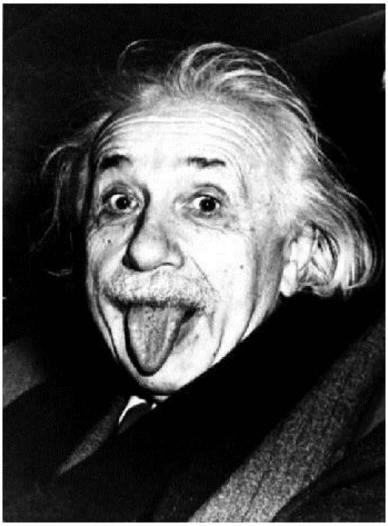
Special and General Relativity



General Relativity

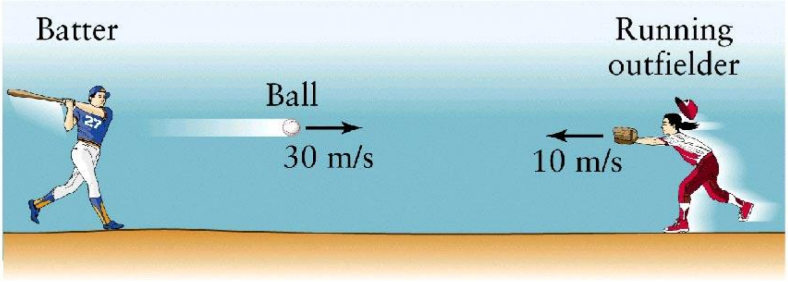
Principle:

There is no experiment that will discern the difference between the effect of gravity and the effect of acceleration.

Einstein says that Newton's concept of gravity is just an illusion of acceleration

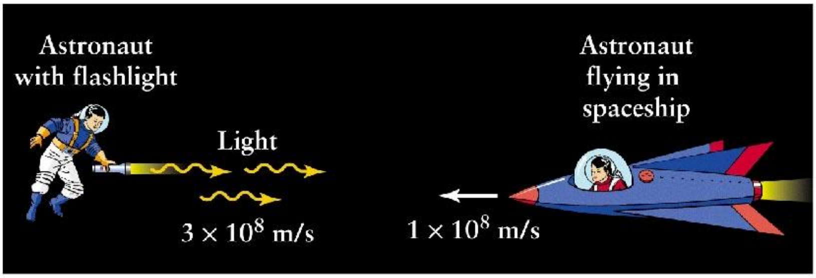
Special Relativity

- **Speed of light is constant**
- **Time dilation**
- **Simultaneity**
- **Length Contraction**



As seen by outfielder, ball is approaching her at
(30 m/s) + (10 m/s) = 40 m/s
a

Speed of light is constant



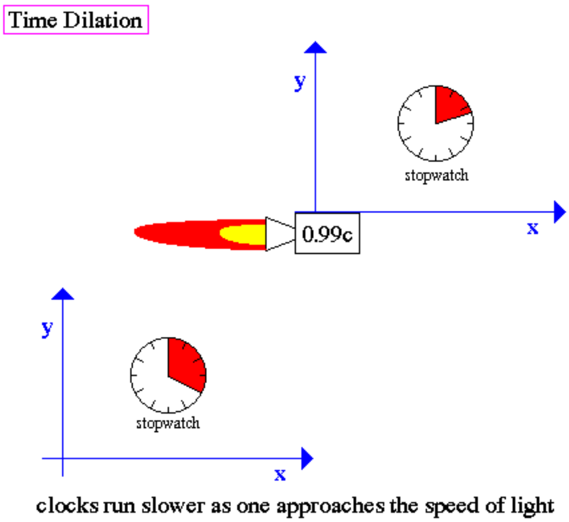
Incorrect Newtonian description:
As seen by astronaut in spaceship, light is approaching her at
$(3 \times 10^8\ \text{m/s}) + (1 \times 10^8\ \text{m/s}) = 4 \times 10^8\ \text{m/s}$

Correct Einsteinian description:
As seen by astronaut in spaceship, light is approaching her at
3×10^8 m/s

Our conceptions of space and time has to be changed.

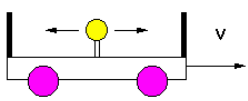
- Facts:
  - Regardless of speed or direction, observers always measure the speed of light to be the same value.
  - Speed of light is maximum possible speed.
- Consequences:
  - The length of an object decreases as its speed increases
  - Clocks passing by you run faster than do clocks in your reference frame

Time dilation

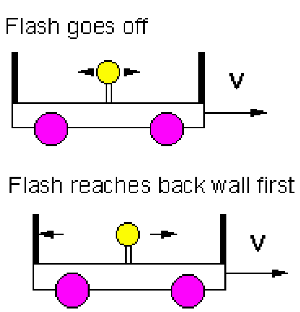


Simultaneity

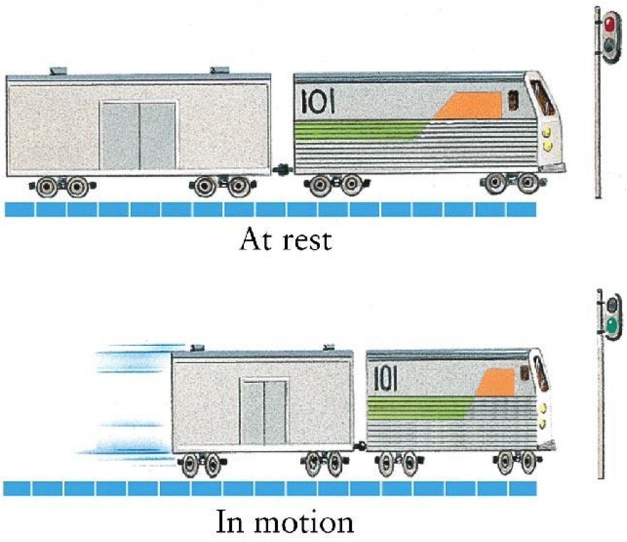
Light in center of car flashes, hits front and back simultaneously.



To an observer watching the car move, the car travels while the light is in motion. So the light hits the back of the car before the front.



Special Relativity: Length Contraction



Special Relativity

Time dilation

$$t' = t \times \sqrt{1 - \frac{v^2}{c^2}}$$

Length contraction

$$l' = \frac{l}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Mass dilation

$$m' = m \times \sqrt{1 - \frac{v^2}{c^2}}$$

As an object speeds up, an observer at rest would see

1. It get longer and its clock run faster
2. It get shorter and its clock run faster
3. It get longer and its clock run slower
4. It get shorter and its clock run slower

How long does it take to get to Vega?

Vega is 25 light years away, assume travel is at 0.999 *c*.

Time for trip should be about 25 years.

But since clocks of moving object slow down, the time elapsed on a clock taken on the trip is only

$$t' = (25\,\text{years}) \times \sqrt{1 - 0.999^2} = 1.1\,\text{years}$$

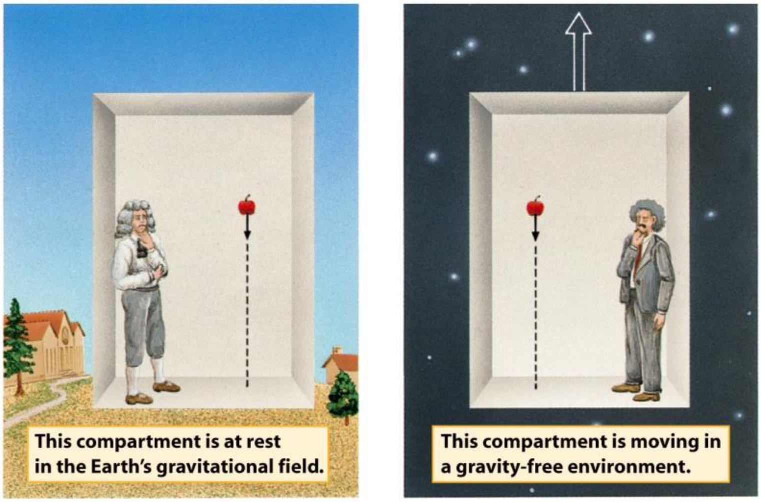
Summarizing Special Relativity

- **The speed of light is constant regardless of the motion of an observer.**
- **Time would appear to tick slower for an object moving near C. It would also appear compressed.**
- **Special relativity deals mostly with the effects of constant speed (velocity)**

General Relativity

- Equivalence principle
- Gravitational redshift
- Geodesics
- Gravitational light bending
- **General relativity deals mostly with the effects of acceleration (change of speed)**

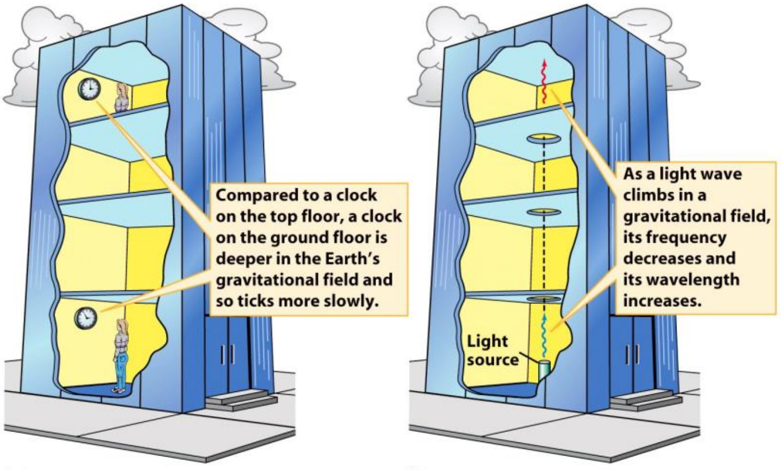
Equivalence principle



(a) The apple hits the floor of the compartment because the Earth's gravity accelerates the apple downward.

(b) The apple hits the floor of the compartment because the compartment accelerates upward.

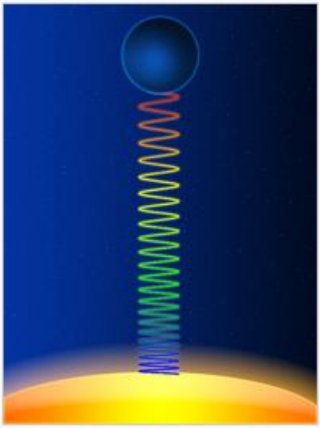
Gravitational redshift



(a) The gravitational slowing of time

(b) The gravitational redshift

Gravitational redshift

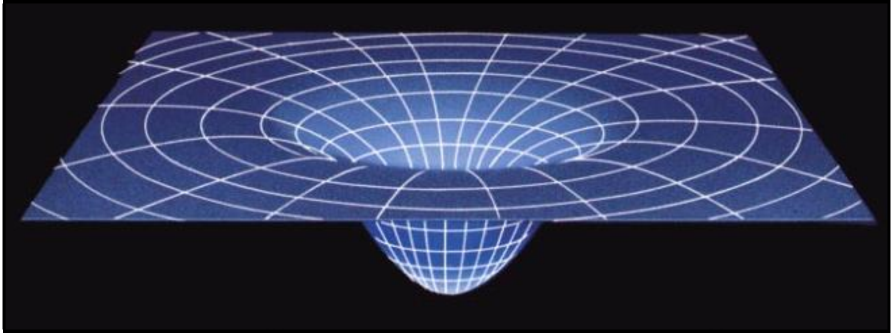


The gravitational redshift of a light wave as it moves upwards against a gravitational field (caused by the yellow star below).

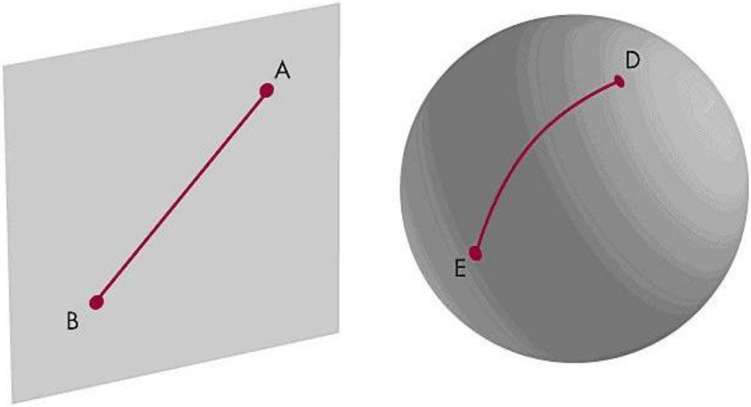
Einstein's theory of gravity is built on the principle that

1. The speed of light is constant.
2. As an object speeds up its clock runs slower.
3. The effects of gravity cannot be distinguished from the effects of acceleration in the absence of gravity.

Gravity deforms space-time



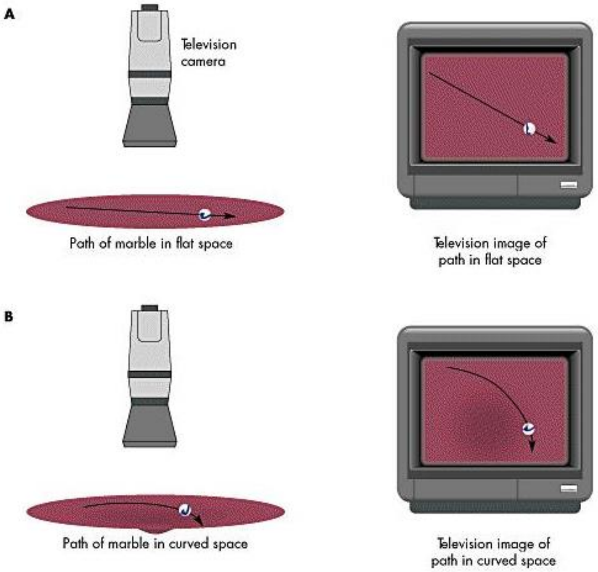
Geodesics in curved spacetime



A Flat two-dimensional space

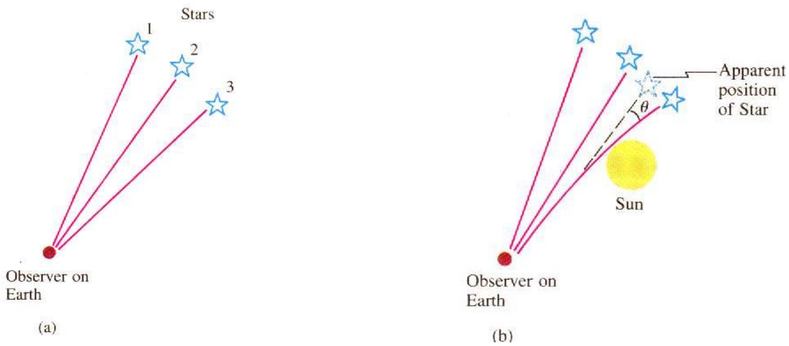
B Curved two-dimensional space

Geodesics in curved spacetime



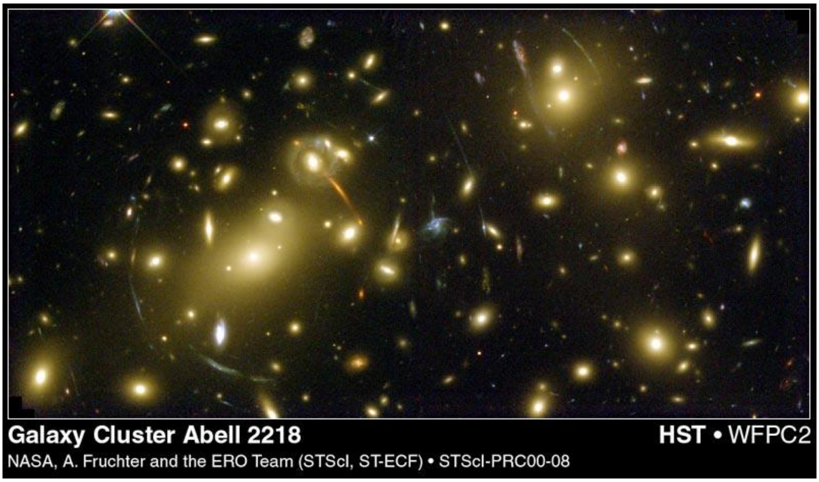
Demo: 1L10.50
Gravity Well

Apparent Curvature of light:

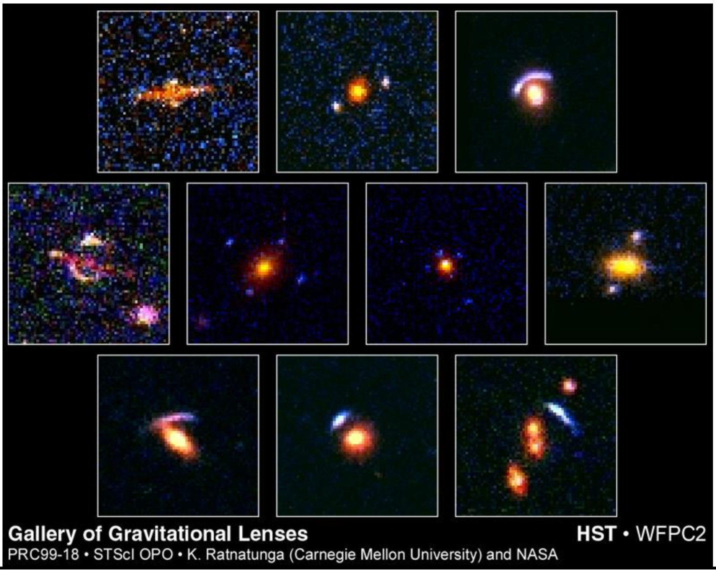


In 1919, Sir Arthur Eddington measured the deflection of light near the sun during an eclipse. Light was bent twice as much as Newton's theory predicted, supporting General Relativity

Gravitational Lensing:



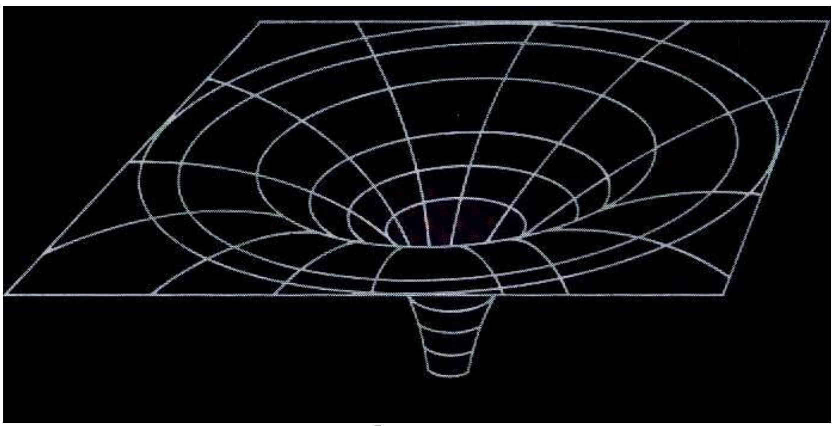
Gravitational Lensing:



Curvature of Space:

- Now that you understand that gravity bends light… Understand that it does not.
- Light travels in a straight line.
- The space itself near a massive object is curved.
- Light is the absolute.
- It travels at the speed of light.
- It travels in a straight line.

Curvature of Space:

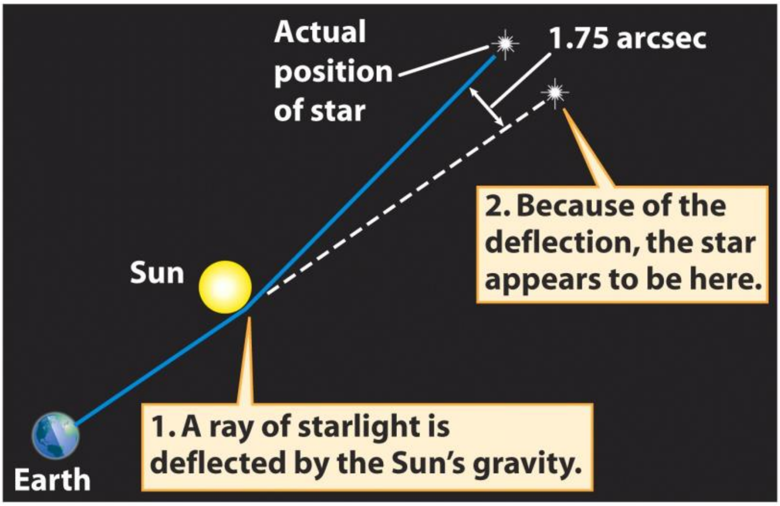


Mass distorts space

Tests of General Relativity

- Gravitational light bending (1922)
- Atomic Clocks on Aircraft
- Gravitational redshift from white dwarf (1924)
- Gravitational redshift on Earth (1960)

Gravity bends the path of light



RELATIVITY

- Laws of Physics are observed the same for everyone.
- Time of events cannot be agreed upon
  -Time Dilation
- Distance between objects cannot be agreed upon
- **-Length Contraction**
- Order of events cannot be agreed upon
  -Simultaneity

What is Reality

- If we cannot agree on the measurements of time, distance, mass, or order of events, what is real?
- CAUSALITY!

-The relationship between cause and effect.