Time-dilation

Pang Yuying (407), Alycia Ong (411)
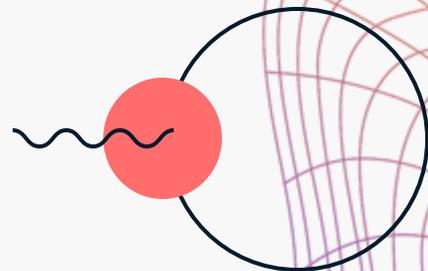
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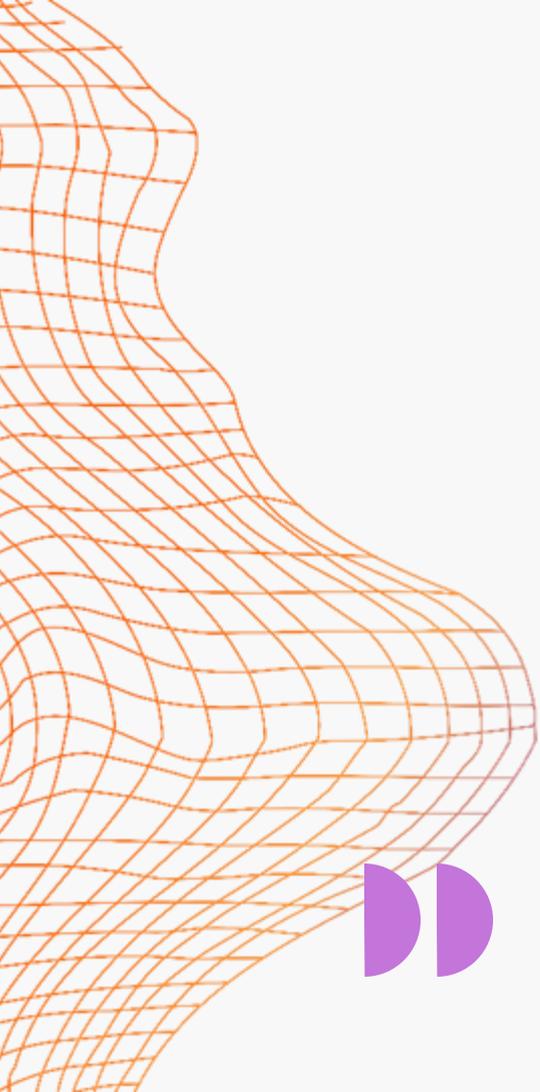
01.
Introduction to Time dilation
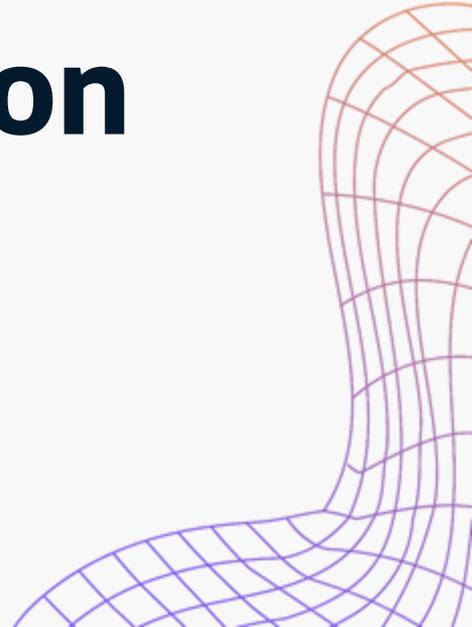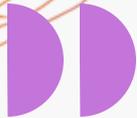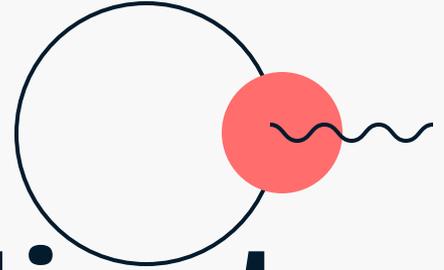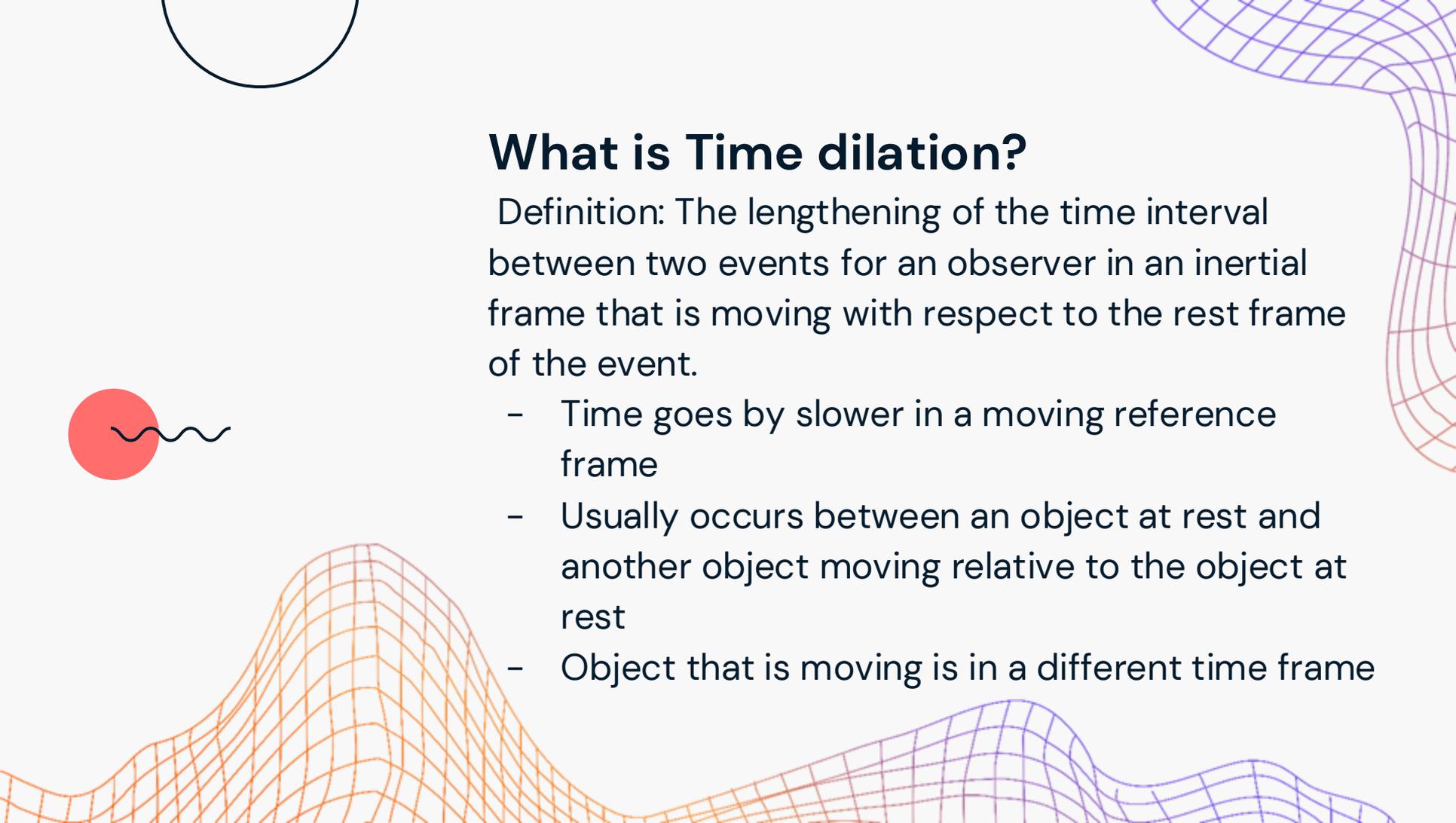
What is Time dilation?

Definition: The lengthening of the time interval between two events for an observer in an inertial frame that is moving with respect to the rest frame of the event.

- Time goes by slower in a moving reference frame
- Usually occurs between an object at rest and another object moving relative to the object at rest
- Object that is moving is in a different time frame

Who thought of it?

Albert Einstein!

Time dilation is a phenomenon predicted by Einstein's theory of relativity where time passes slower for an object in motion relative to a stationary observer.

How exactly was time dilation discovered?

General relativity is to blame!
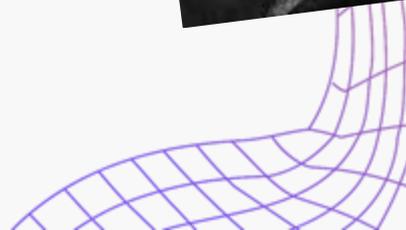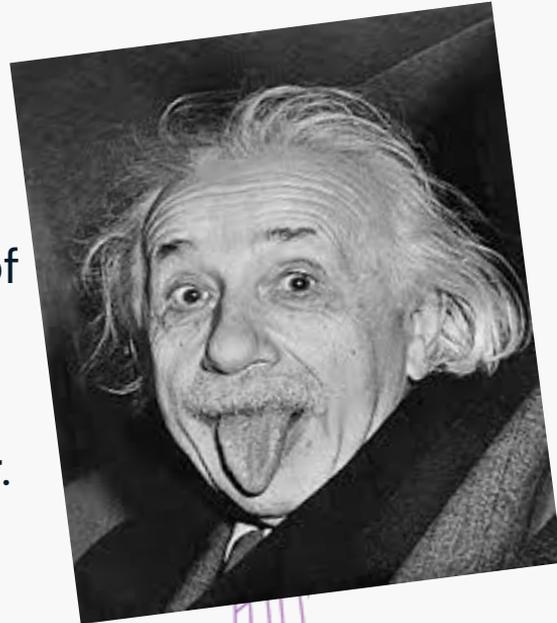
- In 1915, Einstein came up with the general relativity theory explaining how gravity affects the fabric of spacetime
- Massive objects have strong gravitational fields capable of distorting space-time
- Time dilation is a proposed effect of general relativity
- The rate you age depends on the gravitational field (eg. stronger field means slower aging and vice versa)

The mass of the Sun causes spacetime to curve . . .

. . . so freely moving objects (such as planets and comets) follow the straightest possible paths allowed by the curvature of spacetime.

Circles that were evenly spaced in flat spacetime become more widely spaced near the central mass.
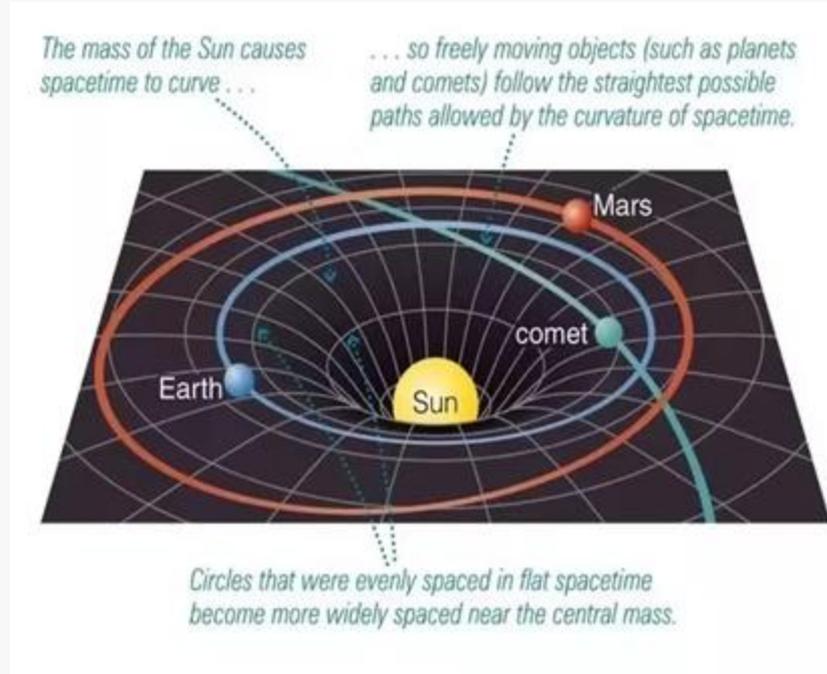
In 1905, time dilation was brought into existence...

Atomic clock experiments

Because of their extreme precision in measuring time

Hafele-Keating experiment 1971

Two clocks. Two planes. All around the world.

### Twin sister paradox

Confusing, even for us.

02.

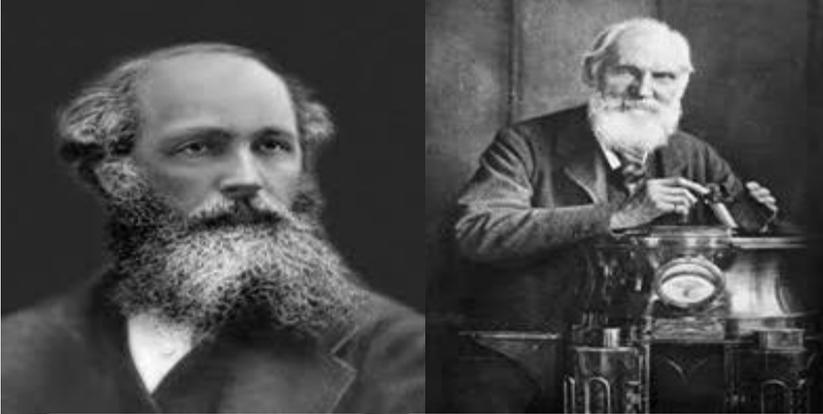# History of Atomic Clock Experiments (ACEs)
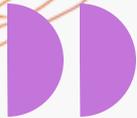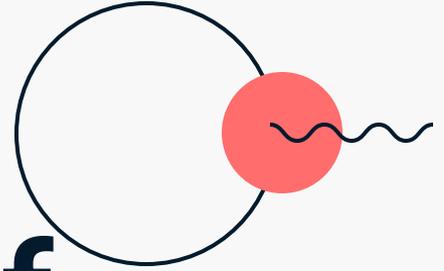
Who thought of ACEs?

Atomic clocks measures time by monitoring the resonant frequency of atoms (atoms have different energy levels).

The ones who thought of Atomic Time first, of course. British scientists **James Clerk Maxwell** and **William Thompson** have a bold and radical dream in the 1870s…
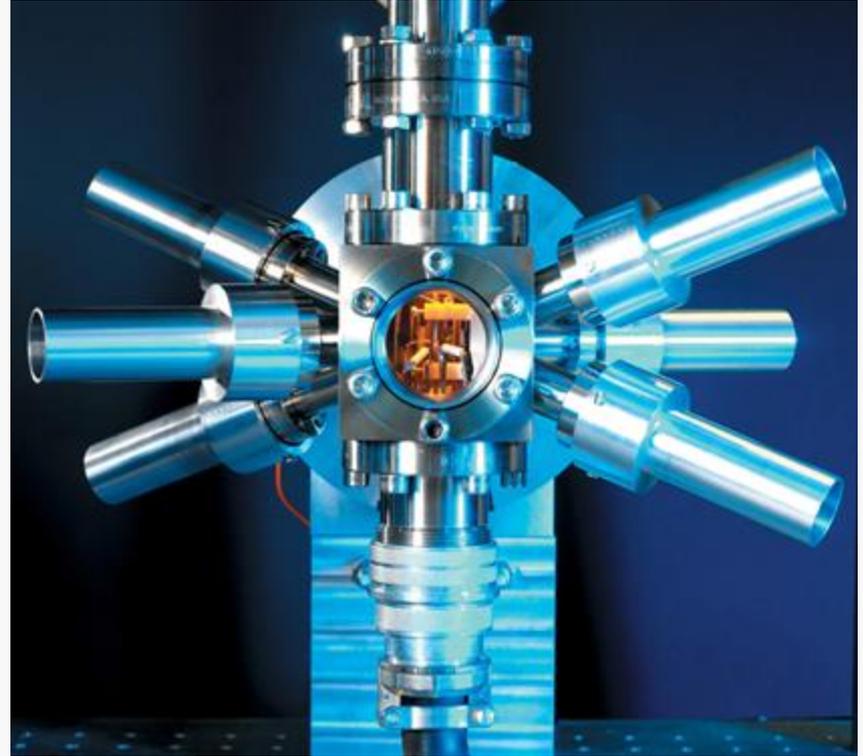
Thus, Atomic clocks were born

- James and William thought of this around the time atoms were recently discovered by physicists
- Atoms emit and absorb light frequencies that never change and are identical to one another
- In theory could thus be used to make perfect clocks (vibration in tandem with the universe)
- Afterwards, a greater milestone was achieved in 1939 to 1948. The **Ammonia clock** by Columbia University physicist **Isidor Isaac Rab**i and his team from National Bureau of Standards (NBS), (which later became the National Institute of Standards and Technology (NIST))

9, 192, 631, 770

Louis Essen, a physicist at the National Physical Laboratory (NPL) in the U.K.developed a clock in 1955 that used a design invented in 1949 by Harvard physicist Norman Ramsey. His device fired **HOT CESIUM ATOMS** stable enough to be used as the **first time standard.** Later on, he and William Markowitz published the resonant frequency of cycles of radiation per second emitted by the cesium atoms in 1958.

WHICH IS THE NUMBER YOU SEE ABOVE YOU!
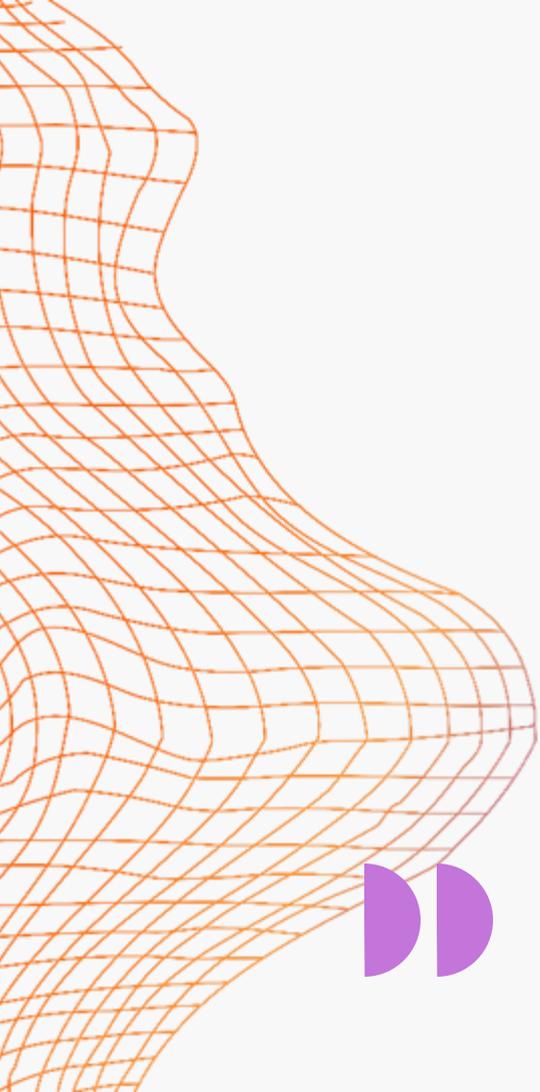
03.
Hafele-Keating experiment
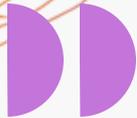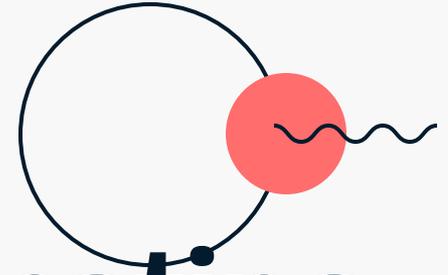
In October 1971,

Joseph C. Hafele and Richard E. Keating from the US Naval Observatory flew four cesium beam atomic clocks around the world twice in both EAST and WEST to test for time dilation.

Results were proven in the following slides (but just a tiny bit compared to a ground-based clock)

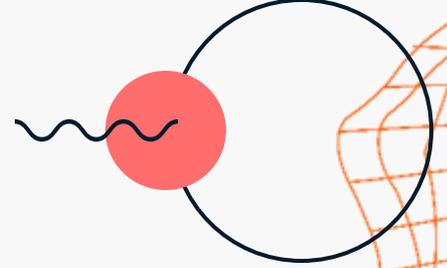(http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/airtim.html#c3)

Results of the Hafele–Keating experiment

Predicted:	Time difference in ns	
	Eastward	Westward
Gravitational	144 +/- 14	179 +/- 18
Kinematic	-184 +/- 18	96 +/- 10
Net effect	-40 +/- 23	275 +/- 21
Observed:	-59 +/- 10	273 +/- 21

The Hafele-Keating Experiment of 1971

Using a series of HP 5061A cesium beam atomic clock

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

rotation of Earth

due west   due east

clock 3   clock 2   clock1
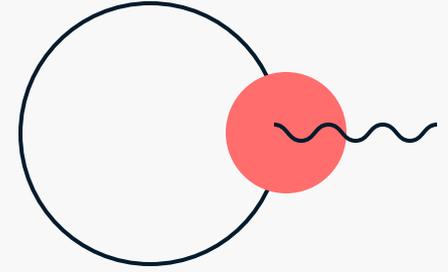
(speed of plane - speed of Earth)   (speed of plane + speed of Earth)

smallest v $t_E < t_P$ largest v $t_E > t_P$
largest t   smallest t

04.

Lorentz factor

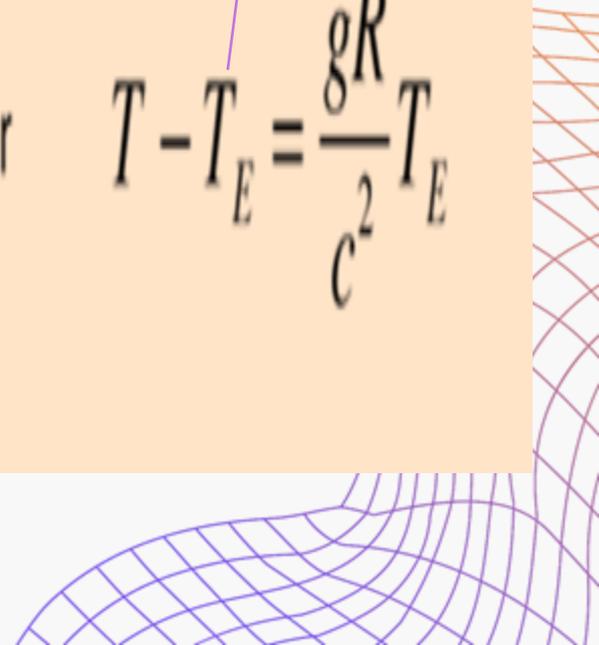$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

What is the Lorentz factor?

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

where:

- v is the relative velocity between inertial reference frames,
- c is the speed of light in vacuum,

Lorentz factor is a quantity expressing how much the measurements of time, length, and other physical properties change for an object while it moves

How is time dilation proven?

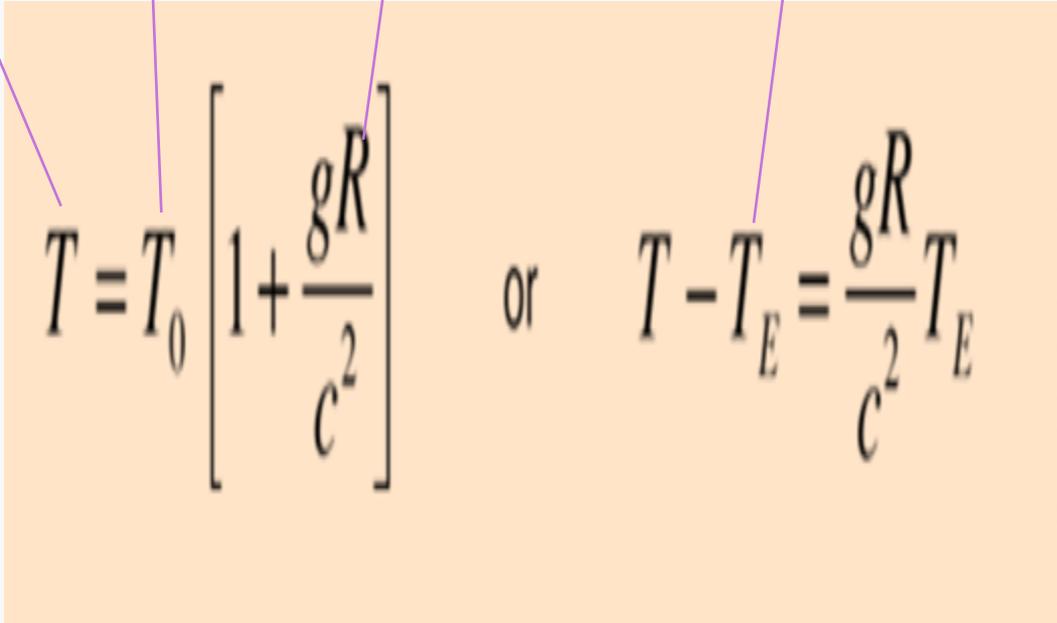- Calculation of the gravitational time shift
- Gravitational time shift is the difference in the passage of time between two locations in different gravitational fields

Time at height h above the Earth's surface

Time measured in stationary frame

Earth's radius

Time measured for a clock on Earth's surface

$$T = T_0 \left[1 + \frac{gR}{c^2} \right] \quad \text{or} \quad T - T_E = \frac{gR}{c^2} T_E$$

How is time dilation proven?

- Equations here are responsible for kinematic time dilation
- Kinematic time dilation is the difference in the rate at which time flows

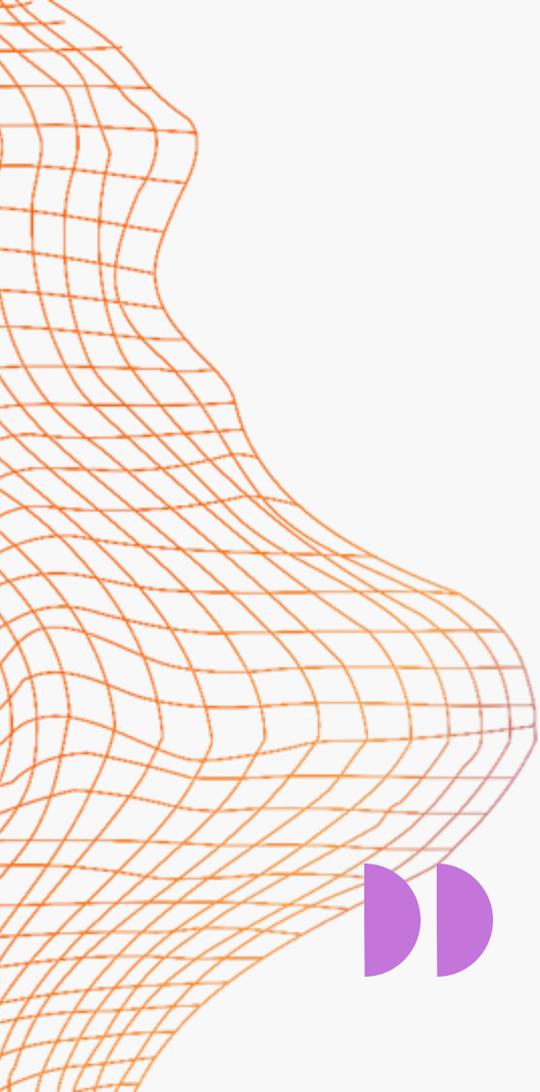$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where T_0 is the "proper time", the time measured in the rest frame of the event.

$$T \approx T_0 \left[1 + \frac{v^2}{2c^2} \right]$$

Velocity of clock resting on Earth's surface

Change of airborne clock compared to surface clock

$$T_A - T_S = -T_S \left[\frac{2R\omega v + v^2}{2c^2} \right]$$

05.
Twin sister Paradox
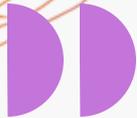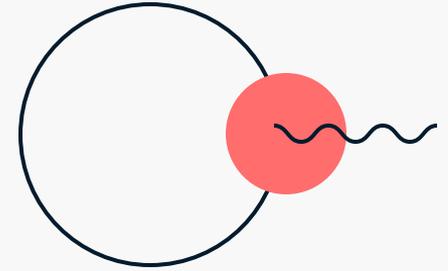
Twin sister (brother) paradox

There was once two twin sisters...

- Alice and Candice were the same age (20 years old)

- Alice was the sedentary twin and just wanted to stay on Earth. However, Candice's dream was to be an astronaut, and she did became one! So she travelled to space and bid goodbye to her twin

- After 6 months in space, Candice returned to Earth on her 21th birthday, only to find out that Alice has aged 50 years! *How can this be?*

The moral of the story...

1. Never go into space for a long time if you don't want to see your friends and family old

1. Travelling into space causes time dilation between person in space and people on earth theoretically

Why it's a paradox

- According to Einstein's theory of special relativity, Candice should have aged more as her reference frame was stationary to herself while Alice's reference frame is moving away from her as she travels into space away from Earth

- However, as can be seen from the story, Alice on Earth appeared to have been the one to age more instead, so how is that possible?

- Scientists have argued for years on whether this paradox could be solved within the concept of relativity, Alice cannot be concluded to be both older and younger at the same time and neither can Candice

- A better clue to this is that both twins think each other are in the moving reference frame while they themselves are stationary

- The paradox does admit that this is an effect of acceleration/gravitational field experienced by Candice
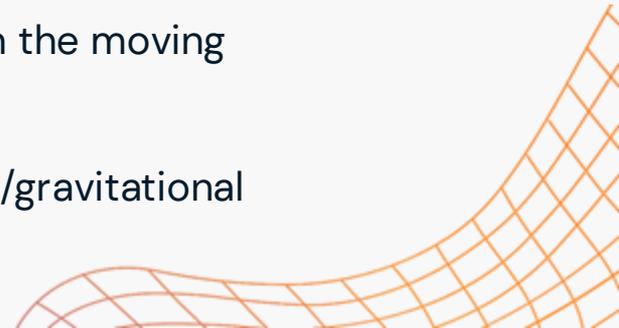
What we think

- It depends on what concept of physics/rules you use to solve the paradox

- Using only rules of special relativity gives you two simultaneous conclusions that contradict each other

- Using the effect of acceleration gives you a more certain answer, where Candice ages slower since she experiences a stronger gravitational field from acceleration (mentioned in previous slides)

- In any case, this paradox proves that time dilation does exist in some form
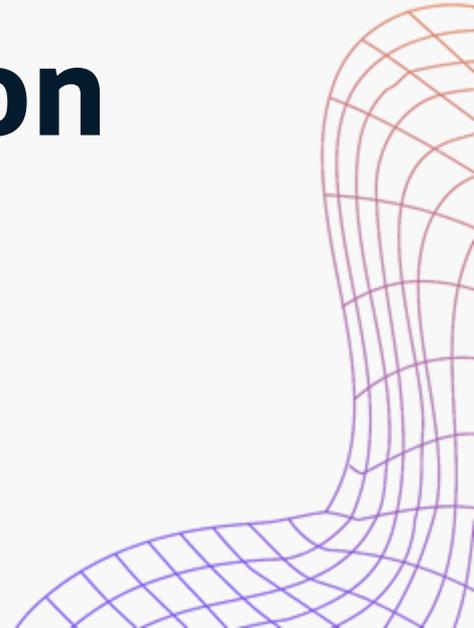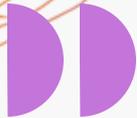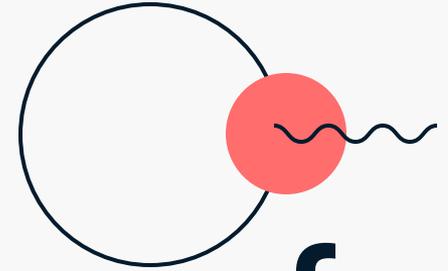
Confusing, isn't it?
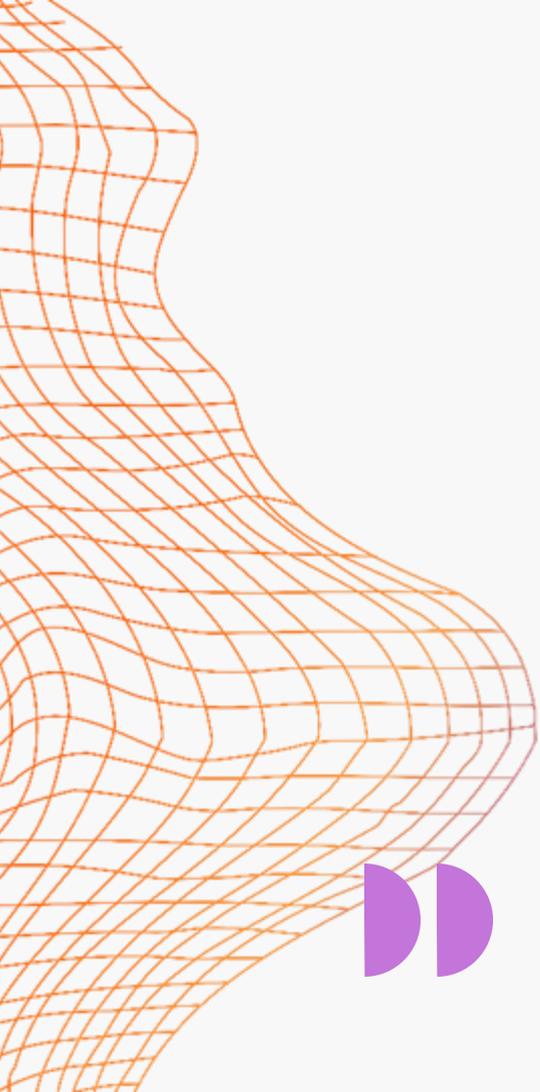
06.
Significance of time dilation

So what if time dilation exists?

- If there was no proper explanation, humanity would be superstitious about differences in age even after seeing this phenomenon so many times

- It reflects the principles of one of the most renowned scientific theories in history (Special Relativity – General relativity)

- It explains the phenomena that occur near black holes due to the immense gravity, helping scientists watch out for space's abyssal nightmares

- GPS satellites experience both speed-related and gravitational time dilation effects. These differences must be accounted for, as corrections of microseconds per day can lead to errors of hundreds of metres in positioning, making GPS technology possible.

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Thanks!

Do you have any questions?

youremail@freepik.com

+34 654 321 432

yourwebsite.com