Origins & structure of Earth

Chapter 2

Topics to learn

- History of the Universe and Earth
- Structure of Earth
- Formation of the atmosphere and oceans
- Origins of life on Earth

Chapter 2, pp. 12-29
11:59:24 p.m.

15,000,000,000 years ago...
The Big Bang
Origin of solar system: Nebular Hypothesis
Sequence

- Explosion
- Eventually, non-uniform distribution of matter due to gravity
- Aggregation
- Repeat

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**Silicates and iron compounds**
- Mercury
- Venus
- Earth
- Mars
- Saturn
- Neptune
- Jupiter

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**Hot inner disk**: heated by young sun, ices and gases cannot condense. Particles that condense here are mainly silicates and iron compounds.

**Cold outer disk**: ices and gases condense here, as well as silicates and iron compounds.
General definitions

- **Atoms**: fundamental building blocks of chemistry; they are conserved in chemical reactions
- **Element**: a compound which cannot be further broken down into another compound with different chemical properties; material composed of one type of atom
- **Gravity**: force of attraction between two bodies; is large when distance between bodies is small
- **Density**: mass per unit volume
## Composition of Universe

<table>
<thead>
<tr>
<th>Element</th>
<th>Abundance relative to silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>40,000</td>
</tr>
<tr>
<td>Helium</td>
<td>3,100</td>
</tr>
<tr>
<td>Oxygen</td>
<td>22</td>
</tr>
<tr>
<td>Neon</td>
<td>8.6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>6.6</td>
</tr>
<tr>
<td>Carbon</td>
<td>3.5</td>
</tr>
<tr>
<td>Silicon</td>
<td>1</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.91</td>
</tr>
<tr>
<td>Iron</td>
<td>0.6</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.38</td>
</tr>
</tbody>
</table>

### The periodic table of the elements

[Periodic table image]
Solar System

- 5,000,000,000 years old
- Formed from stellar dust
- Inner planets
  - Heavier elements
    - (Fe, Si)
- Outer planets
  - Lighter Compounds
    - (H₂, CH₄, NH₃) solid ‘gas’

Earth

- 4,600,000,000 yrs old

(How do we know that?)
Dating Rocks

- **Relative Dating**
  - Early 19th Century
  - Correlate rock *strata* with fossils

- **Absolute Dating**
  - Curies discovered radiation
  - Almost all rocks have radio-isotopes
  - If you know $\tau_{1/2}$, can calculate *exact date*
### Radioisotope and Half-life

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon-222</td>
<td>4 days</td>
</tr>
<tr>
<td>Strontium-90</td>
<td>28 years</td>
</tr>
<tr>
<td>Radium-226</td>
<td>1602 years</td>
</tr>
<tr>
<td>Plutonium-239</td>
<td>24 400 years</td>
</tr>
<tr>
<td>Uranium-235</td>
<td>700,000,000 years</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>5730 years</td>
</tr>
<tr>
<td>Phosphorus-32</td>
<td>14.3 days</td>
</tr>
<tr>
<td>Tritium (H-3)</td>
<td>12.3 years</td>
</tr>
<tr>
<td>Americium-241</td>
<td>432 years</td>
</tr>
<tr>
<td>Nitrogen-13</td>
<td>9.96 minutes</td>
</tr>
</tbody>
</table>

### Earth
- 4,600,000,000 yrs old
  - At first, homogeneous & fluid
Protoearth vs. Earth

- How are they different?
- How did Protoearth become Earth?

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Earth

- Gravity causes "density stratification"

Lighter Elements (Al, Si, Mg, O)

Heavy Elements (Fe, Ni, other metals)

Earth Structure: Chemical

- Crust (0 – 30 km)
  - Continental
    - Light, granite, Si, Al, oxy-minerals
  - Oceanic
    - Heavier, Mg, Fe, oxy-silicates
- Mantle (30 – 2900 km)
  - Most of the Earth’s volume (2400 miles thick)
- Core (2900 – 6370 km)
Earth Structure: Physical

- **Lithosphere** (0-100 km)
  - (crust + mantle)
- **Asthenosphere** (100-700 km)
  - Plastic
- **Mesosphere** (700 - 2900 km)
  - Solid, rock due to pressure
- **Outer Core** (2900-5200 km)
  - Liquid (5500°C)
- **Inner Core** (5200-6370 km)
  - Solid (6600°C)
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Oceans

- Where’d the water come from?
  - Two main hypotheses:
    - Outgassing
    - Extraterrestrial sources
Outgassing

Water trapped in rocks released from volcanic vents.
- Remained as water vapour to create clouds, rain and eventually oceans
- Only need to degas 7% of mantle to create today’s oceans

Extraterrestrial

- Riding on comets
  - Melt when enter Earth’s atmosphere
  - Mostly small (<9m)
  - But: water is very similar to water from meteors
- Open debate
...Changes in the atmosphere

3 Atmospheres in Earth’s history:
1. Initially: H, He (boiled away)
2. Earth cooled, formed crust
   - Volcanoes and outgassing
     - Water, carbon dioxide, ammonia
3. Oxygen-rich
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Origins of Life

• “Life” began ~3.6 bya
• How?
  – From space?
  – In situ, on Earth?
• Either way, WATER, NUTRIENTS & ENERGY are necessary
• STABLE environment helps too
Origins of Life

- **Water**
  - Great solvent - dissolves many chemicals
  - Transports nutrients
  - Moderates temp.
  - Retains heat
- **Nutrients**
  - NH$_3$, CH$_4$, H$_2$
- **Energy**
  - Lightning, UV, geothermal heat, IR light in hydrothermal systems

Origins of Life...

Conditions when life began (3.6 bya):
- Atmosphere = H$_2$O (water), CH$_4$ (methane), NH$_3$ (ammonia)
- uv light
- lightning
Origins of Life

• JS Haldane (1929)
  – H₂O, NH₄, CH₃, H₂ + UV light = complex molecules

• Stanley Miller (1953) tried it
  – Mimic conditions in shallow ocean
  – Add lightning (spark)
Origins of Life

In situ hypothesis: spontaneous synthesis

- Surface Pools - Biosynthesis - evaporation of water in shallow pools may have concentrated organic building blocks. Energy supplied by sunlight (photosynthesis).
- Deep Ocean - Around hydrothermal vents utilizing H$_2$S as energy source (chemosynthesis), or perhaps infrared light.
Primitive life

- Water present ~4.6 billion years ago
- Heterotrophic organisms ~3.8 billion years ago
  - Autotrophs came later
- Oxygen starts to build up ~2.6 billion years ago
  - Photosynthesis & respiration

Ancestors of the first autotrophs
Changes in the atmosphere

1. H, He
2. Outgassing of internal gases (water vapor, carbon dioxide, ammonia)
3. Present atmosphere – oxygen from early photosynthesis! (oxygen, 20%, nitrogen, 78%)

End

• Next class... plate tectonics!