

Chapter 5: Gravity and Motion

Mechanics before Newton

Impetus Theory: motion requires force, an objects natural state is to be at rest.

Galileo, the experimenter

motion as a natural state, force is *required* to stop an objects motion.

rolling (not falling) objects [figure 5-1]

in the absence of other forces, all objects fall to earth at the same rate.

idealization of actual conditions (air resistance and friction)

René Descartes (~1600) French Philosopher

Inertial Motion: An object at rest remains at rest, an object in motion remains in motion at the same speed and in the same direction.

→ Straight line motion in the absence of a force.

Planetary Motion before Newton

Kepler: two forces, one to maintain motion along orbit, another to account for orbit's eccentricity.

Robert Hooke (~1650): planetary motion is inertial motion, requiring a central force (force towards center).[fig 5-3,4 demo]

Force acts between celestial bodies.

Force is also responsible for falling objects.

Isaac Newton (~1700)

worked in optics, discovered Universal Gravitation, invented differential and integral calculus

Principia

Laws of motion

The Law of Inertia: An object at rest will remain at rest or continue in motion at constant velocity unless acted upon by an unbalanced force.

velocity (v): speed and direction (a vector).

acceleration (a): the rate of change of velocity with time.

mass (m): the measure of inertia

momentum (p): the measure of motion

$$= \text{mass} \times \text{velocity} \quad (p = m v)$$

The Law of Force: When an unbalanced force acts on an object, it produces a change in the momentum of the object in the direction in which the force acts. [figure 5-5]

$$F = m a$$

$$v = \frac{\Delta x}{\Delta t} \quad \left| \quad a = \frac{\Delta v}{\Delta t} \quad \left| \quad F = \frac{\Delta p}{\Delta t} = m \frac{\Delta v}{\Delta t}$$

The Law of Action and Reaction: When one body exerts a force on a second body, the second body exerts a force equal in strength but opposite direction on the first. [figure 5-6]

Forces arise because of *interactions* between bodies.

Gravity

Centripetal Acceleration (acceleration towards the center of a circle)[figure 5-7, centripetal.avi]

Centripetal Force: (force directed towards the center of a circle)

Thought Experiment: Falling around the moon [fig 5-8][sim: newton's canon]

The Law of Gravitation:

$$F = G \frac{Mm}{d^2}$$

proportional to each mass

Force is larger for larger masses

inversely proportional to the square of the distance

(distance between centers for spherical objects) [fig 5-9]

Force is smaller for larger distances

Newton's Laws, and gravitation on the surface of the earth

Weight and mass $w = m \frac{GM_{earth}}{R^2} = mg$

weight is the gravitational force of the earth on the object.

acceleration of gravity $g = \frac{GM_{earth}}{R^2}$

force of gravity causes same acceleration for all masses

note: “weightlessness” in Earth orbit is not actually a correct description! Motion is actually freefall around the earth.

Implications of Newton's Mechanics and Universal Gravitation

Kepler's first Law: Elliptical Orbits, sun at focus

Kepler's second law: conservation of angular momentum

angular momentum(L) $L = mrv$ [demonstration]

momentum associated with rotation or revolution

Kepler's third law: $P^2 = \frac{4\pi^2 a^3}{G(m+M)}$

definite relation between masses, orbital distances

determine mass of star from orbiting planets!

determine mass of planet from orbiting satellites!

No improvements upon this theory of gravity until Einstein's
General Relativity

More on Mechanics

Orbital Energy and Speed

Kinetic energy: energy of motion

increases with increasing speed $(\frac{1}{2} m v^2)$

Potential energy: stored energy

associated with position

A circular orbit: object has constant orbital speed [figure 5-11]

$$v_c = \sqrt{GM/d}$$

orbital speed and distance tells mass of what is orbited!!!!

[orbital_velocity_intera.swf]

Escape Velocity: object has just enough speed to escape

$$v_e = \sqrt{\frac{2GM}{d}}$$

Four kinds of trajectories [figure 5-12, sim orbit_1]

Circle (bound to planet)

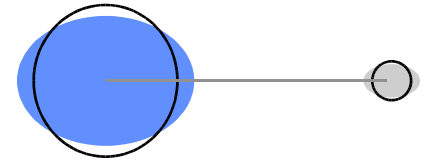
Ellipse (bound to planet)

Parabola (escapes)

Hyperbola (just escapes)

Tides

Tidal Forces: *differences* in gravity [figure 5-14,15,16]



Tides: distortions in shape resulting from tidal forces.

Solid earth tides ~ 20 cm

Ocean tides [figure 5-17]

Spring Tide:

Sun/Moon aligned
greatest tide

Neap Tide

Sun/Moon at right angles
weakest tide