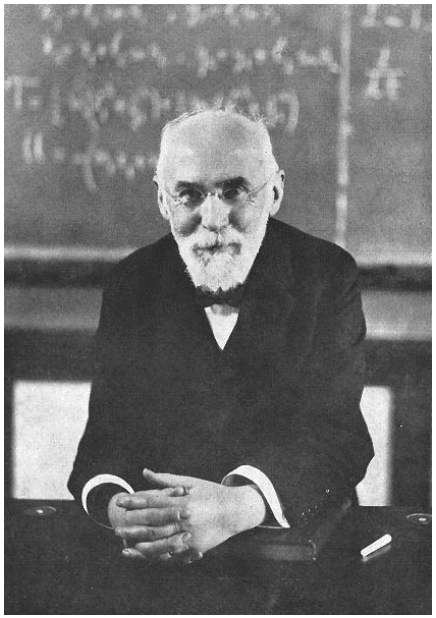
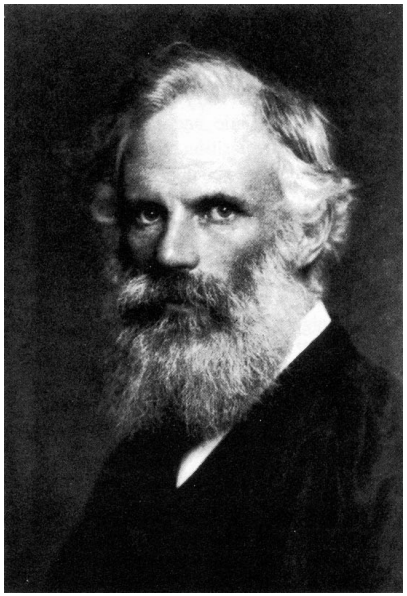
Epilogue to Special Relativity

Contributors



Hendrik A. Lorentz
(1853-1928)

Hermann Minkowski
(1864-1909)



George Fitzgerald
(1851-1901)

Christian Doppler
(1803-1853)

Max Planck
(1858-1947)

Key ideas in Special Relativity

- The speed of light is a Universal constant.
- All inertial observers are equivalent (Principle of Relativity).
- Treat time at the same level to obtain spacetime. The distance is measured by the Minkowski metric (interval).
- Lorentz transformations are relate inertial frames and ensure constancy of the speed of light.
- Lorentz transformations are the rotations of the Minkowski spacetime (keep the interval invariant).

Consequences

- There is no universal notion of time and of simultaneity.
- Causality effects and finite propagation of signals.
- The phenomenon of time dilation.
- The phenomenon of length contraction.
- Doppler effect.
- Equivalence of mass and energy.

What was missing?

- Further effects like aberration of light.
- Electromagnetism: magnetic field as a relativistic effect.

What's next?

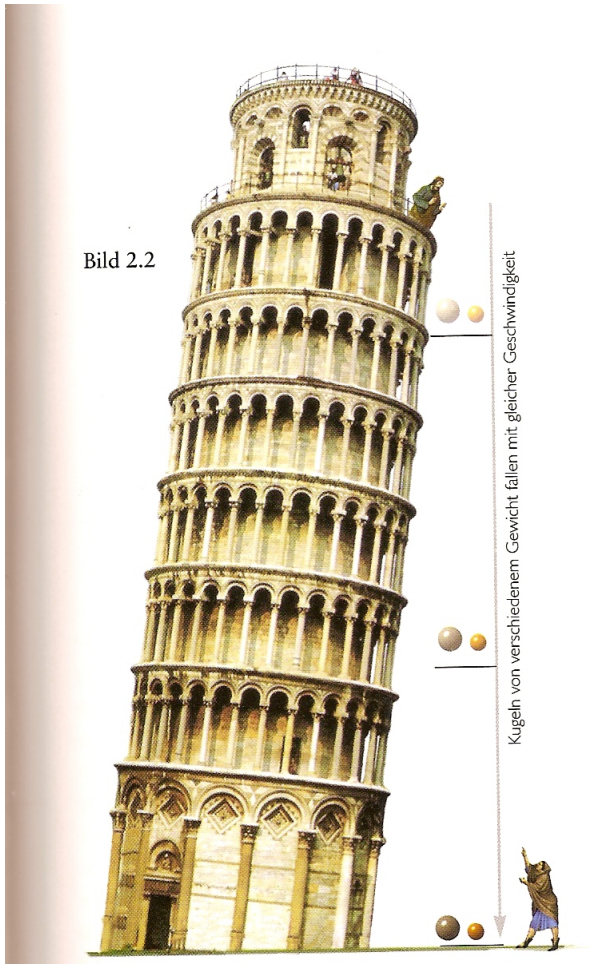
- All the situations discussed up to now have assumed that there is no gravity!
- Need to construct a theory of gravity compatible with the ideas of Relativity (all observers are equivalent).
- This leads to General Relativity!

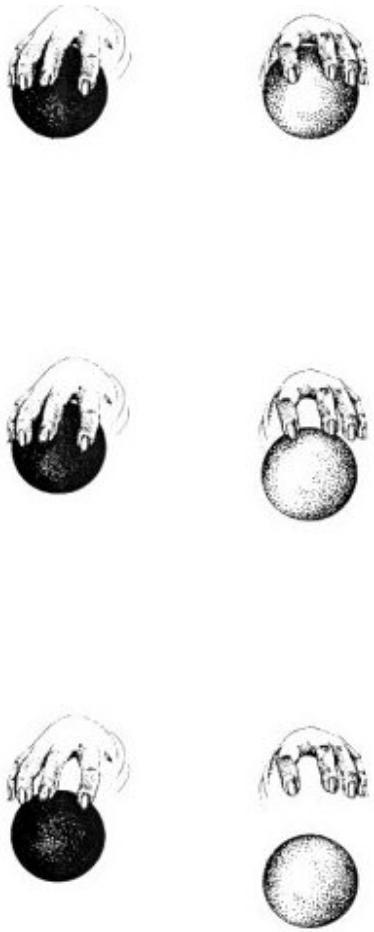
Prelude to General Relativity

What is Gravity?

- Gravity is the Universal force responsible for the mutual attraction between material bodies.
- It is ***Universal*** because it acts on all material bodies in the same way.

Galileo's experiment





Galileo's experiment on the Moon

A video of the demonstration of Galileo's experiment on the Moon by astronaust of the Apollo XV mission can be found at
http://www.youtube.com/watch?v=5C5_dOEyAfk

Principle of Equivalence

- The motion of a test particle in a gravitational field is independent of its mass and composition.
- All matter (**SR:** also energy!) is acted by the gravitational field.

Experimental verification: 1 part in 10^11!

Accelerated frames

- In an inertial frame bodies in uniform motion remain in uniform motion (Newton's 1st law).
- With respect to an accelerated frame bodies in uniform motion will seem to be **accelerated**.
- One can think of this spurious acceleration as due to an inertial force (**inertial force**).

Gravity and inertial frames

- **Question:** can one construct a system of reference for which a freely falling particle seems at rest?

- Yes! As a consequence of Galileo's experiment

A video of zero G in airplane flights can be found at http://www.youtube.com/watch?v=ICL0-ooDZ9c&feature=related

Einstein's lift experiment

- **Morally:** one can eliminate the force of gravity by choosing a freely falling frame.
- **Caveat:** this can only be done in a restricted region (that is locally).

In other words: one can construct a small inertial frame.

General Principle of Relativity

Laws of Nature should be formulated in such a way that they are **invariant under arbitrary transformations of coordinates** (reference frames) and not just Lorentz transformations (as in the case of SR)

This is the physical perspective!

General Covariance

The laws of Physics should have a **tensorial** form.

This is the mathematical implementation of the General Principle of Relativity. One has to use the language of Differential Geometry!