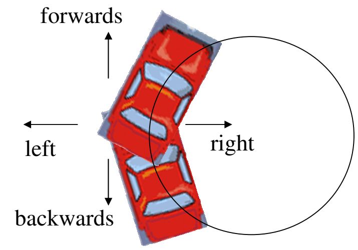
Lecture 14 Announcements

1. Friday offices hours changed. Now my office hours are:
   a. Wed 3-4 pm
   b. Fri 3-4 pm   (instead of 4-5 pm)

   My office hours are still in the Tutorial Lab

2. If you need/want to talk to me about your exam, same rules as last time:
   a. Look over the exam solutions on your own first. They are now posted to the website. Figure out as best you can what you did wrong.
   b. Try to talk to me during my regularly scheduled office hours if at all possible.
   c. If regular office hours not possible, email me to set up an appointment.

Review



You are on right side of the back seat of the car. The car turns right at constant speed, moving in a circle, and you slide slowly to the left (with friction) before running up against the door.

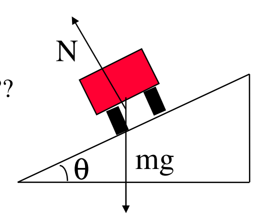
Clicker quiz: The net horizontal force on you *while you are sliding* is:
a. Towards the left
b. Towards the right
c. Forwards
d. Backwards

Clicker quiz: The net horizontal force on you *after you are pressed up against the door* is:
a. Towards the left
b. Towards the right
c. Forwards
d. Backwards

Question: what direction is the friction on the car's wheels?

Problem: turn on banked roadway

Consider sideways friction on wheels…
    What direction if no banking?
    What direction if going slow, $\theta = 90°$?
    In between?



Why do they bank turns?

Problem: what should the banking angle be so that there is no sideways friction force needed? (assume overall turn radius R, speed v)

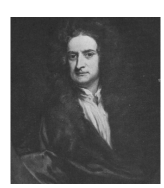
Hardest part: which way to draw the axes??
    Colton: "Make the positive x-axis be along the inclined plane"
    Colton: "Make the positive x-axis be towards the center of the circle"

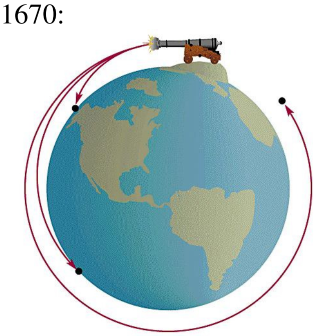
Answer: $\theta = \tan^{-1}(v^2/Rg)$

Gravity!!

Classical physics was invented to understand motion of the planets

Newton's thoughts about the moon's orbit and projectile motion, c. 1670:





Parabola of projectile turns into a circle.

The apple, the cannonball, and the Moon

→ all are in ____________

Newton's Law of Gravity: $F_G = G\dfrac{mM}{r^2}$

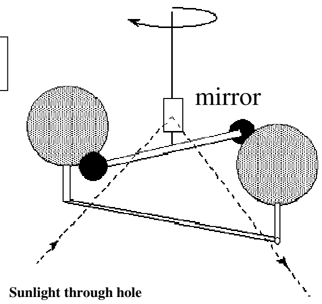
(sometimes with negative sign)

All masses attract all other masses!

1783: first measurement of forces between "regular" masses, by Cavendish.

$G = 6.674 \times 10^{-11}$ N·m^2/kg^2

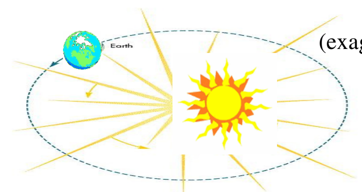
"weighing the world"



How did Newton know it was **inverse square**?

Kepler's laws (about 1600) came from observations of the planets in our solar system:

1. **Elliptical orbits**



2. **Equal areas in equal times**: fastest close to Sun

3. **$T^2 \sim r^3$**
   (T = "orbital period" = __________)

All three can be exactly predicted using Newton's Second Law together with Newton's Law of Gravity!

Worked Problem: Figure out what the proportionality constant is in Kepler's Third Law in terms of *G* and the mass of the sun. Assume a circular planetary orbit.

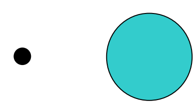
Problem: How long is Jupiter's year? ($r_{Jupiter} \approx 5.2\ r_{Earth}$)

Question: What about satellites orbiting the earth?

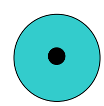
Answers: $k = 4\pi^2/GM$; 11.86 years

All masses attract all other masses!

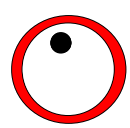
From the outside, a *spherical* mass (planet) acts as though its mass were all at __________.



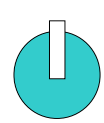
At the center of the earth? (If you could survive the heat)



If you are inside a spherical shell?



Drilling a hole through the earth…



Why does $g = 9.8$ m/s^2 ?

g: "surface gravity", aka "surface acceleration"

R_{Earth} = 6371 km
M_{Earth} = 5.974 × 10^{24} kg

What is g_{Mars}?

R_{Mars} = 3390 km
M_{Mars} = 6.419 × 10^{23} kg

(answer: a little more than 1/3 g_{Earth})

Orbital Velocity

On the moon (no air friction) someone *could* get into orbit by being fired horizontally off the highest mountain.

How fast would you have to shoot that person?

How long would it take him to go around once?
"orbital period"

Answers: v=sqrt(GM/r), 2πr/v

Circular orbits

For each v, only one r will work
For each r, only one v will work!

Clicker quiz: A satellite in a higher orbit will be going
a. faster
b. slower
than a satellite in a lower orbit

Real satellites:

http://science.nasa.gov/RealTime/JTrack/3d/JTrack3d.html

International space station, 340.5 km above surface of Earth
(R_e = 6,371 km) 7.707 km/s
Geostationary orbit, 35,786 km above surface
3.075 km/s
Moon, average R = 381,715 km
1.022 km/s

How long does it take ISS to orbit?

Demo: Gravity well

Answer: 91.2 min

Warmup quiz review:
The Moon does not fall to Earth because:
a. the gravitational pull of the Earth on the moon is weak
b. the moon has a sufficiently large orbital speed
c. the gravitational pull of the sun keeps the moon up
d. the moon has less mass than Earth
e. none of the above

Clicker quiz: Satellites in higher orbits are travelling slower, so to "shoot" a satellite from the surface of the earth into a high orbit (i.e. with a cannon), you would provide it with
a. more
b. less
initial kinetic energy than for a satellite in a low orbit

Gravitational PE

Need new $PE_{gravity}$ PE = mgy just won't work…
Force isn't "mg" any more!

Using calculus to calculate work done against (non-constant) gravitational force…

$$PE_G = -\frac{GMm}{r}$$

Here the negative sign is critically important!!

Before: PE = 0 when ________

With new equation: PE = 0 when __________

Ralph's question: How can PE = -GMm/r "reduce to PE = mgy close to the surface of Earth"?? It's negative!

Worked problems:

How much initial KE (at least) would you have to provide in order to "shoot" a 100 kg satellite into a near orbit like the ISS, 6712 km from center of earth?

…into a much farther geostationary orbit? (42,157 km)

…to an orbit at the moon's distance (381,715 km)

Truth in advertising: Can you actually do this with this energy?

Answers: 3.29E9 J, 5.79E9 J, 6.21E9 J

Escape Velocity

Same question…

…into an orbit VERY FAR AWAY from the Earth??

Hint: What is final kinetic energy? Final potential energy?

What was **velocity** of that satellite?

Escape velocity in general—velocity needed to "escape" the earth/planet/sun… end up very far away

Answers: 6.26E9 J, 11.2 m/s

Tricky maneuvering in orbit

Higher orbits have more total energy, but less KE!
If you want to have a **faster orbit** (less time/orbit) you have to **throw away** energy with your rockets!

Free Computer Game/Simulator: "Orbiter"
http://orbit.medphys.ucl.ac.uk/orbit.html
→ link to a tutorial also available on website
Extra credit available for one person (or maybe a small team): figure out some "cool stuff" you can do with the game, prepare a ~5 minute demo for the class. First come, first served—contact me if you want to do this.

Clicker Quiz: You are on a Planet Xarthon that has a mass of 2× that of the earth, and a radius 2× as big. If you throw a ball at the surface, and you will find that $g_{Xarthon}$ is ___ g_{earth}

a. larger than
b. smaller than
c. the same as