Chapter 05: Earth and Its Moon

Notes and Sketches

5.1: Earth and Moon in Bulk

Physical Properties

- Moon is smaller
- Moon is less massive
- Moon has lower surface gravity
- Moon has lower escape speed
- Moon is 384,000 km from Earth

Overall Structure = Differentiated Layers

- Earth and Moon: Core, mantle, crust
- Earth: Hydrosphere (water), atmosphere (air)

5.2: The Tides

Gravitational Deformation

Average Force

- $F = G(mM)/r^2$
- r: Measure from center of m to center of M
- This F is average and controls the orbital motion

Differential Force

- Force depends on distance: Closer = more force
- Inverse square: Small change in distance = big change in force
- Pull on E due to M at near side of E = bigger F
- Pull on E due to M at far side of E = smaller F

Tidal Force

- Line of action of force: center to center
- Stretch (literally) along line of action
- Earth: Pull on water = tides
- Moon: No water, so no ocean tides, but tidal force still exists

Tidal Bulge

- Easy to see "bulge" on E because of water
- Not easy to see bulge on M, but shape gets stretched

High Tide

- Obvious high tide: Where E directly faces (0°) M, force is greatest (water pulled the hardest)
- Less obvious high tide: Point on E directly opposite (180°) from M

Low Tide

- Points on E at 90° and 270° relative to M
- Water gets pulled toward 0° and 180°, had to come from somewhere

Highest High Tides

- Spring tides
- Moon = new or full
- Alignment means that pull due to sun reinforces pull due to M

Lowest High Tides

- Neap tides
- Moon = 1st or 3rd quarter
- M at 90° relative to sun

Tidal Locking

Moon Slows Earth

- Earth spins faster than moon orbits
- Tidal bulge gets slightly ahead of moon
- Force on bulge (not bulk) pulls "backwards," slows down E
- Rotation slows by 2×10^{-3} sec every 100 years

Earth Locks Moon

- Synchronous orbit: Same time to rotate and revolve
- M spins once on axis = 27.3 days
- M orbits E once = 27.3 days
- M keeps same face towards E all the time

5.3: Atmospheres

Why Air Sticks Around

- Short answer: gravity
- Slightly longer answer: gravity + temperature
- Temperature = average kinetic energy per molecule
- Earth: average speed of average air molecule = 0.6 km/s, but escape velocity is 11.2 km/s

Earth's Atmosphere

- Mostly nitrogen (78%) and oxygen (21%)
- Oxygen is result of biological processes!! Not typical
- Pressure and density decrease with increasing altitude
- Relationship is not linear! 50% within 5km of sea level

Earths's Growing Ozone Hole

- Ozone = O_3 molecule (most atmospheric oxygen = O_2)
- Ozone molecules absorb UV (and some higher frequencies)
- Once you break an ozone molecule, it's hard to replace it
- Man-made CFCs are awesome at breaking O_3 molecules
- This is only a problem if you are a living organism which cannot withstand prolonged UV exposure

The Greenhouse Effect

- This is actually necessary for life as we know it
- If no greenhouse effect, Earth's equilibrium temperature would be about −23°C. Minus.
- CO_2 and H_2O vapor are good at trapping incoming solar energy–just enough to bring the temp up to about +20°C
- Small changes in CO_2 levels have large net effect

Lunar Air?

- Nope
- Low gravity = slow escape velocity
- No permanent atmosphere, but occasional sputtering of atoms and molecules off of surface
- Huge amounts of water locked as ice below the poles

5.4: Internal Structure of Earth and Moon

Seismology

- Earthquakes!
- P-waves: Primary (longitudinal). Can travel through solids and fluids both
- S-waves: Shear (transverse). Can only travel through solids
- Seismology: Study of seismic waves. Seismograph detects waves, can determine origin of wave, wave speed, etc.

Modeling Earth's Interior

- Watch both S- and P-waves: trace back to epicenter/source
- Look at wave speed: Changes with density
- S-waves reflect: Do not transmit through liquid outer core

Crust, Mantle Core

- Synthesize seismic data to determine layered structure
- Crust: Rigid, average thickness about 15 km (very thin)
- Mantle: About 80% of planet volume
- Outer Core: Radius about 3500 km. Liquid, high density
- Inner Core: Radius about 1300 km. Solid! Highest temperature and highest density, predominantly Fe and Ni

Differentiation

- Not precisely the same as solar system differentiation
- Layered structure
- Density decreases with increasing distance from center
- Approximately 12,000 kg/m^3 at core decreases to about 3300 kg/m^3 at surface (water = 1000 kg/m^3)
- Temperature decreases with increasing distance from center
- Approximately 5000 K at center, 300K on surface
- These relationships are not linear

Notes and Sketches

The Lunar Interior

- Lower average density: 3300 kg/m^3 (no dense Fe-Ni core)
- Moonquakes! Not exactly same as on Earth, much less energy released--but still useful to map internal structure
- Solid inner core about 240 km radius
- Liquid outer core about 90 km thick
- Semi-solid mantle about 400 km thick, covered by solid mantle about 900 km thick
- Asymmetric crust: 60 km thick on near side, reaching 150 km thick on far side (short answer: gravity)

5.5: Surface Activity on the Earth

Continental Drift

- Earth's crust not one solid piece: composed of large slabs
- Who knew? This is relatively new science (about 50 years old)
- Ring of Fire: Notice the correlation between volcanoes and the edges of the plates
- Himalayas are growing as Indian plate drives into Eurasian plate
- Atlantic Ocean getting wider as N and S American plates pulls away from African plate

What Drives the Plates?

- Solid plates formed by quick cooling/shrinking of crust
- Mantle below is still fluid: fluids flow
- Heat from core creates convection in mantle
- Plates are literally surfing the mantle, just really slowly

Plate Tectonics on the Moon

- Nope
- No plates (thick crust)
- Not enough mushy mantle

5.6: The Surface of the Moon

Large-Scale Features

Maria

- Latin for sea, because Galileo thought they might actually be water
- Darker, flatter, smoother regions
- Much less cratered

Highlands

- Galileo called them terrae, because he thought they were probably land
- Greater elevation than maria
- Lighter color, much rougher terrain, much more cratering

The Difference Between Them

- Maria and highlands have different composition: we know because we have been there
- Maria = basalt: Darker color, higher density
- Highlands = aluminum salts and silicates = lighter color, lower density

Cratering

The Obvious

- Stuff hits the moon, leaves a crater
- Craters are all over the moon: Lots of stuff hit the moon

The Less Obvious

- Maria have fewer craters: They are geologically younger
- Maria are pretty circular: They are impact craters filled with lunar lava (not completely known why more maria on near side than far side)
- Craters on top of craters: Tells you about cratering rates
- High rate of cratering, drops off significantly about 3.9 billion years ago

Notes and Sketches

Lunar Erosion

- No air or water to erode surface, so features are very old
- Micrometeoroids cause most lunar erosion
- Very few impacts larger than about 1cm recently/ongoing forming

5.7: Magnetospheres

Earth's Magnetosphere

- Magnetic field: Liquid outer core (Fe, Ni) rotating rapidly
- Magnetic dynamo: This is not a refrigerator magnet
- Field lines created continuously: Magnetic N pole is currently not quite aligned with geographic/rotational N pole
- Charged particles (p^+ and e^- from the sun) deflected by magnetic field, get trapped
- Van Allen Belts: e^- form outer "belt" (toroid), p^+ end up in inner belt
- Aurora = charged particles collide with atmospheric molecules, absorption/emission (see Ch 02!)

Lunar Magnetism

- Nope

5.8: History of the Earth–Moon System

Formation of the Moon

Capture

- Hypothesis: Moon formed somewhere/somewhen else
- Captured by Earth's gravity
- Not likely

Condensation (Co-Formation)

- Hypothesis: Both bodies formed at the same time, in the same place
- Differences in density and composition argue against this
- No other examples of this process in the solar system

Catastrophic Impact

- Hypothesis: A planetoid about the size of Mars formed independently of Earth
- Catastrophic collision broke up the planetoid, almost killed the Earth
- Gravity wins in the end: Most matter ends up back on earth, some accretes into the moon

Why We Like This One Best

- Computer modeling demonstrates plausibility
- Collisions are obvious and frequent in early solar system
- Explains why moon has different structure, smaller core:
  - They started out pretty much the same
  - The smaller thing gets obliterated
  - Some of its mass ends up on Earth, and it would be the heavier stuff
  - Moon condenses out of mostly lighter material

Lunar Evolution

Moon

- At least partially solid by 4.4 billion years ago: Rocks are evidence
- Smaller, less dense: Faster cooling
- Volcanic activity: Tidal force due to Earth causes more activity on near side (large maria)
- Few volcanic flows on far side (no maria)
- No current volcanic activity

Earth

- Larger, denser, more internal heat
- Thin crust, hot mantle, molten iron core (solid at very center)
- More geologically active: Plate tectonics, volcanism

Notes and Sketches