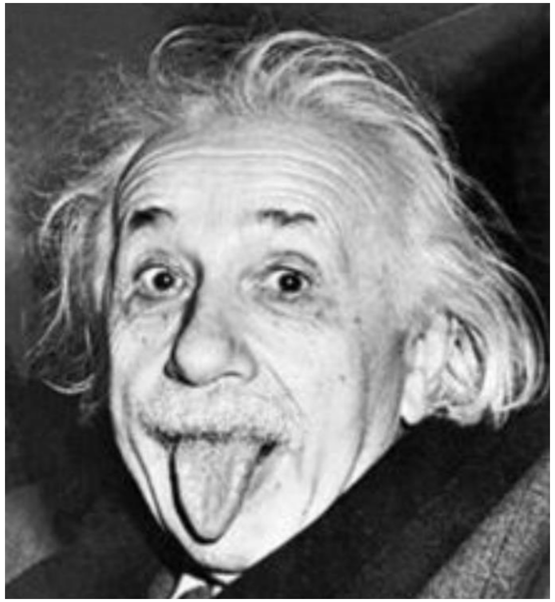
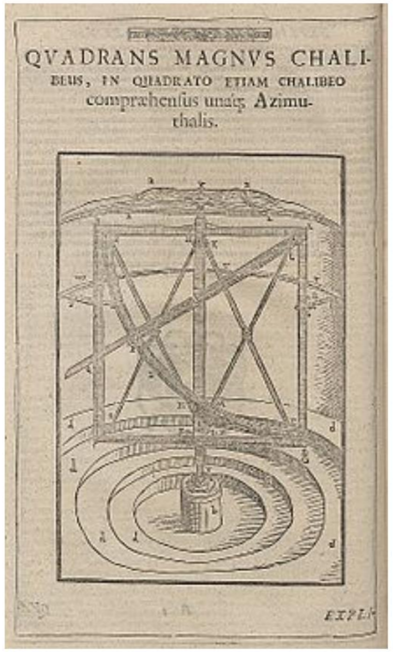
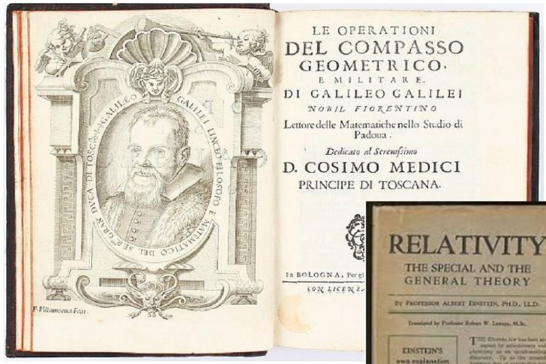
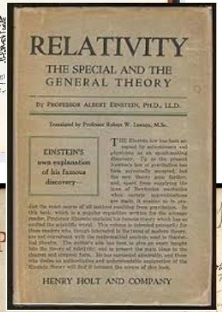
Just in case you thought physics was easy

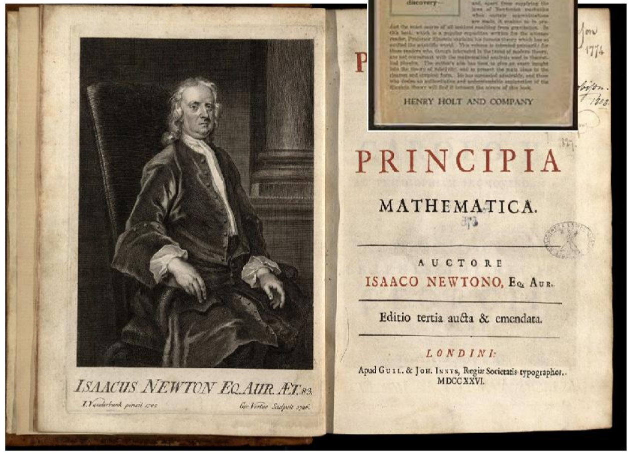


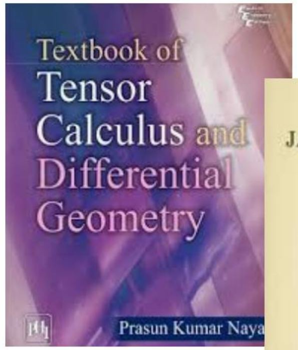
RELATIVITY

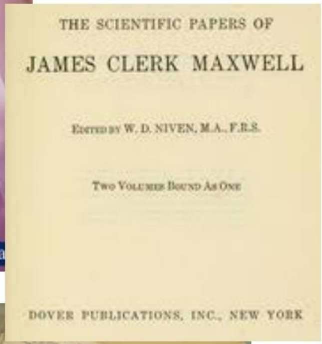


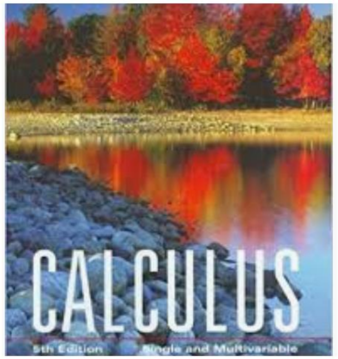










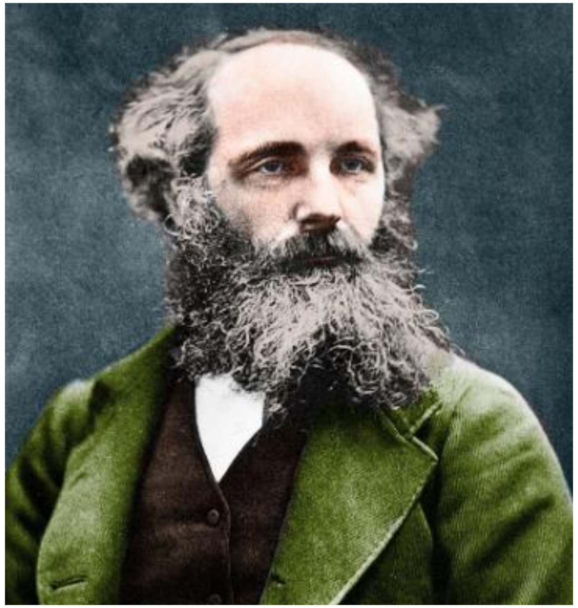


The Special and General Theories of Relativity are the combining of observations and predictions that go back as far as Galileo into two overarching theories.

Einstein's brilliance is shown in his ability to bring together such diverse science.

Quick history

- *In 1865, Scottish physicist James Clerk Maxwell demonstrated that light is a wave with both electrical and magnetic components, and established the speed of light ($3x10^8$ metres per second).*



Relativity

- *Maxwell actually did it backwards;*
  - *He measured the propagation of magnetic fields produced by an electric field and found its speed was c*
  - *The equations he wrote to describe the propagation were later shown to be wave equations*

As an aside – Maxwell found a wave solution (quantum)

- $\vec{E}$ *is electric field*
- ρ *is charge density*
- $\vec{B}$ *is the magnetic field*
- $\vec{J}$ *is electric current*
- t *is time*
- ε_0 μ_0 *are constants*

Maxwell's Equations Differential form	Maxwell's Equations Integral form
$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$	$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{enc}}{\varepsilon_0}$
$\nabla \times \vec{E} = \boxed{-\frac{\partial \vec{B}}{\partial t}}$	$\oint \vec{E} \cdot d\vec{l} = \boxed{-\int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{a}}$
$\nabla \cdot \vec{B} = 0$	$\oint \vec{B} \cdot d\vec{a} = 0$
$\nabla \times \vec{B} = \mu_0 \vec{J} + \boxed{\mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}}$	$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} + \boxed{\mu_0 \varepsilon_0 \int \frac{\partial \vec{E}}{\partial t}}$

- *Physicist A.A. Michelson and chemist Edward Morley calculated that Earth's motion through the universe (which they thought was made up of "ether“) did not change the measured speed of light (1887).*
    - *The conclusion was that light had a constant speed regardless of its direction*

    - *A short history by Professor Dave; https://www.youtube.com/watch?v=rBmYUEnafok*

Gravity

- *There is little record of discussions on gravity prior Galileo*
- *Tycho Brahe (1546-1601) and Galileo Galilei (1564-1642) noted that planets orbited the sun*
- *Johannes Kepler (1571-1630) developed the work, demonstrating that the orbits were elliptical, producing his three laws of planetary motion*
- *Isaac Newton (1642-1727) "discovered" gravity, after lunar observations, thence producing his universal law of gravity*

Gravity II - rise of ~~Skywalker~~ Einstein

- *Einstein (1879-1955)*
  - *1905 produced Theory of Special Relativity, avoiding gravity*
  - *1907 predicted gravitational redshift*
  - *1915 general relativity (gravity is a result of masses warping spacetime)*

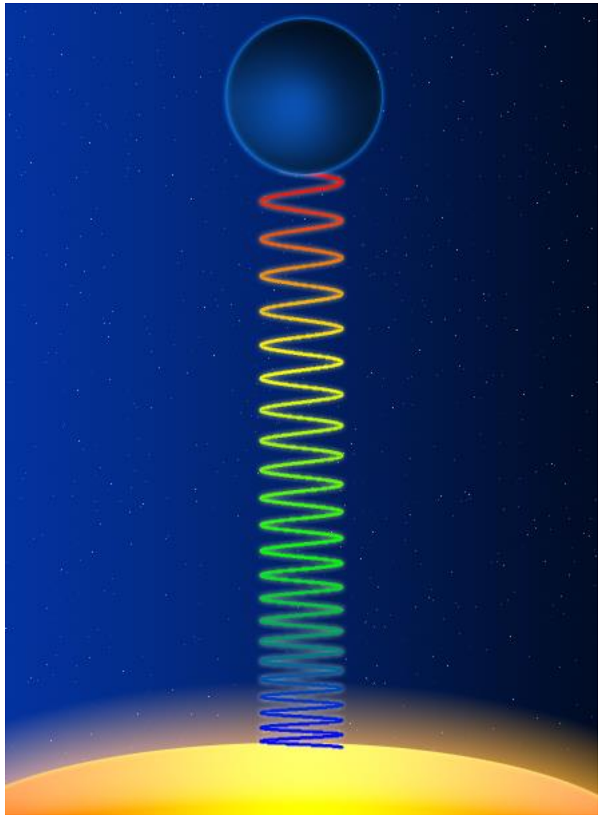
- *Josef Lense (1890-1985) and Hans Thirring (1888-1920) theorise "Frame Dragging"*
  - *the rotation of a massive object in space would "drag" spacetime around with it.*

Gravity III - A New ~~Hope~~ Evidence

- *1919 – gravitational lensing witnessed (the light from stars was bent by our teeny tiny sun)*
- *1925 – first measurement of gravitational redshift (Walter Sydney Adams)*
- *1937 - Prediction of a galactic gravitational lensing*
- *1960s – evidence for black holes grew*
- *1966 – evidence of gravitational time delays*
- *1979 – first observation of galactic gravitational lensing*
- *2004 – frame dragging confirmed*
- *2016 – gravitational wave observation confirmed*

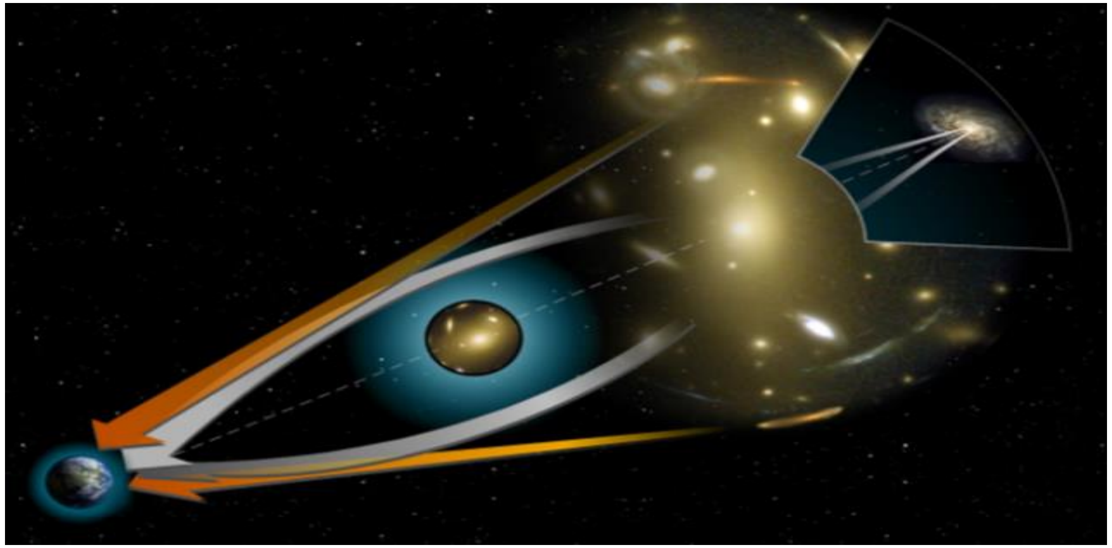
Gravitational redshift

- *A decrease in gravity results in the wavelength of a photon getting longer (getting redshifted)*
- *So … photos emitted in a large stellar mass will redshift as they travel away from the stellar mass.*



Gravitational lensing

- *Bending of light due to gravity*



RELATIVITY

- *Motion can only be measured relative to an observer; length and time are relative quantities that depend on the observer's frame of reference.*

- *Matt Anderson's introduction (calculus); https://www.youtube.com/watch?v=UcY5Gx_WMvI*
- *Example https://www.youtube.com/watch?v=ZImYVq59kOU*

Relativity

- *Observations of objects travelling at very high speeds cannot be explained by Newtonian physics.*
- *Einstein's Theory of Special Relativity predicts significantly different results to those of Newtonian physics for velocities approaching the speed of light.*

- *The Theory of Special Relativity is based on two postulates:*
    - *that the speed of light in a vacuum is an absolute constant**
    - *that the laws of physics are the same in all inertial reference frames.*

the speed of light in a vacuum is an absolute constant*

- *Actually c is the "Speed of causality" – the fastest speed anything in the universe can communicate with anything else*

- *In fact, everything without mass must travel at c*

  - *The speed of light is not about light*
  - *https://www.youtube.com/watch?v=msVuCEs8Ydo*

RELATIVITY

- *In relativistic mechanics, there is no absolute length or time interval.*
- *Two events that appear simultaneous for a stationary observer may not be for an observer in motion.*

  - *Professor Dave explains time dilation; https://www.youtube.com/watch?v=rBmYUEnafok*

RELATIVITY

- *At relativistic speeds, time intervals in moving frames of reference are dilated when observed from a stationary reference frame according to* $t = \gamma t_0$ *where* $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ *is the*

  Lorentz factor
- t_0 *is the time interval in the moving frame of reference*
- t *is the time interval in the stationary observers frame of reference*

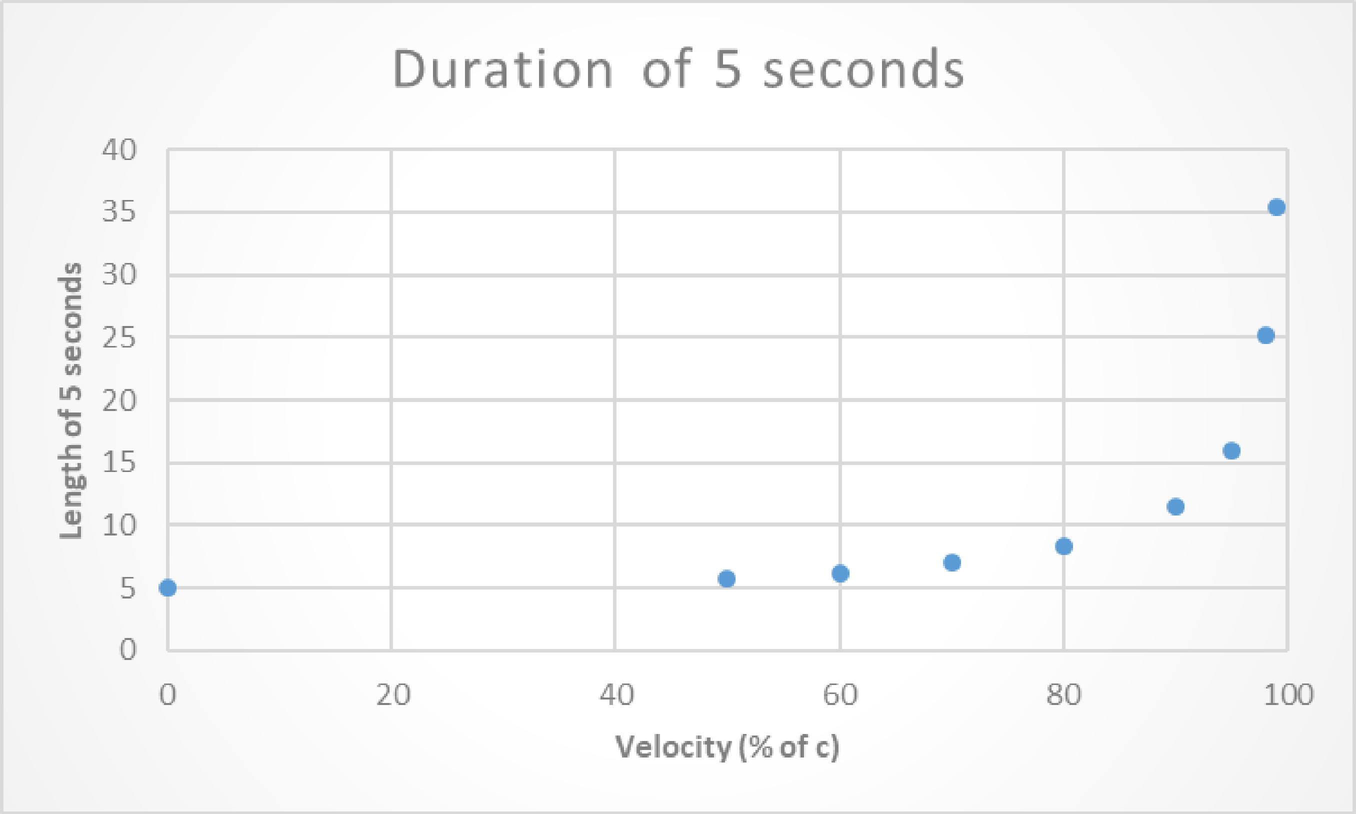
- *As v approaches c,* $\gamma \to \infty$

Go back and re-read that

- *YOU – yes you, That's YOU, will need to do calculations with the Lorentz factor*

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

So if you took 5 seconds and "flew it faster" it would take longer



Avoid the confusion

$$t = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} t_0$$

How do you remember who's time is who's?

The person moving has the slowest time

$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ *is always greater than 1*

So t will always be bigger than t_o

Thus, t_0 *is slower and therefore the travellers time*

and…

$$\rho = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \rho_0 = \gamma m_0 v$$

Momentum gets bigger?

$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ *is always greater than 1*

So ρ will always be bigger than ρ_o

Therefore ρ is momentum at speed, ρ_o momentum at rest

Example

- *Some subatomic particles exist in the laboratory for very short time periods before decaying. These same particles are detected as part of cosmic ray showers in the atmosphere, travelling at relativistic speeds close to the speed of light.*
- *Time dilation effects allow these particles to travel significant distances without decay.*

Example of time dilation

- *Travelling at a mere 99.995% the speed of light, a particle that normally lasts only 5 seconds will last long enough to make it from the sun to the earth – 8 minutes, 20 seconds*

- *However muons only need to travel a fraction of that distance*

Do this

18. Muons can be formed as the by-products of cosmic rays colliding with molecules in the upper atmosphere.

A muon travelling at a speed of $0.998\ c$ is formed at a height of $10\ 000\ \text{m}$ above the surface of the Earth.

(a) Show that the Lorentz factor, γ, for a muon travelling at $0.998\ c$ is 15.8.

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____ (2 marks)

And this

(b) *Using calculations*, explain why relativistic effects allow a muon travelling at $0.998\,c$ to reach the surface of the Earth.

(3 marks)

RELATIVITY

- *An object moving at relativistic speeds always appears shorter to an observer in a stationary frame of reference, and the length is given by* $l = \frac{l_0}{\gamma}$
- $l = l_0 \div \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

- l_0 *is the length of the moving objects frame of reference*
- l *is the length of the stationary observers frame of reference*

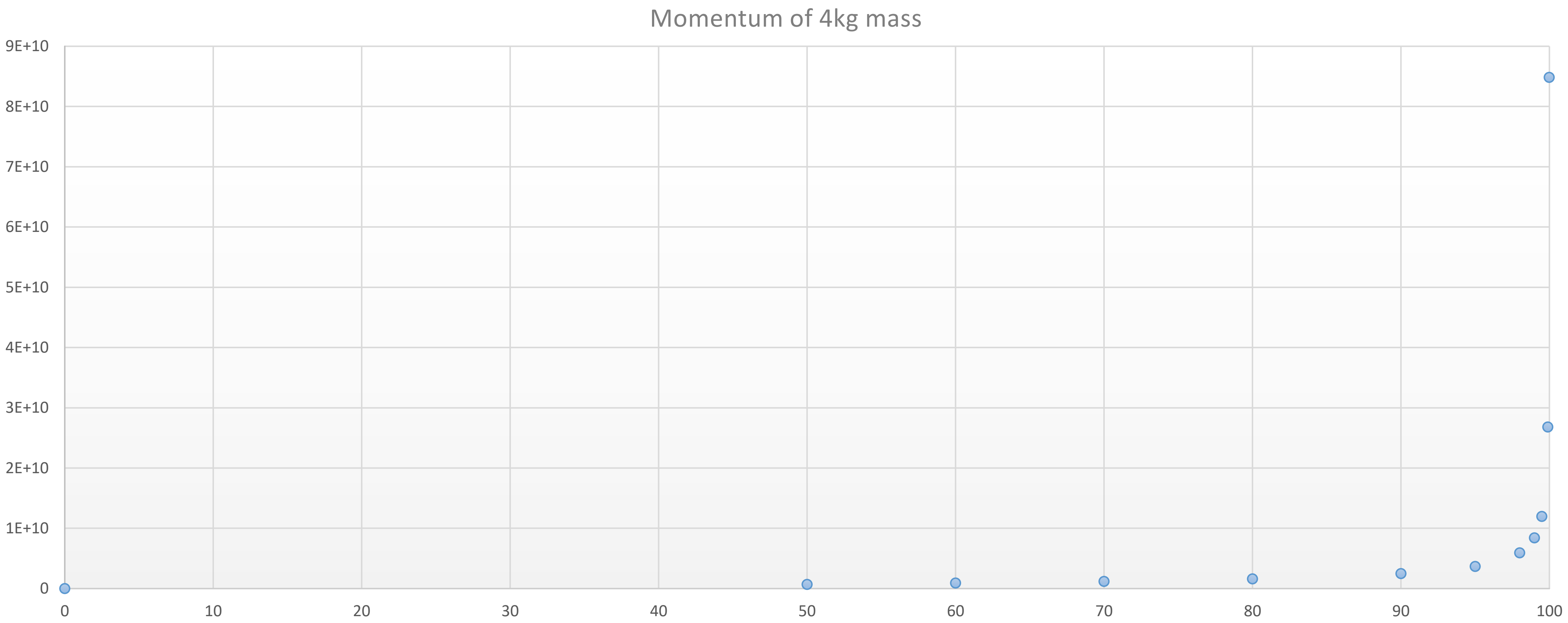
- *Prof Dave explains length contraction;*
- *https://www.youtube.com/watch?v=FPzGAksFCbs*

Relativity

- *The magnitude of the relativistic momentum of a moving object is given by* $\rho = \gamma m_0 v$

- m_0 *is the mass of the object in the frame of reference where it is stationary*

Momentum example



More learning

- *Relativistic addition of velocity*

  - *https://www.youtube.com/watch?v=R5oCXHWEL9A&t=15s*

Twins Paradox

- *The story goes like this; there are two twins, one hangs around on earth whilst the other jumps in a rocket, flies off near the speed of light for a few months then turns around and comes back to earth.*
- *From the perspective of the earth twin, the other was going fast and so would age less*
- *From the perspective of the rocket twin, they were still in the rocket and relative to them, earth twin was moving, so there clock should be slowest*

Why are there so many different explanations

- *Firstly, the internet is full of information from people who know some of the stuff and based on half of what they should know, they make up the rest – and its rubbish*
- *Second, the theory of special relativity is a few hundred pages long and people try and answer questions based on the "readers digest / women's weekly summary"*
- *Third, the real story actually requires some serious maths to transfer between different inertial frames and the three non-inertial frames of take off, speed up / turn around / slow down and land*

Three (and a half) good explanations from people who don’t need to make stuff up

- *Minute Physics*
  - https://www.youtube.com/watch?v=LKjaBPVtvms

- *Fermilab – no maths*
  - https://www.youtube.com/watch?v=noaGNuQCW8A

- *Fermilab – maths*
  - https://www.youtube.com/watch?v=GgvajuvSpF4

- *Science Asylum*
  - https://www.youtube.com/watch?v=UInlBJ4UnoQ