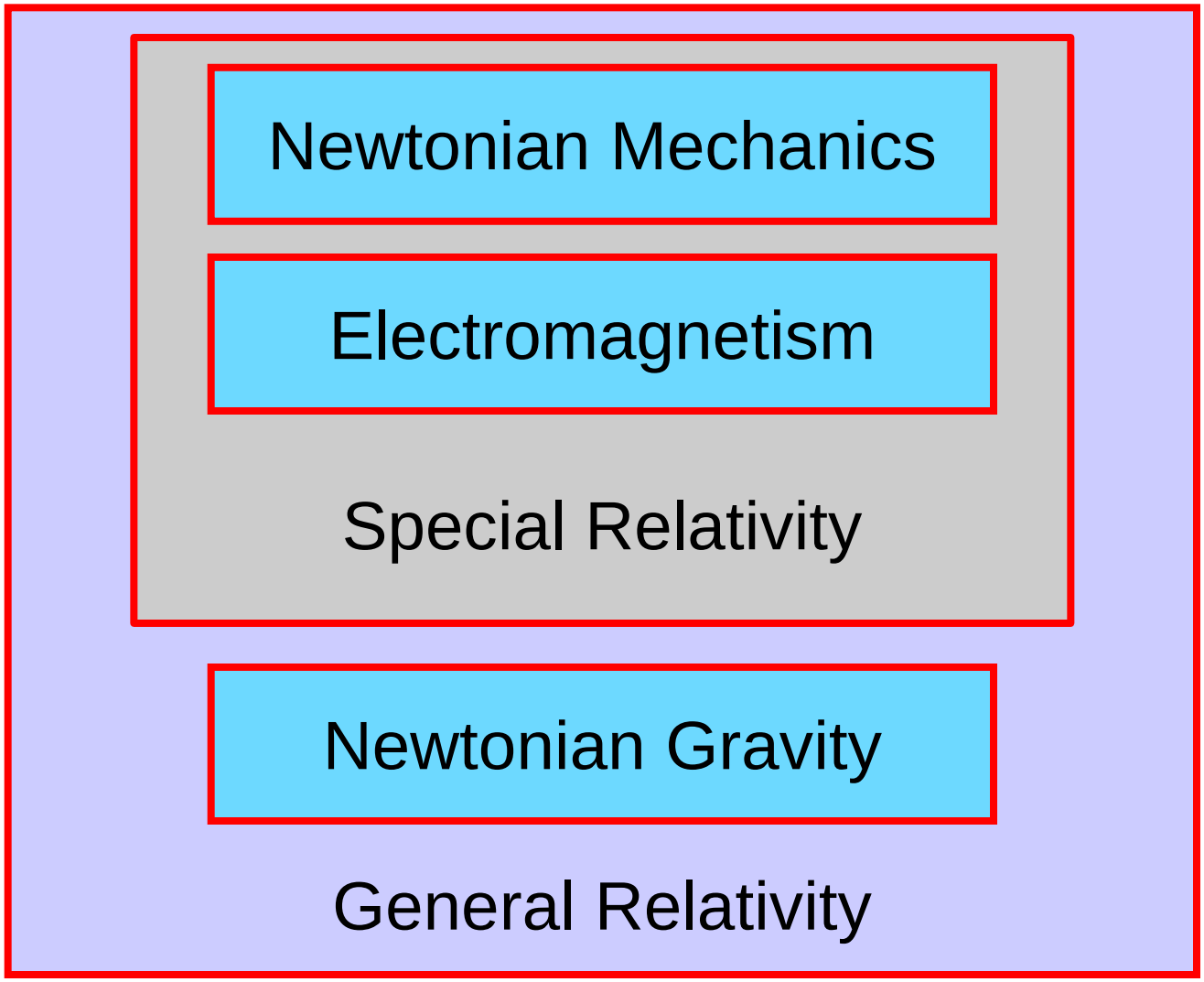
General Relativity I

Special Relativity And Gravity

- Special relativity included Newton's laws as a special case of low speeds. However, the Newton's law of gravity is not included in SR, in particular, according to the Newton's law, the gravitational force propagates with the infinite speed.
- Also, the distance is not absolute but relative. Which distance to use in computing the gravity force?

Physics Theories



Questions, questions...

- On the orbit around the Earth, astronauts in the Space Shuttle feel no gravity: they float around, move objects many times their own mass with one finger, etc. Does it mean that there is no gravity in the outer space?

A. Yes
B. No

Questions, questions...

- When the Space Shuttle lifts up, astronauts often feel several “gee”, i.e. gravity several times larger than the gravity at the surface of the Earth. Does it mean that the gravity is stronger inside the Space Shuttle than outside it?

A. Yes
B. No

Space Shuttle

- We can get a clue to the “weightlessness” of the astronauts if we consider an object, thrown inside the Space Shuttle (an astronaut himself will also suffice). An object will fly in a straight line with constant speed (until it hits a wall or someone’s head). Thus, the Space Shuttle orbiting the Earth is an inertial frame of reference!
- Yes, even if the Shuttle itself does not go in a straight line! (This is a clue to the General Relativity.)
- Since it is an inertial frame, there is no force acting on a freely moving object $\rightarrow$ weightlessness.

Questions, questions...

- What is so special about the Shuttle orbiting the Earth?
  A. It moves really fast.
  B. It is made in the US.
  C. It freely falls in the Earth gravity field.
  D. It has a special shield, protecting it from the Earth gravity.

Equivalence Principle

- If a freely falling object is an inertial frame of reference, then an object that does not fall freely is not in the inertial (i.e. in accelerated) frame of reference.

- Hence, gravitational and inertial forces produce effects that are indistinguishable. This is called the **weak equivalence principle**. It states that all objects will move in the gravity field the same way as in the accelerated frame of reference.

Equivalence Principle

- Recall, that in Newtonian Mechanics we already met the equivalence principle – that “freak coincidence” of the inertial mass being very close to the gravitational mass.

$$m_{\mathrm{in}} = m_{\mathrm{gr}}$$

- The weak equivalence principle actually claims more: not just all objects fall at the same rate, they move the same way in an accelerated reference frame.

Equivalence Principle

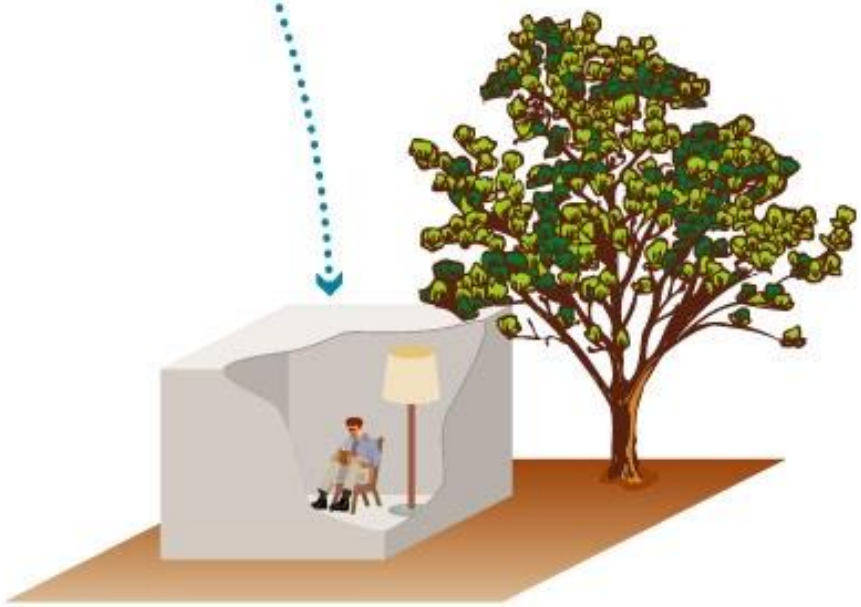
- The gravity force that pulls us downward is equivalent to upward acceleration (several “gee”s of astronauts).
- Einstein went one step further, and formulated the **strong equivalence principle**:

All physical laws are precisely the same in all inertial and freely falling reference frames, there is no experiment that can distinguish them.

The Equivalence Principle

You cannot tell the difference between being in a closed room on Earth . . .

. . . and being in a closed room accelerating through space at 1g.



Ramifications

- Light is also curved by the gravitational force, even if according to the Newton's law, the force of gravity acting on light (massless photon) is zero.
- Light, emitted toward the source of gravity, will experience Doppler blueshift; light emitted from the source of gravity will experience Doppler redshift.
- All physical processes should run slower in the presence of gravity. (Is this actually true?)

Geometry

- In the presence of gravity filed, an inertial observer is not necessarily moving in a straight line (orbiting Space Shuttle). Thus, gravity makes straight lines curved, in other words, it changes the geometry of space, or, more precisely (the SR is still valid!), the geometry of space-time.
- Thus, the GR is a theory of a **curved** (i.e. non-flat) space-time.
- Hence, in GR gravity is not a “normal” force but the effect of the curvature of space-time that we perceive as a force (particle physicists don’t like that).

Euclidean Geometry

- Euclid's book "Elements" served as a main geometry textbook until 20th century.
- Almost nothing is known about his personal life.
- Euclidean geometry is based on five axioms (= postulates).

Euclid (c 300 BC)

Euclidean Geometry

1. It is possible to draw a straight line from any given point to any other point.
2. A straight line of finite length can be extended indefinitely, still in a straight line.
3. A circle can be described with any point as its center and any distance as its radius.
4. All right angles are equal.
5. Given a line and a point not on the line, only one line can be drawn through that point that will be parallel to the first line.

Euclidean Geometry

- For centuries, mathematicians tried to prove the fifth postulate. Finally, Carl Friedrich Gauss (German) and Nickolay Lobachevsky (Russian) showed that by changing the fifth postulate, one can create new, *non-Euclidean* geometries.