Chapter 8
Formation of the Solar System

8.1 The Search for Origins

Our goals for learning:

- What properties of our solar system must a formation theory explain?
- What theory best explains the features of our solar system?

What properties of our solar system must a formation theory explain?

1. Patterns of motion of the large bodies
   - Orbit in same direction and plane
2. Existence of two types of planets
   - Terrestrial and jovian
3. Existence of smaller bodies
   - Asteroids and comets
4. Notable exceptions to usual patterns
   - Rotation of Uranus, Earth's moon, etc.

What theory best explains the features of our solar system?

- The *nebular theory* states that our solar system formed from the gravitational collapse of a giant interstellar gas cloud—the *solar nebula*

  (*Nebula* is the Latin word for cloud)
- Kant and Laplace proposed the *nebular hypothesis* over two centuries ago
- A large amount of evidence now supports this idea

Close Encounter Hypothesis

- A rival idea proposed that the planets formed from debris torn off the Sun by a close encounter with another star.
- That hypothesis could not explain observed motions and types of planets.

What have we learned?

- What properties of our solar system must a formation theory explain?
  - Motions of large bodies
  - Two types of planets
  - Asteroids and comets
  - Notable exceptions like Earth's moon
- What theory best explains the features of our solar system?
  - Nebular theory states that solar system formed from a large interstellar gas cloud.

8.2 The Birth of the Solar System

Our goals for learning:

- Where did the solar system come from?
- What caused the orderly patterns of motion in our solar system?

Galactic Recycling

- Elements that formed planets were made in stars and then recycled through interstellar space

Evidence from Other Gas Clouds

- We can see stars forming in other interstellar gas clouds, lending support to the nebular theory

Interactive Figure

What caused the orderly patterns of motion in our solar system?

Conservation of Angular Momentum

- Rotation speed of the cloud from which our solar system formed must have increased as the cloud contracted

Rotation of a contracting cloud speeds up for the same reason a skater speeds up as she pulls in her arms

Flattening

- Collisions between particles in the cloud caused it to flatten into a disk

Collisions between gas particles in cloud gradually reduce random motions

Collisions between gas particles also reduce up and down motions

Spinning cloud flattens as it shrinks

What have we learned?

- Where did the solar system come from?
  - Galactic recycling built the elements from which planets formed.
  - We can observe stars forming in other gas clouds.
- What caused the orderly patterns of motion in our solar system?
  - Solar nebula spun faster as it contracted because of conservation of angular momentum
  - Collisions between gas particles then caused the nebula to flatten into a disk
  - We have observed such disks around newly forming stars

8.3 The Formation of Planets

Our goals for learning:

- Why are there two major types of planets?
- How did terrestrial planets form?
- How did jovian planets form?
- What ended the era of planet formation?

Conservation of Energy

As gravity causes cloud to contract, it heats up

Inside the ***frost line***: Too hot for hydrogen compounds to form ices.

Outside the ***frost line***: Cold enough for ices to form.

How did terrestrial planets form?

- Small particles of rock and metal were present inside the frost line
- Planetesimals of rock and metal built up as these particles collided
- Gravity eventually assembled these planetesimals into terrestrial planets

Tiny solid particles stick to form ***planetesimals.***

Gravity draws ***planetesimals*** together to form planets

This process of assembly is called ***accretion***

Accretion of Planetesimals

- Many smaller objects collected into just a few large ones

How did jovian planets form?

- Ice could also form small particles outside the frost line.
- Larger planetesimals and planets were able to form.
- Gravity of these larger planets was able to draw in surrounding H and He gases.

Gravity of rock and ice in jovian planets draws in H and He gases

A combination of photons and the ***solar wind*** —outflowing matter from the Sun—blew away the leftover gases

Solar Rotation

- In nebular theory, young Sun was spinning much faster than now
- Friction between solar magnetic field and solar nebular probably slowed the rotation over time

What have we learned?

- Why are there two types of planets?
  - Only rock and metals condensed inside the frost line
  - Rock, metals, and ices condensed outside the frost line
- How did the terrestrial planets form?
  - Rock and metals collected into planetsimals
  - Planetesimals then accreted into planets
- How did the jovian planets form?
  - Additional ice particles outside frost line made planets there more massive
  - Gravity of these massive planets drew in H, He gases

What have we learned?

- What ended the era of planet formation?
  - Solar wind blew away remaining gases
  - Magnetic fields in early solar wind helped reduce Sun's rotation rate

8.4 The Aftermath of Planet Formation

Our goals for learning:

- Where did asteroids and comets come from?
- How do we explain “exceptions to the rules”?
- How do we explain the existence of our Moon?
- Was our solar system destined to be?

Asteroids and Comets

- Leftovers from the accretion process
- Rocky asteroids inside frost line
- Icy comets outside frost line

Heavy Bombardment

- Leftover planetesimals bombarded other objects in the late stages of solar system formation

Origin of Earth's Water

- Water may have come to Earth by way of icy planetesimals

Captured Moons

- Unusual moons of some planets may be captured planetesimals

Giant Impact

Giant impact stripped matter from Earth's crust.

Stripped matter began to orbit…

…then accreted into Moon.

Odd Rotation

- Giant impacts might also explain the different rotation axes of some planets

Was our solar system destined to be?

- Formation of planets in the solar nebula seems inevitable
- But details of individual planets could have been different

What have we learned?

- Where did asteroids and comets come from?
  - They are leftover planetesimals, according to the nebular theory
- How do we explain "exceptions to the rules"?
  - Bombardment of newly formed planets by planetesimals may explain the exceptions
- How do we explain the existence of Earth's moon?
  - Material torn from Earth's crust by a giant impact formed the Moon
- Was our solar system destined to be?
  - Formation of planets seems invevitable.
  - Detailed characteristics could have been different.

8.5 The Age of the Solar System

Our goals for learning:

- How does radioactivity reveal an object's age?
- When did the planets form?

How does radioactivity reveal an object's age?

Radioactive Decay

- Some isotopes decay into other nuclei
- A **half-life** is the time for half the nuclei in a substance to decay

When did the planets form?

- Radiometric dating tells us that oldest moon rocks are 4.4 billion years old
- Oldest meteorites are 4.55 billion years old
- Planets probably formed 4.5 billion years ago

What have we learned?

- How does radioactivity reveal an object's age?
  - Some isotopes decay with a well-known half-life
  - Comparing the proportions of those isotopes with their decay products tells us age of object
- When did the planets form?
  - Radiometric dating indicates that planets formed 4.5 billion years ago