Einstein’s Special Theory of Relativity

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OUTLINE

Einstein’s Miraculous Year 1905
Time and Space before 1905
Einstein’s Paper # 3
Time and Space after 1905
Impact of Einstein’s Ideas
Graduated from Polytechnic Institute in Zurich in 1900
Started working at Swiss Patent Office in Bern
Married Mileva Maric in 1903
Einstein’s Miraculous Year

- In 1905, Albert Einstein published five papers that changed the face of physics forever.
Einstein’s Paper # 3

- The paper “On the Electrodynamics of Moving Bodies” was published in *Annalen der Physik, 17, 891 (1905) – Sept. 1905!*

- Special Theory of Relativity was born!
Modern Revolutions in Physics

- **Special Theory of Relativity** (Einstein 1905)
  New view of time and space

- **General Theory of Relativity** (Einstein 1915)
  New description of gravity

- **Quantum Mechanics** (1925-1927)
  New description of atoms
Newton’s Annus Mirabilis

- In 1666, Isaac Newton laid the foundations for much of the physics and mathematics that revolutionized XVII century science.

- Newton’s laws of dynamics and gravity
Newton’s First Law of Motion

An object at rest remains at rest.

An object in motion continues to move with constant velocity.

Observer

Blue car

Red car

Inertial frames of reference

Absolute time and space
Maxwell’s Unification

- In 1865, James Clerk Maxwell unified the laws of electricity and magnetism into one electromagnetic theory.
- The speed of light \( c \) is the fundamental speed of the theory.
Light as Electromagnetic Wave

Propagation speed
\[ c = 300,000 \text{ km/s} \]

I owe more to Maxwell than to anyone
Einstein (1905)
Before 1905

A star in binary system

Incorrect view!!!
The laws of physics are the same in all inertial frames of reference.
The speed of light in free space is the same in all inertial frames of reference.

The speed of light is ABSOLUTE!!!
Special Theory of Relativity III

The theory applies to objects moving with velocities comparable to the speed of light $c$ and predicts that no material object can travel faster than $c$.

The absoluteness of $c$ requires that space and time are RELATIVE and that they are MIXED together.

The theory cannot describe accelerated motion of these two happy guys because it deals only with inertial systems!
Your time and space

My time and space

K.S. Thorne “Black Holes and Time Warps”
Mixing of Time and Space III

What you call space is a mixture of my time and space.

What I call space is a mixture of your time and space.

No absolute time!
No absolute space!

Newton, forgive me!
Einstein (1905)
Space-Time Diagrams I

Stationary observer at $t = 0$

Events at $t = 0$ and $C$ are simultaneous
Space-Time Diagrams II

Moving observers
Space-Time Diagrams III

Moving observers
Newton and Minkowski Diagrams

- Newtonian Diagram of Space and Time
- Minkowski Spacetime Diagram

Moving inertial frame in absolute space and time

Moving inertial frame in spacetime
Lorentz Transformations

\[ x' = \gamma (x - vt) \]
\[ y' = y \]
\[ z' = z \]
\[ t' = \gamma (t - vx/c^2) \]

with \( \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \)
The Light Cone

The light cone: the set of all paths that would be traveled by light emitted from an event.

Worldlines of two light rays on light cone.
Time Dilation

A clock in motion ticks slower than a clock at rest
Twin Paradox

One of the twins leaves the Earth in a rocket ship traveling at high velocity.

60 years later, the rocket returns to Earth with the astronaut only 40 years old due to Time Dilation.
Space-Time Diagrams for Twin Paradox

Diagram 1:
- t-axis
- x-axis
- t = 5
- t' = 4

Diagram 2:
- ct-axis
- x-axis
- traveling twin
- stationary twin
- simultaneity planes 1
- simultaneity planes 2
One More Space-Diagram

Special Relativity
"Twin Paradox"

\[ v = \frac{6}{10} c \]
Length Contraction

Spaceship Moving at the 10% the Speed of Light

Spaceship Moving at the 86.5% the Speed of Light
Relativistic Addition of Velocities

Classical Mechanics

\[ v'' = v + v' \]

\[ v = 0.75 \, c \]

Relativistic

\[ v'' = \frac{v + v'}{1 + \frac{vv'}{c^2}} \]

\[ v = 0.75 \, c \]

\[ \Delta v = 0.96 \, c \]

not

\[ 1.5 \, c \]
Energy – Mass Relation

\[ E = m c^2 \]
SUMMARY

- Special Theory of Relativity was developed by Albert Einstein and published during Einstein’s Miraculous Year 1905.

- The theory postulates that the speed of light is absolute and that the laws of physics are the same in all inertial frames of reference.

- The theory predicts: a mixing of space and time and formation of space-time, time dilation and twin paradox, length contraction and the energy-mass relation.

- Space-time of Special Theory of Relativity is flat!