I. Solar System Overview

0. Units and calculations

1. Constituents of the Solar System

2. Motions: Rotation and Revolution

3. Formation Scenario
Units

Text uses MKS units (meter, kilo-gram, second); e.g.

\[ G \approx 6.674 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2} \] (gravitational constant).

Astronomers also use non-standard units:

\[ \text{AU} \approx 1.496 \times 10^{11} \text{ m} \] (“average” Earth-Sun distance)

\[ \text{yr} \approx 3.156 \times 10^7 \text{ s} \] (Earth’s orbital period)

\[ M_\odot \approx 1.989 \times 10^{30} \text{ kg} \] (Sun’s mass)
Given that Jupiter’s average density is slightly greater than water, estimate the orbital period of a satellite circling just above the planet.

\[ \rho_J \sim 1000 \text{ kg m}^{-3} \quad G \sim 10^{-10} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2} \]

\[ G\rho_J \sim 10^{-7} \text{ s}^{-2} \]

\[ (G\rho_J)^{-1/2} \sim 10^{3.5} \text{ s} \sim 1 \text{ hour} \]

(More accurate calculation gives 2.9 hours.)
Precision

For most calculations, uncertainties of ~1% are OK. This requires two or three significant figures.

e.g., let \( X = a \times 10^b \)

<table>
<thead>
<tr>
<th>magnitude of ( a )</th>
<th>10% uncertainty</th>
<th>1% uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>a</td>
<td>\geq 5)</td>
</tr>
<tr>
<td>(</td>
<td>a</td>
<td>&lt; 5)</td>
</tr>
</tbody>
</table>

• Don’t exaggerate the precision of your results!

• Remember some operations magnify uncertainty; e.g., if \( X \) has 1% uncertainty, \( X^3 \) has 3% uncertainty.
Overview: Structure

Inner system: terrestrial planets, asteroids.

Outer system: jovian planets and moons, “KBOs”.

Oort Cloud: comets.
### Overview: Two Types of Planets

<table>
<thead>
<tr>
<th>Terrestrial Planets</th>
<th>Jovian Planets</th>
</tr>
</thead>
<tbody>
<tr>
<td>small size &amp; mass</td>
<td>large size &amp; mass</td>
</tr>
<tr>
<td>high density</td>
<td>low density</td>
</tr>
<tr>
<td>rock &amp; metal</td>
<td>H, He, H₂O, CH₄, NH₃, …</td>
</tr>
<tr>
<td>solid surface</td>
<td>no solid surface</td>
</tr>
<tr>
<td>few moons, no rings</td>
<td>many moons &amp; rings</td>
</tr>
<tr>
<td>close to sun, warm</td>
<td>far from sun, cold</td>
</tr>
</tbody>
</table>
A Brief Tour: The Sun

• Largely H and He
• Over 99.9% of solar system’s mass
• Self-regulating nuclear furnace
A Brief Tour: Mercury

- Large iron core and desolate rock crust
A Brief Tour: Venus

• Earth’s “twisted sister”
• Extreme greenhouse effect
A Brief Tour: Earth

- Liquid surface water!
- Complex and dynamic atmosphere
- Remarkably large moon
A Brief Tour: Mars

- Cold & dry, but water flowed long ago
- Complex and interesting topography
A Brief Tour: Jupiter

• Largest gas-giant planet — no solid surface!

• Many different moons, some as big as planets
A Brief Tour: Saturn

- Spectacular ring system
- Titan, a moon with atmosphere
A Brief Tour: Uranus

- Water and other hydrogen molecules
- Extreme axis tilt
A Brief Tour: Neptune

- Most distant major planet
- Large moon with “backwards” orbit
A Brief Tour: Pluto and Other “Icy Dwarfs”

• Tiny compared to major planets

• Ices of $\text{H}_2\text{O}$ & other H-rich compounds

• Many still to be discovered!
A Brief Tour: Small Objects

**Asteroids:**
- small (< 1000 km)
- rock & metal (?)
- inner system

**Comets:**
- small (~ 10 km)
- ice & rock
- Kuiper belt & Oort cloud

**Dust & Debris:**
- meteoroid streams on cometary orbits
- zodiacal dust
A Brief Tour: The Solar Wind

- Outflow of charged particles
- Speeds of 300 to 800 km s\(^{-1}\)
- Interacts with planetary magnetic fields
Diurnal Motion

Due to rotation of Earth.

Sidereal Day:
86,162 s ($\approx 23^{\text{h}}56^{\text{m}}$)

Solar Day:
86,400 s ($= 24^{\text{h}}$)
Planetary Motion

The Sun & Moon *always* move west-to-east relative to the stars.

The planets *usually* move west-to-east as well, but sometimes they move the *other* way!
Planetary Motion: Mars Goes Retrograde

All planets undergo retrograde motion.
1. Heavenly motions are uniform, eternal, and circular or compounded of several circles.

2. The center of the universe is near the Sun.

3. Around the Sun, in order, are Mercury, Venus, Earth and Moon, Mars, Jupiter, Saturn, and the fixed stars.

4. The Earth has three motions: daily rotation, annual revolution, and annual tilting of its axis.

5. Retrograde motion of the planets is explained by the Earth's motion.

6. The distance from the Earth to the Sun is small compared to the distance to the stars.
Revolution and Rotation

All planets and most moons *revolve* in the same direction and stay close to the same plane.

The sun and most planets also *rotate* in that direction.

This provides a clue to the Solar System’s formation.
Formation Scenario
1. A gas cloud starts to collapse due to its own gravity.

2. It spins faster and heats up as it collapses.

3. Vertical motions die out, leaving a spinning disk.

4. The solar system *still* spins in the same direction.
Collapse: Angular Momentum and Energy

1. *Angular momentum conservation* causes the cloud to spin faster as it contracts:

\[
\text{(rotation speed)} \propto \frac{I}{\text{(cloud diameter)}}
\]

Collapse stops when the cloud spins at orbital speed.

2. *Energy conservation* causes the cloud to heat up:

- Potential energy
- Kinetic energy
- Thermal energy

- Gravitational collapse
- Gas shocks
Planet Formation: The Frost Line

The disk was hot at the center, and cool further out.

*Inside* the **frost line**, only rocks & metals can condense. *Outside*, hydrogen compounds can also condense.

The frost line was ~4 AU from the Sun — between the present orbits of Mars and Jupiter.
1. Within the frost line, bits of rock and metal clumped together to make **planetesimals**.

2. As the planetesimals grew, they became large enough to attract each other.

3. Finally, only a few planets were left.
Planet Formation: Jovian Planets

1. *Outside* the frost line, icy planetesimals were *very* common, forming planets about 10 times the mass of Earth.

2. These planets *attracted* nearby gas, building up *giant* planets composed mostly of H and He.

3. The disks around these planets produced moons.