SESSION SEVEN: INTRODUCTION TO THE SOLAR SYSTEM

ORBITAL AND PHYSICAL CHARACTERISTICS OF THE PLANETS

Planet	AU	Orbital Period Sidereal / Synodic	i (degrees)	e	Rotation Period	Axial Tilt (degrees)
Mercury	0.387	87.969d / 115.9d	7.0	0.21	58.646d	0.1
Venus	0.723	224.70d / 583.9d	3.4	0.01	243.019d	177.4
Earth	1.00	365.24d / --------	0.0	0.02	23.935h	23.5
Mars	1.52	686.97d / 779.9d	1.9	0.09	24.623h	25.2
Jupiter	5.20	11.859y / 398.9d	1.3	0.05	9.925h	3.1
Saturn	9.55	29.457y / 378.1d	2.5	0.06	10.656h	26.7
Uranus	19.2	84.323y / 369.7d	0.8	0.05	17.240h	97.9
Neptune	30.1	164.79y / 367.5d	1.8	0.01	16.110h	29.6

sidereal period (P) (revolution) synodic period (S) (configuration) equ = equatorial diameter

Planet	Mass (Earth = 1)	Radius (Earth = 1)	Average Density (gm/cm^3)	Surface Gravity (Earth = 1)	No. of Ring(s) Systems	Number of Satellites
Mercury	0.055	0.38	5.4	0.39	0	0
Venus	0.81	0.95	5.2	0.91	0	0
Earth	1.00	1.00	5.5	1.00	0	1
Mars	0.11	0.53	3.9	0.38	0	2
Jupiter	318	11.21 equ	1.3	2.54	5	92+
Saturn	95.2	9.45 equ	0.7	1.07	15	83+
Uranus	14.5	4.01 equ	1.3	0.87	12	27+
Neptune	17.1	3.88 equ	1.6	1.14	6	14+

$F = Gm_1m_2/r^2$ Newton's Universal Gravity $L = (mr^2)\omega$ Angular Momentum

$G = 6.674 \times 10^{-8}$ dyne cm^2/gm^2 $(m_1 + m_2)p^2 = (4\pi^2/G)a^3$ Newton's derivation of Kepler's Third Law

Inferior Planet: $^1/_S = {}^1/_P - 1$ or $^1/_P = 1 + {}^1/_S$ Mercury and Venus
Superior Planet: $^1/_S = 1 - {}^1/_P$ or $^1/_P = 1 - {}^1/_S$ Mars, Jupiter Saturn, Uranus, and Neptune

Kepler's third Law = $p^2 = ka^3$ k = 1 when p, the sidereal period is given in years and a, the semi-major axis or average distance from the sun is given in AUs.

The definitions for the terms at the head of the columns are crucial to understanding the information in this unit. These definitions can be found in the vocabulary for this session.

CHARACTERISTICS OF THE SOLAR SYSTEM

1. **The sun is the most massive object in the solar system** containing over 99.86 percent of the solar system's matter.
2. **The rotational axis of the sun is perpendicular** (within 7 degrees) to the plane of the planets' orbits, i.e., the ecliptic. Stated in another way, planetary orbits lie near the plane of the sun's equator.
3. **Low Inclinations:** Planetary orbits all lie near the plane of the ecliptic.
4. **Counterclockwise revolutions:** The planets revolve around the sun in the same direction.
5. **Circular orbits:** Planetary orbits have low eccentricities and appear circular.
6. **Planetary rotations are all direct** (counterclockwise) and **axial tilts are perpendicular** to the plane of the planets' orbits. Venus and Uranus are exceptions to this rule.
7. **Satellite systems imitate planetary systems.** Most of the solar system's large satellites revolve in the same direction that their primaries rotate and revolve. Their orbital planes lie near or in the plane of the equators of the planets which they revolve around. Neptune's Triton is the best exception to this rule. Its orbit is retrograde.
8. **Planetary distances can be mathematically stated** through a simple formula known as the Titius-Bode relationship (1772)--Johann E. Bode and Johann D. Titius. The distances given below are stated in AUs.

Distance	Mercury	Venus	Earth	Mars	Asteroids	Jupiter	Saturn	Uranus	*Neptune*
Bode-	0.0	0.3	0.6	1.2	2.4	4.8	9.6	19.2	*38.4*
Titius	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	*0.4*
Relation	0.4	0.7	1.0	1.6	2.8	5.2	10.0	19.6	*38.8*
Actual AU	**0.4**	**0.7**	**1.0**	**1.5**	**2.8**	**5.2**	**9.5**	**19.2**	**30.1**

9. **There are two major classifications of planets in the solar system:** the terrestrials (earth like) and the Jovians (Jupiter like). Between these two groups there is a distinct difference in size, mass, density and composition. For the purposes of a quiz or test, these four characteristics may be stated separately as long as the statements are complete. Remember, the Jovian planets are not the jovial planets. The word jovial means cheerful or jolly.
10. **Jupiter and Saturn contain 99 percent of the angular momentum of the solar system** (the momentum is predominantly orbital). The sun contains only one percent the angular momentum of the solar system.
11. **Dwarf Planets are a separate class of solar system bodies.** They have all of the characteristics of the planets but are not massive enough to clear their orbital spaces.
12. **Small Solar System Bodies form a distinct class of objects.** The group is composed of comets, most asteroids, meteoroids, and most members of the Kuiper belt, and Oort cloud. Their orbital eccentricities and inclinations are higher than the planets, while their sizes are smaller than the planets and dwarf planets.

Name __________________________________ Date _________________ Moravian University

GRAPHICALLY UNDERSTANDING SOLAR SYSTEM CHARACTERISTICS

(6 points)

Instructions: The opening page of Session Seven, "Introduction to the Solar System," is comprised of a chart showing the major characteristics of the solar system. Your assignment will be to create representations of these characteristics in the form of bar graphs. Along the "X" axis, list the eight planets of our solar system with Mercury being closest to the graph's origin. Start several blocks away from the graph's origin. About three blocks per planet seems reasonable for adequate spacing. Only one characteristic will be assigned per student. Along the "Y" axis create a scale appropriate to the information which is given. Suggestions are given for each category in order to utilize as much of the graph's space as possible. **Indicate the value which you are graphing at the top of each "bar."** The following data will be graphed along the "Y" axis:

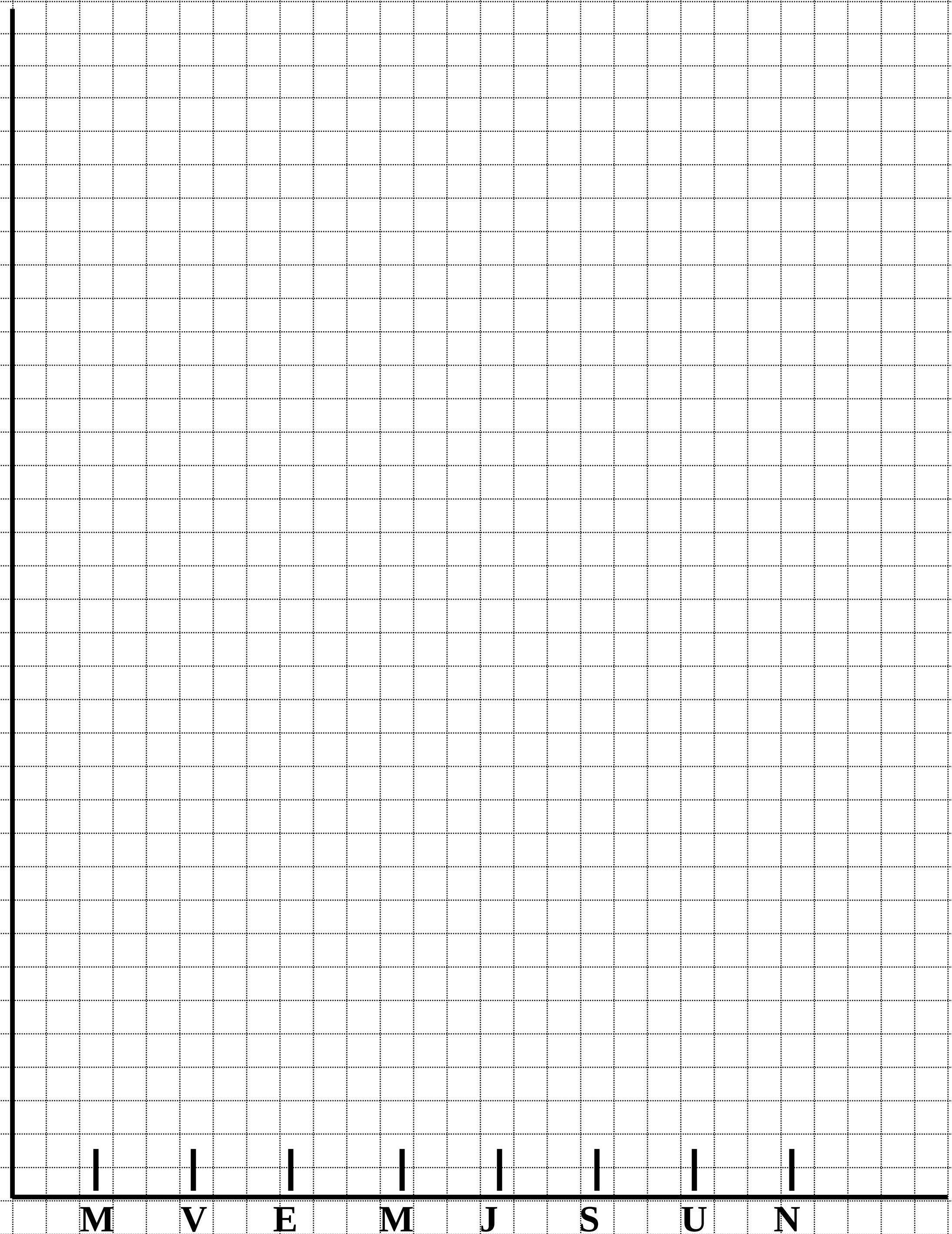
1. **astronomical units**: 0-30 AU—Each block along the y-axis will count for one AU with the origin equaling zero.
2. **orbital inclination**: 0-180 degrees—Each block along the y-axis will count for five degrees with the origin equaling zero.
3. **eccentricity**: 0-1—Each three blocks along the y-axis will count for 0.1 eccentricity with the origin equaling zero.
4. **axial tilt**: 0-180 degrees—Each block on the y-axis will count for five degrees with the origin equaling zero.
5. **mass**: 0-320 Earth masses—Each block along the y-axis will count for 10 Earth masses with the origin equaling zero.
6. **radius**: 0-12 Earth radii—Each three blocks on the y-axis will count for one Earth radius with the origin equaling zero.
7. **density**: 0-6 gm/cm^3—Each five blocks along the y-axis will count for one gm/cm^3 with the origin equaling zero.
8. **number of satellites**: 0-70—Each block on the y-axis will count for two satellites with the origin equaling zero.

Rubric: Your grade will be based upon the following criteria:

a. Two points: Accuracy of the values plotted…
b. One point: Labeling axes, planets, and titling of your graph…
c. One point: Noting the numerical values which you are graphing at the top of each bar…
d. One point: Neatness of your graphical presentation…

Name: **Date:** **Moravian University**

Title of Graph:



INVASION OF THE SARBRA PEOPLE!

(12 points)

The Sarbras, oxygen breathing aliens with a capitalistic spirit, have fully exploited the Sagittarius arm of the Milky Way galaxy and have begun an intensive period of exploration in the nearby Orion arm. That is where our Solar System can be found! The Sarbras have been compiling statistical data on the thousands of stellar systems which they have encountered that contain planets in the hopes of narrowing down their choices to obtain their best profit margins. Their entire technological success and rise to power has been based upon their ability to manufacture products from compact planetary sources of hydrogen. They normally use smaller, rockier worlds as their bases of operation and have noticed that an orderly planetary system containing two major classifications of planets suits their purposes very well. The Sarbra formula for successful stellar system selection has been noted above. Based upon the data collected by the Sarbra Empire about our own Solar System found on the first page of Session Seven and the criteria listed below, is our planetary system ripe for an invasion? UFO sighting on Earth have been a common occurrence for over half a century.

In this exercise there are 21 point that can be accrued. The exercise, however, is worth 12 points.

LIST YOUR TEAM MEMBERS (NO LESS THAN TWO, AND NO MORE THAN FOUR):

1. ____________________________________ Date: ________________________________

2. ____________________________________ 4. ____________________________________

3. ____________________________________

IS THE SOLAR SYSTEM AN ORDERLY PLACE?

Yes/No (circle one)

Examine the following criteria which the Sarbras use in determining whether a stellar system is orderly. Explain below:

1. Yes/No (circle one) **<u>Orbital directions</u>**

   <u>STATE YOUR REASONING</u>:

2. Yes/No (circle one) **<u>Inclination of planetary orbits</u>**

   <u>STATE YOUR REASONING</u>:

3. Yes/No (circle one) **Eccentricity of planetary orbits**

   STATE YOUR REASONING:

4. Yes/No (circle one) **Planetary distances**

   STATE YOUR REASONING:

5. Yes/No (circle one**) Axial tilts of the planets**

   STATE YOUR REASONING:

DOES THE SOLAR SYSTEM HAVE TWO MAJOR CLASSIFICATIONS OF PLANETS?
Yes/No (circle one)

Examine the criteria which the Sarbras use in establishing whether a stellar system has two major classifications of planets. Explain your reasoning below:

1. Yes/No (circle one) **Mass of the planets**

   STATE YOUR REASONING:

2. Yes/No (circle one) **Size (radius) of the planets**

   STATE YOUR REASONING:

3. Yes/No (circle one) **Average density of the planets**

   STATE YOUR REASONING:

4. Yes/No (circle one) **Composition of the planets**

   USE DEDUCTIVE REASONING BASED UPON ANSWERS 1-3 ABOVE:

WILL THE SARBRA HIGH COMMAND DECIDE TO INVADE THE SOLAR SYSTEM?
Yes/No (circle one)

NOTES

NOTES

CONSERVATION OF ANGULAR MOMENTUM

1. **Angular Momentum:** A property of any rotating or revolving system. Its value depends on the distribution of mass and velocity about the axis of rotation or revolution.

   $L = (mr^2)\omega$ $I = mr^2$ therefore $L = I\omega$

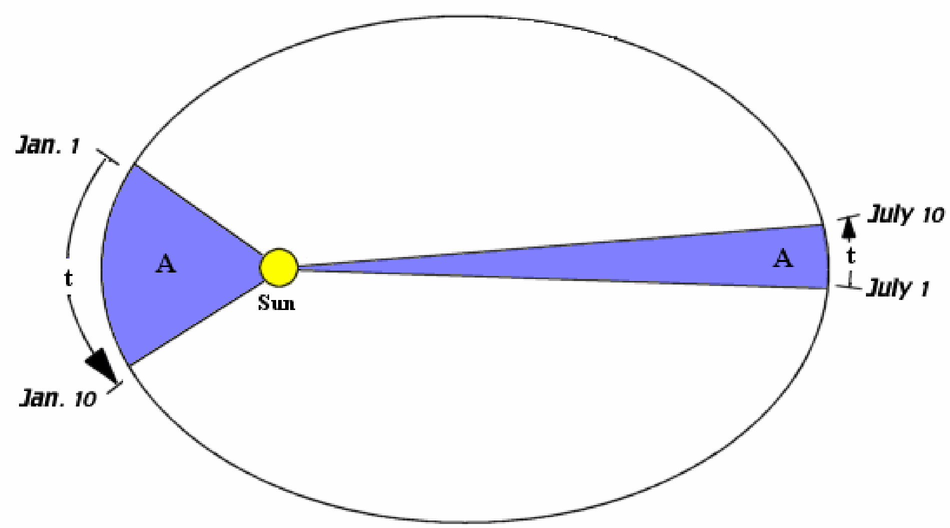
   Where L = angular momentum
   I = inertia = resistance to change = mr^2 in a rotating system
   ω= (omega) angular rate of spin (usually in radians per second). One radian = 57.3°
   m = mass of the object
   r = distance of the mass from the center

2. **Conservation of Angular Momentum:** The principle that in any system of rotating and/or revolving bodies, the angular momentum is conserved (remains the same) provided that no external force is applied to the system. In the early solar system, where a large cloud of gas and dust was contracting, the rate of rotation of the proto-sun had to increase dramatically if angular momentum was conserved. As "r" decreased, "I" became less which caused "ω" to increase.

KEPLER'S THREE LAWS OF PLANETARY MOTION

1. **First Law:** Planets revolve around the sun in elliptical orbits.

2. **Second Law:** The radius vector connecting the sun and a planet sweeps out equal areas in equal time periods. Planets sweep out equal areas in equal time periods. The shaded regions in the elliptical orbit found below are the same.



3. **Third Law:** The square of the sidereal (orbital) period of a planet is equal to a constant multiplied by the cube of the semi-major axis (average distance) of a planet from the sun. If the period is measured in years and the average distance in astronomical units, k becomes equal to one. **Mathematically this can be stated as $P^2 = a^3$.**

NEWTON'S THREE LAWS OF MOTION

1. **First Law:** An object in motion will stay in motion until acted upon by an outside force.
2. **Second Law:** F = ma; Force is equal to the mass of the object multiplied by the acceleration of the body. Acceleration is a change in acceleration of an object is directly related to the applied force on that body and indirectly related to the mass of that object.
3. **Third Law:** For every action there is an equal and opposite reaction.

NEWTON'S UNIVERSAL LAW OF GRAVITATION

$$F = \frac{G\, m_1\, m_2}{r^2}$$

- F: Force of attraction
- G: Gravitational constant $6.674 \times 10^{-8} \frac{\text{dynes cm}^2}{\text{gm}^2}$
- m_1: Mass of the first object (more massive)
- m_2: Mass of the second object (less massive)
- r: Distance between objects, center to center

From Newton's Second Law $F = m_2 a$
Where m_2 = mass of the second object
a = acceleration of the body

Substituting $m_2 a$ for F in Newton's Universal Law of Gravity yields

$m_2 a = \frac{G\, m_1\, m_2}{r^2}$ and canceling the m_2 results in $a = \frac{G\, m_1}{r^2}$

The acceleration of a falling body is only the result of the mass of the more massive object and the square of the distance between their centers. Remove the constant G and use relative units in Earth masses and Earth radii and it is possible to solve for accelerations, i.e., gravitational attractions for the other planets or other objects as a ratio of the acceleration due to Earth's mass at the Earth's surface.

NEWTON'S DERIVATION OF KEPLER'S THIRD LAW

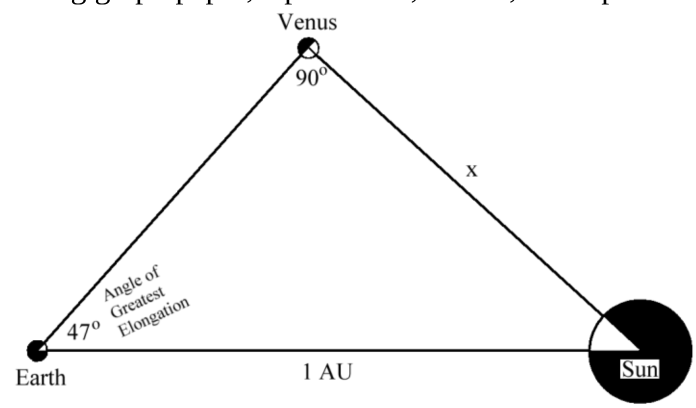
$$(m_1 + m_2)p^2 = (4\pi^2/G)a^3$$

- $(m_1 + m_2)$: Mass of the first and second object
- p: Period of revolution
- G: Gravitational constant
- a: average distance from sun

SOLAR SYSTEM MATHEMATICS

<u>Instructions</u>: Answer all of the questions on a separate sheet of paper using a pencil. All mathematical work and unit cancellations must be shown. In some cases a problem may be solved through an accurate geometrical construction. This is a sample exercise with solutions provided.

1. The greatest elongation of Venus is 47 degrees. What is Venus' distance from the sun in AU? Assume circular orbits for both Venus and the Earth. Sketch the planetary configuration. This problem can also be solved by constructing a geometrically accurate representation using graph paper, a protractor, a ruler, and a pencil.



$\sin 47^o = \frac{x}{1\ AU}$ $\quad 0.7314 = \frac{x}{1\ AU}$ $\quad x = 0.7314 \times 1\ AU$ $\quad x = 0.7314\ AU$

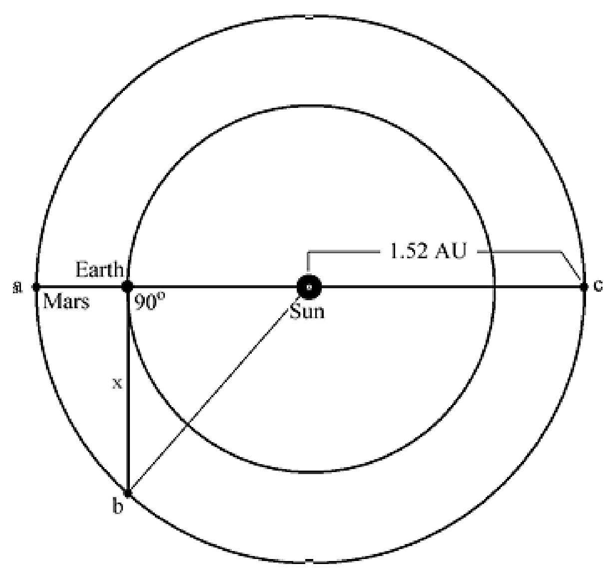
2. Mars is at a distance of 1.52 AU from the sun. Earth is at a distance of _____ AU from the sun. Assuming circular orbits, determine the distance from the Earth to the planet Mars at opposition, conjunction, and at quadrature (geometry construction friendly).

a = <u>opposition</u>:
= 1.52 AU – 1.00 AU = 0.52 AU

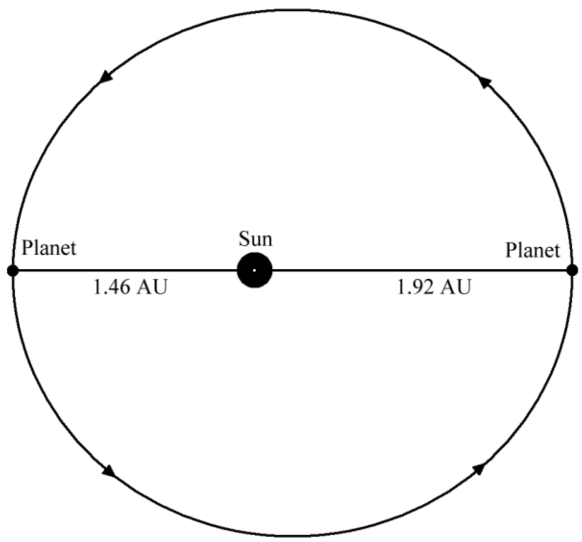
b = <u>quadrature</u>: In a right triangle, the square of the hypotenuse equals the sum of the squares of the two sides. The square of the hypotenuse minus the square of one of the sides, yields the square of the unknown side.

$x^2 = (1.52\ AU)^2 - (1.00\ AU)^2$
$x^2 = 2.31\ AU^2 - 1.00\ AU^2$
$x^2 = 1.32\ AU^2$
$(x^2)^{1/2} = (1.32)^{1/2} \quad (x)^{1/2} = \text{square root}$
$x = 1.14\ AU$

c = <u>conjunction</u>:
= 1.00 AU + 1.52 AU = 2.52 AU



3. A hypothetical planet travels around the sun in an elliptical orbit with a perihelion distance of 1.46 AU and an aphelion distance of 1.92 AU. Determine (a) the semi-major axis and (b) the eccentricity of this planet's orbit (geometry construction friendly).



a. semi-major axis = $\frac{\text{major axis}}{2} = \frac{1.92 \text{ AU} + 1.46 \text{ AU}}{2} = \frac{3.38 \text{ AU}}{2}$ = 1.69 AU

b. eccentricity = $\frac{\text{distance between foci}}{\text{major axis}} = \frac{\text{major axis} - 2(\text{perihelion distance})}{\text{major axis}}$

$e = \frac{3.38 \text{ AU} - 2(1.46 \text{ AU})}{3.38 \text{ AU}}$ $e = \frac{3.38 \text{ AU} - 2.92 \text{ AU}}{3.38 \text{ AU}}$

$e = \frac{0.460 \text{ AU}}{3.38 \text{ AU}} = 0.136$

4. The planet Saturn has a synodic period (S) of 378.1 days. What is the sidereal period (P) of the planet? The sidereal and synodic periods are always calculated in years. Note that units are not used when solving these types of problems.

$\frac{1}{P} = 1 - \frac{1}{S}$ where P = synodic period in years and S = sidereal period in years

378.1 days x $\frac{1 \text{ year}}{365.2 \text{ days}}$ = 1.035 years

$\frac{1}{P} = 1 - \frac{1}{1.035}$ $\frac{1}{P} = 1 - 0.964$ $\frac{1}{P} = 0.036$ 1 = 0.036 P

0.036 P = 1 P = $\frac{1}{0.036}$ P = 27.8 years

5. The planet Mercury has a sidereal period of 88 days. What is the synodic period of Mercury? P (sidereal period) and S (synodic period) are in years. Note that units are not used when solving these types of problems.

$\frac{1}{P} = 1 + \frac{1}{S}$ sidereal period of Mercury is 87.96 days

88.96 days x $\frac{1 \text{ year}}{365.2 \text{ days}}$ = 0.2434 year

$\frac{1}{P} - 1 = \frac{1}{S}$ $\frac{1}{S} = \frac{1}{P} - 1$ $\frac{1}{S} = \frac{1}{0.2434} - 1$ $\frac{1}{S} = 4.105 - 1$ $\frac{1}{S} = 3.105$

$S = \frac{1}{3.105}$ S = 0.3221 year x 365.24 $\frac{\text{days}}{\text{year}}$ = 117.6 days

6. A hypothetical planet has a sidereal period of 24 days. Assuming a circular orbit, what is its distance from the sun in AU and in miles? What would the angle of greatest elongation of this planet be when viewed from the Earth? Units are not used to solve these types of problems when "p" is in years and "a" is given in astronomical units.

Sidereal period of the planet is 24.0 days or 24.0 days x $\frac{1 \text{ year}}{365.24 \text{ days}}$ = 0.0657 year

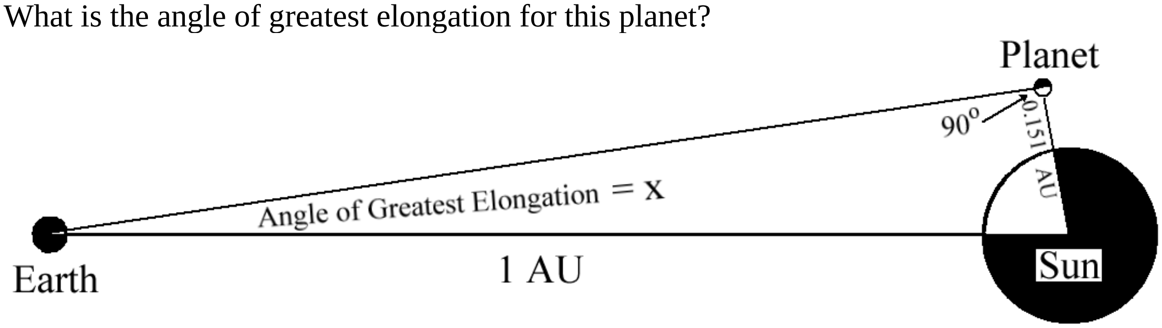
$p^2 = a^3$

$(6.57 \times 10^{-2})^2 = a^3$ $43.2 \times 10^{-4} = a^3$

$(a^3)^{1/3} = (43.2 \times 10^{-4})^{1/3}$

a = 0.163 AU x 9.30×10^7 $\frac{\text{miles}}{\text{AU}}$ = 1.51×10^7 miles = 15,100,000 miles

What is the angle of greatest elongation for this planet?



sin x = $\frac{0.151\text{AU}}{1 \text{ AU}}$ = 0.151 = The angle that has a sin of 0.151 = $\sin^{-1}$ = 8.68 degrees

7. A hypothetical planet revolves around the sun in an orbit with a semi-major axis of three AU. Determine the sidereal and synodic periods of this planet.

Sidereal period of the planet follows:

$p^2 = a^3$ $p^2 = (3.00)^3$ $p^2 = 27$ $(p^2)^{1/2} = (27.0)^{1/2}$ p = 5.20 years

Synodic period of the planet follows: S = synodic period; P = sidereal period

$\frac{1}{P} = 1 - \frac{1}{S}$ $\frac{1}{P} + \frac{1}{S} = 1$ $\frac{1}{S} = 1 - \frac{1}{P}$

$\frac{1}{S} = 1 - \frac{1}{5.18}$ $\frac{1}{S} = 1 - 0.193$ $\frac{1}{S} = 0.807$ $0.807S = 1$ $S = \frac{1}{0.807}$

S = 1.24 years S = 1.24 years x 365.24 $\frac{\text{days}}{\text{year}}$ = 453 days in a synodic period

8. What is the force of attraction acting between the Earth and a person on the surface of the Earth who weighs 150.0 pounds?

Mass of Earth = 5.997×10^{27} gm

Radius of Earth = 6.378×10^{8} cm

One pound = 453.6 gm

$G = 6.674 \times 10^{-8} \frac{\text{dyne cm}^2}{\text{gm}^2}$ $1 \text{ dyne} = \frac{\text{gm cm}}{\text{sec}^2}$

$G = 6.674 \times 10^{-8} \frac{\text{gm cm cm}^2}{\text{gm}^2 \text{ sec}^2} = 6.67 \frac{\text{cm}^3}{\text{gm sec}^2}$

150.0 pounds x $\frac{453.6 \text{ gm}}{\text{Pound}}$ = 68,040 gm = 6.804×10^4 gm

From Newton's Universal Law of Gravitation

$F = \frac{G\, m_1 m_2}{r^2}$ $F = \frac{G\, m_{Earth}\, m_{person}}{(\text{radius of Earth})^2}$

$F = 6.674 \times 10^{-8} \frac{\text{cm}^3}{\text{gm sec}^2} \frac{5.997 \times 10^{27} \text{ gm } 6.804 \times 10^4 \text{ gm}}{(6.378 \times 10^8 \text{ cm})^2}$

$F = \frac{272.3 \times 10^{23} \text{ cm}^3 \text{ gm}^2}{40.68 \times 10^{16} \text{ cm}^2 \text{ gm sec}^2} = 6.694 \times 10^7 \frac{\text{gm cm}}{\text{sec}^2} = 6.694 \times 10^7$ dynes

9. What is the difference in the force of attraction between the moon and the Earth when the moon is at apogee and at perigee?

Mass of the Earth = 5.972×10^{27} gm
Mass of the moon = 7.348×10^{25} gm
Moon's distance at perigee = 3.626×10^{10} cm
Moon's distance at apogee = 4.054×10^{10} cm
$G = 6.674 \times 10^{-8} \frac{\text{dyne cm}^2}{\text{gm}^2}$

Newton's Universal Law of Gravitation $= F = \frac{G\, m_1\, m_2}{r^2} = \frac{G\, m_{Earth}\, m_{moon}}{(\text{Earth/moon distance})^2}$

Force of attraction of Earth/moon at perigee

$$F = 6.674 \times 10^{-8} \frac{\text{dyne cm}^2}{\text{gm}^2} \frac{5.972 \times 10^{27}\text{ gm } 7.348 \times 10^{25}\text{ gm}}{(3.626 \times 10^{10}\text{ cm})^2}$$

$$F = \frac{292.9 \times 10^{44}\text{ dynes cm}^2\text{ gm}^2}{13.15 \times 10^{20}\text{ cm}^2\text{ gm}^2} = 22.27 \times 10^{24}\text{ dynes} = 2.227 \times 10^{25}\text{ dynes}$$

Force of attraction of Earth/moon at apogee

$$F = 6.674 \times 10^{-8} \frac{\text{dyne cm}^2}{\text{gm}^2} \frac{5.972 \times 10^{27}\text{ gm } 7.348 \times 10^{25}\text{ gm}}{(4.054 \times 10^{10}\text{ cm})^2}$$

$$F = \frac{292.9 \times 10^{44}\text{ dynes cm}^2\text{ gm}^2}{16.43 \times 10^{20}\text{ cm}^2\text{ gm}^2} = 17.83 \times 10^{24}\text{ dynes} = 1.783 \times 10^{25}\text{ dynes}$$

Difference in forces = x = Force at perigee – Force at apogee

$x = 2.227 \times 10^{25}$ dynes – 1.783×10^{25} dynes = 0.4440×10^{25} dynes = 4.440×10^{24} dynes

10. How far is the barycenter from a star of three solar masses in a double star system in which the other star has a mass equal to that of the sun and a distance of four AU from the first star?

Where is the location of the barycenter with respect to the more massive star?

The location of the barycenter is inversely proportional to the ratio of the masses of the objects being considered. Total separation between the two stars equals 4 AU.

$$\frac{\text{A mass}}{\text{B mass}} = \frac{\text{B distance}}{\text{A distance}} \quad \frac{\text{A (1) solar mass}}{\text{B (3) solar masses}} = \frac{\text{B (1) unit distance}}{\text{A (3) unit distances}} = \begin{matrix} 1/4 \times 4\text{ AU} = 1\text{ AU} \\ 3/4 \times 4\text{ AU} = 3\text{ AU} \end{matrix}$$

The barycenter will be located one astronomical unit from star B.

11. Calculate in relative units of Earth's mass and Earth's radius the acceleration of a body at the cloud tops of Jupiter and the acceleration of an object dropped onto the surface of Mars. The mass and radius of the Earth equals one. The relative masses and radii of Jupiter and Mars expressed in terms of the Earth can be found in the tables on the first page of this chapter.

$$F = \frac{G\,m_1\,m_2}{r^2} \qquad F = m_2 a \qquad \text{therefore} \qquad m_2 a = \frac{Gm_1\,m_2}{r^2} \qquad a = \frac{Gm_1}{r^2}$$

When using relative units, G, the gravitational constant, also drops out and the problem for Jupiter and Mars simplifies as noted below:

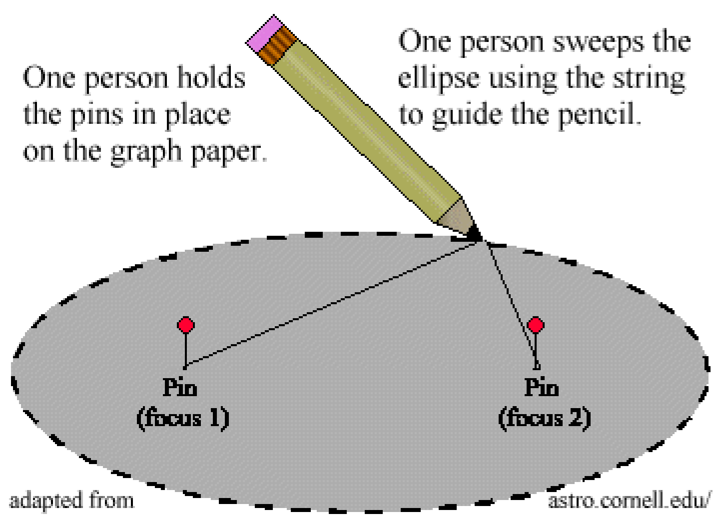
$$a_{Jupiter} = \frac{m_{Jupiter}}{(r_{Jupiter})^2} \quad \text{and} \quad a_{Mars} = \frac{m_{Mars}}{(r_{Mars})^2}$$ where mass and radius are expressed as multiples of Earth's mass and radius.

$$a_J = \frac{318}{(11.21)^2} \quad \text{and} \quad a_M = \frac{0.11}{(0.53)^2}$$

$$a_J = \frac{318}{125.7} \quad \text{and} \quad a_M = \frac{0.11}{0.28}$$

$$a_J = 2.53 \quad \text{and} \quad a_M = 0.39$$

12. **<u>Construct an Ellipse</u>:** Using the technique shown in the drawing below, construct an ellipse. Draw the upper half of the ellipse. Then flip the string over to construct the lower half. Label the two focus points. Quantify the length of the major axis (also identify), the length of the minor axis (also identify), and the distance between the two foci. Calculate the eccentricity of the ellipse. Also designate one of the foci as the sun and identify the locations of the perihelion and aphelion positions for an orbiting object. This is really a two person construction. Graph paper will be supplied. Have another team check your work for accuracy and sign their names at the bottom right of the drawing.



ADIABATIC HEATING

If a gas is compressed, the temperature goes up. If a gas is expanded the temperature goes down. In adiabatic heating, energy (heat) is neither subtracted from, nor added to the parcel. By rapidly compressing air in a tube it is possible to reach the kindling temperature of wood (use tissue) 451^{o}F and cause combustion. Adiabatic heating affected the early solar system.

MAGNETIC FIELDS

The concept of a field involves a force which is created by a property or a condition of matter which goes beyond the boundaries of that material object. Gravity is a force which seems to be inherent in all material things, no matter how big or small. Although scientists have no problem quantifying the force of gravity, their ability to explain exactly what gravity is has only being understood recently (graviton). The same can be said for magnetic fields which are created when electrons flow in a current or atoms are aligned so that their spin axes point in the same direction.

All magnetic fields ultimately come from electrical charges in motion. A bar magnet has no outward sign of motion, but outer electrons orbiting in the same direction around iron nuclei creates the magnetic field. One electron swirling around a nucleus generates a minuscule magnetic field. Electrons of innumerable atoms, all orbiting in the same direction, will create a magnetic field detectable at a distance away from the matter.

You have probably seen an electromagnet in operation. Here an electric current, a flow of charged particles passing through a loop of wire, creates a magnetic field. The Earth's magnetic field is probably generated by the internal circulation of electrons which are made to move in a series of loops by the fairly rapid rotation of the planet. The magnetic fields around the Earth and the sun have two poles. This dipolar nature allows us to visualize these fields arising from giant bar magnets buried in the Earth and the sun.

A magnetic field line (flux line), is a region where the magnetic field is more intense. As a concrete analogy, imagine the magnetic field lines consisting of numerous elastic rubber bands stretched before you. Charged particles and magnetic fields interact in such a way that the particles find it difficult to cross the field lines. Instead the charged particles tend to spiral along the field lines and travel wherever the flux lines go. The direction of the spiraling plasma depends upon whether the particle is positively or negatively charged. Continuing with the rubber band analogy, if a charged particle attempts to plow across the band, it encounters resistance which stretches the field lines. The particle, instead of breaking through the band, takes the path of least resistance and spirals along the band. Charged particles and magnetic fields are linked together by their interactions.

This linking is important for understanding what happens to a magnetic field that is immersed in an ionized gas (plasma) like the sun. If the ionized gas moves, it carries the magnetic field lines with it. Since the sun rotates differentially, fastest at the equator and slowest at the poles, magnetic field lines become bunched, rising into the photosphere to become the sunspots that we observe.

Moving charged particles produce magnetic fields. In turn, magnetic fields affect the motions of charged particles. This linking of magnetic fields and charged particles has important astrophysical consequences.

Adapted from Michael Zeilik, Astronomy: The Evolving Universe (New York, 1963), 147-148.

NOTES

A POSSIBLE SEQUENCE OF EVENTS FOR THE FORMATION OF THE SOLAR SYSTEM

A. **Gas and dust nebula collapses**
   1. Time: Began about five billion years ago
   2. Duration: 10 million years
   3. An interstellar cloud of gas and dust, approximately 50,000 AU in diameter, began to collapse gravitationally. Its mass may have been a few thousand solar masses. The cloud fragmented and one area with at least 1.1 to 2.0 solar masses, continued to collapse. Several mechanisms could have initiated such an event.
      a. **Collection of mass from the explosion of a supernova.** When a shock wave from a supernova event moves through space, a region of higher density is generated immediately behind the wave front.
      b. **Magnetic fields** which originate in the center of a galaxy give rise to shock fronts which move through the medium. As charged particles come in contact with the field lines, they are slowed, collecting matter which creates the necessary densities and generate stars. This mechanism may create the arms of spiral galaxies like the Milky Way.
      c. **O B Associations:** Hot luminous blue supergiant stars create interstellar winds from their tremendous outpourings of radiation. This radiation has the ability to collect matter to form new stars. This occurs in large, interstellar clouds of hydrogen.

B. **Pressure and density increased. Rotation of the nebula increased.** The cloud formed a disk about 60 AU across and about one AU thick. Temperatures rose more rapidly near the center where the density and opacity were greatest. The center of the cloud may have been about 2000 K (3000° F), while the edge remained cold at about 100 K (-300° F). Dust vaporized near the center of the cloud, and atoms became ionized creating a magnetic field which permeated throughout the contracting mass.

C. **Transfer of angular momentum**
   1. Duration: Perhaps as short as a few thousand years
   2. **Magnetohydrodynamic effect transferred the sun's spin** away from the inner to the outer solar system (Alfven-1954).
      a. Early contracting sun had a strong magnetic field.
      b. Area immediately surrounding the sun was composed of ionized particles. Charged particles interacted with the magnetic field so that they spiraled outward along the magnetic lines of force. These magnetic lines returned to the sun, trapping the ions.
      c. The sun was rotating faster than the ions in its vicinity.
      d. The magnetic field lines of the sun, sweeping through the plasma tended to accelerate the cloud, increasing its rotational velocity at the expense of the sun's spin. Angular momentum was transferred away from the sun.
      e. The drag effect of the cloud against the sun also tended to decrease the rotational velocity of the sun.
      f. **Differences in composition between the inner and outer planets** can be accounted for.

1) The magnetic field of the sun tended to accelerate the more positively charged ions (which were mostly volatile substances) away from the sun while the more refractory materials condensed in the cooling solar nebula. The condensation process is not yet understood, but it must have happened. Once condensation occurred, refractory substances such as iron, nickel, and silicate grains would no longer have been affected by the solar magnetic field, because they would have been neutral. This matter would have collected into the more refractory terrestrial planets of the inner solar system.

2) The volatiles would have remained charged and thus affected by the sun's magnetic field for a longer period of time. These materials would have spiraled away from the sun along the sun's magnetic field lines and condensed much farther away in the cooler regions where the Jovian planets orbit the sun today.

g. The basic problem with the Magnetohydrodynamic Effect lies with the strength of the sun's magnetic field. It would have been at least 150,000 times stronger than it is today. Presently the field strength of the sun is approximately two Gauss, which is four to six times that of the Earth's field strength.

D. **Formation of grains and planetesimals**

1. **Grains condensed** with their composition dependent upon the temperature of the immediate environment. Generally, the denser terrestrial materials formed nearer to the sun, while icy materials condensed farther away.
2. **Grains collided to form planetesimals,** small bodies ranging in size from millimeters to 10 kilometers. They grew through direct physical collisions with each other.

E. **Evolution of the planets from protoplanets**

1. **Planetesimals became protoplanets** once their masses became great enough to possess an effective gravitational field. The ability of protoplanets to obtain more mass was not limited strictly to their cross sectional areas, as it was for planetesimals. At this point the protoplanet population rapidly assembled into the solar system that we know today.
2. **The sun initiates thermonuclear fusion.** Solar wind (particles) and solar radiation (energy) swept out the remaining gaseous materials from the nebular disk.
3. **The inner planets became heated and melt.** Their primordial atmospheres were lost. Outgassing from these bodies through volcanic eruptions eventually created secondary atmospheres. The Jovian planets because of their great masses retained their primeval atmospheres which are similar to the composition of the present-day sun.

F. **Demonstrations**

1. Conservation of angular momentum wheel
2. Conservation of angular momentum using a ball, string, and spool
3. Fahrenheit 451 demonstration (tube and plunger)
4. Size of the solar system modeled from a sun 84 inches in diameter. **If a hydrogen atom were enlarged to the same size as the sun, the electron would be in orbit around the nucleus 3.3 times the distance from the sun to Neptune.** There is more empty space in an atom than there is in the solar system.
5. Solar system distances demonstrated by using a roll of paper towels. Each towel equals 1 AU.

NOTES

WORD LIST FOR THE INTRODUCTION TO THE SOLAR SYSTEM

1. **Accretion:** The building process which occurs as planets and other objects are formed. This can either happen through direct collision as with grains and planetesimals or helped along through gravitation attraction from larger proto-planets.
2. **Angular Momentum:** A property of any rotating or revolving system whose value depends on the distribution of mass and velocity about the axis of rotation or revolution (***Facts on File Dictionary of Astronomy,*** third ed., p. 14).
3. **Astronomical Unit (AU):** The earth-sun distance, equal to 93,000,000 miles.
4. **Axial tilt:** The inclination of the imaginary line about which a planet rotates to the perpendicular of that planet's orbital plane.
5. **Bode-Titius Relationship:** An arithmetical formula which allows for the accurate calculation of the spacing of the planets (and asteroids) from the sun. The exception to this relationship is Neptune.
6. **Celestial longitude and latitude:** A coordinate system similar to latitude and longitude, except based upon the ecliptic (latitude) and vernal equinox (longitude) as its major reference positions.
7. **Conservation of Angular Momentum:** The principle that in any system of rotating and/or revolving bodies the angular momentum of the system remains the same.
8. **Conjunction:** The alignment of two bodies in the solar system so that they have the same celestial longitude as seen from the earth.
9. **Counterclockwise:** Motion opposite to the direction of the movement of the hands of a clock. It is the preferred rotation and revolution directions of the planets and their larger moons.
10. **Density:** Mass divided by volume
11. **Dwarf Planets:** Bodies which meet all of the characteristics of a planet, except that they are not massive enough to clear their orbital spaces of debris.
12. **Eccentricity:** The "ovalness" of an elliptical orbit. It is more precisely defined as the distance between the foci of an ellipse divided by the major axis, or the distance between one focus and the center of the ellipse divided by the semi-major axis of the ellipse.
13. **Elongation:** The angular separation of an astronomical body from the sun measured from zero to 180 degrees.
14. **Field:** A force which goes beyond the properties of the matter which is creating it.
15. **Flux line:** An area of higher magnetic intensity found within a magnetic field…
16. **Grains:** The very first and smallest particles which are formed as the result of the condensations of neutral atoms and molecules in the cooling solar or stellar nebula. The process which allows this to happen is currently not understood by astronomers.
17. **Greatest Elongation:** The largest angle that an inferior planet can be found east or west of the sun. If the elongation is east of the sun, the planet sets in the west after sundown. If the elongation is to the sun's west, the planet rises before the sun in the east.
18. **Inclination** (with respect to orbits)**:** The tilt of a planet's orbital plane with respect to the orbital plane of the earth (ecliptic). The solar system's thickness with respect to its size is equivalent to stacking three CD disks together.
19. **Inferior Conjunction:** A planet interior to the earth's orbit which has an elongation of zero, and is located between the sun and the earth.
20. **Inferior planet:** A planet that revolves around the sun the sun inside of earth's orbit.

21. **Magnetic field**: A field created by the flow of similarly charged particles in the same direction or the alignment of the spin axes of atoms in a substance.
22. **Magnetohydrodynamic Effect:** A process through which a hot proto-star with a very strong magnetic field transfers volatile materials away from its center while leaving unaffected condensed refractory materials nearer to the star. During the course of events angular momentum is transferred from the proto-star to the objects that will condense at much greater distances from it.
23. **Mass:** The quantity of matter an object contains.
24. **Natural Satellite:** An object of lesser mass revolving around a body of greater mass created without human intervention.
25. **Nebular Hypothesis:** The general theory of solar system formation which supposes that a large cloud of dust and gas gravitationally contracted to form the sun, planets, dwarf planets, and small solar system bodies.
26. **OB Associations:** A cluster of massive blue supergiant stars is created by a stellar wind/shock front in a large hydrogen cloud. This OB association in turn creates a shock front which leads to the formation of other clusters of blue supergiant stars which ripple through the hydrogen cloud. OB stars are the hottest, most massive, and the first stars formed in a stellar cluster.
27. **Opposition:** A superior planet located at an elongation of 180 degrees from the sun. At opposition, the planet rises when the sun sets and sets when the sun rises.
28. **Planet:** A natural satellite of the sun or another stellar system. Officially it must be (1) round, (2) orbit the sun, (3) cannot orbit another planet, and (4) it must clear its orbital space of debris.
29. **Planetesimals:** Pebble-sized objects to perhaps bodies several miles (km) in diameter. Accretion occurs from direct collisions with other grains and planetesimals because these bodies have low masses and very small gravitational fields.
30. **Proto-Planets:** The final stage in the accretion process which produces planetary bodies. These objects grow rapidly because they possess a sufficient amount of mass to attract debris gravitationally.
31. **Proto-Sun/Proto-Star:** A star in the process of gravitational collapse, but without sufficient internal temperatures and pressures to initiate thermonuclear fusion.
32. **Quadrature:** A superior planet that is located at an angle of 90 degrees east or west of the sun. If the planet is located east of the sun, it is in eastern quadrature and it is visible after sundown; if the planet is located 90 degrees to the west of the sun, it is at western quadrature and it is visible in the morning before sunrise.
33. **Radius:** Linear distance measured from the center to any point along the boundary of a circle or sphere. The volume of a sphere equals $^4/_3\ \pi\ (r)^3$.
34. **Refractory:** Materials which have a high melt and high boil temperature. Iron or rocky substances are good examples of this.
35. **Revolution Period:** The amount of time an object requires to complete one orbit around its primary.
36. **Rotation Period:** The amount of time a body requires to complete one spin about its axis.
37. **Shock Front:** An area of higher density moving within a medium of lower density. Shock fronts are considered one of the prime ingredients in the triggering of star formation.
38. **Sidereal Period:** The amount of time it takes a planet to complete one revolution around the sun.

39. **Small Solar System Bodies:** The general classification of solar system objects which do not meet the criteria of planets and dwarf planets. They generally revolve around the sun in orbits of higher inclination and eccentricity, and include asteroids, comets, Kuiper belt objects, members of the Oort cloud, and meteoroids.
40. **Superior Conjunction:** An inferior planet which has an elongation of zero as seen from the earth. The sun is located between the earth and the planet beyond earth's orbit.
41. **Superior planet:** A planet that revolves around the sun outside of earth's orbital path.
42. **Supernova:** An old massive red supergiant star that explodes, seeding the universe with heavier elements.
43. **Surface gravity:** The force of attraction acting on a less massive object at the radius of a more massive body.
44. **Synodic period:** The amount of time it takes a planet to repeat two similar elongations.
45. **Volatiles:** Materials which have low melt and boil temperatures. As an example, water would be considered a volatile substance.

NOTES

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT THE FORMATION OF THE SOLAR SYSTEM?

SCIENTIFIC THEORY/INTRODUCTION

1. A theory cannot gain acceptance with the scientific community unless ________________ verify the concepts of the hypothesis.

2. The ___________________________ involves the recognition of a problem, the collection of data through observations and experimentation, and the formulation and testing of hypotheses.

3. The theory which explains that the planets and their moons were born from the collision or near collision of the sun and another star is the major idea expressed by the ____.

4. The ________________ hypothesis basically states that the solar system had its origin from the collapse of a large cloud of gas and dust about five billion years ago.

5. If the ________________ theory is correct then stars with planets revolving around them should be quite COMMON/RARE (circle one) in our galaxy.

6. Write the names of the planets in their traditional order from the sun.

DEFINITIONS

7. A natural satellite of the sun or another star is referred to as a ____________________.

8. The distance from the sun to the earth, 93 million miles (150 million km), is the basis for a unit of measurement called the ______________________________.

9. The amount of time it takes for a planet to make one _______________ around the sun or a primary body is called a planet's s______________ or orbital period.

10. The plane of the Earth's orbit, created by Earth's motion as it sweeps around the sun, is referred to as the ________________.

11. The tilt of a planet's orbital plane with respect to Earth’s orbital plane is referred to as that planet's orbital ________________.

12. _______________ is a measurement of the "ovalness" of an elliptical orbit. More precisely it is the measurement of the distance between the foci of an ellipse divided by the major axis of the ellipse.

13. The time period it takes for a body to make one complete spin about its axis is referred to as that body's ________________ period.

14. The _____________________ of a planet represents the inclination of the imaginary line about which a planet rotates to the perpendicular of that planet's orbital plane.

15. The quantity of matter an object contains represents that object's ________________.

16. Which is more massive, 100 pounds of lead or 100 pounds of feathers? Explain your reasoning.

17. A body has a mass of 50 kilograms at the surface of the Earth. What will be the mass of the same body at an altitude of 6000 kilometers above the earth's surface?

18. The distance from the center of a circle or sphere to its boundary is called the _________________.

19. The area of a circle is a "squared" relationship while the volume of a sphere is a __________________ relationship.

20. Mass divided by volume equals the __________________ of the body.

21. The force of attraction acting on a less massive body at the radius of a more massive object equals the ______________________ of that object.

22. A natural __________________ is a body of lesser mass revolving around a body of greater mass formed as a consequence of natural evolution.

THE ELLIPSE

23. Planets revolve around the sun in orbits which are in the shape of an ________________.

24. The longest axis of an ellipse, the ______________________, intersects the center of the ellipse, the two _________________, and the orbital point where the planet is closest and farthest from the sun.

25. The sum of the distances from one focus to any point on the boundary of an ellipse to the other focus must always be the _________________, and always be equal to the _____________________ of the ellipse.

26. The point in a planet's orbit where it is closest to the sun is called _________________.

27. The point in a planet's orbit where it is farthest from the sun is called ________________.

28. The perihelion distance plus the aphelion distance of a planet from the sun divided by two equals the ________________ distance of the planet from the sun.

29. The average distance of a planet from the sun, multiplied by the ________________, plus or minus the average distance of the planet from the sun, allows for the calculation of the ________________ and ________________ distance of the planet from the sun.

CHARACTERISTICS OF THE SOLAR SYSTEM

30. The sun comprises more than ________________ of the total mass of the solar system.

31. Planetary orbits all lie near the plane of the ________________.

32. The rotational axis of the sun is nearly ________________ to the plane of the solar system.

33. Planetary eccentricities are so small that the orbital paths of these bodies look basically like ___________________.

34. The direction of revolution of all of the planets is the ________________. With respect to a clock face, this directional motion is always represented as _____________________.

35. Planetary rotations are in the same ________________ as the planet revolves, and the axial tilts of the planets are basically ________________ to a planet's orbital planes.

36. The Bode-Titius "law" indicates that there may be a ________________ relationship with respect to the distances of the planets from the sun.

37. Jupiter and Saturn contain 99% of the _____________________ of the solar system.

38. The formula which represents the answer to the last question is $L = (mr^2)\omega$; where "L" equals ______________________, "r" is the ________________, "m" is equivalent to the ________________, and "ω" represents the ______________________.

39. If a rotating body could be made to contract, the rate of its spin would INCREASE/DECREASE (circle one).

40. In the solar system there are two distinct classes of objects, the Jovian planets and the terrestrial planets. These can be identified by their differences in ________________, _______________, _______________, and ________________.

41. _______________, _______________, and _______________ form distinct classes of objects in the solar system which must be explained with respect to their origin and evolution. Why are these objects classified uniquely?

MODERN NEBULAR HYPOTHESIS REVEALED

42. Name two methods for collecting gas and dust in sufficiently large quantities that would allow gravity to initiate the collapse of this material to possibly form a star and planetary system.
a. ___________________________________ b. ___________________________________

43. In order for the nebular hypothesis to work, a large cloud of gas and dust must obtain a high enough _________________ for it to collapse due to the force of _________________ acting upon itself.

44. Once a cloud of gas and dust begins to collapse, gravitational forces acting on the nebula causes it to ________________ (hint: a shape) and spin more ________________. Temperatures in the interior of the cloud become LOWER/HIGHER (circle one).

45. The early sun possessed large quantities of plasma which was in rapid motion. Anytime large quantities of charged particles are made to move or flow, a _____________________ is produced.

46. A large magnetic field was inherent in the early sun. It affected the motion of the plasma in the near vicinity of the sun, causing it to _______________ around the field lines and move AWAY/TOWARDS (circle one) the sun.

47. Once the plasma reached a cooler area of the solar system it became _______________ and was no longer affected by the sun's magnetic field.

48. Not only was a large quantity of matter transported away from the sun, but this situation also caused the sun to spin more slowly as **a_______________m________________** was transferred from the inner solar system to the region of Jupiter and Saturn.

49. In the formula $L = (mr^2)\omega$, a change in "m"/"r" (circle one) was responsible for slowing the rotation of the sun?

50. Materials which boil and condense at low temperatures are considered _________________.

51. Since the region around the early sun was very hot, the low melt, low boil materials remained in a plasma state for a much longer time period. The inner planets were able to accrete (come together) from material with a much HIGHER/LOWER (circle one) condensation temperature. This type of material is called _________________ matter. These inner planets would be expected to have much higher densities and therefore possess proportionately larger amounts of rocky material, as well as proportionately larger nickel-iron cores than the Jovian worlds.

52. The volatiles which remained in an ionized state for a much longer period of time and were affected by the early sun's magnetic field for a much longer period of time, eventually cooled and became neutral in the OUTER/INNER (circle one) solar system.

53. The whole process which explains the sun's loss of angular momentum and the differentiation of the inner planets from the outer planets is called the ____.

54. Cooling and condensation continued resulting in the formation of small bits and pieces of dust and ice which accreted by colliding with other particles of similar size. These small particles of material are called __________________.

55. When clumps of matter were massive enough to possess a sufficiently strong enough gravitational field, so that they could accrete with other concentrations of mass through gravitational interactions, the bodies were then called __________________. The solar system, as we know it today, then fell rapidly into place.

56. Provide a proper sequence for the following stages in the evolution of the solar system.
    a. Protoplanets
    b. Collapse of rotating nebula
    c. Angular momentum transferred/planetary differentiation occurs/sun forms
    d. Planetesimals
    e. Mechanism which collects matter
    f. Solar system as we know it today

57. The age of the solar system is about __________________ years.

GEOMETRY OF THE SOLAR SYSTEM

58. A planet which is nearer to the sun than the earth is termed an _________________ planet.

59. List below the superior planet in the solar system.

60. Two cars are moving down a highway in the same direction. Observing the motion of the slower moving vehicle from inside the faster moving vehicle, as the faster moving vehicle is passing the slower moving vehicle, will show the slower moving vehicle to be moving _________________ relative to the faster moving vehicle.

61. The phenomenon mentioned in the last problem, as it applies to the motion of the planets, is called ______________________.

62. Draw the following planetary configurations and list their times of rise and set: opposition, quadrature, conjunction, inferior conjunction, superior conjunction, greatest western elongation and greatest eastern elongation.

63. The ________________ period of a planets is simply another word for the revolution period of the planet.

64. The time period it takes a planet to move from one configuration to the next similar configuration is termed the planet's _______________ period.

65. Draw the four planetary configurations for an inferior and a superior planet.

ANSWERS TO SESSION SEVEN QUESTIONS

SCIENTIFIC THEORY/INTRODUCTION

1. observations
2. scientific method
3. catastrophic hypothesis
4. nebular (modern concept)
5. nebular, COMMON
6. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune

DEFINITIONS

7. planet
8. astronomical unit
9. revolution, sidereal
10. ecliptic
11. inclination
12. eccentricity
13. rotational
14. axial tilt
15. mass
16. neither. Both are 100 pounds and represent the same quantity of mass, even though the density (mass per unit volume) is much less for the feathers. The feathers are therefore bulkier, but not more massive than the lead.
17. the same. Mass is not weight, nor is it a measurement of a force like weight. Mass is simply the quantity of matter an object contains. The mass will remain unchanged regardless of its location in the universe.
18. radius
19. cubed
20. density
21. surface gravity
22. satellite

THE ELLIPSE

23. ellipse
24. major axis, foci
25. same, major axis
26. perihelion
27. aphelion
28. average
29. eccentricity, aphelion, perihelion

CHARACTERISTICS OF THE SOLAR SYSTEM

30. 99 percent
31. ecliptic
32. perpendicular
33. circles

34. same, counterclockwise
35. direction, perpendicular
36. mathematical
37. angular momentum
38. angular momentum, radius, mass, rate of spin
39. INCREASE
40. mass, size, density, composition
41. asteroids, comets, Kuiper Belt objects. They possess higher orbital inclinations (average 30 degrees) and eccentricities (average 0.3), and much smaller sizes which make them unique with regards to the planets in the solar system.

MODERN NEBULAR HYPOTHESIS REVEALED

42. a) supernova explosions, b) magnetic fields, c) O B associations
43. density, gravity
44. flatten, rapidly, HIGHER
45. magnetic field
46. spiral, AWAY
47. neutral
48. angular momentum
49. "r"
50. volatiles
51. HIGHER, refractory
52. OUTER
53. magnetohydrodynamic effect
54. planetesimals
55. protoplanets
56. e., b., c., d., a., f.
57. five billion

GEOMETRY OF THE SOLAR SYSTEM

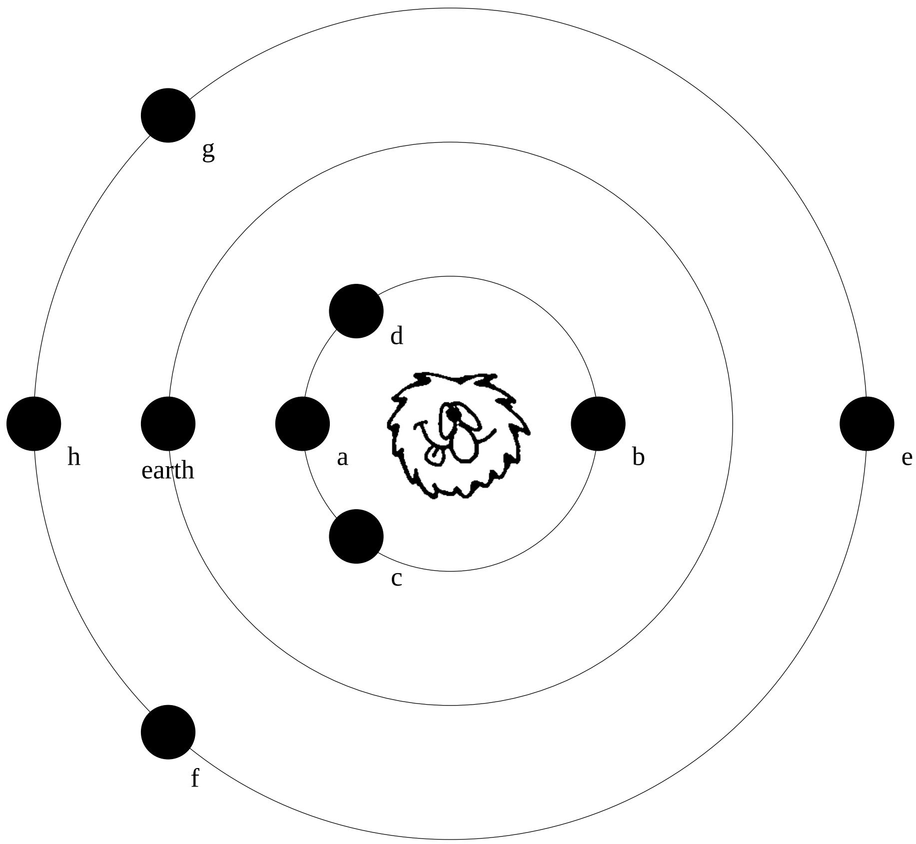
58. inferior
59. Mars, Jupiter, Saturn, Uranus, Neptune, Pluto
60. backwards
61. retrograde motion
62. See drawing on this page.
63. sidereal
64. synodic

65. INFERIOR PLANETS

a. inferior conjunction
R: 06:00 S: 18:00
b. superior conjunction
R: 06:00 S: 18:00
c. greatest western elongation
R: before sun
d. greatest eastern elongation
S: after sun

SUPERIOR PLANETS

e. conjunction
R: 06:00 S: 18:00
f. quadrature (western)
R: midn. S: noon
g. quadrature (eastern)
R: noon S: midn
h. opposition
R: 18:00 S: 06:00



December 30, 2013

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