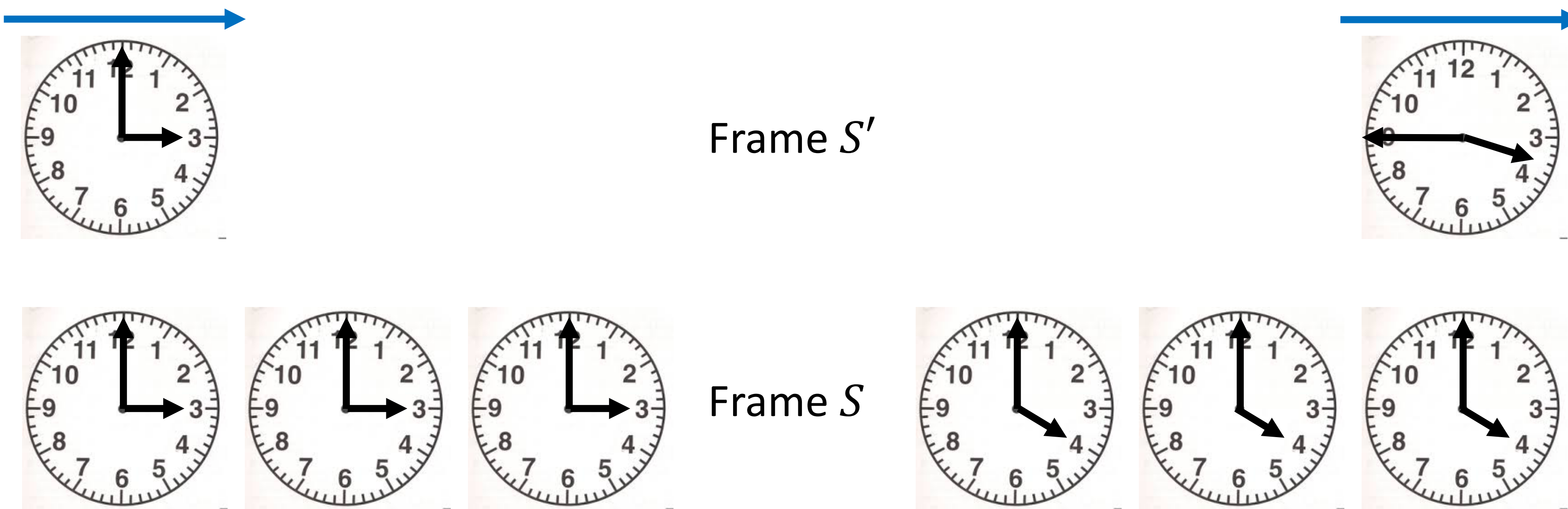
Clock B at rest,
"Clock A runs slow"

- We have an apparent paradox: **both clocks cannot run slow**!

Paradoxical thinking

- This paradox has arisen because we have not been very precise in describing the situation. Let's do better!

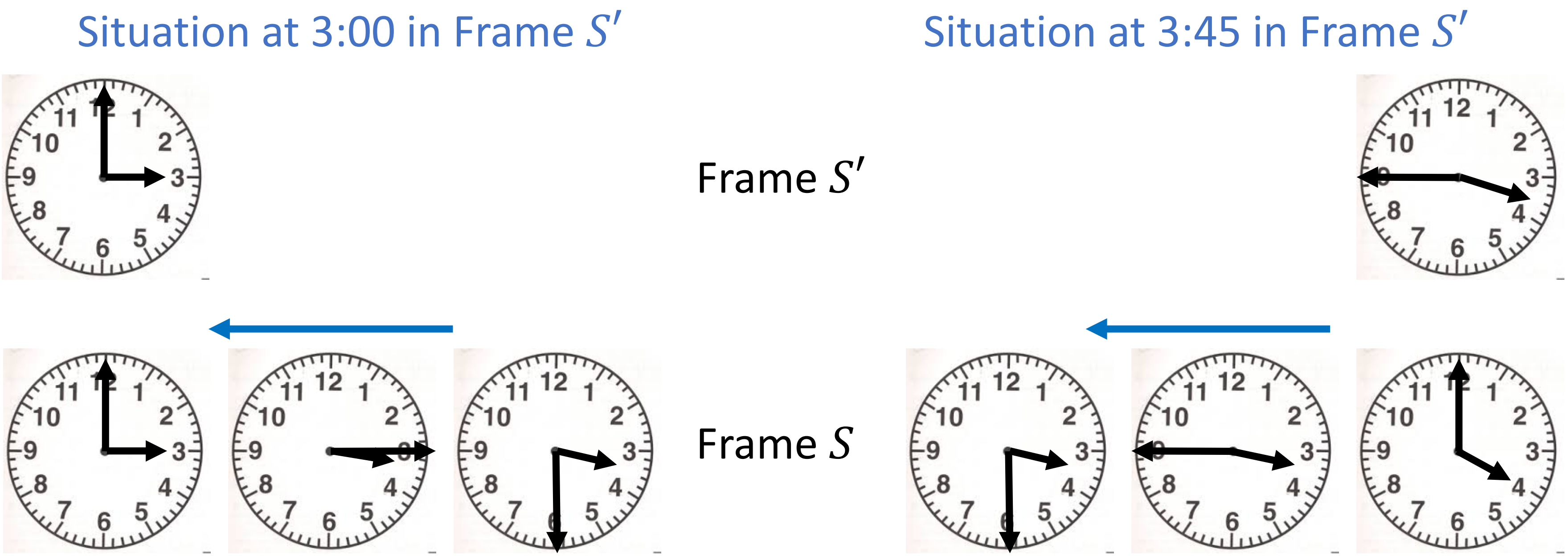
Situation at 3:00 in Frame S Situation at 4:00 in Frame S



- Frame S observers think: clock in S' has only advanced by 45 mins during 1 hour – "moving clocks run slow"

Paradoxical thinking

- Now let's pivot to the view-point of frame S'. As mentioned before, **frame S' observers think that the frame S clocks are out of synchronization**



- Frame S' observers: "frame S observers think our clocks are running slow, because theirs are out of synchronization!"

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