

Chapter 4: Newton's Law of Universal Gravitation

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Newton Discovers Gravity

4.1. Law of Universal Gravitation

- Newton decided that the force of gravity on earth must also extend to the heavens
- Newton applied his three Laws to the moon and the planets
- He decided that all such motion could be accounted for with a centrally directed force, gravity

The moon's
path is bent
into a circle
by gravity

- Newton decided that gravity must fall off with distance, but how fast?
- Based on observations of the moon's orbit, Newton determined that gravity dropped off as the inverse square of the distance from the earth
- Since more massive things on earth had more weight, the

gravitational force must also be proportional to mass

The earth's
gravity drops
off with distance

- So: $F \sim M_1 M_2 / d^2$
- Newton confirmed this by showing that it predicted Kepler's Three Laws of planetary motion

4.2. The Universal Gravitational Constant, G

- $F = G M_1 M_2 / d^2$
- $G = 6.67(2) \times 10^{-11} \text{ Nm}^2/\text{kg}^2$
G is very small and hard to measure
- The Cavendish experiment in 1798 measured G

The
Cavendish
Experiment

- $F = G M_e m / r_e^2$
 $F = (GM_e / r_e^2) m$
 $= (9.8 \text{ m/s}^2) m = gm$

where $M_e = 5.98 \times 10^{24} \text{ kg}$
and
 $r_e = 6.37 \times 10^6 \text{ m}$

4.3. Gravity and Distance

The Inverse Square Law

- $F = G M_e m / d^2$
where M_e is the earth's mass
- At $d = 2 r_e$ (2 earth radii)

$F = mg/4$ (one-fourth of
the normal weight)

The Inverse Square Law

Gravity Falls With Distance

- There are variations with height and mountains
- Mass con(centrations)
- Continental crust is lighter
- Force Fields - E&M, gravity, etc.

Distance is
measured from
the Center
of the Earth

4.4. Weight and Weightlessness

- Elevator: $F_N = mg + ma$
- Weight in space
- Normal force is apparent weight

- Weightlessness Bone/muscle loss
- Rotating Space Station
- Centrifuge/astronaut training
- High-g effects and stunt pilots
- Negative-g effects

4.5. Tides

- Are caused by the difference in gravitational force from the moon and the sun
- The tidal bulges are permanent
- The earth rotates "beneath" them causing two tides per day
- The sun has about half the effect of the moon

The Oceans Stretch a Little Bit Due to the Gravitational Force

- The moon has a 24 hour and 50 minute periodicity
- The tidal effect raises the water level about 1 meter up and down
- Spring tides occur when the sun, moon, and earth are in a line

- Neap tides occur when the sun and moon are at right angles with respect to the earth
- The tidal force obeys an inverse cube force law
- Not in smaller bodies of water (lakes, seas)
- The extreme tides around La Rance in Brittany, France power a 200 MW electrical power plant built in 1968

4.6. Universal Gravitation

- The mass of planets and stars can be found using Newton's Law of Universal Motion and astronomical observations
- In 1845 and 1846 J.C. Adams and Urbain Leverrier used the perturbations of Uranus to predict the location of a new planet, Neptune
- But the new planet was not found at the predicted distance from the sun
- Percival Lowell predicted the existence of the planet Pluto (discovered 1930) based on the perturbations of Neptune
- Pluto was discovered by Clyde Tombaugh
- Planets and stars are round; smaller rigid bodies are not always round