Galileo and the physics of motion

Studies of motion important : planetary orbits, cannonball accuracy, basic physics. Galileo among first to make careful observations

- Looked at velocity, acceleration, effects of friction
- studies pendulums, use as clock
- rate at which objects fall do not depend on their mass (ignoring friction)
- found that acceleration of falling bodies is a constant

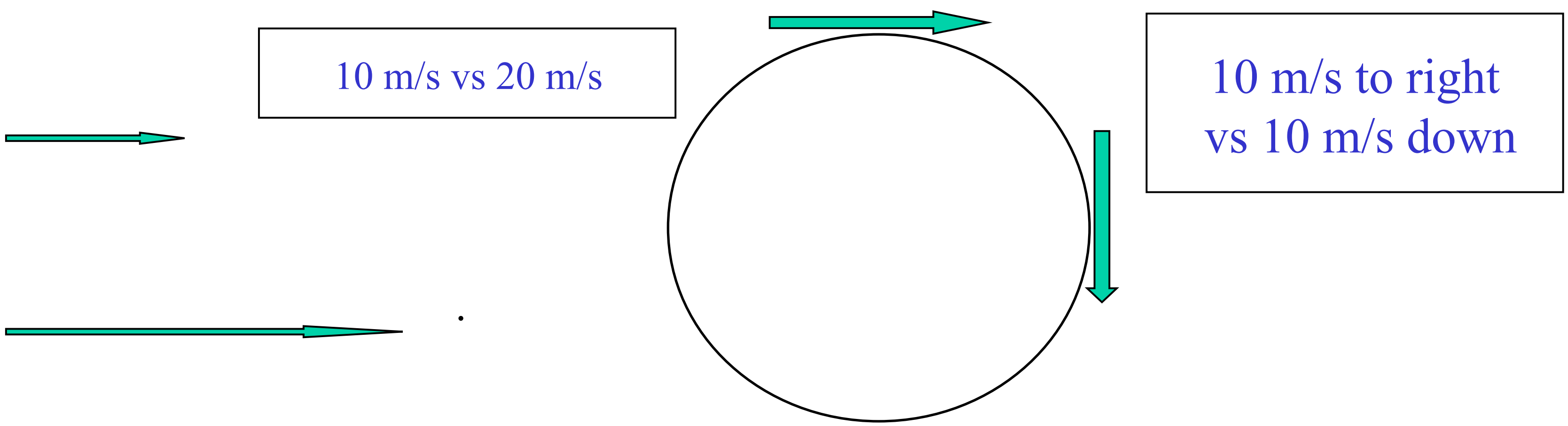
Galileo and Motion and Gravity

- Galileo and many of his contemporaries developed the concept of motion
  - velocity and acceleration
  - importance of friction
- Galileo used inclined planes
- and (perhaps) the Leaning Tower in Pisa

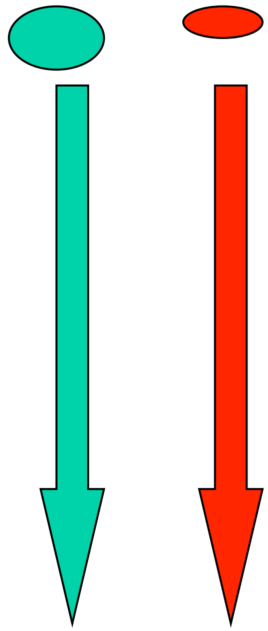
Motion: velocity and acceleration

MOTION: concepts

- acceleration = change in velocity either speed or direction.
  acc = dv/dt change in velocity per unit time
- Change in velocity depends on forces exerted. Cause acceleration. Gravity causes downward acceleration



Speed vs Mass vs Acceleration



Experiments done by Galileo and others showed that the heavier (green) ball and the lighter (red) ball hit the ground at the same time

Galileo also showed that the gravitational acceleration was a constant   32 ft/sec/sec

Theories based on experimental observations are best way to do science.

see http://nicadd.niu.edu/~hedin/Galileo.htm for a fake news story and some background on the history

Newton 1642-1727 : Motion and Gravity

MOTION: concepts

- Developed calculus and so provided mathematical tool to relate acceleration to velocity to position
- Developed 3 law's of motion to relate acceleration to the applied force
- Developed form for gravitational force

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Newton's Laws of Motion

1. A body continues at rest in uniform motion in a straight line unless a force is imposed on it. (Inertia)
2. Change of motion is proportional to the force and is made in the same direction.

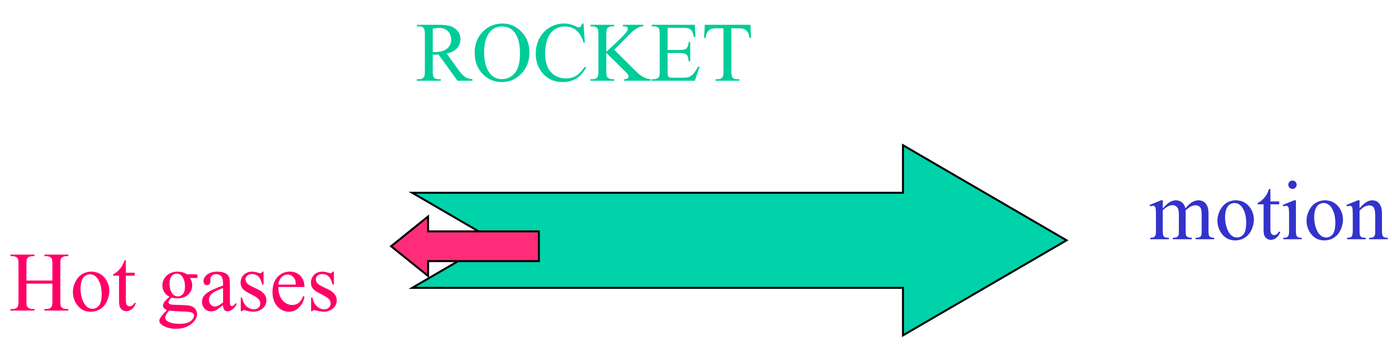
   F = ma Force = mass x acceleration

   acceleration= change in velocity per time

- If F=0 than a=0 and velocity (and direction) stay the same

Newton's Laws of Motion

3. To every action there is an equal and opposite reaction (action depends on mass and velocity and is related to momentum)



Newton's laws plus calculus allows motion to be determined if forces known

Forces in Nature

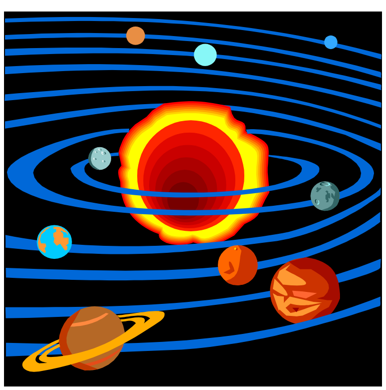
- Gravity
- Electromagnetism
- Strong Nuclear Force
- Weak Nuclear Force

Gravity

- The first force to be understood was gravity

•Newton used results from Galileo, Kepler and others on motion on Earth's surface and orbits of the planets

•Gave simple relationship for gravitational force between 2 objects separated by distance R

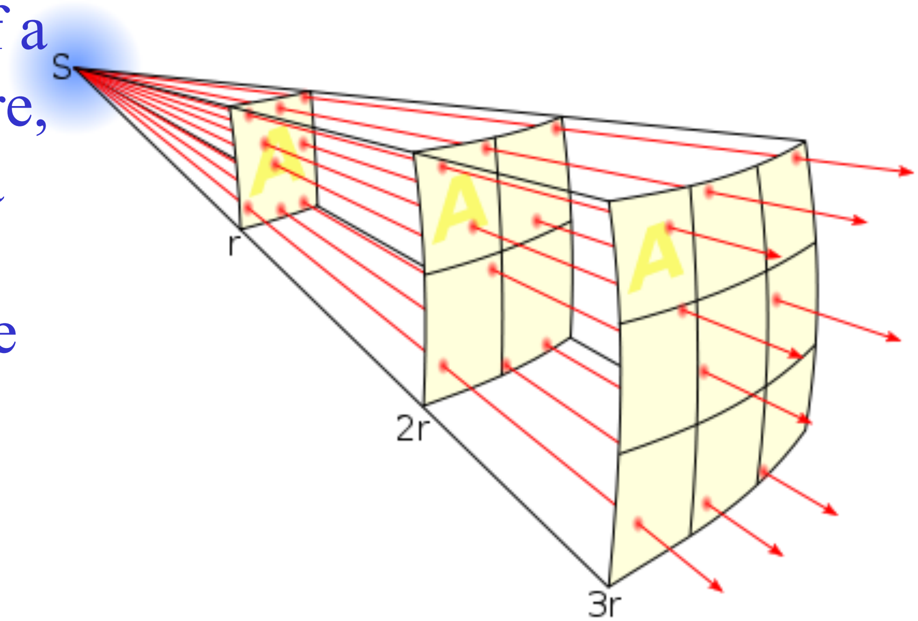


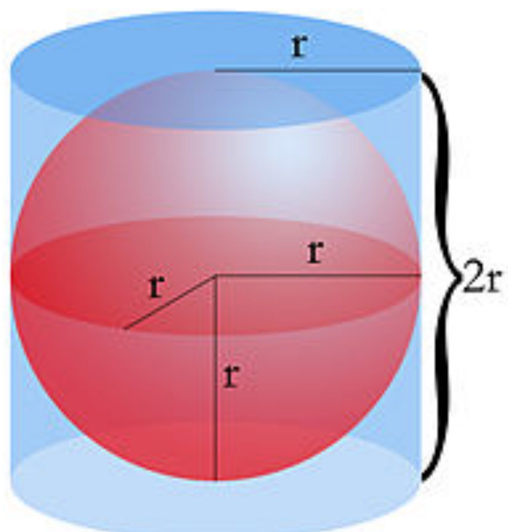
$$F = G\frac{mass_1 mass_2}{R^2}$$

Breaking down the Force….

- Space is homogeneous and isotropic implies that gravity emanates equally in all directions in 3 dimensional space ...

The surface of a sphere = $4\pi R^2$. If a source is at the center of the sphere, its flux is **spread out** over an area that is increasing in proportion to the square of the distance from the source.





The lines represent the flux emanating from the source. The total number of flux lines depends on the strength of the source and is constant with increasing distance.

Gravity (Newton)

- There is a force between any two bodies 1 and 2

$$F = G\, m_1 m_2/r^2$$

with m_1 and m_2 being the masses and r being the distance between 1 and 2

- Always attractive
- Depends on the masses of the two bodies
- Decreases as the distance increases
- Is the same force everywhere in the Universe
- Weakest force but dominates at large distances

Gravity Examples

- Body A on surface of Earth with mass m_A

  $$F_A = G\, m_A\, m_{Earth}/r^2_{Earth}$$

- If object B has a mass 10 times that of object A, the Force of gravity is 10 times larger on B
- But F = ma or acceleration = Force/mass so the acceleration due to gravity is $G\, m_{Earth} / r^2_{Earth}$
- Does not depend on mass so all objects have same acceleration (ala Galileo). Does depend on mass, radius of Earth
- G is universal constant

Surface Gravity

- Acceleration due to gravity at the surface of any planet is

$$g = G\ m_{planet}/r^2_{planet}$$

- different planets, different surface gravity
- Mars: mass = 0.11 mass(Earth) and radius = 0.53 radius(Earth)
- so g(mars) = $.11/.53^2$ g(Earth) or about 40% that of Earth
- Impacts escape velocity from given planet (or moon) and what type of atmosphere planets have

Planetary Orbits

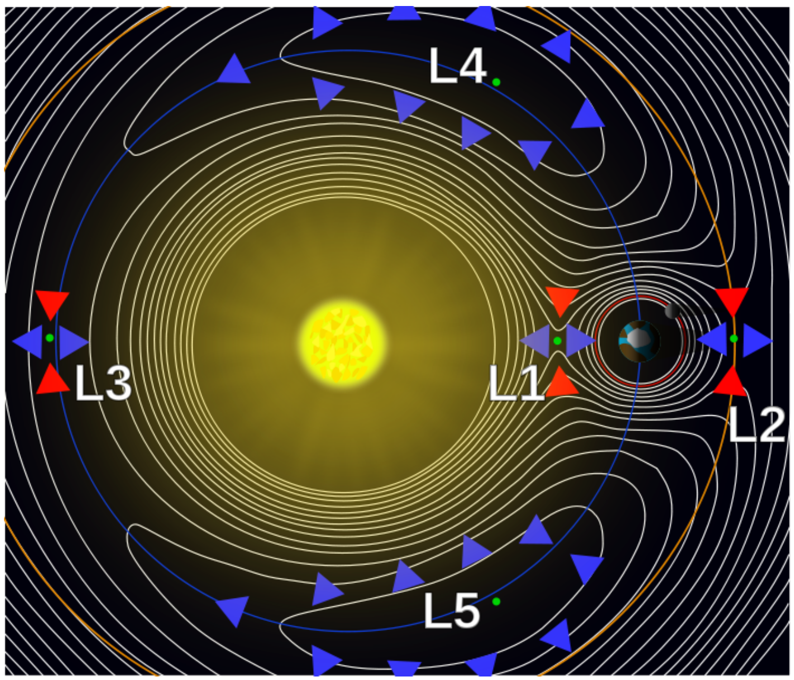
- Gravitational force between Sun and planets causes orbits with D being the planet's distance from the Sun

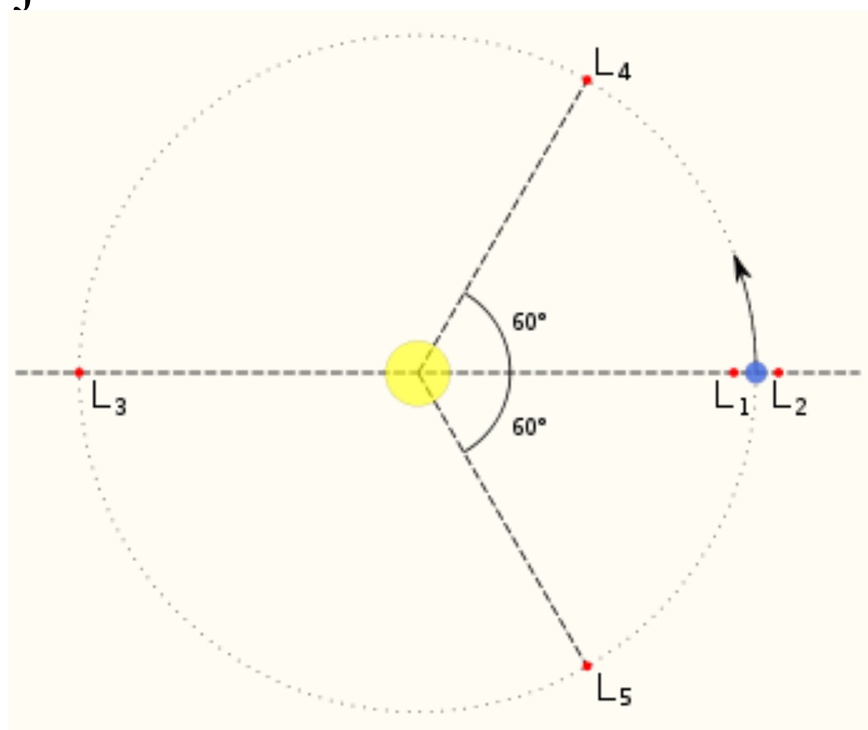
$$\text{Force} = G\, m_{Sun} m_{planet} / D^2_{orbit}$$

- as $a = F/m = G\, m_{Sun}/D^2$ does not depend on the planet's mass, all objects the same distance from the Sun will have the same orbits
- Also true for orbits around other objects (Earth, Jupiter) - means satellites around Earth can have similar orbits even if different masses

Orbits of other objects – Lagrange points

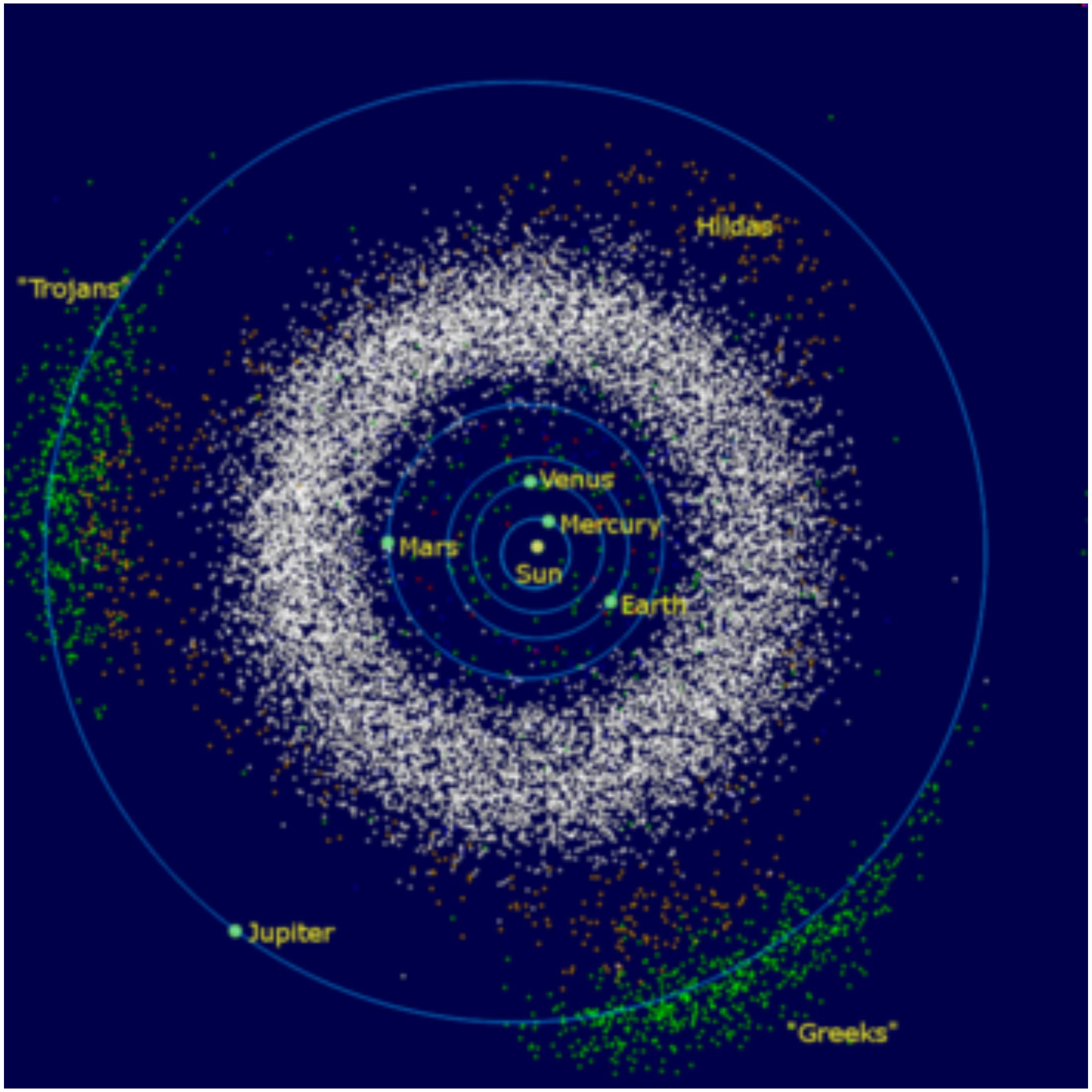
- Five positions in an orbital configuration where a small object affected only by gravity can theoretically be part of a constant-shape pattern with two larger objects





Only two points, L4 and L5 are stable – can capture asteroids

Trojan points of Jupiter



One asteroid found at Earth's Trojan point. See 162 webpage

Kepler's Laws

- Kepler's Laws can all be derived from Newton's laws of motion and force of gravity
- gravity causes elliptical orbits where planet moves faster when closer to the Sun as force of gravity is larger there
- Third Law actually

$$D^3 = (\text{Mass(sun) and Mass(earth)}) \times P^2$$

D=distance from Sun and P=period

- As mass Sun much larger can mostly ignore mass planet (but Sun does move slightly due to planet's pull)

Orbital Periods

- Study orbital periods → get masses
  - planets around Sun → Sun's mass
  - Jupiter's moons around Jupiter → Jupiter's mass
- Also used for stars (more on this later)
  - two nearby stars orbiting each other → their masses
  - an exoplanet orbiting a star will cause the star to wobble a bit → can give mass of exoplanet
- see some animations at (from wikipedia) http://nicadd.niu.edu/~macc/162/Center.html