Other Terrestrial Worlds

**Moon**
- Moment of inertia coefficient (0.393) indicates nearly uniform density
- Core is 13-26% R (compare Earth 19% inner and 53% outer)
- Gravity geoid attributable to different crustal thicknesses (0 to 107 km)
- Had magnetic field 3-4 Gyr ago

**Mercury**
- 60% of planet mass is Fe
- Core extends to 75% R

**Venus**
- 3% less dense than Earth … missing some heavy element?
- No magnetic field … core frozen and/or lack of rotation
- No tectonics … lack of H₂O … stagnant lid
  - Heat doesn’t escape … hot mantle quenches core convection

**Mars**
- No tectonics … heat lost in past via volcanism
- Geoid highly correlated with topography, so thick, rigid lithosphere
- Ancient magnetic field evidence now shattered
- Far more FeO than on Earth … Fe-Ni core or Fe-FeS core?
Earth’s Geoid

blue/purple = high gravity ... orange/red = low gravity
Mars’ Surface Gravity

MGM2011 surface gravity

[m/s/s]
Venus’ Surface Gravity
Venus’ Surface
Jovian Interiors

Jovian type 1  "Gas Giants"

Jupiter  \( \sim 80\% \) R below \( \text{H}_2 + \text{He} \)
Saturn  \( \sim 55\% \) R below \( \text{H}_2 + \text{He} \)

Jovian type 2  "Ice Giants"

Uranus  \( \sim 85\% \) R below \( \text{H}_2 + \text{He} + \text{CH}_4 \)
Neptune  \( \sim 85\% \) R below \( \text{H}_2 + \text{He} + \text{CH}_4 \)
Jovian Interiors: H

hydrogen behavior

temp range: 50-150K at tropopause to 10000-20000K at center

pressure range: 0 bar to 20-80 Mbar at center
  < 1 Mbar hydrogen is H₂ solid or liquid
  > 1 Mbar hydrogen is mixed molecular/atomic

in Jovians

fluid particles closely packed … molecules overlap … e− swap
  “molecular metallic hydrogen”

deeper … H₂ dissociated … H₂ → 2H occurs 0.95 R to 0.80 R in Jup
  “atomic metallic hydrogen”

convection leads to magnetic fields
Jovian Interiors: He and H$_2$O

helium behavior

temp and pressure never high enough to go to metallic form

He not fully mixed in Jupiter and Saturn
  Saturn has lower temp/pressure than Jupiter,
  so even less mixed

water behavior

15 different crystalline forms (P,T) conditions

mixtures with trace molecules … conductive fluid
  explains magnetic fields of Neptune and Uranus
Earth Flow Patterns
Jupiter Flow Patterns
Ice Giant Interiors

- Uranus
  - Rocky core
  - Highly compressed water
  - Liquid hydrogen and helium

- Neptune
  - CH₄ + H₂O + NH₃
  - rock?
Solar System Magnetic Fields

Diagram showing the magnetic fields and rotation axes of Jupiter, Saturn, Earth, Uranus, and Neptune.
Jupiter’s Giant Magnetosphere
Planets in Solar Systems

Protosun

Hydrogen-Helium gas envelope

Accreting rocky planetesimals

"Frost line"

Accreting planetesimals of rock and ice

$\text{Ni Fe SiO Mg FeS FeO}$

$\text{H}_2\text{O NH}_3 \text{ CH}_4 \text{ N}_2$
Predicted sizes of different kinds of planets

1 $M_\odot$:
- Pure iron planets
- Silicate planets
- Carbon planets

5 $M_\odot$:
- Pure water planets
- Pure carbon monoxide planets
- Pure hydrogen planets

Earth analog

10,000 mi

Sun-like star
Variation of Planet Density with Mass

- Earth
- Neptune
- Uranus
- Jupiter
- Saturn

- Kepler Discoveries
- Known Exoplanets
GJ 1214’s Planet

density $\sim 1 \text{ g/cm}^3$
Solar System Explorers 10

Describe an observation that yields information about a particular world’s interior, e.g. seismic data on Earth tell us that the size of the solid core is 1200 km.

1. Earth has liquid core based on P and S waves
2. Io 1/3 Fe core based on Galileo
3. Earth magnetic field changes based on orientation changes of ferrous materials in rocks
4. Earth 12km hole in Russia no transition between granite and basalt at 7km as predicted + H2O
5. Europa non-synchronous rotation of shell vs. inner mantle indicates liquid mantle
6. Venus gravity field measurements by Magellan indicate liquid core, but not convective
7. Io no magnetic field measured by Galileo so core is not convective
8. Mercury lack of basaltic, iron, and titanium rich material indicates volcanism shut off early, weak core
9. Enceladus radio timing from Cassini suggest subsurface ocean
10. Mars MRO found that crust was not sagging under ice caps as expected so thick lithosphere
11. Mercury’s precession measurement by Messenger indicates liquid core
12. Ganymede/Callisto have salty oceans based on Galileo magnetometer readings
13. meteorites give clues about core/mantle compositions
14. Saturn excess heat (He rain) indicate settling
15. Io volcanism indicative of molten mantle
16. Tethys density plus surface ice indicates that it must be almost ALL ICE!
17. …
18. …
19. …
20. …
Solar System Explorers 11

Name a minor body with semimajor axis greater than Mars’ orbit (1.52 AU) and describe three of its physical characteristics, e.g., *Pluto has density 2.03 g/cm³ and is roughly 70/30% rock/ice by mass, where the ice is primarily N₂.*

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