Today's Topics

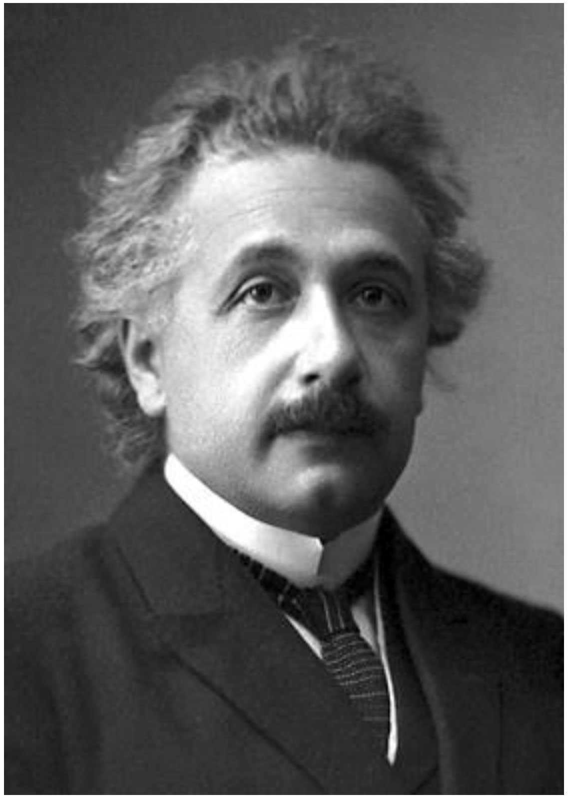
Monday, November 24, 2019 (Week 13, lecture 31) – Chapter 24.

1. Einstein's Theory of Relativity.
2. Special Relativity.
3. General Relativity.

Einstein's Theory of Relativity

1905: Annus Mirabilis

- Brownian motion (motion of atoms in a gas).
- Photo-electric effect (discovery of the photon, $E = hf$)
- **Special theory of relativity**.
  → Major revision of Galilean relativity.
  → Equivalence of energy and matter: $E = mc^2$



Albert Einstein, 1921.
(1879-1955)

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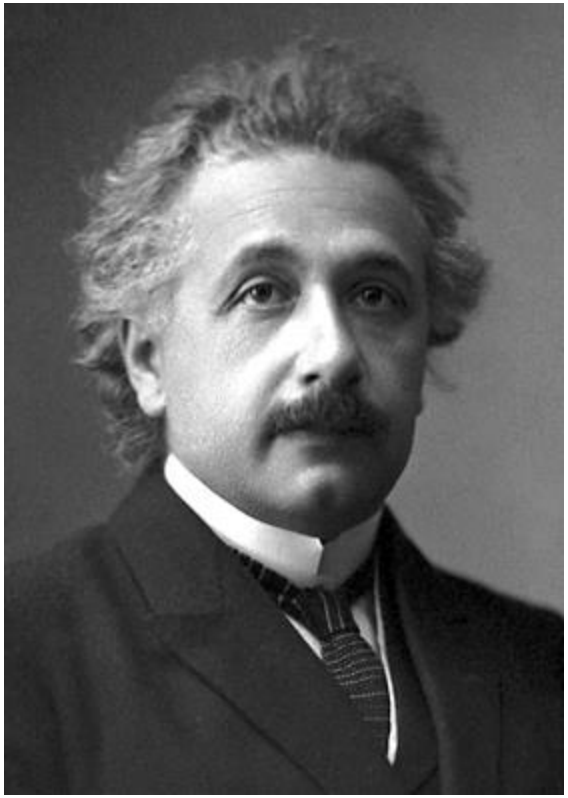
1907-15: General Relativity

Theory of relativity applied to gravity.
→ gravity = curved space-time.



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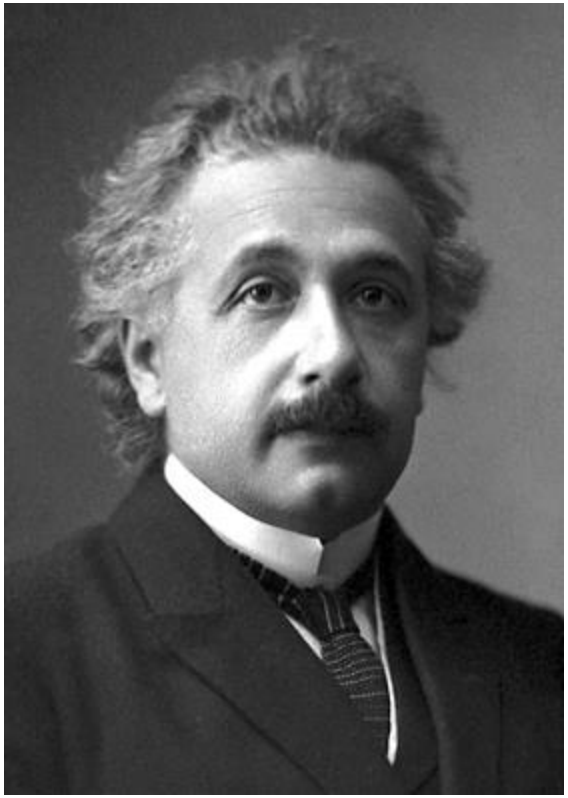
1921: Nobel Prize for photo-electric effect.

1924: Bose-Einstein Condensation
Predicts the existence of a new type of quantum matter.
→ Builds on the work of Satyendra Bose.
→ First observed in 1995
→ There is a BEC in the basement of Small Hall (room # 069).



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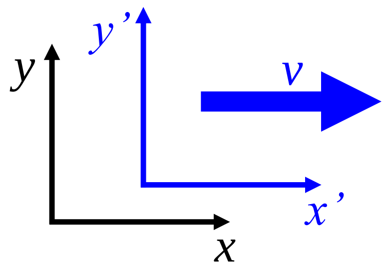
Inertial Frames (Galileo & Einstein)

Inertial Frame

Coordinate system at constant velocity in a rest frame.

think of it as a box



Rest Frame

A coordinate system that is not moving.

Note: a rest frame is an inertial frame.

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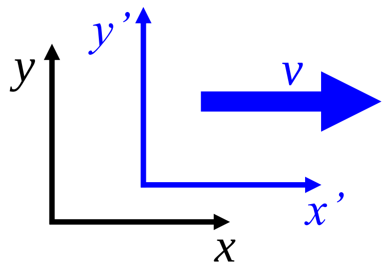


Rest Frame

A coordinate system that is not moving.

Note: a rest frame is an inertial frame.

Important

- **You cannot tell if you are moving** based on local measurements inside your inertial reference frame (the frame attached to you).
- If you are **accelerating/decelerating**, then you can tell based on local measurements (i.e. there is a force on you that you can measure, $F = ma$).

Special Relativity (Einstein)

Principle of Relativity

The laws of physics are the same in all inertial reference frames.

Corollary #1

You cannot tell if you are moving (based on local measurements) in an inertial frame.

Corollary #2: Universal speed of light

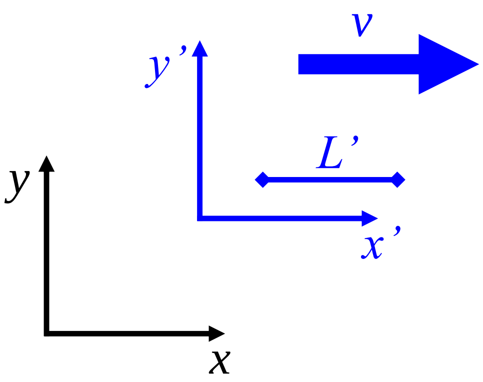
The speed of light in vacuum is the same in all inertial frames, regardless of the motion of the source.

Special Relativity
Length Contraction

In the x'-y' inertial frame

Consider a rod of length $L' = L_0$, as measured in the x'-y' inertial frame (i.e. the rest frame of the rod).

Note: The rod is aligned with the axis of motion along x'.



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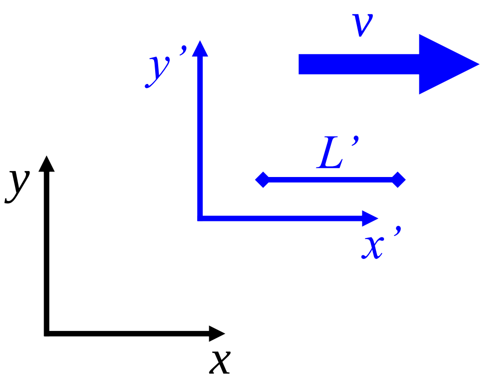


In the x-y inertial frame

If you measure the length of the rod, then you will get a shorter length: $L = \frac{L_0}{\gamma}$.

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

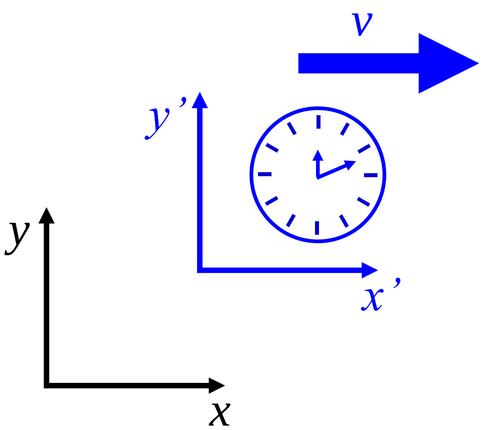
$\gamma \geq 1$

Note: the length contraction is only along the axis of motion. Along axes perpendicular to the motion, there is no change in length.

Special Relativity
Time Dilation

In the x'-y' inertial frame

Consider a clock at rest in the x'-y' inertial frame that measures a time interval of $\Delta T' = T_0$, i.e. the time for the big clock hand to go from noon to the 2 o'clock position (10 minutes).



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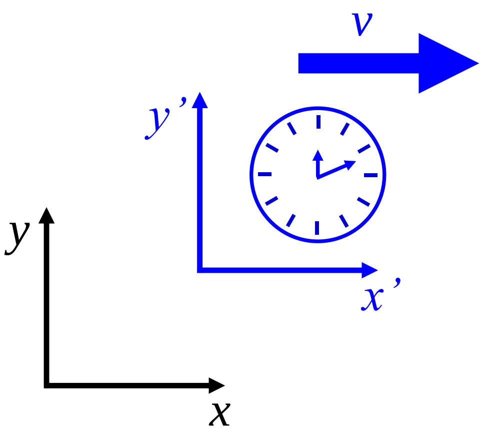


In the x-y inertial frame

If you measure the same elapsed time from the x-y inertial frame (i.e. as the clock flies past you), then you will measure a longer elapsed time: $T = \gamma T_0$

General Relativity

Equivalence Principle

A coordinate system that is falling freely in a gravitational field is (equivalent to) an inertial frame.

Corollary

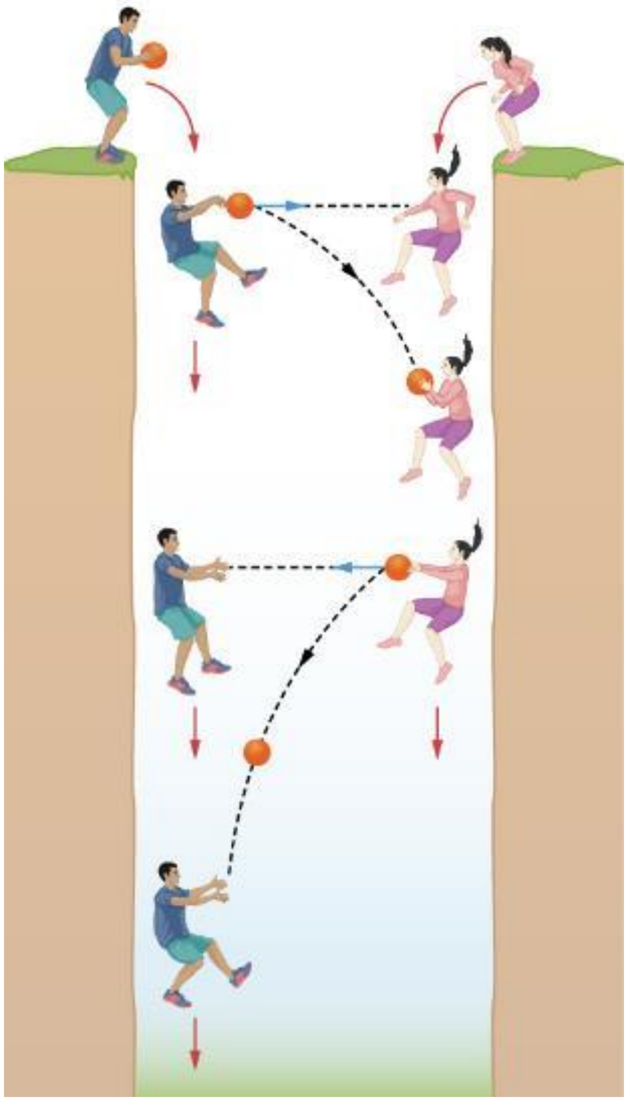
You cannot tell if you are at rest in a non-gravitational field (i.e. in a standard inertial frame) or freely falling under gravity based in based on local measurements.

Equivalence Principle

You cannot tell if you are at rest in free space (i.e. in a standard inertial frame) or freely falling under gravity based in based on local measurements.

Example

- Two people play catch as they descend into a bottomless abyss.
- Since the people and ball all fall at the same speed, it appears to them that they can play catch by throwing the ball in a straight line between them.
- Within their frame of reference, there appears to be no gravity.

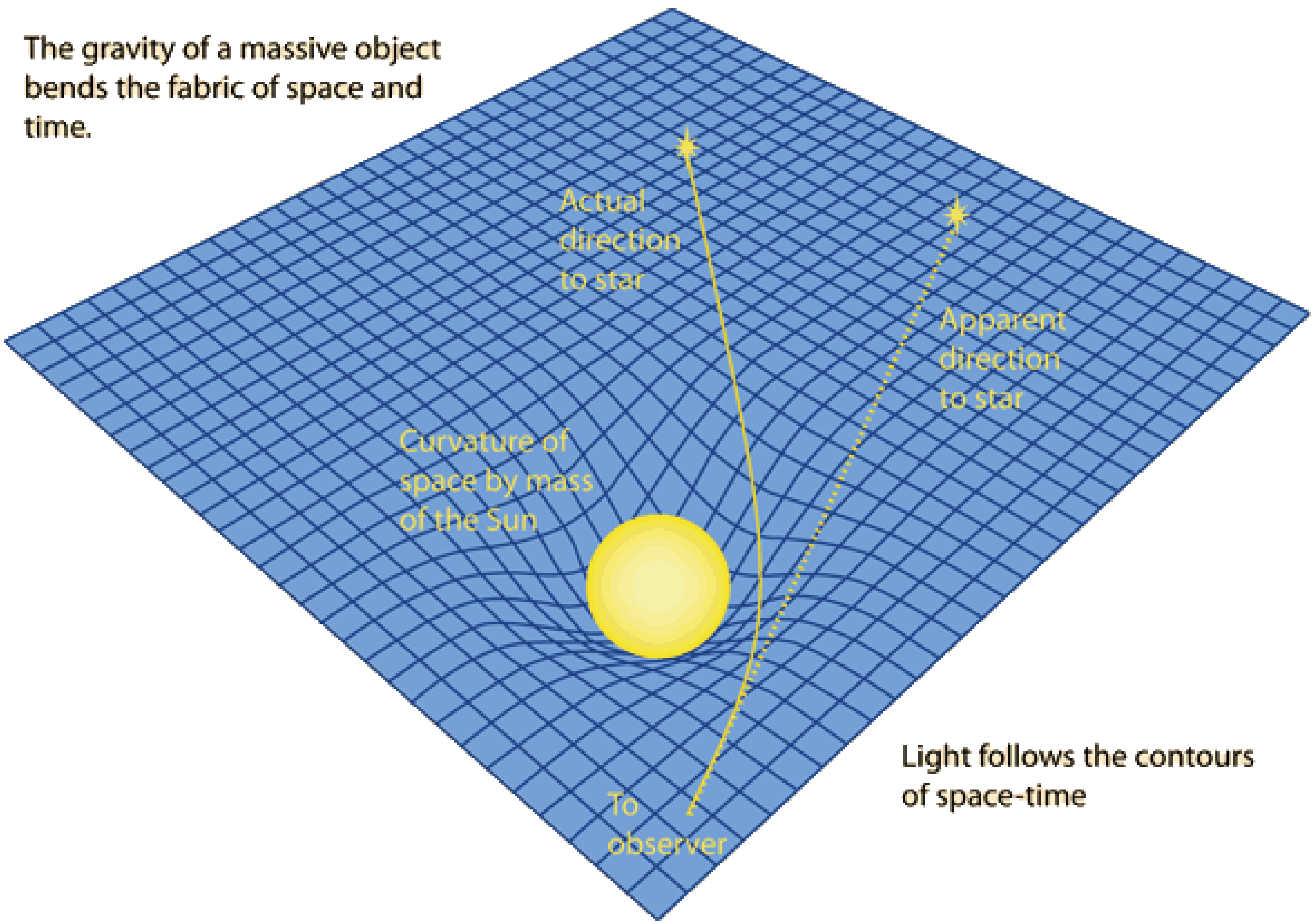


[OpenStax: Astronomy]

Equivalence Principle on ISS

[NASA]

Curved Space-Time

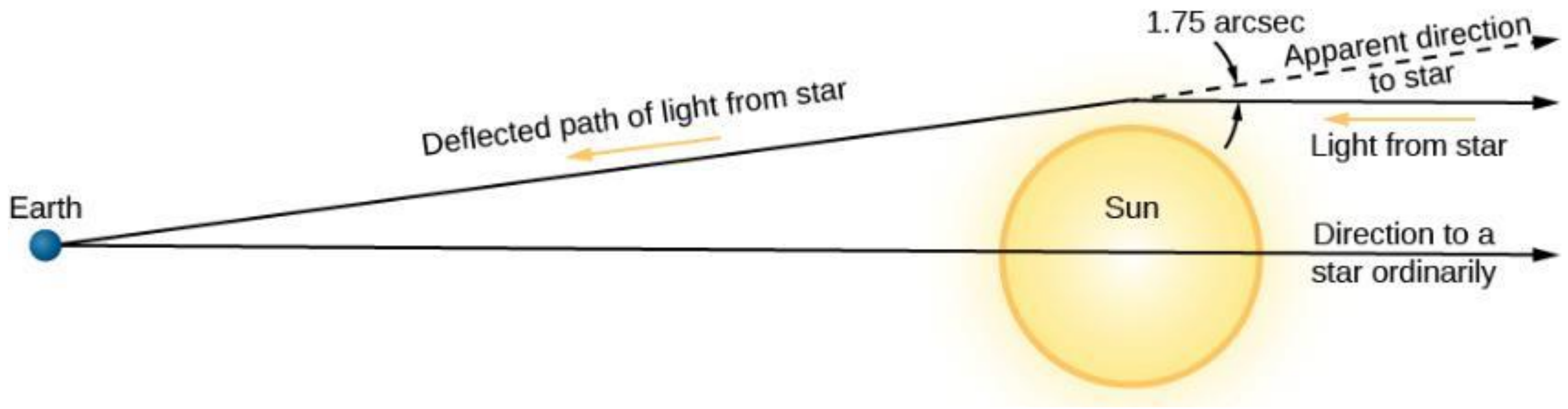


[http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/grel.html]

Curved Space-Time

Eddington's measurement of deflection of light

- Arthur Eddington measures the deflection of starlight by the Sun.
- 1919 solar eclipse: West Africa & Brazil.
- The star appears shifted: Measurements show deflection that agrees with General Relativity.



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Gravitational Redshift

Clocks in a gravitational field run slower than clocks in free space.

For small changes in height Δh:

$$\frac{\Delta f}{f} = \frac{g \Delta h}{c^2}$$

f = frequency of clock

g = acceleration of gravity
= 9.8 m/s^2 at Earth's surface