Name:____________________________ Section:____________________

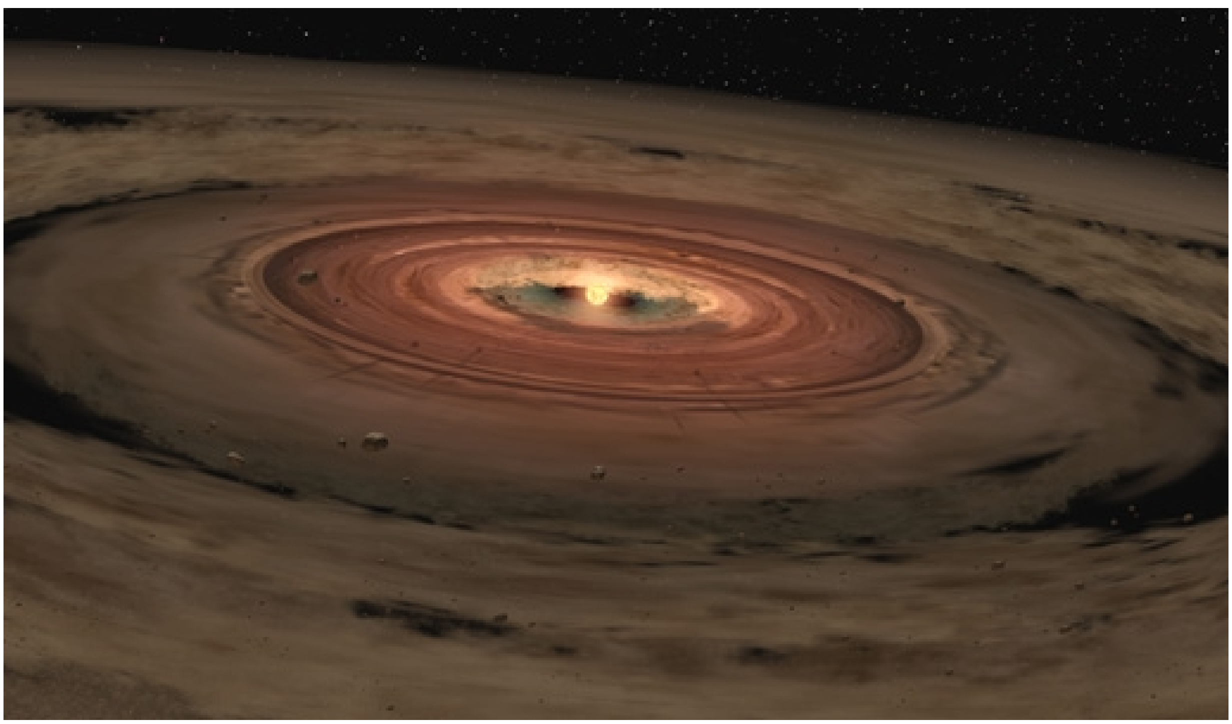
Earth 110 – Exploration of the Solar System

Assignment 2: Solar System Formation Due in class Tuesday, Jan. 26, 2016

Can we use our observations of the solar system to explain how it formed? Humans have been observing the heavens ever since we knew how to look up, but what good are observations if you don't use them? People used the patterns of planetary motion to come up with hypotheses on how our solar system formed. Two 18th century scholars proposed the hypothesis that would ultimately result in modern theory of solar system formation, but it wasn't until the 20th century that we were able to combine more detailed observations with computer models that incorporate groundbreaking mathematical and physical concepts. From this, we were able to reject certain hypotheses that didn't fit the data, and further test hypotheses that made sense of the world around us. One hypothesis in particular was able to explain the data in a logical way and is now known as the nebular theory. Observations of solar systems other than our own have required a few modifications to the nebular theory but the basic process of formation is well established.

This assignment draws from material presented in Chapters 7 and 8. Chapter 7 outlines the planets in our solar system, giving some detailed information for each. Chapter 7 provides the observations that Chapter 8 uses to establish the theory of solar system formation and how scientists are able to determine how long ago this process began.

For all calculations, make sure to show your work, include units, and clearly mark your answers. Working in pencil is HIGHLY recommended.



Artist's concept of solar system formation (Image credit: NASA/JPL-Caltech).

Features of our Solar System

There are four important features about our solar system that can help explain how it formed. We will be using an interactive application developed by NASA to explore the solar system. Go to eyes.nasa.gov and click on the “DOWNLOAD THE APP TO GET STARTED” box. Download the program and install it. Open NASA’s Eyes, and run the “Simple” mode of “Eyes on the Solar System”. You will have to switch into “Advanced” mode to zoom in and out for some of the answers.

1. *Motion*
   Look down onto the planets. What do you notice about the shape of their orbits?

   Now look at the planets edge on. What pattern do you see?

   What direction do the planets orbit in? Do they all orbit in the same direction? What about their rotation?

   Do all of the moons share the same motion properties as the planets they orbit? If not, which don’t?

2. *Types of Planets*
   In our solar system, there are two major types of planets. The terrestrial, or rocky, planets make up the inner solar system and the jovian, or gas giants, make up the outer solar system.
   What are the average densities of the two types? What does this tell us about their average composition (compare with densities of metal, rock, ice, and gas)?

3. *Asteroids and Comets*
   While using NASA's Eyes, click "Destination", then choose Asteroids and then Comets. What are three main differences between asteroids and comets?

4. *Exceptions to the Rule*
   What are some exceptions you found while answering the above questions?

<u>Exploration Missions</u>

There are four types of exploration missions: flyby, orbiter, lander/probe, and sample return. While using NASA's Eyes, click on "Missions" and select a mission of your choice (except for the Astronomy Missions).

Which mission is it and where did it go? What type of mission is it? What was its objective? How did it help us learn more about the object it visited and the solar system as a whole? Be specific. You may have to do some extra searching for some of this information.

Solar System Formation

The nebular hypothesis was first developed around 1755 by German philosopher Immanuel Kant and about 40 years later independently by French mathematician Pierre-Simon Laplace. In this hypothesis, he proposed that our solar system formed as a result of the gravitational collapse of an interstellar gas cloud. Today, we call this the *nebular theory* because it explains the four major features of our solar system (discussed above).

In the nebular theory, the solar nebula probably began as an interstellar gas cloud. This cloud gets perturbed in some way (like a shock wave from a nearby supernova) that causes the gas and dust to group together and collapse. Once it starts to collapse, its gravity starts to increase (the diameter of the cloud gets smaller but its mass doesn't change) which creates a positive feedback loop (remember that gravity pulls *inward*). As the nebula shrank, three things happened:

- **Heating**: The nebula began to heat up because its potential energy was converted to kinetic energy. The highest temperatures and densities were at the center and formed the Sun.
- **Spinning**: Just like an ice skater spins faster as she pulls her arms inward, the nebula rotated faster as it shrank. The rapid rotation ensured that gas and dust would not all collapse to the center: a greater angular momentum of a rotation means material will be more spread out (think about the spinning carnival ride: the faster you spin, the greater the force is that pins you to the wall because it's trying to fling you outward).
- **Flattening**: Particles within the cloud began colliding and merging with each other, reducing random motions and creating order. As these particles clumped and slowed down, they began to sink and gather at the mid-plane, forming a flattened disk.

Since the original nebula was not homogeneous, it meant that some regions in the disk contained different material than other regions. For example, rock and metal have much higher condensation temperatures (temperatures at which solids can form) than ices, so they are more stable closer to the Sun. As material condensed, it collided, clumped, and began forming planetesimals, a process known as *accretion*.

How are the first three features of our solar system (from pgs. 2 and 3) explained by the nebular theory?

Why are the gas giants so big compared to rocky planets (think about the amount of material present as you move farther from the center of the disk)? Why were they able to retain so much gas before it was cleared by the solar wind and radiation? How would the gas surrounding the jovian planets affect the objects around them (think about what happens when two particles with different speeds interact)?

As planetesimals grew into protoplanets, their gravity increased thus causing their interactions with other objects to become more violent. How could these violent interactions explain some of the exceptions to the rule, the fourth major feature of our solar system?

Check out Figure 8.13 for a nice summary of the nebular theory.

The Age of the Solar System

How do we know the age of the solar system? Rocks contain radioactive isotopes, which are chemical elements that are unstable because they have a different number of neutrons than their stable counterparts. Each isotope has a specific, predictable radioactive decay time and process. For example, Potassium-40 (called the *parent* isotope, which is still radioactive) decays to Argon-40 (called the *daughter* isotope, which is stable) with a half-life of 1.25 billion years. So, if you have two grams of Potassium-40, in 1.25 billion years half of it (one gram) will have decayed to Argon-40. Scientists are able to use radiometric dating to determine a rock's age, indicating how long ago the rock solidified.

How is radiometric dating of an Earth rock not completely accurate when determining the age of the Earth, or the age of the solar system?

You date a rock using the Potassium-Argon system and find that it contains three times as much Argon-40 than Potassium-40. How old is the rock?

You are analyzing a Moon rock using Uranium-238, which decays to Lead-206 with a half-life (t_{half}) of 4.47 Gy (billion years). How old is the rock (t) if 58% of the original U-238 is present, while the other 42% has decayed to Pb-206? Use the equation

$$t = t_{half} \times \frac{\log_{10}\left(\frac{current\_\_radioactive\_amount}{original\_radioactive\_amount}\right)}{\log_{10}\left(\frac{1}{2}\right)}$$

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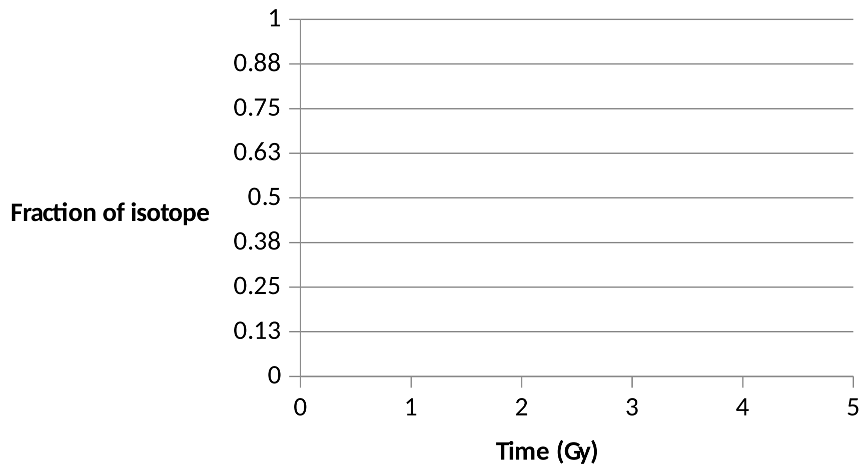
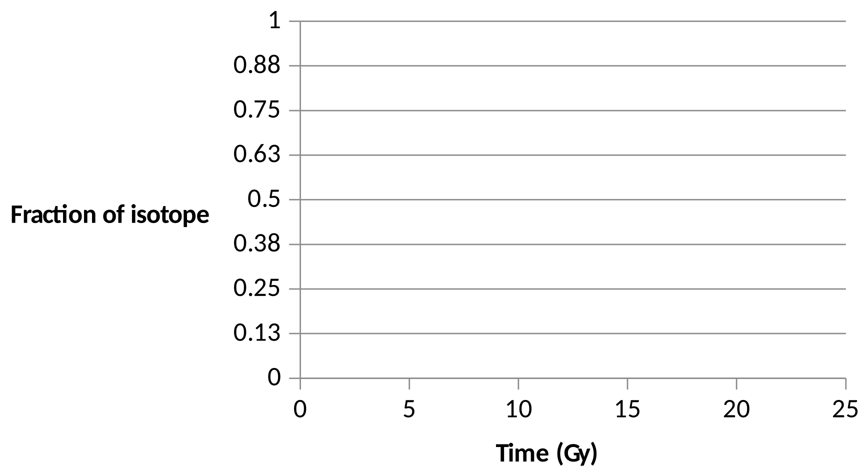
On the graphs below, plot the fractional amount of parent and daughter isotopes over time for two systems: Uranium-238 decaying to Lead-206 (t_{half} = 4.47 Gy) and Uranium-235 decaying to Lead-207 (t_{half} = 713 My (million years)). Include the graph title, curve labels, and work showing how you got each x-y point. Use Figure 8.14 as a reference.





Use the graphs from the previous page to answer the following questions:

Which system is best used to date most Earth rocks? Meteorites? Why?

Which system is more radioactive?

How many half-lives before there is almost no (<1%) Uranium-238 left? Almost no Uranium-235?

Why isn't the curve a straight line (why does it plateau)?