Chapter 2:- Solar System

The solar system consists of the Sun; the eight official planets, at least three "dwarf planets", more than 130 satellites of the planets, a large number of small bodies (the comets and asteroids), and the interplanetary medium. (There are probably also many more planetary satellites that have not yet been discovered.)

- The inner solar system contains the **Sun, Mercury, Venus, Earth** and **Mars**.
- The planets of the outer solar system are **Jupiter**, **Saturn**, **Uranus**, and **Neptune** (**Pluto** is now classified as a dwarf planet).

The main asteroid belt lies between the orbits of **Mars** and **Jupiter**.

The first thing to notice is that the solar system is mostly empty space. The planets are very small compared to the space between them.

The orbits of the planets are ellipses with the Sun at one focus, though all except Mercury are very nearly circular. The orbits of the planets are all more or less in the same plane (called the ecliptic and defined by the plane of the Earth's orbit). The ecliptic is inclined only 7 degrees from the plane of the Sun's equator. They all orbit in the same direction (counter-clockwise looking down from above the Sun's North Pole).

The eight bodies officially categorized as planets are often further classified by:

- Composition:
  - Terrestrial or rocky planets: ***Mercury***, ***Earth***, and ***Mars***.
  - Jovian or gas planets: ***Jupiter***, ***Saturn***, ***Uranus***, and ***Neptune***.
- Size:
  - Small planets: ***Mercury***, ***Venus, Earth, Mars***. (have diameters less than 13000 km).
  - Giant planets: ***Jupiter***, ***Saturn, Uranus*** and ***Neptune***. (have diameters greater than 48000 km).
- by position relative to Earth:
  - Inferior planets: ***Mercury*** and ***Venus***.
  - ***Earth***.
  - Superior planets: ***Mars, Jupiter, Saturn, Uranus*** and ***Neptune***.

❖ *The Sun*:-

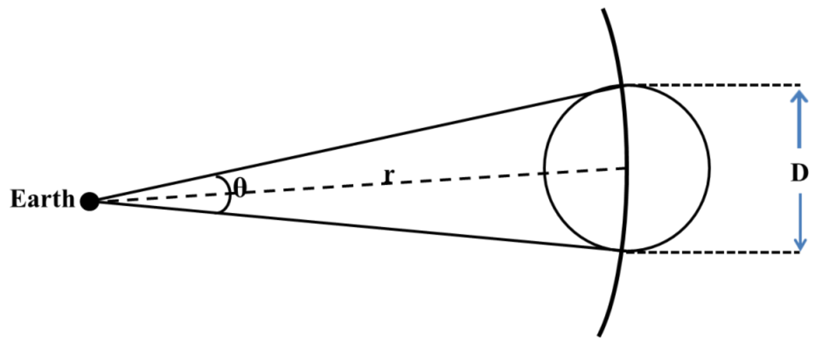
Our Sun is a normal main-sequence G2 star, one of more than 100 billion stars in our galaxy. The Sun is by far the largest object in the solar system. It contains more than 99.8% of the total mass of the Solar System. The Sun is, at present, about 70% hydrogen and 28% helium by mass everything else ("metals") amounts to less than 2%. This changes slowly over time as the Sun converts hydrogen to helium in its core. The outer layers of the Sun exhibit differential rotation: at the equator the surface rotates once every 25.4 days; near the poles it's as much as 36 days. This odd behaviour is due to the fact that the Sun is not a solid body like the Earth. The differential rotation extends considerably down into the interior of the Sun but the core of the Sun rotates as a solid body.

The physical properties:-

- Mean distance from Earth about 1.496×10^{8} km.
- The Sun light reaches the Earth in 8 min 19 s.
- Diameter ~ 1391000 km.
- Mass ~ 1.99×10^{30} kg.
- Mean density ~ 1.41 gm/cm^{3}.
- Mean effective temperature ~ 5760 K.
- The Sun is about 4.5 billion years old.
- The power ~ 3.86×10^{26} Watts, produced by nuclear fusion reactions.

1- Determination of Diameter:-

We can determine the Sun's diameter using the angular diameter of the Sun which is equal to 0.533°, by the relation below as in the figure:



$$\frac{D}{\theta} = \frac{2\pi r}{360°}$$

Where *r* is the distance between the Sun and Earth (150 x 10^6 km) and D is the Sun diameter.

$$D = \frac{0.533 \times 2 \times \pi \times r}{360°} = 1391650\ km$$

2- The Solar mass:

We can determine the solar mass using Kepler's third low as in the relation below

$$M_{\odot} + M_{\oplus} = \frac{4\pi^2 r^3}{GP^2}$$

Where $M_{\odot}$ *is the solar mass.*

$M_{\oplus}$ *- Earth mass.*

r - mean distance between the Sun and Earth.

P - Earth's rotational time around the sun 31.56 x 10^6 second.

G - Gravitational constant~ 6.667x10^{-11} N.m^2/kg^2.

3- Surface temperature:

a- Stefan-Boltzmann Law:

It states that the total energy (E_{tot}) radiated in all wavelengths by a black body per unit area per unit time is proportional to the forth power of the absolute temperature of the body. Hence

$$E_{tot} = \rho T_e^4$$

Where ρ *is Stefan-Boltzmann constant = 5.67 x 10^{-5} erg/cm.sec.K^4.*

T_e *is effective temperature (K).*

The total energy radiated form the Sun is (*3.8 x 10^{33} erg/sec*) and the surface area of the Sun is (*6.1×10^{22} cm^2*), so

$$E = \frac{3.8 \times 10^{33}}{6.1 \times 10^{22}} = 6.23 \times 10^{10}\ erg/cm^2.sec$$

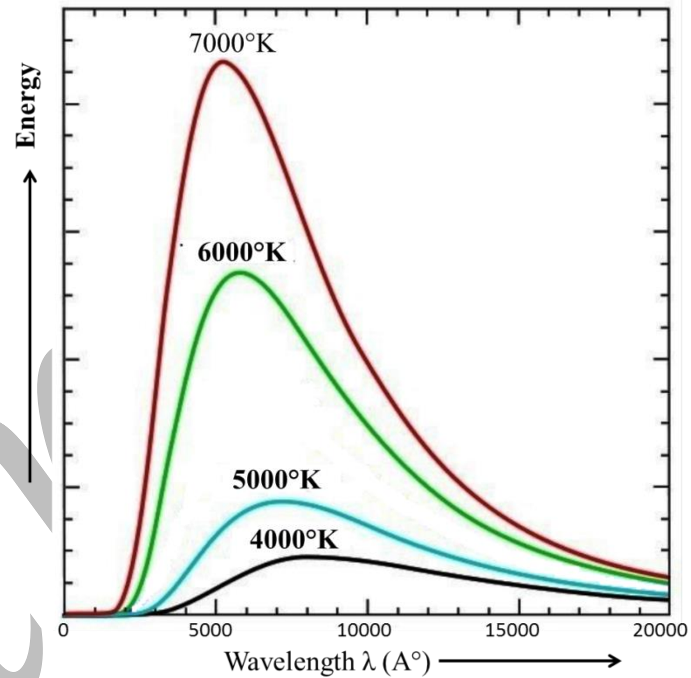
$$T_e = \frac{6.23 \times 10^{10}}{5.67 \times 10^{-5}} = 5750\ K.$$

b- Plank's law

Planck's law describes the spectral-energy distribution of radiation emitted by a blackbody (a hypothetical body that completely absorbs all radiant energy falling upon it, reaches some equilibrium temperature, and then reemits that energy as quickly as it absorbs it). The Planck law gives the intensity radiated by a blackbody as a function of frequency (or wavelength). We can apply this law for stars roughly.

The graph below shows energy curves for a source of radiation as a function of wavelength for different temperatures. We could see that:

1- At higher temperatures, the total radiated energy increases, (i.e. hot blackbody radiates energy more than cold blackbody).
2- The intensity peak of the emitted spectrum shifts to shorter wavelengths (λ_{max}).



By comparing the energy curves of the Sun with this graph we can find the effective temperature of the Sun.

c- Wien's Law:

It states that the product of the wavelength (λ_{max}, in *cm*) at which the maximum radiation is liberated and the temperature of the black body is a constant, i.e.

$$\lambda_{max} T = a$$

Where *(a) is a constant ~(0.28969) cm/K*, (λ_{max} = *4700 A°*), so

$$T_e = \frac{0.28969\ cm.K}{4.7 \times 10^{-5} cm} = 6.166\ K$$

The Moon:-

The moon is Earth's only natural satellite. The moon is a cold, dry orb whose surface is studded with craters and strewn with rocks and dust. The moon has no atmosphere. Recent lunar missions indicate that there might be some frozen ice at the poles.

The moon revolves around the Earth in about one month (27 days 8 hours). It rotates around its own axis in the same amount of time. The same side of the moon always faces the Earth; it is in a synchronous rotation with the Earth. If you were standing on the moon, the sky would always appear dark, even during the daytime.

Lunar Physical properties

a- Mean diameter ~3476 km.

b- Mass ~ 1/81.3 Earth mass.

c- Mean density ~ 3.34 gm/cm3.

d- Mean gravity ~ 1/6 Earth gravity.

e- Escape velocity ~ 2.4 km/sec.

f- Maximum temperature ~ 130 °C during the day.

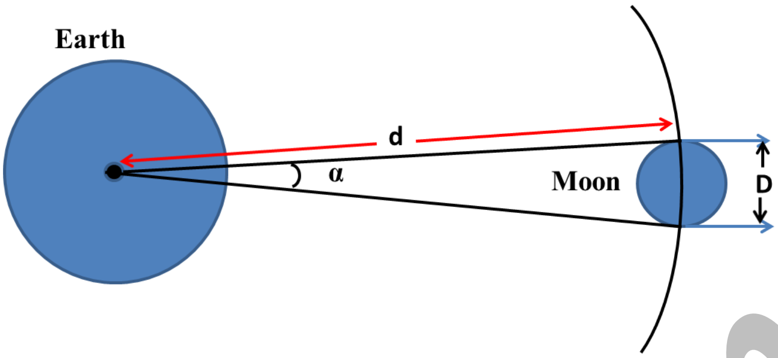
g- Minimum temperature ~ -170 °C during the night.

h- Magnetic field is weak, about 1% Earth magnetic field.

i- Eccentricity ~ 0.055

1- Determination the diameter of the Moon

We assume that the Earth is in a centre of a circle which its radius is equal to the distance between the Earth and moon (384404 km) as in figure below. Hence we can calculate diameter from the relation:

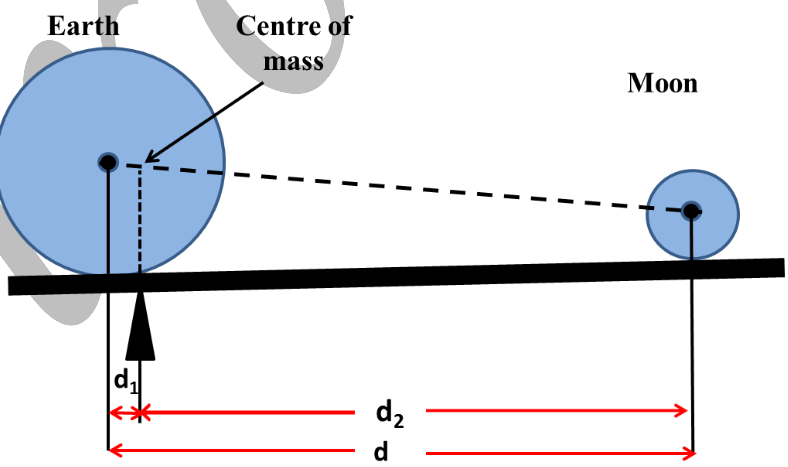


$$\frac{D}{\alpha} = \frac{2\pi d}{360^\circ}$$

Where 2πd is the circumference of the circle which its radius is d and α is the angular diameter of the moon (~ 0.518°).

2- **Mass**

We can calculate the mass of Moon by studying the motion of the Earth and Moon with respect to the centre of mass, as in figure below, using the relation



$$\frac{m_1}{m_2} = \frac{d_2}{d_1}$$

where

d_1 is the distance between the centre of mass and centre of Earth.

d_2 is the distance between the centre of mass and centre of Moon.

d is the distance between the centre of Moon and centre of Earth.

m_1 - mass of Earth.

m_2 - mass of Moon.

From observation

d_1= 4670.7 km

d = 384404 km

$d_2 = d - d_1 = 379733.3$ km

$$\frac{m_2}{m_1} = \frac{d_1}{d_2} = \frac{1}{81.3}$$
$$m_1 = 81.3m_2$$

Since the mass of Earth is 5.98 x 10^{24} kg, so mass of Moon is 7.35 x 1022 kg.

3- **Mean density (ρ)**

$$\rho = \frac{m}{v}$$

Where v is the volume of Moon

$$\rho = \frac{m}{\frac{4}{3}\pi R^3}$$

Where R is the radius of Moon which is about 1738 x 10^5 cm, so ρ = 3.34 gm/cm3.

4- Mean surface gravity of Moon

According to Newton's law, the mean acceleration of any body (a) is directly proportional with its mass (m) and inversely with its radius (R), i.e.

$$a = G\frac{m}{R}$$

Where G is the universal gravitational constant ~ 6.67 x 10^{-5} dyne.cm^2/gm.

So a=162.3 cm/sec^2

Since the gravitational acceleration (g) is 980 cm/sec^2 so

$$\frac{a}{g} = 0.1656$$

Bode Law

The Titius-Bode Law is rough rule that predicts the spacing of the planets in the Solar System. The relationship was first pointed out by Johann Titius in 1766 and was formulated as a mathematical expression by J.E. Bode in 1778. It lead Bode to predict the existence of another planet between Mars and Jupiter in what we now recognize as the asteroid belt.

The law relates the mean distances of the planets from the sun to a simple mathematic progression of numbers.

To find the mean distances of the planets, beginning with the following simple sequence of numbers:

0 3 6 12 24 48 96 192 384

With the exception of the first two, the others are simple twice the value of the preceding number.

Add 4 to each number:

4 7 10 16 28 52 100 196 388

Then divide by 10:

0.4 0.7 1.0 1.6 2.8 5.2 10.0 19.6 38.8

$$\boldsymbol{r_p = 0.4 + 0.3 \times 2^n\ A.U}$$

$$r_p = 0.6 + 0.45 \times 2^n \times 10^8\ km$$

Where n= -∞, ***0, 1, 2, 3, 4, 5 …etc.***

The resulting sequence is very close to the distribution of mean distances of the planets from the Sun:

Body	***n***	**Actual distance (A.U.)**	**Bode's Law**
Mercury	-∞	0.39	0.4
Venus	0	0.72	0.7
Earth	1	1.00	1.0
Mars	2	1.52	1.6
	3		2.8
Jupiter	4	5.20	5.2
Saturn	5	9.54	10.0
Uranus	6	19.19	19.6

Origin of the Solar System:

There are several hypothesises have been produced to explain the origin of our solar system.

1- **Descartes Hypothesis:-**

2- **Buffon Hypothesis:- (Cometary collision hypothesis)**
This hypothesis stated that a comet struck the Sun and broke off fragments which formed the planets. This was the first version of the cataclysmic hypothesis of the origin of the solar system. Buffon mistakenly assumed that comets can be approximately as large as stars.

3- **Chamberlain & Moulton Hypothesis:-**
Chamberlin and Moulton (1904) considered that a wandering star approached the sun, and a cigar-shaped extension of material was separated from the solar surface.
As the passing star moved away, the material separated from the solar surface continued to revolve around the sun and it slowly condensed into planets. Obviously, according to this hypothesis the origin of planets is supposed to be due to severe tidal eruptions and disruption of some of the sun's mass.

4- Jeans-Jeffreys Hypothesis:-

Championed by James Jeans and Harold Jeffreys, this explained the origin of the solar system as a result of a close encounter between the Sun and a second star.

As a result of a detailed mathematical analysis, Jeans concluded in 1916 that the tidal interaction between the Sun and a passing star would raise tides on the Sun resulting in the loss of a single cigar-shaped filament of hot gas, rather than separate streams of gas as in the Chamberlin and Moulton scenario. This hot gas would then condense directly into the planets instead of going through a planetesimal stage. The central section of the "cigar" would give rise to the largest planets – Jupiter and Saturn – while the tapering ends would provide the substance for the smaller worlds.

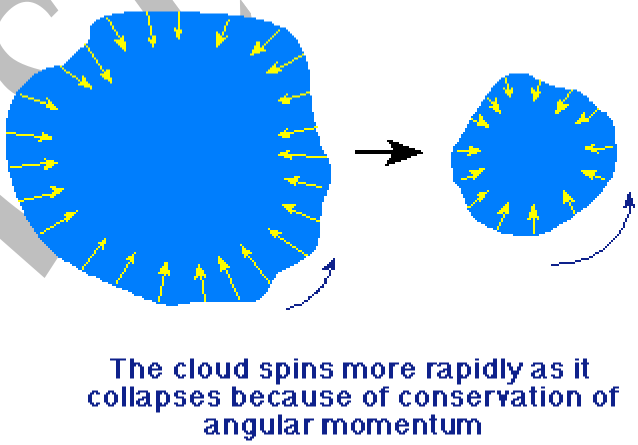
5- Henry Russell Hypothesis:-

This hypothesis states that the sun was one of a binary system. The Sun's companion may have exploded, throwing out debris from which the planets were made.

6- Nebular Hypothesis:-

The Nebular Hypothesis in its original form was proposed by Kant and Laplace in the 18th century. The initial steps are indicated in the following figures.

Collapsing Clouds of Gas and Dust

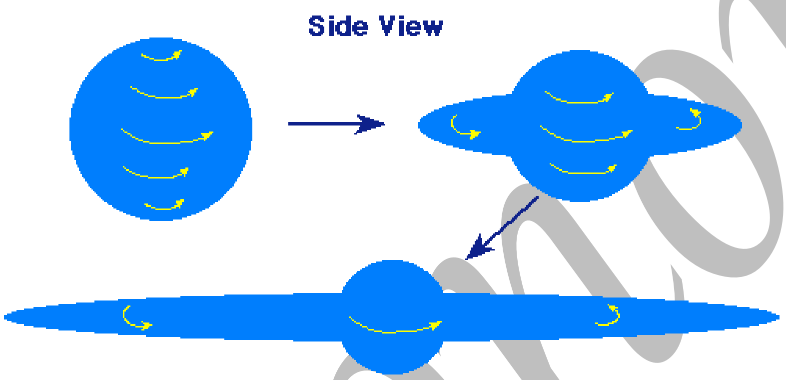


A great cloud of gas and dust (called a nebula) begins to collapse because the gravitational forces that would like to collapse it overcome the forces associated with gas pressure that would like to expand it (the initial collapse might be triggered by a variety of perturbations---a supernova blast wave, density waves in spiral galaxies, etc.).

In the Nebular Hypothesis, a cloud of gas and dust collapsed by gravity begins to spin faster because of angular momentum conservation

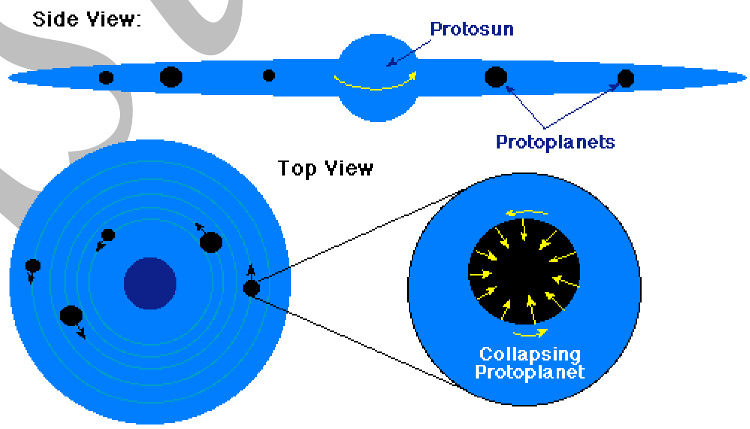
It is unlikely that such a nebula would be created with no angular momentum, so it is probably initially spinning slowly. Because of conservation of angular momentum, the cloud spins faster as it contracts.

The Spinning Nebula Flattens



Because of the competing forces associated with gravity, gas pressure, and rotation, the contracting nebula begins to flatten into a spinning pancake shape with a bulge at the center, as illustrated in the following figure.
The collapsing, spinning nebula begins to flatten into a rotating pancake

Condensation of Protosun and Protoplanets



As the nebula collapses further, instabilities in the collapsing, rotating cloud cause local regions to begin to contract gravitationally. These local regions of condensation will become the Sun and the planets, as well as their moons and other debris in the Solar System.

As the nebula collapses further, local regions begin to contract gravitationally on their own because of instabilities in the collapsing, rotating cloud. While they are still condensing, the incipient Sun and planets are called the protosun and protoplanets, respectively.

Evidence for the Nebular Hypothesis

Because of the original angular momentum and subsequent evolution of the collapsing nebula, this hypothesis provides a natural explanation for some basic facts about the Solar System: the orbits of the planets lie nearly in a plane with the Sun at the centre (let's neglect the slight eccentricity of the planetary orbits to simplify the discussion), the planets all revolve in the same direction, and the planets mostly rotate in the same direction with rotation axes nearly perpendicular to the orbital plane.

The nebular hypothesis explains many of the basic features of the Solar System, but we still do not understand fully how all the details are accounted for by this hypothesis. Scientists, now, have some direct observational evidence in support of the nebular hypothesis.