MICHIGAN STATE UNIVERSITY

Lecture 4

Gravity and Orbits

No office hours this week!

Prof. Richard H. Cyburt

MICHIGAN STATE UNIVERSITY

History of Observation of the Stars

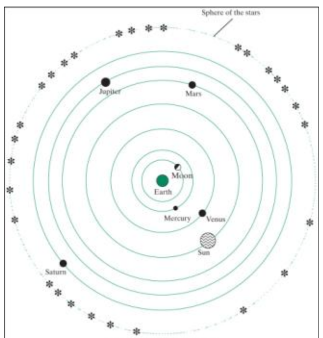
© 2010 Pearson Education, Inc.

- Detailed, recorded observations of the stars go back more than 5000 years. Many star names come from Babylonian and Chaldean times (4000 BC).
- 300 BC Aristarchus of Samos proposed a Sun centered solar system. This was rejected because it did not make sense that the Sun would be more important than the Earth.

MICHIGAN STATE UNIVERSITY

Earth centered models

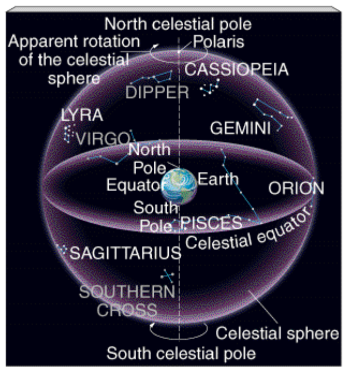
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

MICHIGAN STATE UNIVERSITY

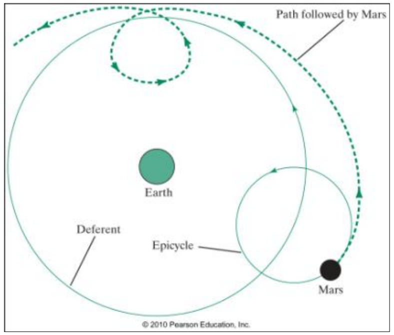
The Celestial Sphere



To us on Earth, it appears that all of the stars, Sun, Moon, and planets move on the underside of a large sphere.

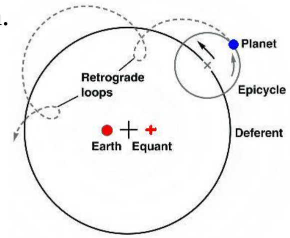
This sphere is called the **Celestial Sphere**.

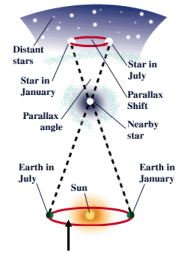
Problem: retrogade planet motion



Ptolemy

- Ptolemy devised an earth centered (geocentric) system.

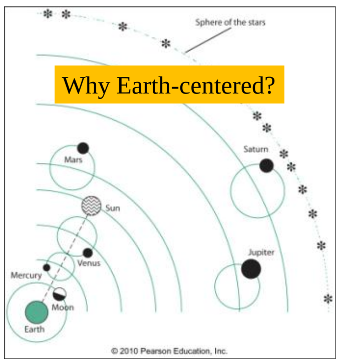




- It explains retrograde motion, why no stellar parallax was observed, and described all data.

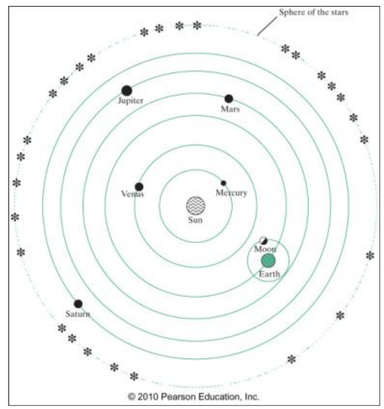
Ptolomy's model

"If the Lord Almighty had consulted me before embarking upon the creation, I should have recommended something simpler."
King Alfonso X



Copernicus model

** In 300 B.C, Aristarchus had the same idea!



Brahe, Kepler, Galileo

- Tycho Brahe (1546-1601)
  - Observation: life's goal to prove the Earth Centered hypothesis.
  - His observatory made observations 20 times better than any other. He reduced the errors from 10 minutes of arc to 0.5 arcmin.
  - At its peak his observatory used 1-1.5% of the Danish national budget.
- Johannes Kepler (1561-1630)
  - Was a brilliant mathematician (and astrologer)
  - Based on the data of Brahe, he deduced three laws of planetary motion
- Galileo (1564 – 1642) – Motion, Telescope, Solar System
  - First used a telescope to study the heavens
  - Studied motion and devised the concepts of acceleration, etc.

MICHIGAN STATE UNIVERSITY

Success of Kepler's theory

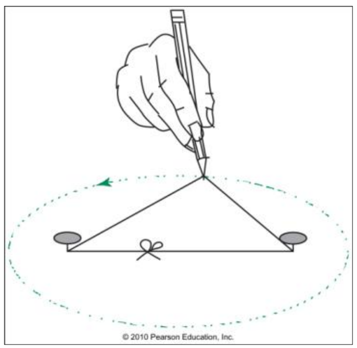
- Kepler was able to construct models to describe Brahe's observations on Mars to within 8 minutes of arc based on Ptolemy's assumption of uniform speed. (The width of the tip of your thumb held at arms length is 60 arcmin = 1 degree).

- Brahe's measurements were good to 0.5 arcmin (20 times better than previous measurements).

ISP209 Lecture 4

MICHIGAN STATE UNIVERSITY

Kepler gave up the circular orbit

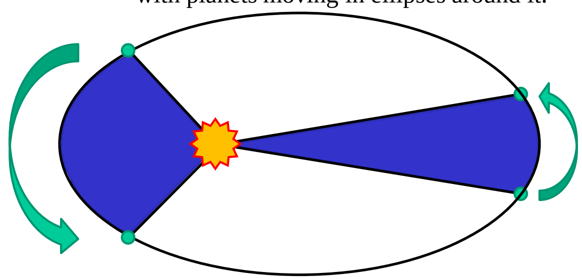


ISP209 Lecture 4

MICHIGAN STATE UNIVERSITY

Kepler's 1st & 2nd Laws

Law of Orbits: The Sun is at the center of the solar system with planets moving in ellipses around it.



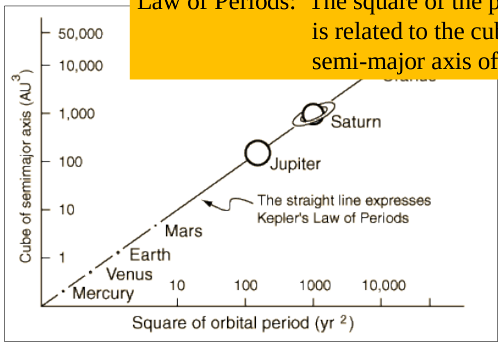
Law of Areas: The planet moves faster when it is closer to the Sun, sweeping out equal areas in equal times.

ISP209 Lecture 4

MICHIGAN STATE UNIVERSITY

Kepler's 3rd Law

Law of Periods: The square of the period is related to the cube of the semi-major axis of the orbit.



http://hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

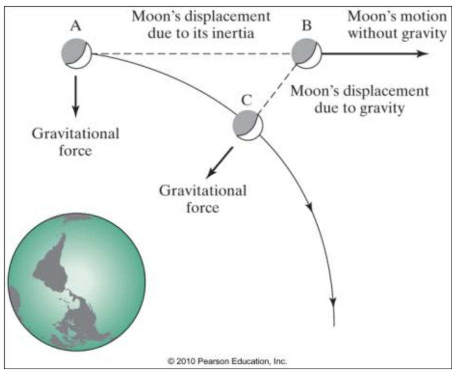
MICHIGAN STATE UNIVERSITY

Make Headway……

- How does this align with ideas of motion?

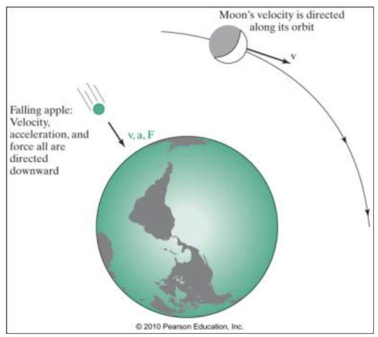
MICHIGAN STATE UNIVERSITY

Decartes: the inertial view

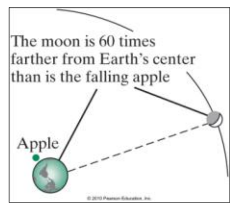


MICHIGAN STATE UNIVERSITY

Newton's brilliant thought



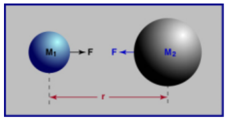
The force on the apple is of the same type as the force on the moon.



Newton and the Universal Law of Gravity

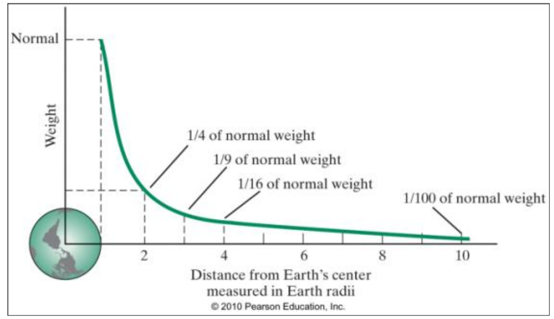
- Gravity extends from the Earth to the moon!
- Newton's Universal Law of Gravity:

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E-11\, {Nm^2}/{kg^2}$$



- Explains all observations of planetary motion, including Kepler's three laws!!

Newton's Gravitational Law



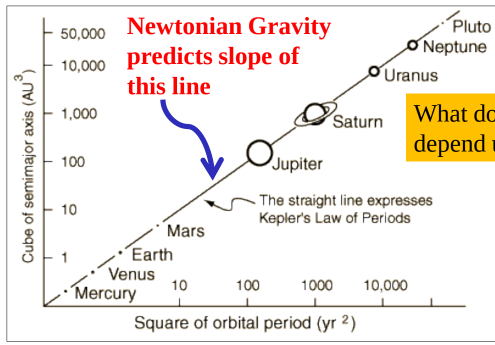
Newton Explains Kepler's Laws

- Explains all observations of planetary motion. **<u>One equation unifies three laws!</u>**

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E-11\, {Nm^2}/{kg^2}$$

- Elliptical orbits
- The stronger force means more acceleration when the planet is closer to the star
- A larger distance means less force and a longer time for the orbit

Kepler's 3rd Law



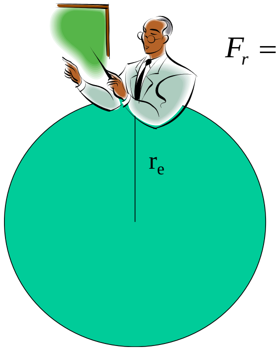
What does prediction depend upon?

http://hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

MICHIGAN STATE UNIVERSITY

The Law of Gravity

What is the force of gravity on a 90 kg professor standing on the surface of the Earth?



$$F_r = \frac{Gm_1 m_2}{r^2}; G = 6.673E-11 \, {Nm^2}/{kg^2}$$

Data: r_{earth} = 6.378E+6 m,
m_{earth} = 5.974E+24 kg

MICHIGAN STATE UNIVERSITY

The Law of Gravity

What is the force of gravity on a 90 kg professor standing on the surface of the Earth?

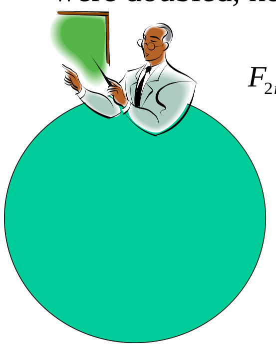
$$F_r = \frac{Gm_p m_e}{r_e^2} = \frac{\left(6.673E-11 \, {Nm^2}/{kg^2}\right) 90kg \times 5.974E24 \, kg}{(6.378E6 \, m)^2} = 882 \, N$$

Data: r_{earth} = 6.378E+6 m, m_{earth} = 5.974E+24 kg

MICHIGAN STATE UNIVERSITY

Example using the Law of Gravity

- What would happen if the mass of the Earth were doubled, keeping the same radius?



$$F_{2r} = \frac{G(2m_e)m_p}{(r_e)^2} = 2\frac{Gm_e m_p}{(r_e)^2} = 2 \times F_r$$

MICHIGAN STATE UNIVERSITY

Example using the Law of Gravity

- What would happen if the radius of the Earth were doubled, but the mass was the same?

$$F_{2r} = \frac{Gm_e m_p}{(2r_e)^2} = \frac{Gm_e m_p}{4(r_e)^2} = \frac{1}{4} \times F_r$$

MICHIGAN STATE UNIVERSITY

The Law of Gravity

What is the force of gravity on a 90 kg professor standing on the surface of the Earth?

$$F = \frac{Gm_p m_e}{r_e^2} = \frac{\left(6.673E-11 \, {Nm^2}/{kg^2}\right) 90kg \times 5.974E24\,kg}{(6.378E6\,m)^2} = 882\,N$$

Data: r_{earth} = 6.378E+6 m, m_{earth} = 5.974E+24 kg

The professor exerts the same 882 N force on the earth. That is Newton's third law.

*Recall, the force of gravity on the professor is called his **Weight***

MICHIGAN STATE UNIVERSITY

Weight and Gravity

Wait a second! We also defined the object's weight on the surface of the earth by:

$F_{gravity} = w = mg$ (where g = 9.8 m/s²)

But in the previous problem we used a different equation!

$$F_{gravity} = \frac{G\,m_e\,m}{r_e^2} = \left(\frac{G\,m_e}{r_e^2}\right) m = mg$$

Nothing tricky. Plug in values for Gm_e/r_e^2 gives 9.8 m/s²

ISP209 Lecture 4

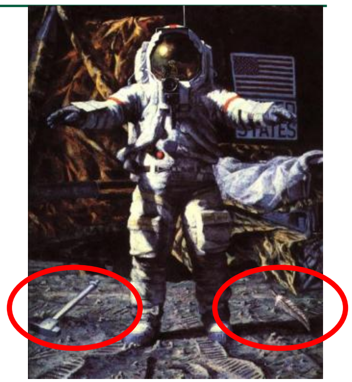
MICHIGAN STATE UNIVERSITY

Acceleration and gravity

- $F_{Gravity}$ = mg (mass & radius of Earth are inside the g)
- Also $F_{Gravity} = ma_{gravity}$ by Newton's 2nd Law. Therefore, neglecting other forces like air resistance

  $mg = ma_{gravity}$

- Note how the "m" cancels out, ie. $a_{gravity} = g$
- **Same is true on Moon!!!**



ISP209 Lecture 4

http://history.nasa.gov/SP-4214/cover.html

MICHIGAN STATE UNIVERSITY

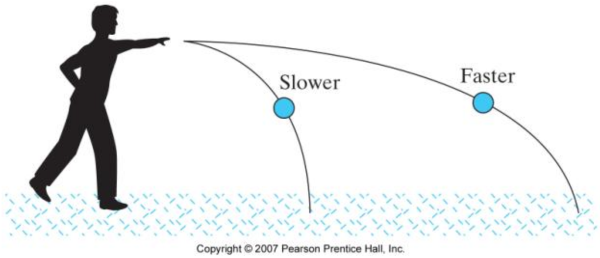
How strong is gravity

- If all objects with mass have gravity, why don't all objects in the class room clump together?
- If I release two tennis balls, why don't they accelerate toward each other?
- How can we beat Earth's gravity?

ISP209 Lecture 4

MICHIGAN STATE UNIVERSITY

Orbital Motion

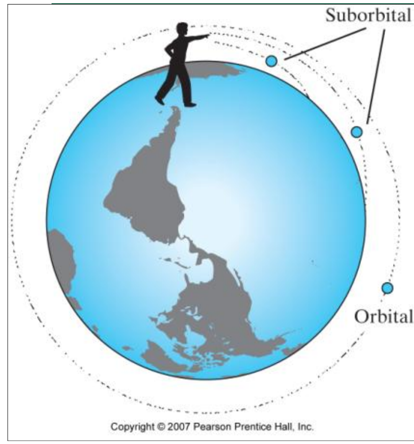


If you throw a ball faster, it has a longer trajectory
(I.e., it goes further before gravity brings it to the ground)

Claim: ball orbits the earth if you throw it fast enough

MICHIGAN STATE UNIVERSITY

What happens if you go too fast?



Escape from Earth's influence!

For earth, this critical velocity is 11 km/s (25000 mph)

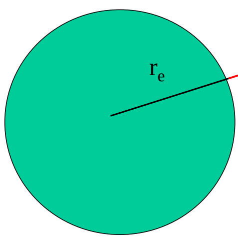
1) Escape velocity increases with the planet's mass

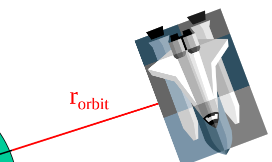
2) Nothing can go faster than Velocity of light c.
So what happens for a sufficiently massive body?

MICHIGAN STATE UNIVERSITY

Force of gravity on an astronaut

What is the force if the 90 kg professor is in the space shuttle at 300 km above the Earth?





Same as before, but now we use
$R = r_{earth} + r_{orbit}$ in the eqn. where

r_{orbit} = distance above earth

MICHIGAN STATE UNIVERSITY

Force of gravity on an astronaut

What is the force if the 90 kg professor is in the space shuttle at 300 km above the Earth?

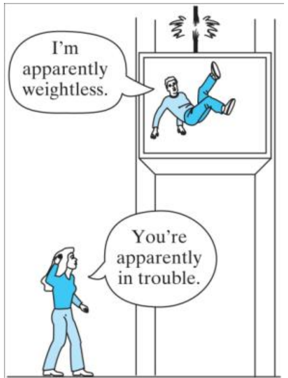
$$300km = 300km \times \frac{1000m}{km} = 3.00E5\,m$$

$$F = \frac{Gm_e m_p}{r_e^2} = \frac{\left(6.673E-11\,{}^{Nm^2}\!/_{kg^2}\right)90kg \times 5.974E24\,kg}{(6.378E6\,m + 3.00E5\,m)^2} = 804\,N$$

r_e + r_{orbit}

Weird! Why are the astronauts in satellites "floating" if their Weight is not zero?

Why are astronauts floating?



Copyright © 2007 Pearson Prentice Hall, Inc.

Astronauts orbiting the earth are actually free-fall like. Just as this poor fellow in the falling elevator!

In both cases, you would "feel" weightless, but gravity is still acting on you (and "weight" is defined as the Gravitational force acting on you).

Newtonian View of the Universe

- The Mechanical Universe or "**Everything is Predictable**"
- Suppose we know the positions and velocities of every atom in the universe at some instant
- According to Newton's laws of motion, the future behavior of the universe can be exactly predicted **for all time**.

Nature was thought to be 100% understood

From 1894:
"The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote.... **Our future discoveries must be looked for in the sixth place of decimals**." - Albert. A. Michelson, speech at the dedication of Ryerson Physics Lab, U. of Chicago 1894

From 1900:
"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement" - Lord Kelvin

The Quantum and Relativistic Revolutions

- Just when many thought there was nothing else to discover thanks to Newton's theories…
- Evidence starts to emerge that Newtonian Physics fails in certain situations:

  1) High Speeds (Special Relativity)
  2) Tiny distances (Quantum Physics)
  3) Huge distances (Cosmology)
  4) Huge masses (General Relativity)

- The Newtonian Universe is only an approximation. Reality is **much** stranger as we will see…