Special Relativity

The Road Towards Modern Physics

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Physics Problem Solving
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Prior Knowledge

- $v = \frac{s}{t}$
- The speed of light is **constant for all observers**
- Nothing else

What we will talk about

- Lorentz Transforms
- Consequences of Special Relativity
- A taste of Minkowski Space

Why Special Relativity

Late 19th Century

- Maxwell's electromagnetism gave rise to the idea of light as an **electromagnetic wave**.
- Many believed that it propagated through something called the **aether**, which filled the universe.
- They believed that the aether could represent an **absolute reference frame**.

Einstein

- Unfortunately this was experimentally falsified (Michelson-Morley) …
  - but nobody really noticed its significance until Lorentz …
  - whose paper inspired Einstein to discover what we are going to talk about today.

- Einstein's solution was to argue that:
  a. The Aether didn't exist
  b. The laws of physics - **including the measurement of the speed of light** - is the same for any **inertial** reference frame.

- This would mean that if I travel at 100,000 m/s, **I still measure speed of light to be 299,792,458 m/s and so would a 'stationary observer'**

The Lorentz Transform

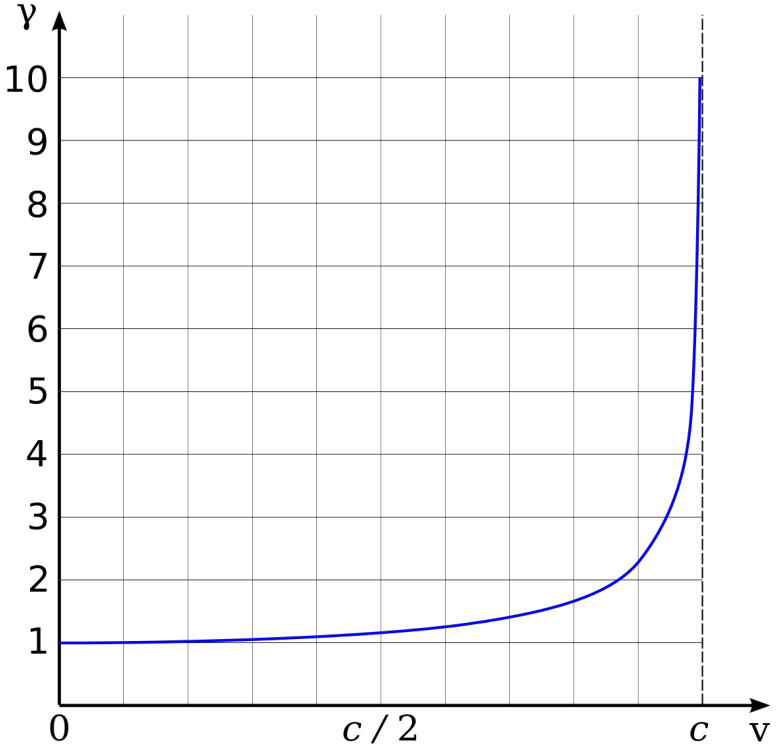
Mathematical Formulation

- To formulate the effects of time dilation, we can make use of a **photon clock**
- Use the diagram that Dara is drawing on the board to derive what is known as **the Lorentz Factor:**

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

Visualisation

For your Lorentz factor to be **2**, you need to travel at **87%** the speed of light!



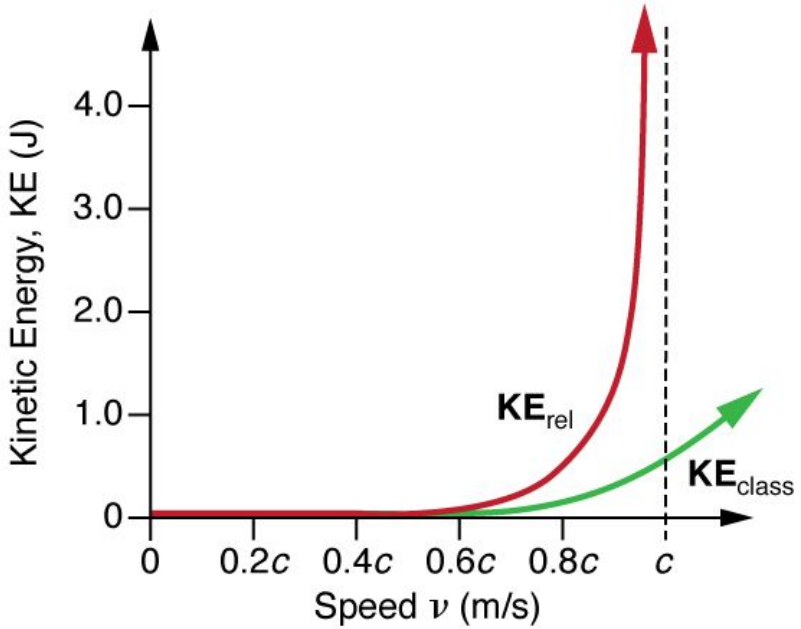
More Consequences

- Kinetic Energy (try doing a binomial expansion)

$$\mathrm{KE} = (\gamma - 1)m_0c^2$$

- Lorentz Transformation (1D)

$$x' = \gamma(x - vt)$$



Direct Results

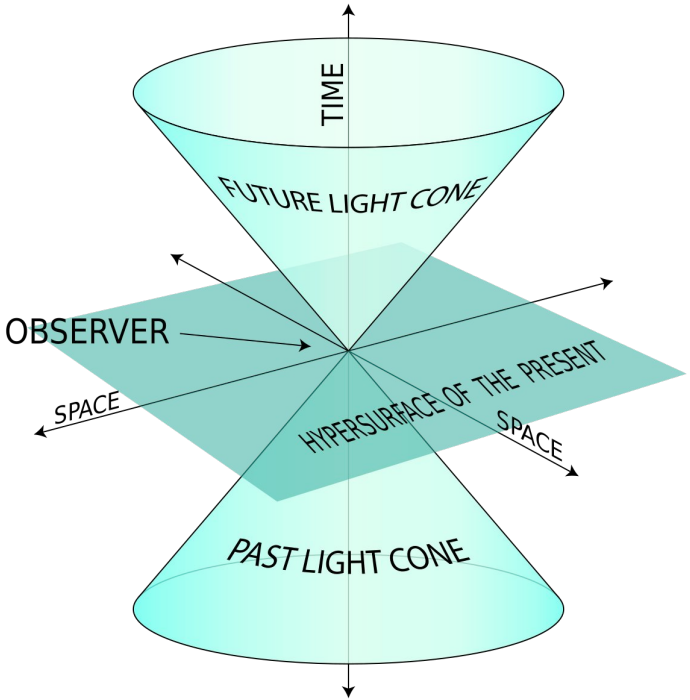
Cosmic Rays

- Muons are formed at the top of the atmosphere (~ 12000m) due to the decay of cosmic rays. We observe 25% of them reaching the surface of the earth.
- Without relativity, because of their half life of just 1.5 microseconds, how fast would they have to travel in order to cause this result?
- How does relativity save us here?

Light Cone

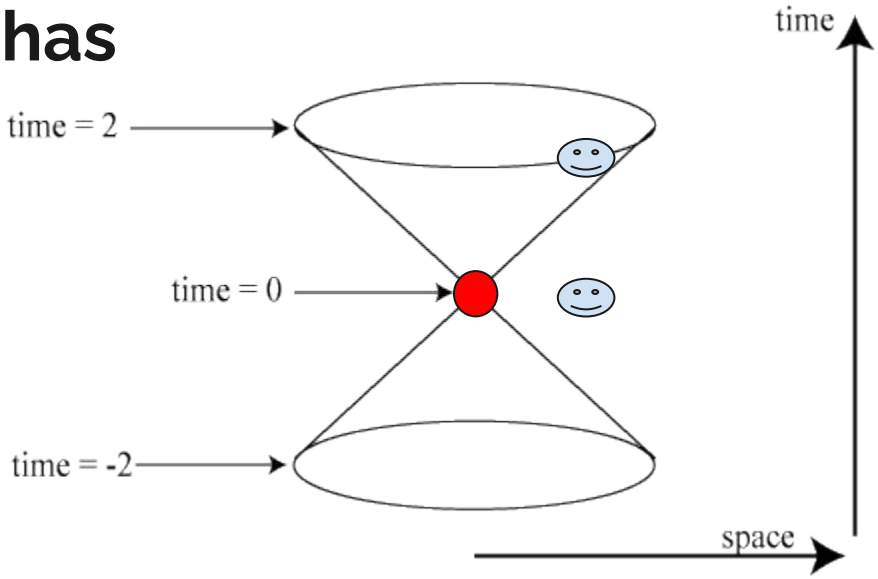
The Light Cone

You may have seen pictures like this in videos or articles about special relativity, but what does it tell us?



It is a reminder that light has finite speed

- Light takes time to go between you and me, therefore **you are seeing me in the past**.
- The “vertex” of this light cone represents an **event**
- To be able to observe or interact with this event, you must be in the **light cone**
- Note the labels on the axes.



A Taste of Minkowski Space

Eason will try and talk about the very basics …

https://www.desmos.com/calculator/wtoyyzbwml (Eason loves Desmos as usual …)

If you want to go beyond this, some terms that you might wish to search on Google/Wikipedia:

- Minkowski Plane, Space, Metric & Pseudo-Euclidean Space (Some Maths)
- Hyperbolic Orthogonality (Some More Maths)
- Spacetime Diagram (Minkowski & Loedel Diagrams)
- Lorentz Transformation (Physical, Mathematical & Tensor formulation)
- Lorentz Group (which is related to Lie Groups & Lie Algebra)

Thanks!

Please ask questions.

Google Classroom: JE3ZZL6