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LIGHTYEAR
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A (RELATIVELY) SIMPLE GUIDE TO RELATIVITY

A key part of the 'Lightyear' story centres around the idea of time jumps – time moves differently for Buzz when he is travelling in his spaceship compared to everyone else, resulting in more time passing for those 'left behind'.

Time really does move at different 'speeds' for moving, or orbital objects (at least, with respect to a stationary observer). These time differences are 'relative' and so, the theory behind it is called relativity.

Relativity is a tricky subject (there is a reason that it's not even covered in A-level physics except very briefly in one of the option topics!). However, it is a central premise of the movie, and a subject which fascinates visitors. This brief guide is going to attempt to give you a version of an explanation that you can use for a family audience, a breakdown (mostly maths free!) of a classic thought experiment, as well as some links to videos and tools that will allow you to further deepen your own understanding of the topic.

Frames of reference – a key point to understanding relativity

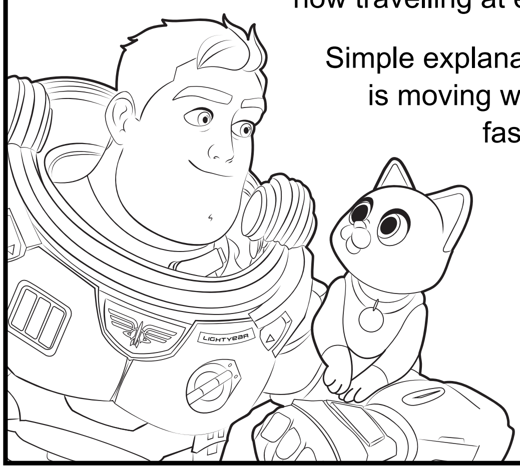
The concept of a frame of reference is important here, and we notice it ourselves. If you are sat on a train moving on a smooth track, as long as you are not accelerating, from YOUR frame of reference, you are stationary (the scenery outside looks as if it is moving past you). An observer on a train platform watching you go past will have their own reference frame, where they are stationary, and you are moving. In physics terms, both are right (it's all relative!).

It's generally pretty special…

When we talk about Einstein's theory of relativity, we have already simplified things. There are in fact two theories – **General relativity** (dealing with the effect of being at different points in the gravity well of a large body like a planet or star) and **special relativity** (which deals with the effects of time dilation for a moving passenger with respect to a stationary observer – e.g. deep space travel). Special relativity is most relevant to the movie.

Special relativity

Special relativity deals with how speed affects time, space and mass and was the theory from which Einstein's famous E = mc2 equation was derived. For the purposes of this project, we will focus on how travelling at extremely fast speeds (close to the speed of light) affects time.



Simple explanation: Moving clocks run slow (time 'runs slower' for someone who is moving with respect to a stationary observer's frame of reference. And the faster you go, the slower time moves for you). If you are on a fast moving spaceship, when you return, everyone back on Earth will have experienced more time than you, aging more than you did on the trip.

www.sciencecentres.org.uk/projects/lightyear

A bit more depth and the classic thought experiment:

At first this is a little counter-intuitive, but the theory, and mathematics behind it has been proven with atomic clocks on satellites in orbit. The key thing Einstein stated for this theory is that the **speed of light in a vacuum is constant for all observers, regardless of their frame of reference**.

Intuition is wrong here…

Let's conduct a quick thought experiment. Astronaut Mansi is in a spaceship travelling at half the speed of light. She fires a laser in front of the spaceship. How fast would she observe the light as travelling? Well, this one is easy – it travels at the speed of light (300 000 000 m/s) away from her (in her frame of reference).

Now, imagine astronaut Kelsey is observing Mansi cruise past as she fires her laser. Kelsey in on a stationary spaceship. How fast would he observe the light as travelling?

Common sense suggests that Kelsey would observe the light as having a total speed of:

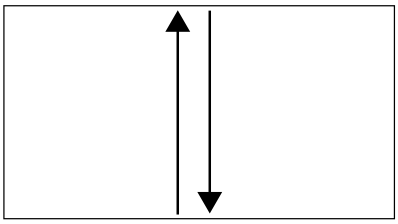
Observed speed of light = speed of light + speed of Mansi's spaceship (so faster than the speed of light).

However, nothing can go faster than the speed of light in a vacuum – you cannot make light go any faster. This hard limit of the Universe leads to our second though experiment…

Mansi has a new laser – a laser clock. She fires the laser at a mirror on the far side of her spaceship, it reflects back and returns to her. Mansi times how long it takes for the laser pulse to complete this journey and calls this '1 tick'. The path the light travels in Mansi's frame of reference is shown below along with the time it takes for 1 tick.

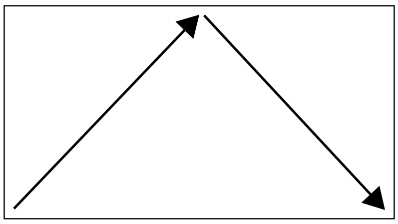
Kelsey can see the laser pulse through the spaceship's windows. But since Mansi's spaceship is moving, he observes the light travelling a different path (it still travels the same 'vertical' distance, but since Mansi's ship is moving, it has travelled an additional horizontal distance in the same time). So from Kelsey's frame of reference, the light has travelled further to complete this 'one tick'.

Mansi's frame of reference



Distance = 10m
Speed of light = 300,000,000 m/s
1 tick = 0.00000001s

Kelsey's frame of reference



Distance = 15m
Speed of light = 300,000,000 m/s
1 tick = 0.000000015s

Since speed = distance/time, and the speed of light is constant, then since Kelsey observes the pulse travelling further, the time for this one tick must also be longer (to preserve the speed of light in the equation). One second of Mansi's 'time' equates to 1.2 seconds of Kelsey's – Mansi's clock is running slower – we call this **time dilation**.

The faster Mansi travels, the further Kelsey will observe the light beam travelling in a tick, and the bigger this relative time difference becomes. It's fair to say that at the speeds Buzz is likely travelling, these time dilation effects would be very noticeable indeed!

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Orbital applications of special relativity – astronaut twins!

The International Space Station (ISS) is orbiting the Earth at a speed of 7.66 km/s. While this is nowhere near the speed of light, it is fast enough for the effect of special relativity to be noticeable. An astronaut on the ISS will experience time ever so slightly slower than someone back on Earth. Scott and Mark Kelly are twin astronaut brothers. In 2016, Scott finished a 340 day stint on the ISS. The special relativity time dilation effect means that he aged ever so slightly less than his twin in that time (although we are talking microseconds, so not really noticeable).

General Relativity

General relativity appears to have less relevance to the movie but is still worth briefly mentioning.

Simple explanation (in terms of Earth): Higher clocks run fast. The higher you are above the surface of the Earth, the faster time runs for you relative to an observer on the ground.

This means that for objects in orbit, we have to take into account that time is running slower due to special relativity, and time is moving faster due to being higher above the planet!

By far, the best way to wrap your head around this is with the use of videos. This video, presented by Professor Anu Ojha, Director of the National Space Academy is a nice summary of both Special and general relativity: www.youtube.com/watch?v=q1iqSRRtmmE

Additional links:

Special relativity time dilation calculator: www.omnicalculator.com/physics/time-dilation

Veritassium video detailing how an error led to an excellent test of general relativity: www.youtube.com/watch?v=aKwJayXTZUs

This resource was created by National Space Centre with support from ASDC as part of Project Lightyear: Disney and Pixar have teamed up with ASDC to engage people with exciting science topics inspired by the film "Lightyear".

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