1. Properties
   - General Properties
   - Differentiation, Age

2. Interior and Magnetic Field
   - Interior
   - Earth’s Quakes, P and S Waves, Crust, Mantle and Core
   - Magnetic Field (Dynamo), Magnetosphere and Belts
   - Aurora

3. Atmosphere
   - Origin of Atmosphere
   - Greenhouse Effect

4. The Earth in the Future
   - Young Sun Paradox
   - Death of the Sun

- **Mean density**: 5.5 (gm/cm\(^3\))
- **Atmospheric composition**
  - Nitrogen 77%, Oxygen 21%, Other 2%

---

**Age of Rocks**

Radioactive Isotope Dating Measures the time since a rock solidified!

<table>
<thead>
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<th>Age</th>
<th>HL</th>
<th>AM</th>
</tr>
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<tbody>
<tr>
<td>4.5 BY</td>
<td>1</td>
<td>1/2</td>
</tr>
<tr>
<td>9 By</td>
<td>2</td>
<td>1/4</td>
</tr>
<tr>
<td>13.5 By</td>
<td>3</td>
<td>1/8</td>
</tr>
<tr>
<td>etc</td>
<td></td>
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</tr>
</tbody>
</table>

Half-Life = 4.5 BY

Radiometric dating requires that neither the parent nuclide nor the daughter product can enter or leave the material after its formation.
Age of Earth Rocks

The Earth is geologically active, so that surface rocks are being melted & re-processed all the time.

Rocky Mountains ~60 Myr old
Most of the crust is less than 100 Myr old
Continental Shields: Australian (4.3 Gyr), Canadian (3.96 Gyr)

Age of Earth and Solar System

The Earth and Solar System are 4.6±0.1 Billion Years old.

Age of rocks in this picture are ~3.8 By.

Differentiation of the Earth

- First hot and molten
- Heavy material sank to the center and lighter material rose.
- Separation (Differentiation) took place during the first few 100 million years of the planets’ lifetime.
- Earth cooled from outside in, however radioactivity continues to heat the interior.

Heat Sources

1. Impacting bodies (Accretion) bombard the Earth and convert their energy of motion (kinetic energy) into heat.
2. Decay of short-lived radio active elements

Today the decay of long lived radioactive elements is a steady source of heat.

Cooling

Planetary bodies cool by convection of material inside the body Brings hot material from the deep interior closer to the surface where heat is released by volcanic activity.

Earth’s Interior:
Crust, Mantle and Core

The Earth and Solar System are 4.6±0.1 Billion Years old.

Meteorites

These rocks are remnants from the formation of the Solar System, and possibly unchanged since they formed. Expect the Earth to be of the same age (i.e., it formed at the same time as the other planets).
The outer core is liquid where the temperature is greater than the melting point. Melting point increases with increasing pressure toward the center. Inner core becomes solid because the pressure is increasing. Rapid, rotating, conducting, liquid outer core explains the Earth's magnetic field.

The core is rich in Nickel and Iron! The outer core is liquid! pornum is liquid! Solid mantle! Liquid core! Solid core! The core is rich in Nickel and Iron! P and S Wave Paths! P- waves can pass through a liquid! S- waves cannot pass through a liquid!

Crust, Mantle and Core
- The core is rich in Nickel and Iron
- Outer core is in liquid state
- Inner core, where the pressure is high, is solid

Average Density ≈ 5.5 gm/cc
- Crust 2.6–3.1 gm/cc
- Mantle 3.5–5.7 gm/cc
- Core 10-14 gm/cc
Earth’s Magnetic Field: **Dynamo Theory**

Requires: Hot liquid metallic core and Fast Rotation

**Electromagnet**

Flow of charges

caused by Rotation

Magnetic field

Electric current—flow of charged particles

The field is compressed on the day side, where the solar wind flows over it. It is also stretched into a long tail like the wake of a ship, which is called the **magneto tail**, and points away from the Sun.

**Van Allen Belts**

The magnetosphere contains two doughnut-shaped regions of magnetically trapped charged particles.

- discovered by Dr. James Van Allen in 1958 with first flight of a U.S. Earth-orbiting satellite.

The outer Van Allen belt contains mainly electrons;

The “inner belt” contains mainly protons

The Solar wind is always pushing on the Earth’s magnetic field, changing its shape.

**Earth’s magnetosphere**

The magnetosphere is the region around the Earth where charged particles from the solar wind are deflected.

Most solar wind particles are deflected around planets with strong magnetic fields.

Some solar wind particles infiltrate magnetosphere near poles.
Aurora

Near the poles, the charged particles collide with the atmosphere and create a glowing light called an aurora.

During solar storms the wind is intensified, the electrons spiral along the magnetic field into Earth's polar regions.

Loss of magnetic Field

- if the liquid core was to cool to the point where the liquid Fe-Ni core was to solidify, the magnetic dynamo would shutdown, resulting in the loss of the magnetic field and magnetosphere

- this is likely what happened on Mars - the loss of the magnetic field allowed the solar winds to quickly strip away the atmosphere and surface water, exposing its surface to cosmic radiation

- it will take billions of year to cool sufficiently for the Earth’s dynamo to die

Our unique atmosphere

78% Nitrogen, 21% Oxygen, little CO₂

Questions

- What is the origin of our atmosphere
- Why does our atmosphere have so much O₂ when Venus and Mars have hardly any?
- Why is our atmosphere so poor in CO₂ compared to that of Venus and Mars?

Origin of Earth’s atmosphere

1. (Primary atmosphere)
   Early Earth atmosphere (Primary atmosphere)

2. These early gases, being light, escaped from Earth

3. Secondary atmosphere
   a. created from volcanic activity - lots of H₂O, CO₂, N₂
   b. Comets added some water and oxygen
   c. Life appeared over 3.5 billion years ago - > oxygen appears Now - - 78 % N₂ and 21 % O₂
### Origin of the Oceans

- $\text{H}_2\text{O}$ degassed from the Earth's interior simultaneously with gases in the atmosphere.
- Earth's surface cooled enough for water droplets to form and rain fell to the surface.
- 71% of Earth's surface is covered in water.

### Oceans and loss of Carbon Dioxide

Loss of $\text{CO}_2$: Atmospheric $\text{CO}_2$ dissolves in the oceans and in the rocks. Silicates react with dissolved $\text{CO}_2$ to form carbonate minerals (like limestone).

### Life and the Presence of Oxygen

- Blue-green bacteria put the oxygen in the atmosphere.

Photosynthesis:

$$\text{CO}_2 + \text{H}_2\text{O} + \text{sunlight} \rightarrow \text{organic compounds} + \text{O}_2$$

Oxygen appeared gradually between 2 and 1 billion years ago.

### Atmosphere Layers

- The blue curve shows the temperature at each altitude.
- Ionosphere is ionized by solar radiation, and is a good conductor. Reflects radio waves in the AM range, but transparent to FM and TV.
- Ozone layer absorbs ultraviolet radiation.
- Troposphere is where convection takes place – responsible for weather.
The greenhouse effect

\[ T = -23 \text{ Celsius with no greenhouse} \]
\[ T = 15 \text{ Celsius with greenhouse} \]

The greenhouse effect is controlled by the amount of greenhouse gases. These gases are primarily \( \text{H}_2\text{O}, \text{CO}_2, \text{CH}_4, \text{NH}_3 \).

Young Sun Paradox:
Why didn’t the oceans freeze in the beginning and why aren’t they boiling today?

Our Sun warmed over time as the fusion of hydrogen to helium has proceeded, building up a core of helium at the center of the Sun and pushing the fusion zone nearer to the surface.

- The early Sun had only 70\% the energy output that it has today.
- In the beginning the surface temperature would have been below freezing and today it should be above boiling.

Resolution
In the past there was a higher level of greenhouse gas (notably \( \text{CO}_2 \)), which increased the temperature.

Today, the \( \text{CO}_2 \) has been removed from the atmosphere allowing heat to escape.

In about five billion years our Sun will expand, eventually becoming a type of star called a "Red Giant."

In this image the Sun has just started its journey toward becoming a Red Giant.

The intense heat has started to boiled off Earth’s oceans and drive away its atmosphere.

Earth five billion years from now

The Sun will continue to expand until it fills the sky and eventually engulfs the Earth, leaving a lifeless, molten surface.
After the Red Giant Phase, its outer layers will lift off producing a Planetary Nebula. What is left will be a star no bigger than the size of the Earth (Called a White Dwarf).

White Dwarf

End of Chapter 7a

Go to Chapter 7b