Physics 1408-002
Principles of Physics

Lecture 10
– Chapter 6 –
February 12, 2008

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Announcement I

Lecture note is on the web
Handout (6 slides/page)
http://highenergy.phys.ttu.edu/~slee/1408/

*** Class attendance is strongly encouraged and will be taken randomly. Also it will be used for extra credits.

HW Assignment #4 is placed on MateringPHYSICS, and is due by 11:59pm on Wendseday, 2/18

Announcement II

SI session by
Reginald Tuvilla

SI sessions will be at the following times and location.

No SI session on Thursday
Next one: Monday 4:30 - 6:00pm - Holden

Chapter 6

Gravitation & Newton's Synthesis

1. Newton's Law of Universal Gravitation
2. Gravity Near the Earth's Surface; Geophysical Applications
3. Satellites and "Weightlessness"
4. Kepler's Laws and Newton's Synthesis
5. Types of Forces in Nature

Newton's Law of Universal Gravitation

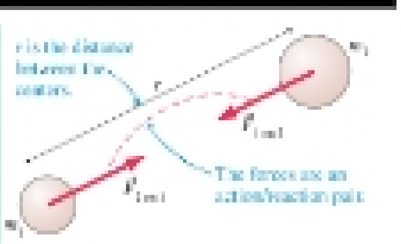
Newton proposed that every object in the universe attracts every other object with a force that has the following properties:

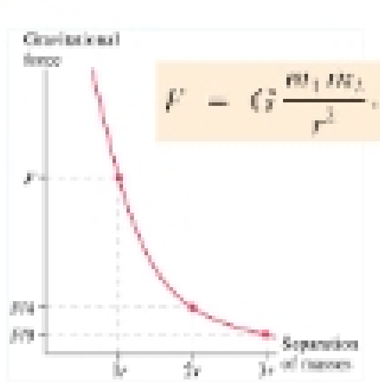
1. The force is inversely proportional to the distance between the objects.
2. The force is directly proportional to the product of the masses of the two objects.

$$F_{1\ on\ 2} = F_{2\ on\ 1} = G\frac{m_1 m_2}{r^2}$$

$$G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}.$$

[Universal gravitational constant]





$$F = G\frac{m_1 m_2}{r^2}.$$

Moon's Acceleration

- Newton looked at proportionality of accelerations between the Moon and objects on the Earth
  i.e. F ≈ acceleration ≈ $(1/\text{distance})^2$

$$\frac{a_M}{g} = \frac{\left(\frac{1}{r_M}\right)^2}{\left(\frac{1}{R_E}\right)^2} = \left(\frac{R_E}{r_M}\right)^2$$

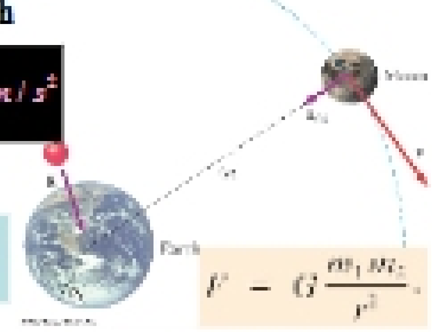
Centripetal Acceleration

- The Moon experiences a centripetal acceleration as it orbits the Earth

$$a_M = \frac{v^2}{r_M} = r_M\omega^2 = \frac{4\pi^2 r_M}{T^2} = 2.72 \times 10^{-3}\ m/s^2$$

We know that $r_M = 60\ R_E$

Universal gravitation predicts
$a_M = g(R_E/r_M)^2 = g/3600 = 2.7\text{e-}3\ m/s^2$



$$F = G\frac{m_1 m_2}{r^2}.$$

Surface Gravity

- Near the Earth's surface, the distance to the center of the earth is roughly constant for heights h which is small compared to the radius of the earth:

$$|F_g| = G\frac{M_E m}{R_E^2} = m\left(G\frac{M_E}{R_E^2}\right)$$

$= g$

Experimentally, this is just as observed: $|F_g| = mg = ma$

- $a = g$

$$g = G\frac{M_E}{R_E^2} = 9.81\ m/s^2$$

- If an object is some distance h above the Earth's surface, R_E becomes $R_E + h$

$$g = \frac{GM_E}{(R_E + h)^2}$$

Variation of g with Height

$$g = \frac{GM_E}{(R_E + h)^2}$$

Altitude h (km)	g (m/s²)
1 000	7.33
2 000	5.68
3 000	4.53
4 000	3.70
5 000	3.08
6 000	2.60
7 000	2.23
8 000	1.93
9 000	1.69
10 000	1.49
50 000	0.13
∞	0

TABLE 6–1
Acceleration Due to Gravity at Various Locations on Earth

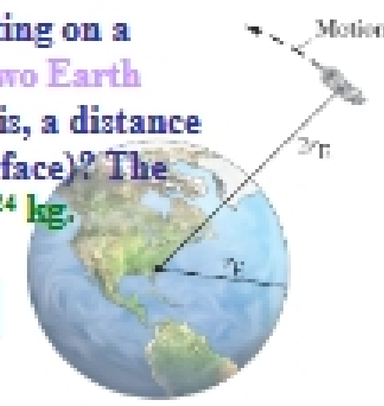
Location	Elevation (m)	g (m/s²)
New York	0	9.803
San Francisco	0	9.800
Denver	1650	9.796
Pikes Peak	4300	9.789
Sydney, Australia	0	9.798
Equator	0	9.780
North Pole (calculated)	0	9.832

The acceleration due to gravity varies over the Earth's surface due to altitude, local geology, and the shape of the Earth

6-4 Satellites and "Weightlessness"

(a) An object in an elevator at rest exerts a force on a spring scale equal to its weight; F = w-mg = 0, w=mg
(b) In an elevator accelerating upward at ½ g, the object's apparent weight is 1 ½ times larger than its true weight;
F = w – mg = ma, w = mg + ma, w=3/2g, where a = ½ g
(a) In a freely falling (a=-g) elevator, the object experiences "weightlessness": the scale reads zero;
w = mg + ma = mg + m(-g) = 0

What is the force of gravity, F_G, acting on a 2000-kg spacecraft when it orbits two Earth radii from the Earth's center (that is, a distance r_E = 6380 km above the Earth's surface)? The mass of the Earth is $m_E = 5.98 \times 10^{24}$ kg.

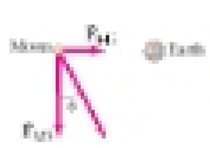


F ≈ acceleration ≈ (1/distance)²

APPROACH We could plug all the numbers into Eq. 6–1, but there is a simpler approach. The spacecraft is twice as far from the Earth's center as when it is at the surface of the Earth. Therefore, since the force of gravity decreases as the square of the distance (and $\frac{1}{2^2} = \frac{1}{4}$), the force of gravity on the satellite will be only one-fourth its weight at the Earth's surface.

SOLUTION At the surface of the Earth, $F_G = mg$. At a distance from the Earth's center of $2r_E$, F_G is $\frac{1}{4}$ as great:

$$F_G = \tfrac{1}{4}mg = \tfrac{1}{4}(2000\,\text{kg})(9.80\,\text{m/s}^2) = 4900\,\text{N}.$$



Find the net force on the Moon ($m_M = 7.35 \times 10^{22}$ kg) due to the gravitational attraction of both the Earth ($m_E = 5.98 \times 10^{24}$ kg) and the Sun ($m_S = 1.99 \times 10^{30}$ kg)

The Earth is 3.84×10^5 km $= 3.84 \times 10^8$ m from the Moon, so F_{ME} (the gravitational force on the Moon due to the Earth) is

$$F_{ME} = \frac{(6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(7.35 \times 10^{22}\,\text{kg})(5.98 \times 10^{24}\,\text{kg})}{(3.84 \times 10^8\,\text{m})^2} = 1.99 \times 10^{20}\,\text{N}.$$

The Sun is 1.50×10^8 km from the Earth and the Moon, so F_{MS} (the gravitational force on the Moon due to the Sun) is

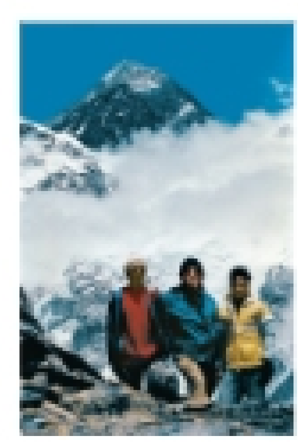
$$F_{MS} = \frac{(6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(7.35 \times 10^{22}\,\text{kg})(1.99 \times 10^{30}\,\text{kg})}{(1.50 \times 10^{11}\,\text{m})^2} = 4.34 \times 10^{20}\,\text{N}.$$

The two forces act at right angles in the case we are considering (Fig. 6–5), so we can apply the Pythagorean theorem to find the magnitude of the total force:

$$F = \sqrt{(1.99 \times 10^{20}\,\text{N})^2 + (4.34 \times 10^{20}\,\text{N})^2} = 4.77 \times 10^{20}\,\text{N}.$$

The force acts at an angle θ (Fig. 6–5) given by $\theta = \tan^{-1}(1.99/4.34) = 24.6°$.

Estimate the effective value of g on the top of Mt. Everest, 8850 m (29,035 ft) above sea level. That is, what is the acceleration due to gravity of objects allowed to fall freely at this altitude?



$$g = G\frac{m_E}{r_E^2}.$$

SOLUTION We use Eq. 6–4, with r_E replaced by $r = 6380\,\text{km} + 8.9\,\text{km} = 6389\,\text{km} = 6.389 \times 10^6$ m:

$$g = G\frac{m_E}{r^2} = \frac{(6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(5.98 \times 10^{24}\,\text{kg})}{(6.389 \times 10^6\,\text{m})^2}$$

$$= 9.77\,\text{m/s}^2,$$

which is a reduction of about 3 parts in a thousand (0.3%).

A Little History

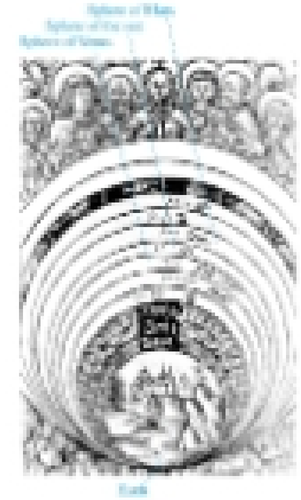
The Pre-History of Gravitation

The study of the structure of the universe is called cosmology.

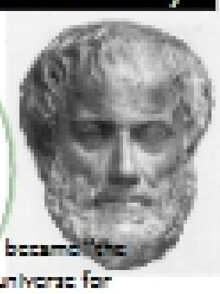
The ancient Greeks developed a cosmological model (see the picture) that placed the earth at the center of the universe.

The ancients observed that the stars were "fixed", while the planets moved against the background of fixed stars.

They were very interested in the stars because the movements of the stars were correlated with the seasons, growing cycles, etc.



Aristotle (384 BC - 322 BC)



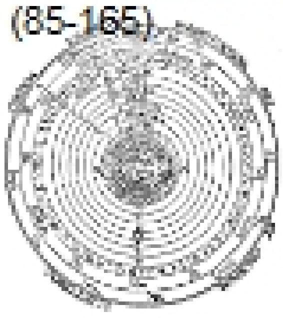
earth was at the center of a nested set of transparent spheres, with the fixed stars on the outer sphere and the planets

Nicolaus Copernicus (1473-1543)

argued that the Sun was the center of the universe, and that the Earth was one of the planets revolved about it in circular orbits.

Ptolemy's cosmology became "the Standard Model", of the universe for ...

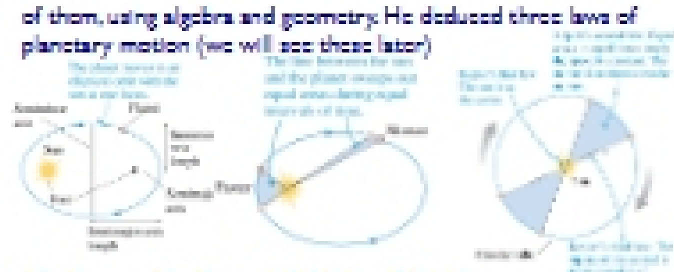
Claudius Ptolemy (85-165)



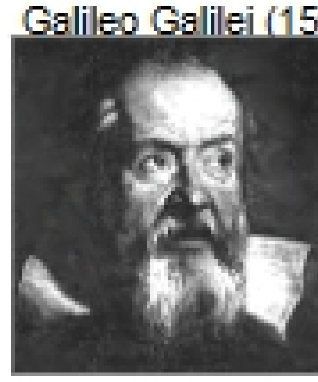
From 1570 to 1600, Danish astronomer Tycho Brahe compiled a set of extremely accurate astronomical observations.

Johannes Kepler (1571-1630)

Kepler inherited Tycho's observations and tried to make sense of them, using algebra and geometry. He deduced three laws of planetary motion (we will see these later)

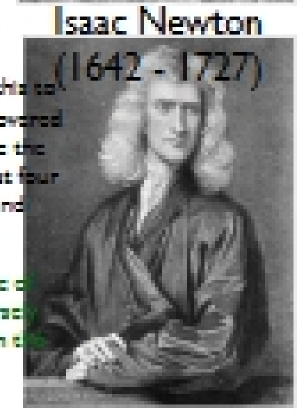


Galileo Galilei (1564 -1642)



He discovered the telescope, used this to view the stars and planets. He discovered that the planet Venus has phases, like the Moon, that Saturn had rings, and that four tiny points of light can be seen around Jupiter.

Isaac Newton (1642 - 1727)

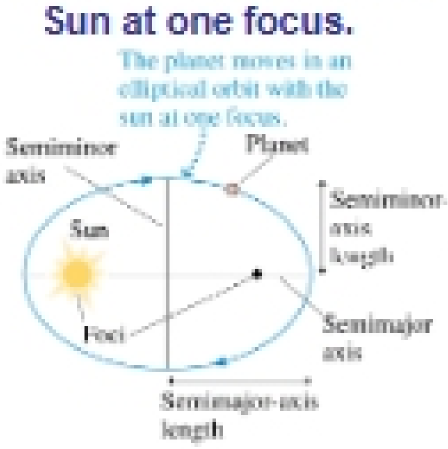


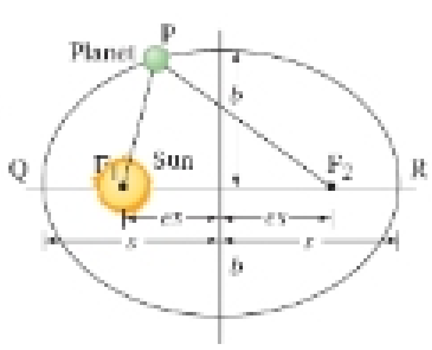
Newton hypothesized that the force of gravity acting on the planets is inversely proportional to their distances from the Sun.

6-5 Kepler's Laws and Newton's Synthesis

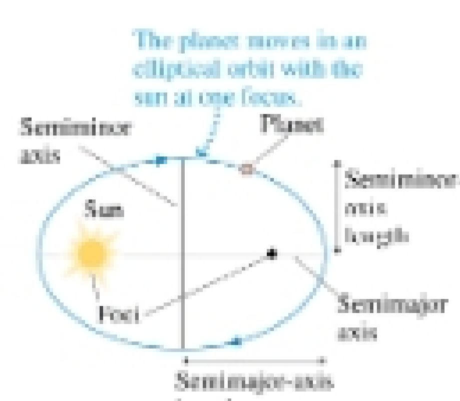
Kepler's laws describe planetary motion.

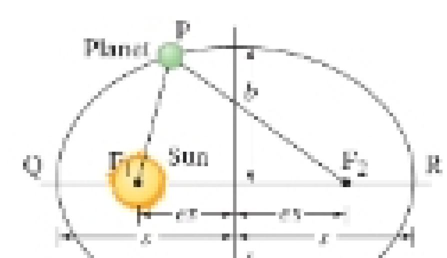
1. The orbit of each planet is an ellipse, with the Sun at one focus.





6-5 Kepler's Laws and Newton's Synthesis





An ellipse is a closed curve such that the sum of the distances from any point P on the curve to two fixed points (called the foci, F_1 and F_2) remains constant. That is, the sum of the distances, $F_1P + F_2P$, is the same for all points on the curve.