Solar System Formation II:

I. Nebular Theory of solar system formation
   A. Solar system formed out of a large cloud of dust and gas
      1. Cloud comes from
         a. Primordial material - H & He
         b. Material ejected from stars
         c. Supernova material - heavy elements
      2. Assume roughly spherical
      3. Gravitationally bound
   B. Gravitational Collapse
      1. Conserved quantities during collapse?
      2. If cloud has no average angular momentum?
      3. A cloud with an average angular momentum conserves angular momentum
         \[ L_t = \sum_{\text{all particles}} m_i \vec{v}_i \times \vec{r}_i \]
      4. Positions and velocities are relative to the cloud center.
      5. \( L_t \) is absolutely conserved - as the diameter of the cloud, \( r \) shrinks, what has to expand?
      6. Collapsing, rotating sphere forms a disk because of collisions.
         a. When particles collide with other particles they both change orbit and/or break up.
         b. Particles in the same, circular orbit, traveling at the same speed will not collide.
         c. Particles collide until they happen into the disk then they stop colliding.
         d. Circular orbits also favored over elliptical.
   C. Condensation - forming larger particles
1. Proto-solar system was hot in the center and colder further out.
2. Different materials condense at different temperatures:
   a. Metals first ~1600K
   b. Rocks 500-1300K
   c. H compounds & water 150-250K
   d. He and H do not condense
      • The proto-nebula was mostly composed of H and He
      • Smaller amounts of other materials
      • The H and He originated mostly in the big bang
      • The heavier elements were created or spread in the explosions of large stars called super-nova explosions.

D. Model predictions
1. Inner planets (Terrestrial)
   a. Mercury highest concentrations of Metals (also rocky)
   b. Venus and Earth have a little less metal and more rock
   c. Mars is rockier than Earth
2. Asteroids in Asteroid belt are mostly rock and some ice
3. Outer Jovian planets
   a. Some metal and rocks but much more ice and H compounds.
   b. Satellites of gas giants are icy and rocky.
   c. Most H compounds are added through accretion rather than condensation.

E. Accretion
1. Bodies become large enough to gravitationally attract and bind matter.
2. Easy to bind rocks and metals - hard to bind gases
3. Gas molecules with a thermal velocity > the escape velocity, escape the atmosphere
4. Kinetic theory
   a. Atoms and molecules in a gas move at a range of velocities
   b. Show figure: 10.23

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c. Average Kinetic energy, $E_k$, of monotonic atom is

$$E_k = \frac{3}{2}kT$$

- $k = 1.38 \times 10^{-23}$ J/K, the Boltzmann constant
- $T =$ Temperature in Kelvin
- The 3/2 only works for monatomic gases.

d. Average kinetic energy is $\overline{\frac{1}{2}mv^2} = \frac{1}{2}m\overline{v^2}$ where

- $m$ is the molecular weight such as for $H = 1.7 \times 10^{-27}$ kg
- $\overline{v^2}$ is the average $v^2$ of all atoms of a single type.

e. Average speed of a gas molecule,

$$v_t = \sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{m}}$$

f. Example: Will Earth retain H gas?

$$v_t = \sqrt{\frac{3 \times 1.38E - 23 \text{ J/K} \times 280K}{1.67E - 27\text{kg}}} = 2,600m/s$$

g. What $v_{escape}$ 11km/s

h. Will Earth retain H gas over many years? No

i. To retain gas $s < V_{escape}/6$.

j. How about He gas?

5. Gas giants retain H and He because?

F. Clearing of the Nebula

1. Little interplanetary gas and dust remain today

2. Solar wind

   a. Outward pressure pushes unbound nebular material out.
   b. Young stars have stronger stellar wind than older stars.
   c. Observed in regions of star formation

3. Only planets and planetesimals such as asteroids and comets remain in large amounts.

G. That is the Nebular Theory
H. What aspects of the modern solar system are unaccounted for? Backward orbits of some moons and Venus, our huge moon...

II. Collisional modifications of the Solar System
   A. Most phenomena not accounted for by nebular theory appear to result from collisions
   B. Examples: Moons going clockwise
   C. Modern examples of collisions ??
      1. Show Arizona meteor crater
      2. Show moon & Mercury
      3. Meteors
         a. Small - sand size
         b. Monthly - m diameter
         c. Every 100 years 30 m diameter
         d. 100M years km+ diameter - disaster
      4. Shoemaker-Levy 9
   D. Early solar system
      1. Much more common
      2. Many of the craters of the moon date from more than 4 Gyears ago.
      3. Meteorites modify planets. How???
      4. Giant Impacts
         a. The moon
            • The moon is composed of material similar to the Earth's crust
            • Mars sized asteroid colliding with Earth
            • Proto-moon ejected from proto-Earth
            • Volatiles boil off Proto-moon
            • Model fits information about composition of moon well
      5. Captured moons
         a. Difficult - must loose momentum & energy
         b. What can slow a planetesimal?
c. Counter rotating moons around Jupiter & Neptune

d. Mars' moons Phobos & Deimos probably are captured
   (show pix)

6. Mercury - high metal content and non-ecliptic orbit

7. Venus - counter rotates

8. Rotational axis of planets not aligned with ecliptic

E. Impacts used to fill holes in nebular theory.