I. Origin of the Earth: The Nebular Hypothesis

A. Initial
   1. Nebula or Cloud of matter (from supernova of pre-existing star)
   2. Containing all 92 elements created during earlier supernovas
   3. Heterogeneous distribution (non-random)
   4. Spinning

B. Forces acting to form the solar system
   1. Gravitational attraction \( f = G \frac{M_1 M_2}{r^2} \) (Newton’s law of gravitational attraction)
   2. Internal Pressure (gas in a balloon) acting to support system
   3. ‘Centrifugal Force’ acting away from the center results from spinning around center.
   4. Result:
      a. Resultant vector down to plane and in to center
      b. Collapse to rotating disc begins

C. Formation of Proto-Sun & Accretion of the Planets
   1. Sun
      a. Mater/particles in center of disk collide and slow (loose angular momentum, thus loss of centrifugal vector)
      b. Condenses to a sphere, compresses and begins to heat-up and radiate
      c. Continues heating until > 10^6 °K, where nuclear reactions or ‘hydrogen burning’ begin and ‘a star is born’.
         i. Very hot at center (Sun)
         ii. Is it hot at distant edges?
      d. Produces thermal gradient.
   2. Accretion of the terrestrial planets simultaneous with sun
      - Mercury, Venus, Earth, Mars, (asteroid belt)
      a. Continued collisions create planetesimals -> embryos -> planets
b. Only refractory elements (i.e. no H for water) were solid at these temperatures (recall thermal gradient), so only they could condense to form the ‘rocky’ or terrestrial planets.
c. solar wind (H and He from sun) ‘blows’ away light elements

3. Accretion of the Giant planets (Jupiter, Saturn, Uranus, Neptune)
   a. Larger: Giant planets are larger & can retain light elements (H, He etc.)
   b. Cooler: The region the giants formed in is further from the sun and thus cooler.
      Therefore, gasses didn’t move as fast and could be retained.
      - Cool enough for H$_2$O and CH$_4$ to form solids and condense easier.
   c. ‘light’ solar wind, so light elements not ‘blown’ away
d. Result: large, gas-rich (low density) planets

III. Origin of Earth-Moon System
   A. Early stage of Earth: Planetesimals condense to Form Earth.
      1. Bulk composition:
         a. Recall: solar wind blew light elements away from terrestrial planetesimals
         b. Thus, heavier elements form Earth (and terrestrial planets)
            - Fe – 35%, O – 30%, Si – 15%, Mg – 10%, remaining 10% all 88 other elements.
      2. Collisions between Embryos & Planetesimals
         a. Collisions release heat (kinetic energy liberated as heat = 1/2mV$^2$).
            - ENOUGH HEAT TO MELT!
         c. Additional heat from condensation of the planetesimal (compression heating) and decay of short-lived radioactive elements.
      3. Magma Ocean
         a. Earth is partly molten from heat due to 2 above
         b. Chilled crust due to heat loss at surface.
         e. Stratified Earth results
            i. Fe-core from drips of immiscible liquid Fe
            ii. Si-Fe, Mg Mantle immiscible liquid
            iii. Si-oxygen crust.
B. Formation of the Moon

1. Characteristics of the Moon.
   - \( r = 1738 \text{km} \), mass \( \sim 1.2\% \) of Earth, age = 4.4 b.y.

2. Formation Hypotheses: Giant impact origin
   a. Initially a segregated planetesimal with magma ocean, like earth but smaller.
   b. Glancing impact with earth.
   c. Core sucked back into earth, splashed moon and earth mantle condenses to moon.

III. Earth’s structure results from this segregation:

A. Crust:
   1. Continental
      a. 35km, under mountains <75 km,
      b. felsic (Si-rich) to mafic (Fe-Mg rich)
   2. Oceanic
      a. < 10 km
      b. Mafic to Ultramafic (very rich in Mg-Fe)

B. Mantle = most of earth’s volume
   1. \( \sim 3000 \) km thick
   2. Ultramafic

C. Core Fe-Ni-S
   1. \( \sim 3,370 \) km thick
   2. Inner solid (6370 - ~5000)
   3. outer liquid (~5000 to 2,900) – circulation here produces Earth’s magnetic field!

D. Earth’s Rheologic or mechanical Layers: defined by mechanical behavior (Strength)
   1. Lithosphere – brittle (flexural rigidity)
      a. contains crust and upper part of mantle
      b. 0-100 km (oceans) 0-150 km under continents
   2. Asthenosphere
      a. plastic at about 1280°C
      b. Base (arbitrarily) set at base of transition zone (700 km)
   3. Mesosphere extends to outer core
   4. Outer Core and inner core