Agenda

Introduction
- Space, Time and Matter ✓
- Early views of the cosmos ✓
- Important Ideas from Classical Physics ✓

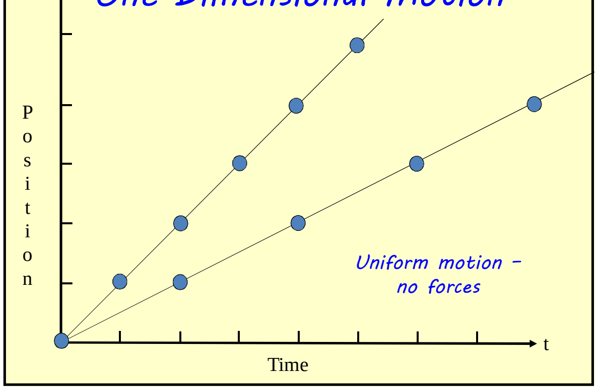
Two 20th Century revolutions in Physics
- Relativity ✓
- Quantum Theory

Interwoven with Ideas from Astronomy and Cosmology

"Perhaps the greatest obstacle to understanding the theories of special and general relativity arises from the difficulty in realizing that a number of previously held assumptions about the nature of space and time are simply wrong".

Robert Wald,
"General Relativity"

One-Dimensional Motion



$$F_{gravitation} = G\frac{m_1 m_2}{r^2}$$

$$F_{electric} = k_e \frac{q_1 q_2}{r^2}$$

$$\frac{F_{magnetic}}{Length} = 2k_m \frac{I_1 I_2}{r}$$

James Clerck Maxwell
(1831 –1879)

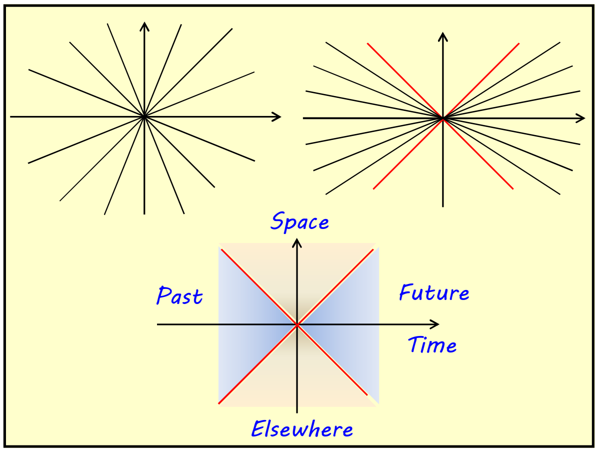
$$\frac{k_e}{k_m} = c^2$$

$$c = \text{speed of light}$$

This result forces a change in how we think of space and time.

Trail of ideas we are following

- There is no preferred place in the universe.
- The laws of physics are the same everywhere.
- The speed of light appears in physical laws, so it must be the same everywhere.
- This implies we change how we think of space and time.
- This leads to Special Relativity.



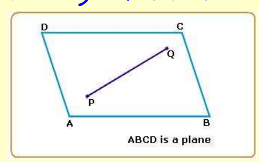
Consequences of Special Relativity

Simultaneity
Length contraction
Time dilation
Velocity combination
Change in conception of energy & momentum
Interchangeability of mass and energy

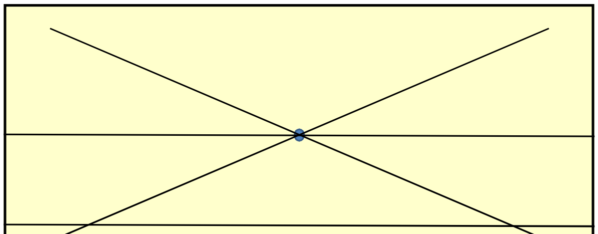
$$E = mc^2$$

Geometry of Euclid


Euclid
~300 BC



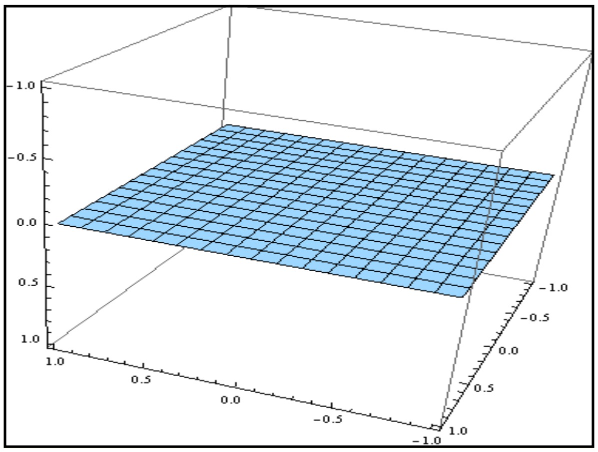
Plane Geometry deals with points, lines and regular figures in a plane.



Inventors of Non-Euclidean Geometry

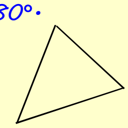
Nikolai Ivanovich Lobachevsky (1792–1856) Russian mathematician and geometer, renowned primarily for his pioneering works on hyperbolic geometry, otherwise known as Lobachevskian geometry.

Bernhard Riemann
(1826 - 1866) an influential German mathematician who made lasting contributions to analysis and differential geometry, some of them enabling the later development of general relativity.

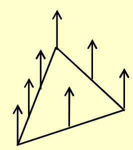


Main Features of Plane Geometry

Angles in a triangle add up to 180°.



Parallel transport



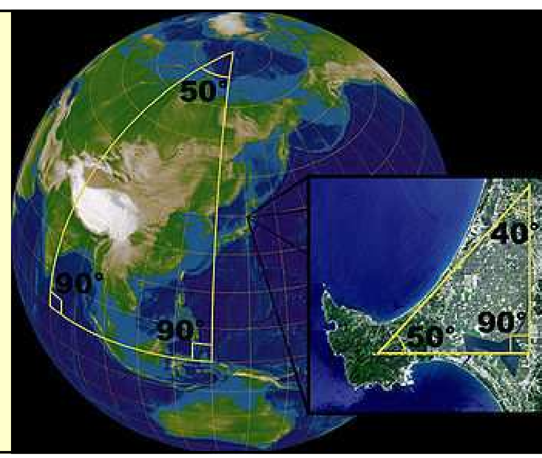
Infinite

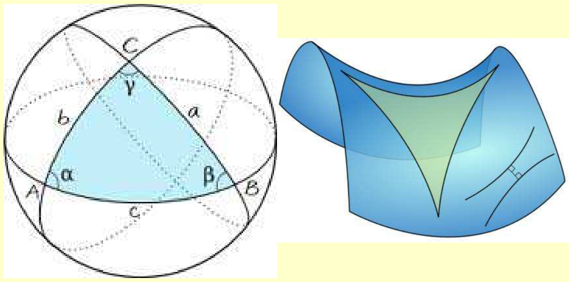
What is Geometry on a Curved Surface?

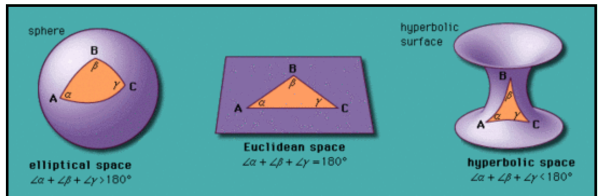
Straight line between two points becomes the shortest distance (called geodesics).

The sum of angles in a triangle do not add up to 180°.

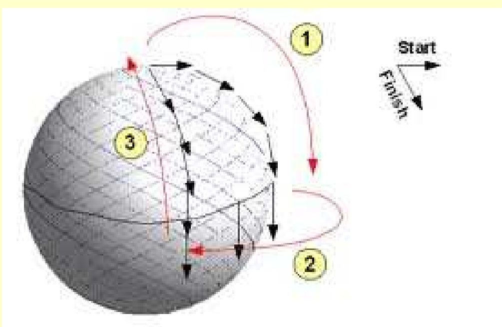
Parallel transport around a loop results in a shift in direction.

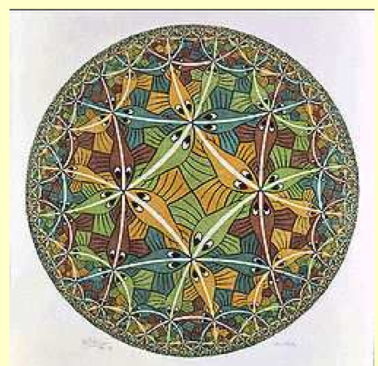






Three possible geometries for space time.





Problem visualizing the universe

Einstein finds space and time intertwined in 4-dimensions.

4-dimensions cannot be drawn in our 3 spatial dimensions.

We have to "practice" visualizing this as 2-dimensional surfaces in 3-dimensional space.

2 Dimensional Surfaces In 3-Dimensional Space

Flat 2-d surface (plane)

Spherical 2-d surface

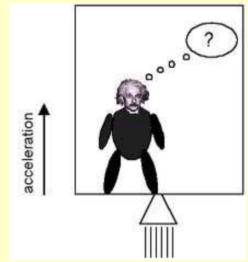
Hyperbolic 2-d surface

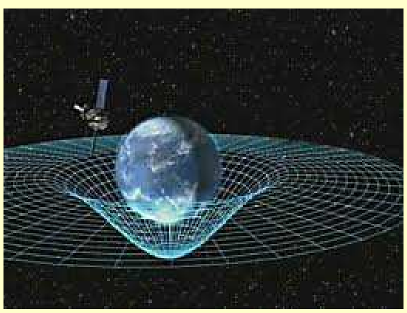
The Theory of General Relativity

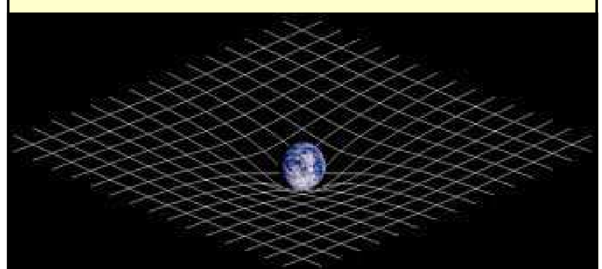
Modern theory of gravity introduced by Albert Einstein to replace Newton's Gravitation.

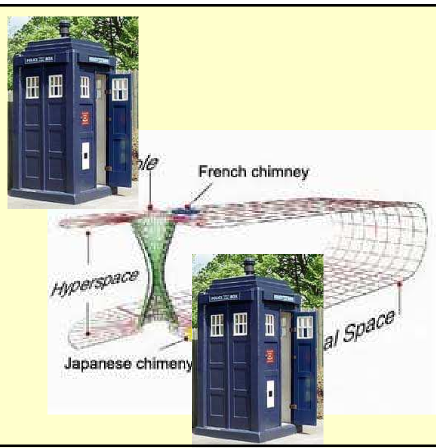
Main Idea:
Replace the idea of force with curvature of space-time.

Matter distorts the space around it.
This distorted space affects the motion of particles nearby.









General Relativity

Riemann Metric $g_{\mu\nu}$ describes ST

Geometry of ST = Matter-Energy Distribution

3 Parameters Involved:
G is the Gravitation Constant (Newton) } *well known*
C is the speed of light

Λ is the Cosmological Constant } *not well known*

If we know how matter and energy are distributed throughout the universe W can calculate how space – time is curved and determine how things move about.

The Cosmological Principle

To apply the Theory of Relativity on a cosmic scale we need to know how matter is distributed.

The Cosmological Principle asserts that matter is distributed throughout the universe more or less uniformly.

Averaged over large enough regions the universe looks the same everywhere. It is homogeneous and isotropic.

This concept is an extension of Copernicus's Principle "There is no preferred place in the universe".