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ENVI.2030L - The Solar System

I. **Physical characteristics of the solar system**

The solar system consists of the sun and 9 planets. Table 2 lists a number of the properties and characteristics of the sun and the planets. For questions 1 - 3 use the data in Table 2.

1. a. Determine the total mass of the planets.

   b. The total mass of the solar system is the mass of the sun plus the mass of the planets. The planets, on a percentage basis, comprise how much of the solar system? If we determine the chemical composition of the sun would this be a reasonable estimate of the chemical composition of the solar system? Why or why not?

2. Density is defined as mass per unit volume. For each of the planets determine the density in kg m^{-3} and fill in this row on Table 2. The formula for the volume of a sphere is $4/3\pi r^{3.}$

3. The planets are often divided into two groups: Terrestrial (or rocky) and Gaseous. Divide the planets into two groups using the various characteristics listed in Table 1. Fill in the table below. Which group represents the Terrestrial planets, which group the Gaseous planets?

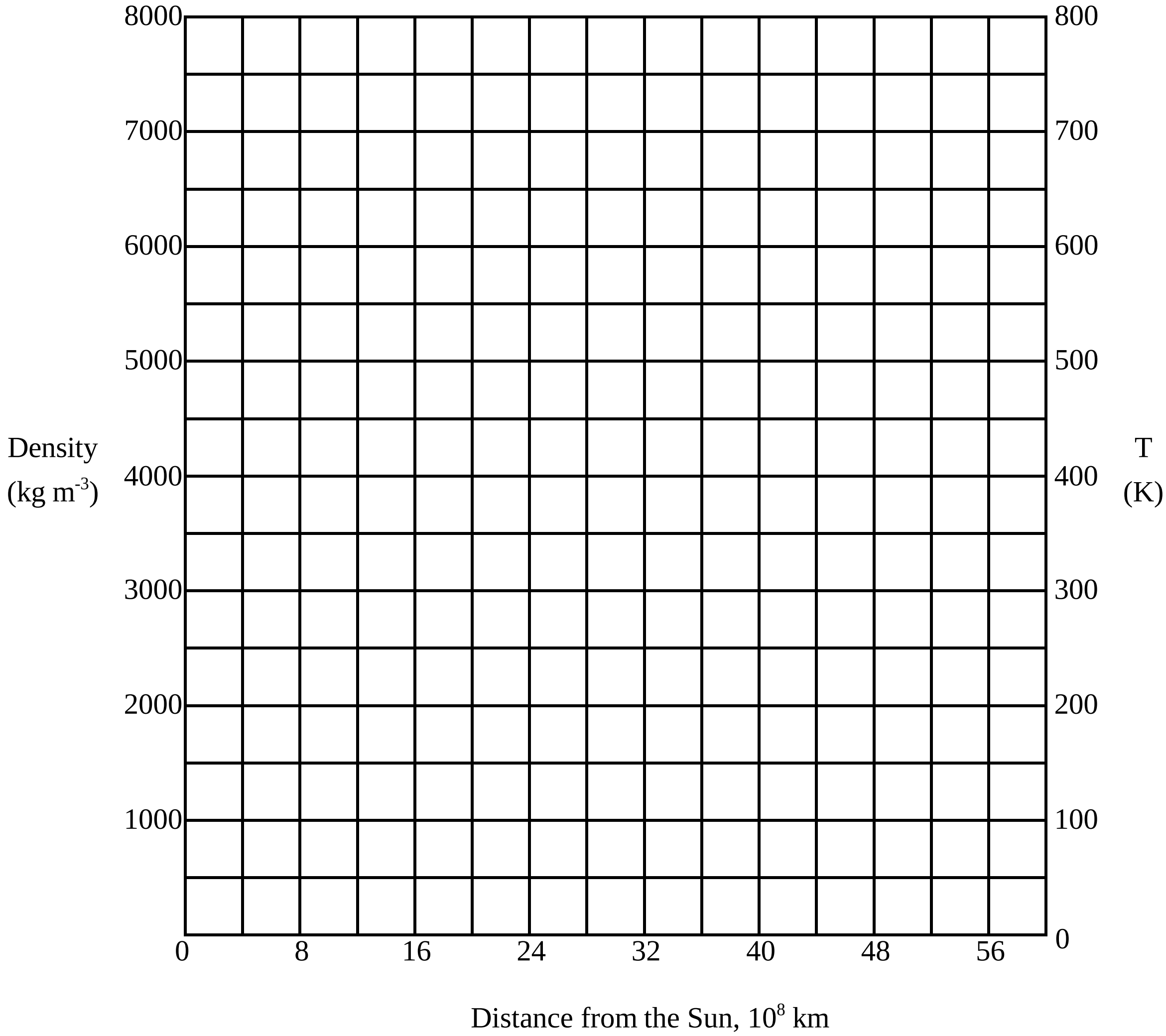
Table 1. Characteristics of the planets

	Group 1	**Group 2**
Planets in Group		
Characteristics		
Range in masses		
Range in diameters		
Range in densities		
Nature of surfaces		

Table 2. Summary of the physical characteristics of the sun and planets

	Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Average distance from sun (km)		$5.79x10^7$	$1.08x10^8$	$1.50x10^8$	$2.28x10^8$	$7.78x10^8$	$1.43x10^9$	$2.87x10^9$	$4.5x10^9$	$5.9x10^9$
Mass (kg)	$1.99x10^{30}$	$3.31x10^{23}$	$4.87x10^{24}$	$5.98x10^{24}$	$6.42x10^{23}$	$1.90x10^{27}$	$5.69x10^{26}$	$8.72x10^{25}$	$1.03x10^{26}$	$1.30x10^{22}$
Equatorial diameter (km)	$1.39x10^6$	4880	12,104	12,756	6796	142,796	120,660	51,118	49,500	2200
Density (kg m^{-3})	1415									
Length of Day (in Earth days)		58.6	243	1	1.05	0.41	0.44	0.72	0.67	6.4
Length of year (Earth years)		0.24	0.615	1	1.88	11.9	29.5	84	164.8	248.5
No. of moons		0	0	1	2	16	19	15	8	1
Surface character	Plasma	Rocky	Rocky	Rocky	Rocky	Gaseous	Gaseous	Gaseous	Gaseous	Icy
Avg. surface T (K)	5228	738	733	287	218	128	95	49	55	53
Atmos. P (Atm.)		0	99	1	0.0052	?	?	?	?	0
Atmos. Chemistry (Volume %)										
Co_2			96	0.05	95					
N_2			3	78	3					
o_2			0	21	trace					
Ar			trace	1	1.6					
H_2o			<1	<1	<0.1					
H						86	93	84	Not well known; Mainly H, He & CH_4	
He						14	6	14		
CH_4							trace	2		

On the graph below plot the density of each planet and the surface temperature of each planet as a function of distance from the sun. Use either different line styles or colors for density and temperature.



4. How does density vary with distance? Consider this in the context of question 3. You will also find this relationship useful when you do the section on the condensation of the planets from the solar nebula.

5. How does the temperature vary with distance from the sun?

II. ***Bode's Law***.

The spacing between the principal planets follows a simple relationship known as Bode's Law (formulated by Bode in 1772). The relationship is derived by writing the series 0, 3, 6, 12 ....(obviously you are doubling each succeeding number), adding 4 to each number and dividing the result by 10. The first number in the series corresponds to Mercury. The results of these calculations can then be compared to the observed spacing of the planets using the *Astronomical Unit (A.U.) - the distance from the sun to the earth*. Fill in Table 3 using the sun-planet distances from Table 2. For the Asteroid belt the average distance from the sun is 4.05 x 10^8 km.

Table 3. Data table for Bode's Law calculations

Planet	Series (+4)	Sum/10	Distance from Sun (A.U.)
Mercury	4	0.4	0.39
Venus			
Earth			
Mars			
Asteroids			
Jupiter			
Saturn			
Uranus			
Neptune			
Pluto			

6. How well does the spacing predicted from Bode's Law agree with the actual spacing of the planets? If there are some disagreements what might be the cause? The year when Bode's Law was formulated is an important factor in answering the second half of the question.

7. It has been suggested that the asteroids represent either fragments of a planet that was disrupted by the gravitational field of Jupiter or planetesimals that were never able to coalesce to form a planet because of the close proximity of Jupiter. In the context of Bode's Law is this a reasonable conclusion? Why?

III. Formation of the planets

The sun and the planets are thought to have formed from the solar nebula, a rotating cloud of interstellar gas that collapsed under its own gravitational forces. The nebula consisted largely of hydrogen and helium with smaller amounts of carbon, oxygen, nitrogen, iron, magnesium, silicon, calcium, titanium and other elements. The planets formed as the hot gaseous material cooled and condensed to form solids. The temperature at the location where condensation occurs determines the type of compounds that condense from the nebula (Figure 1).

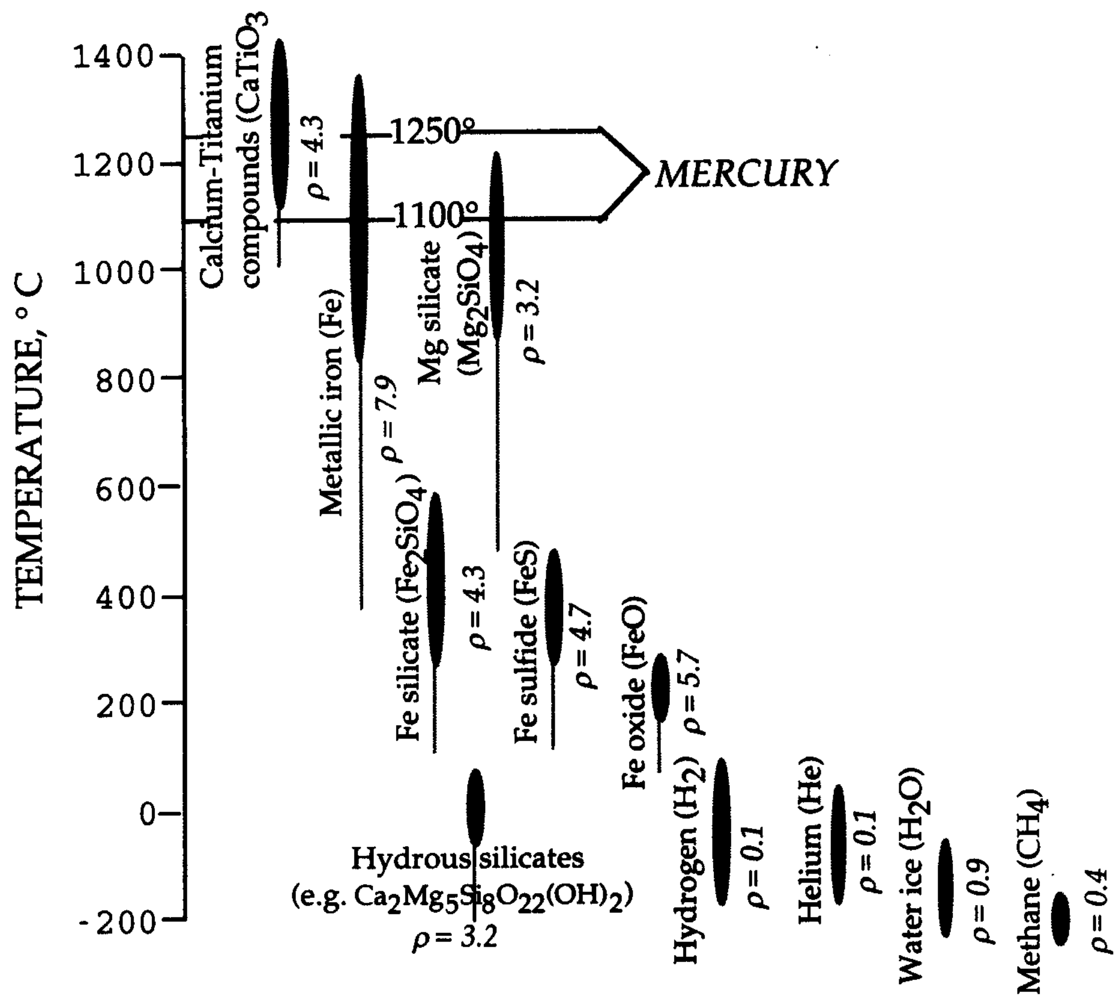


Figure 1. Compounds that would condense from the solar nebula with decreasing temperatures. Densities (ρ) are in g cm^{-3}. From Bj0rnerud, M. G., 1999. *Laboratory Manual to accompany the Blue Planet*. New York: John Wiley & Sons, p. 9.

The temperature of the solar nebula decreased with distance from the sun. Table 4 gives the inferred temperatures in the solar nebula when compounds were condensing at the distances now occupied by the planets. Using the data in Table 4 plot the maximum and minimum temperatures at each location on the graph below and draw two curves connecting the maximum and minimum temperatures respectively.

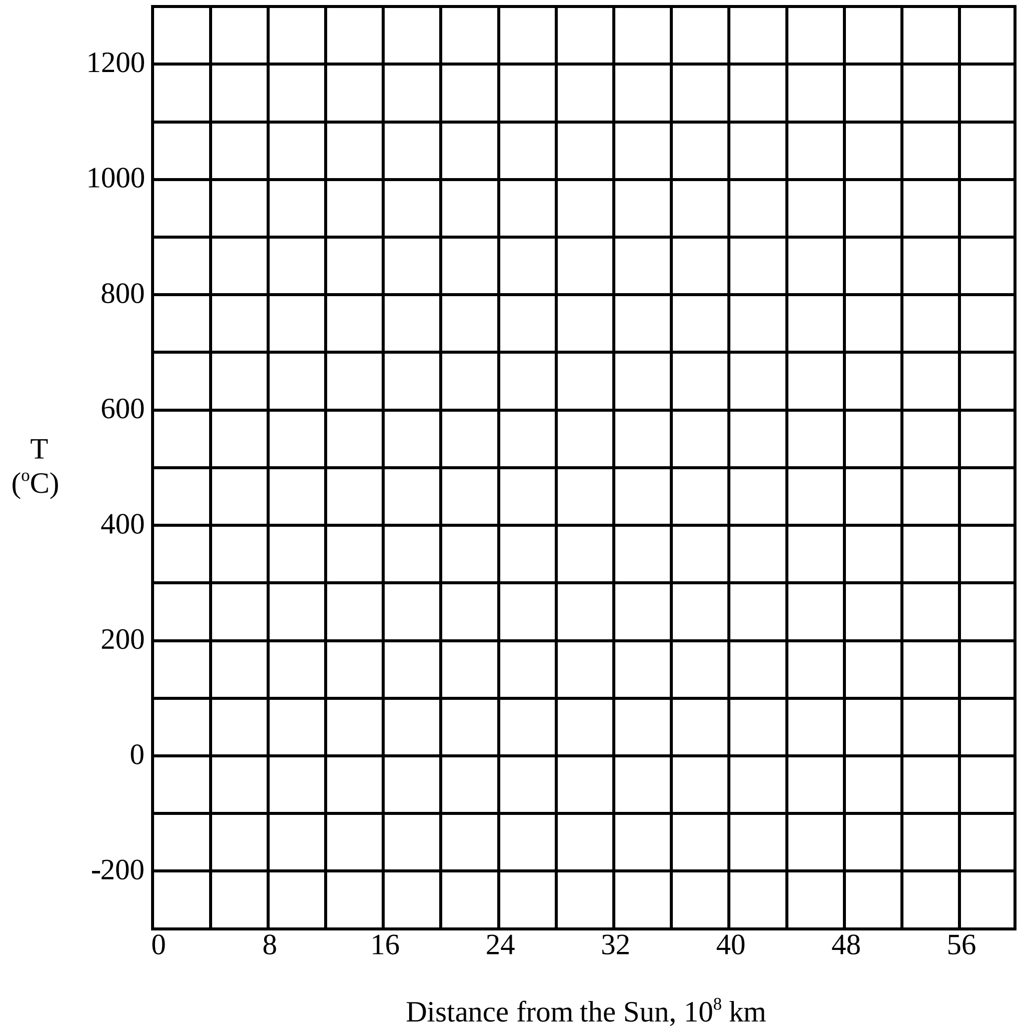


Table 4. Data for condensation of solids from the solar nebula

Planet	**Temperature (ºC)**	**Chemical Composition**	**Density Range (g cm^{-3})**
Mercury	1100 → 1250	Metallic Fe, $CaTiO_3$, Mg_2SiO_4	3.2 → 7.9
Venus	600 → 900		
Earth	250 → 550		
Mars	150 → 250		
Jupiter	0 → 100		
Saturn	-100 → 0		
Uranus & Neptune	-150 → -100		
Pluto	-200		

8. On Figure 1 draw lines, as illustrated for Mercury, that represent the lowest and highest temperature for the condensation of solids at the distance for each planet. In Table 4 enter the chemical compositions in order of abundance for the main compounds that would have condensed from the solar nebula at each location. Also enter the range of expected densities.

9. Given the characteristics for the planets that you listed in Table 1, is this model of planet formation realistic? Explain.

10. At the average distance for the asteroid belt, what would be the range of temperatures during condensation from the solar nebula. What compounds would you expect to condense at these temperatures and what would be the range of densities. Is it reasonable to conclude that the asteroids may represent pieces of a terrestrial planet? Why or why not?