What is a Planet?

IAU RESOLUTION 5
Definition of a Planet in the Solar System

Contemporary observations are changing our understanding of planetary systems, and it is important that our nomenclature for objects reflect our current understanding. This applies, in particular, to the designation "planet". The word "planet" originally described "wanderers" that were known only as moving lights in the sky. Recent discoveries lead us to create a new definition, which we can make using currently available scientific information. The IAU therefore resolves that planets and other bodies, except satellites, in our Solar System be defined into three distinct categories in the following way:

1. A planet is a celestial body that
   a) is in orbit around the Sun,
   b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
   c) has cleared the neighborhood around its orbit.

2. A "dwarf planet" is a celestial body that
   a) is in orbit around the Sun,
   b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape,
   c) has not cleared the neighborhood around its orbit,
   d) is not a satellite.

3. All other objects, except satellites, orbiting the Sun shall be referred to collectively as "Small Solar System Bodies".

What is Pluto?

IAU RESOLUTION 6
Pluto

The IAU further resolves:

Pluto is a "dwarf planet" by the above definition and is recognized as the prototype of a new category of Trans-Neptunian Objects.

There are two broad categories of planets: Terrestrial and Jovian

- All of the planets orbit the Sun in the same direction and in almost the same plane
- Most of the planets have nearly circular orbits

Tycho Brahe's astronomical observations (unaided eye) provided evidence for heliocentric model of the solar system
Kepler’s Laws (no longer in textbook, but you should be aware of them)

- Using data collected by Tycho Brahe, Kepler deduced three laws of planetary motion:
  - the orbits are ellipses
  - with Sun at one focus
  - Planets sweep out equal areas in equal times
  - a planet’s speed varies as it moves around its elliptical orbit
  - The period squared equals the semi-major axis cubed

• a planet’s speed varies as it moves around its elliptical orbit

Galileo’s observations with a telescope supported the heliocentric model

- Galileo’s observations reported in 1610
  - the phases of Venus*
  - the motions of the moons of Jupiter*
  - “mountains” on the Moon
  - Sunspots on the Sun

Density

\[ D = \frac{m}{V} \]

- The average density of any substance depends in part on its composition
- An object sinks in a fluid if its average density is greater than that of the fluid, but rises if its average density is less than that of the fluid
- The terrestrial (inner) planets are made of rocky materials and have dense iron cores, which gives these planets high average densities
- The Jovian (outer) planets are composed primarily of light elements such as hydrogen and helium, which gives these planets low average densities

The Terrestrial Planets

<table>
<thead>
<tr>
<th>Planet</th>
<th>Characteristics of the Planet</th>
<th>Mars</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
<th>Pluto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distance from Sun (AU)</td>
<td>1.524</td>
<td>5.203</td>
<td>9.582</td>
<td>19.180</td>
<td>30.064</td>
<td>39.532</td>
<td></td>
</tr>
<tr>
<td>Average distance from Sun (km)</td>
<td>149.6</td>
<td>778.5</td>
<td>1427</td>
<td>2871</td>
<td>4023</td>
<td>5906</td>
<td></td>
</tr>
</tbody>
</table>

- The four inner planets are called terrestrial planets
  - Relatively small (with diameters of 5000 to 13,000 km)
  - High average densities (4000 to 5500 kg/m^3)
  - Composed primarily of rocky materials

Jovian Planets

<table>
<thead>
<tr>
<th>Planet</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distance from Sun (AU)</td>
<td>5.203</td>
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<tr>
<td>Average distance from Sun (km)</td>
<td>778.5</td>
<td>1427</td>
<td>2871</td>
</tr>
</tbody>
</table>

- The four giant outer planets are called Jovian planets
  - Large diameters (50,000 to 143,000 km)
  - Low average densities (700 to 1700 kg/m^3)
  - Composed primarily of hydrogen and helium.

Pluto

- Pluto is a special case
  - Now called a “dwarf planet”
  - Smaller than any of the terrestrial planets
  - Intermediate average density of about 1900 kg/m^3
  - Density suggests it is composed of a mixture of ice and rock
Seven large satellites are almost as big as the terrestrial planets

- Comparable in size to the planet Mercury
- The remaining satellites of the solar system are much smaller

<table>
<thead>
<tr>
<th>Planet</th>
<th>Earth</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (au)</td>
<td>1.02</td>
<td>5.20</td>
<td>9.58</td>
<td>1.78</td>
<td>3.86</td>
</tr>
<tr>
<td>Mass (10^24 kg)</td>
<td>6.64 x 10^24</td>
<td>1.90 x 10^30</td>
<td>5.68 x 10^26</td>
<td>1.05 x 10^26</td>
<td>1.04 x 10^27</td>
</tr>
</tbody>
</table>

Spectroscopy reveals the chemical composition of the planets

- The spectrum of a planet or satellite with an atmosphere reveals the atmosphere’s composition
- If there is no atmosphere, the spectrum indicates the composition of the surface.
- The substances that make up the planets can be classified as gases, ices, or rock, depending on the temperatures at which they solidify
- The terrestrial planets are composed primarily of rocky materials, whereas the Jovian planets are composed largely of gas
Small chunks of rock and ice also orbit the Sun.

- Asteroids are small, rocky objects, while comets and Kuiper belt objects are made of dirty ice.
- All are remnants left over from the formation of the planets.
- The Kuiper belt extends far beyond the orbit of Pluto.
- Pluto can be thought of as the largest member of the Kuiper belt.

Cratering on planets and satellites is the result of impacts from interplanetary debris.

- When an asteroid, comet, or meteoroid collides with the surface of a terrestrial planet or satellite, the result is an impact crater.
- Geologic activity renews the surface and erases craters, so a terrestrial world with extensive cratering has an old surface and little or no geologic activity.
- Because geologic activity is powered by internal heat, and smaller worlds lose heat more rapidly, as a general rule smaller terrestrial worlds are more extensively cratered.

A planet with a magnetic field indicates a fluid interior in motion.

- Planetary magnetic fields are produced by the motion of electrically conducting liquids inside the planet.
- This mechanism is called a dynamo.
- If a planet has no magnetic field, that is evidence that there is little such liquid material in the planet’s interior or that the liquid is not in a state of motion.

The diversity of the solar system is a result of its origin and evolution.

- The magnetic fields of terrestrial planets are produced by metals such as iron in the liquid state.
- The stronger fields of the Jovian planets are generated by liquid metallic hydrogen or by water with ionized molecules dissolved in it.

<table>
<thead>
<tr>
<th>Table 7.1</th>
<th>Comparing Terrestrial and Jovian Planets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial Planets</td>
<td>Jovian Planets</td>
</tr>
<tr>
<td>Distance from the Sun</td>
<td>Less than 2 AU</td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
</tr>
<tr>
<td>Composition</td>
<td>Mostly rocky materials, including iron, oxygen, chlorine, xenon, neon, and sulfur</td>
</tr>
<tr>
<td>Density</td>
<td>High</td>
</tr>
</tbody>
</table>

- The planets, satellites, comets, asteroids, and the Sun itself formed from the same cloud of interstellar gas and dust.
- The composition of this cloud was shaped by cosmic processes, including nuclear reactions that took place within stars that died long before our solar system was formed.
- Different planets formed in different environments depending on their distance from the Sun and these environmental variations gave rise to the planets and satellites of our present-day solar system.
Planetary Observations

- Planets formed at the same time as Sun
- Planetary and satellite/ring systems are similar to remnants of dusty disks such as that seen about stars being born
- Planet composition dependent upon where it formed in the solar system

Other Observations

- Radioactive dating of solar system rocks
  - Earth ~ 4 billion years
  - Moon ~ 4.5 billion years
  - Meteorites ~ 4.6 billion years
- Most orbital and rotation planes confined to ecliptic plane with counterclockwise motion
- Extensive satellite and rings around Jovians
- Planets have more of the heavier elements than the sun

Planetary Summary

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass (Earth=1)</th>
<th>Density (g/cm³)</th>
<th>Major Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.06</td>
<td>5.4</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Venus</td>
<td>0.82</td>
<td>5.2</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>5.5</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Mars</td>
<td>0.11</td>
<td>3.9</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Jupiter</td>
<td>318</td>
<td>1.3</td>
<td>H, He</td>
</tr>
<tr>
<td>Saturn</td>
<td>95</td>
<td>0.7</td>
<td>H, He</td>
</tr>
<tr>
<td>Uranus</td>
<td>14</td>
<td>1.3</td>
<td>Ices, H, He</td>
</tr>
<tr>
<td>Neptune</td>
<td>17</td>
<td>1.7</td>
<td>Ices, H, He</td>
</tr>
</tbody>
</table>

Nebular Condensation (protoplanet) Model

- Most remnant heat from collapse retained near center
- After sun ignites, remaining dust reaches an equilibrium temperature
- Different densities of the planets are explained by condensation temperatures
- Nebular dust temperature increases to center of nebula
Nebular Condensation Physics

- Energy absorbed per unit area from sun = energy emitted as thermal radiator
- Solar Flux = Lum (Sun) / 4 x distance^2
- Flux emitted = constant x T^4 [Stefan-Boltzmann]

Concluding from above yields

\[ T = \text{constant} / \text{distance}^{0.5} \]

Nebular Condensation Chemistry

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Freezing Point</th>
<th>Distance from Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_2</td>
<td>10 K</td>
<td>&gt;100 AU</td>
</tr>
<tr>
<td>H_2O</td>
<td>273 K</td>
<td>&gt;10 AU</td>
</tr>
<tr>
<td>CH_4</td>
<td>35 K</td>
<td>&gt;35 AU</td>
</tr>
<tr>
<td>NH_3</td>
<td>190 K</td>
<td>&gt;8 AU</td>
</tr>
<tr>
<td>FeSO_4</td>
<td>700 K</td>
<td>&gt;1 AU</td>
</tr>
<tr>
<td>SiO_4</td>
<td>1000 K</td>
<td>&gt;0.5 AU</td>
</tr>
</tbody>
</table>

Nebular Condensation Summary

- Solid Particles collide, stick together, sink toward center
  - Terrestrials -> rocky
  - Jovians -> rocky core + ices + light gases
- Coolest, most massive collect H and He
- More collisions -> heating and differentiating of interior
- Remnants flushed by solar wind
- Evolution of atmospheres

Thought Questions

- Describe the surface and atmospheric conditions on Mars.
- What evidence exists that Mars at one time had abundant liquid water?
- If Mars did have liquid water at one time, what happened to it and why?
- Describe the internal structure of Jupiter and Saturn.

Surface features indicate that water once flowed on Mars

- Flash-flood features and dried riverbeds on the Martian surface indicate that water has flowed on Mars at least occasionally
- No liquid water can exist on the Martian surface today
  - Check phase diagram

Jupiter and Saturn Interior

- Temperature at core = 15,000 K
- Pressure at core = 3 million bars
**Jupiter and Saturn Atmosphere**

![Jupiter and Saturn Atmosphere Diagram]

**Thought Questions**

- Describe some unusual features found on the moons of Jupiter, Saturn and Neptune.
- What are the similarities and differences between the Sun and Jupiter?
- What evidence exists today that the number of rocks and rock particles floating around in the solar system was much greater in the past soon after the planets formed?

**Thought Questions**

- Explain why oxygen is a major component of Earth's atmosphere but not the atmospheres of Venus or Mars.
- Using the properties of the planets other than Earth, discuss the possibilities of life on each.
- What are “shooting stars”? Where do they come from? Where do they go?

**Thought Questions**

- What is an asteroid? What evidence indicates that asteroids are parts of a broken-up planet? What evidence indicates that asteroids are not parts of a broken-up planet?
- Where do comets come from? Why are astronomers so interested in studying the physical and chemical structure of a comet?

**Comets and Asteroids**

![Comets and Asteroids Image]
Thought Questions

• What is a meteorite? What is the most likely source of meteorites?