Astronomy 217

Inside Planet Earth
Earth Facts

**Mass** = $5.974 \times 10^{24}$ kg

**Radius** = 6,371 km

**Escape Velocity**
= 11.2 km/s

**Density** = 5515 kg m$^{-3}$

**Orbital**
- **Semi-major axis**
  = $1.496 \times 10^8$ km

**Eccentricity** = 0.0167

**Mean Surface Temperature** = 287 K

**Albedo** = .367, 29% of surface is land.
Structure of Our Planet

Understanding the structure of the Earth provides a template for understanding the structure of other terrestrial planets, both in our Solar system and beyond.

Chemically, the Earth is differentiated into:
- Inner and outer core
- Mantle
- Thin crust
- Hydrosphere
- Atmosphere
- Magnetosphere
While light is unable to penetrate the Earth’s surface, seismic waves pass through.

Earthquakes produce both pressure and shear waves.

**Pressure** (sound) waves are longitudinal and travel through both liquids and solids.

**Shear** waves are transverse and do not travel through liquid, as liquids do not resist shear forces.

Wave speed depends on the density of the material.
Seismology

The waves from a single earthquake will travel throughout the Earth revealing information about the layers traversed. Studying a series of earthquakes reveals the interior structure of Earth.

The travel time reveals the sound speed.

Absence of S-waves and direct P-waves from 103° to 142°, reveals liquid core.

P-waves near 180° arrive earlier than expected, revealing solid inner core.
Core is metallic, largely iron and nickel. It is 16% of Earth’s volume, but 32% of mass.

Outer core is liquid; inner core is solid, due to pressure.

Mantle is rocky, much less dense than core.

Volcanic lava comes from mantle, allowing analysis of its composition (O 44%, Si 22%, Mg 23%, Fe 6%).

Crust is only 0.5% M⊕, made of O (47%), Si (28%), Al (8%), Fe (5%).
The Earth as it formed by coalesce was a **homogeneous** conglomerate of planetesimals.

Accretion of planetesimals, short-lived radioactivity and contraction heated the Earth, forming a **molten surface** layer.

Heavier materials sank to the center, producing additional energy by **differentiation**.

With the clearing of the orbit and the completion of differentiation, a **solid surface** formed.
Radioactive Heating

Though the exhaustion of short-lived radioactive species have reduced the rate of nuclear energy generation, radioactive decay continues to be a significant source of heat in the Earth’s interior.

Total heat flow from the Earth’s core is determined from temperature gradients near the surface.

\[
F_{\text{geo}} \approx 0.09 \text{ W m}^{-2}
\]

\[
L_{\text{geo}} = 4\pi R_{\oplus}^2 F_{\text{geo}}
\]

\[
\approx 4.6 \left( \pm 3 \right) \times 10^{13} \text{ W} = 46 \left( \pm 3 \right) \text{ TW}
\]

The KamLAND & Borexino neutrino detectors measured geoneutrinos from uranium and thorium decay, implying

\[
L_{\text{decay}} = 23^{+8.8}_{-8.6} \text{ TW}
\]
Molten Core

The flow of energy from the Earth’s core represents a potential cooling of the core, which could one day affect the molten iron core, if not balanced by radioactive decay, etc.

\[ L_{\text{geo}} - L_{\text{decay}} \approx 23 \text{ TW} \]

An estimate of the total thermal energy of the Earth is

\[ E_{\text{therm}} = \frac{3kT}{40m_p} M_\oplus \approx 1.1 \times 10^{31} \text{ J} \]

where 40 m_p is the average atomic mass

The cooling timescale is

\[ \tau_{\text{cool}} = \frac{E_{\text{therm}}}{(L_{\text{geo}} - L_{\text{decay}})} \approx 1.4 \times 10^{10} \text{ yr} \]

Thus the Earth will remain geologically active for billions of years.
Radioactive Families

The radioactive species in the Earth decay by fission, releasing alpha-particles, neutrons and electrons. Each radioactive nucleus has a unique decay chain.

- **Parent**
  - Uranium 238 (Half-life: 4,500,000,000 Years)
    - Decays to **Helium** + **Electrons** + **Lead 206**
  - Uranium 235 (Half-life: 713,000,000 Years)
    - Decays to **Helium** + **Electrons** + **Uranium 238**
  - Thorium 232 (Half-life: 13,900,000,000 Years)
    - Decays to **Helium** + **Electrons** + **Lead 209**
  - Plutonium 241 (Half-life: 2,400,000 Years)
    - Decays to **Helium** + **Electrons** + **Plutonium 241**

- **Daughter**
  - Lead 206
  - Lead 207
  - Lead 209
  - Thorium 232
  - Bismuth 209
A decay chain is a series of reactions linking the parent to daughter.

\[ ^{238}\text{U} \rightarrow ^{206}\text{Pb} \]
Radioactive Dating

Radioactive dating requires determining the ratio of the current abundance of the radioactive species and its original abundance.

The abundance of the daughter nucleus allows us to determine the original radioactive abundance.

This works best for chemically selected samples where the original abundance of the daughter nucleus was small.
The crust is divided into **plates**, which move atop the mantle. Most of the Earth’s **surface features** are the result of these **plate movements**; collisions and the like.
If we follow continental drift backward 200 million years, the continents merge to form **Pangaea**.
Plates *sliding* along or over each other create faults, where tension builds. Earthquakes mark the *release* of this tension.
Colliding plates can raise or sink mountains.

The subduction of the Indian plate under the Eurasian plate creates a thrust fault, lifting and folding the crust into the Himalayan mountains.
The plates are part of the *lithosphere*, the solid surface of the Earth, consisting of the crust plus the *solid upper mantle*. Plates move atop the partly molten *asthenosphere*.

A *subduction zone* occurs where one plate slides below another, with material from the crust reaching the molten layers.
When crustal plates move away from each other, either mid-continent or under the ocean, rising material from the mantle fills the void, creating rift valleys or undersea ridges. Collectively these are called rifts.
The **driving force** for plate tectonics is **convection** in the upper mantle.

Crustal plates ride the upper surface of **convective cells** in the mantle. These cells provide the **energy** to collide and deform the plates.
Next Time

Turn in Homework #8

Earth’s Atmosphere and Magnetosphere.