Lecture 3: Equivalence

Note Title 1/23/2011

There is a good discussion of this topic in our text.

Fundamental Question: Do all objects accelerate at the same rate when dropped in a gravitational field?

Galileo: 1st to consider (others: Eotvös (late 1800's)
Dicke (60's)
Huygens)

$F_g = m_g g$ but $F = m_i a$

m_g: gravitational mass

m_i: inertial mass

$$\boxed{a = \left(\frac{m_g}{m_i}\right) g}$$ ← Our question is whether $\frac{m_g}{m_i} = 1$.

By no means is it obvious that $m_g = m_i$. For instance in E+M, the force couples to the charge, so the gravitational force might couple to something other than the inertial mass.

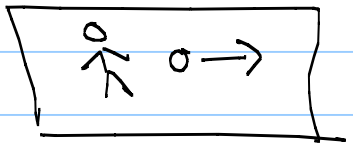
Weak Equivalence Principle (WEP)

"The motion of a neutral test body released at a given point in spacetime is independent of its composition."

$\Rightarrow$ or $m_i = m_g$

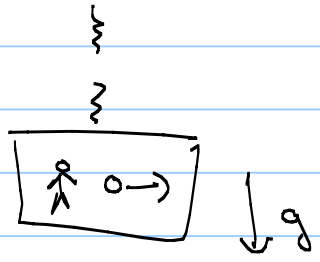
Strong equivalence thinks about gravity and accelerations.

$\Rightarrow$ If you are in deep space, floating, with no gravitational field:



balls travel in straight lines, etc.

Suppose you are in an elevator & the cord breaks, so you are in free fall

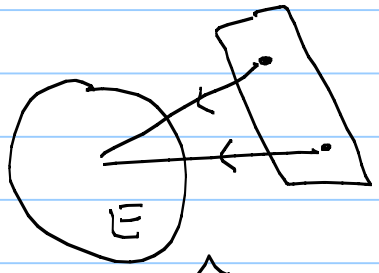


Again, in your frame, the ball travels in a straight line.

"Can an astronaut inside a capsule in free fall in a uniform gravitational field determine her state of motion?"

→ If the field is uniform, the answer is no!

→ Suppose the field is not uniform:



By dropping two balls, over time they will come towards one another if you are in the field of the earth.

These are called **tidal effects.**

Local: A region of spacetime small enough that tidal effects can be neglected. (So the field is uniform.)

Note: At any point in spacetime, there is one "special" reference frame — the one which is in free fall.

Very, very important

Strong Equivalence Principle (SEP)

(1) The results of all local experiments in a frame in free fall are independent of the motion

(2) The results are the same for all such frames at all places and at all times.

→ Physics is the same in all freely falling frames.

In constrast to the 1st Postulate of SR!

→ But Implicit Idea: (3) Physics in a free fall frame is consistent with SR.

⟹ Note: In SR, there is 1 prefered frame which covers the entire universe, but at the cost of neglecting acceleration.

→ In GR, the SEP means that at any pt, there is a prefered frame where physics looks like SR, and all of spacetime is covered by a patchwork of these frames.

⟹ Why is SEP an extension of WEP?

→ If $m_g \neq m_i$ — 2 different objects would behave differently in a field but the same in deep space.

So if WEP is not true, then you can tell whether you are in a gravitational field or not.

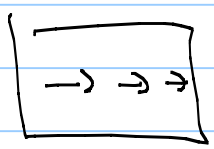
Some Consequences of SEP (brief - we will return to these later)

(1) Doppler Shift & Time delays

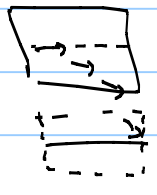
↳ clocks deep in a gravity field run slow

(2) Light rays bend in the field

In SR, light rays travel in straight lines. If SEP is true, then free fall frame is the SR frame



In elevator



from outside, light rays bend.

Note that SEP is a key ingredient, but more is needed,

↑ Bending computed w/ just SEP gives ½ of correct value.