

Life in Universe

ASTRON 1141 – Chapter 7 Extinction, Bare Necessities of Life and Terrestrial Planets

Extinction

1. The last (non-avian) dinosaurs died in the **K-T mass extinction**, 65 million years ago
 2. A large asteroid (or comet) struck the Earth 65 million years ago, triggering the mass extinction
 3. Asteroid impacts may have caused some of the other mass extinctions in the past (& the future...)
- Dinosaurs lived from 220 Myr ago to 65 Myr ago
 - The extinction event that killed off the dinosaurs 65 Myr ago killed about 70% of **all** species on Earth
 - **The mass extinction 65 Myr ago is called the K-T extinction.**
 - Why? It marks the boundary between the **Cretaceous** & **Tertiary** periods
 - Cretaceous is spelled with a **K** in German
 - **An explanation for the K-T mass extinction must account for:**
 - The extinction of many **non-dinosaur** species, large and small, on land and in the sea, all over Earth
 - The **rapidity** of the extinction (< 1 Myr)
 - **The favored explanation is the impact hypothesis**
 - **Impact hypothesis**: Earth was struck by an asteroid (rock & metal) or a comet (ice) about 10 kilometers across.
 - An asteroid this big carries the energy equivalent of 2 million fusion bombs, and gouges a crater 100 kilometers across.
 - More evidence for an asteroid impact at the end of the Cretaceous: a layer of **iridium-rich** clay
 - **Iridium is a very dense metal (twice as dense as lead). Differentiation left most of the Earth's iridium in its core**
 - However, **undifferentiated** asteroids are rich in iridium!
 - Between Cretaceous and Tertiary rocks, iridium-rich clay layers are found all over the Earth
 - Did the asteroid impact cause the extinction, or was it coincidental?
 - **Indirectly, a large impact can cause mass extinctions.**
 - Collision ejects dust into atmosphere.
 - Months of darkness & cold.
 - Death of plants.
 - Death of herbivores.
 - Death of carnivores.
 - **Other side effects:**
 - Tsunamis
 - Firestorms
 - Acid rain
 - **Mass extinctions have occurred 5 times in the Phanerozoic Eon:**

- The biggest mass extinction known was actually the “Great Dying” at the Permian-Triassic boundary, 251 Myr ago.
 - 96% of marine species
 - 70% of land species became extinct in the Great Dying.
- Extinctions open up ecological niches and accelerate evolution by natural selection
- Near-Earth Objects (NEOs) are asteroids and comets that have orbits that bring them near Earth
 - A recent census concludes that there are nearly 1000 NEOs bigger than 1 kilometer across
 - Small stuff hits the Earth frequently: the meteorite that hit Chelyabinsk, Siberia last February was 20 meters across
 - Energy released was 0.4 megatons
- Larger stuff hits the Earth less frequently: the asteroid or comet that hit Tunguska, Siberia in 1908 was 60 meters across
- Energy released was 10 megatons; such a large event occurs about once per century
- Chicxulub-like impacts should occur once per 100 million years, on average

Bare Necessities of Life

1. Life requires: a source of **energy** (definitely), complex **chemistry** (probably), and a liquid **solvent** (possibly).
 2. **Sunlight** is the main source of energy in the Solar System, but other sources exist.
 3. A planet's **equilibrium temperature** helps to determine whether it has oceans and atmosphere
- What are the **bare necessities of life**?
 - All life **on Earth** uses DNA & RNA to store information, and ATP to transport energy within cells
 - Other molecules could do the same jobs: DNA, RNA, & ATP aren't absolutely **required** for life in the universe
 - The requirements of life on Earth suggest some **general** necessities for life elsewhere
 - A source of energy (a **star** works well)
 - A liquid solvent (**water** works well)
 - A way of storing information (**carbon-based molecules** work well)
 - The Sun is the main energy source in the Solar System
 - The Sun's **luminosity** (the rate at which it produces radiant energy) is $L = 4 \times 10^{26}$ watts
 - That is, light carries away 400 trillion trillion joules of energy from the Sun **each second**
 - Light is “**diluted**” as it streams away from the Sun
 - **Earth** (1 AU from Sun, warm, liquid water)
 - **Eris** (97 AU from Sun, too cold for liquid water)
 - The **flux** of sunlight (luminosity per unit area) decreases with **distance** from the Sun
 - f = flux luminosity
 - L = Sun's luminosity
 - d = distance from sun
- $$f = \frac{L}{4 \pi d^2}$$
- The surface of a planet absorbs solar energy and warms up
 - Warm objects radiate infrared light

- A planet reaches **equilibrium temperature** when the rate at which it **absorbs** solar energy equals the rate at which it **emits** infrared energy
- **Temperature** is a measure of the average **kinetic energy** of an atom or molecule's random motion

$$v = \sqrt{\frac{3kT}{m}} \quad \text{Boltzmann constant} \quad - \text{Kinetic Energy} = \frac{1}{2}mv^2 = \frac{3}{2}kT$$

- Random motions stop at **absolute zero** temperature.
- **Kelvin = Celsius + 273**
 - Water boils: 373 K
 - Water freezes: 273 K
 - Absolute zero: 0 K
 - Room temperature: about 300K
 - Surface of Sun: about 5800 K
- **Equilibrium temperature of a planet in the Solar System depends on:**
 1. The flux of sunlight it receives (& thus its distance from the Sun)
 2. Its **albedo** (the fraction of light that it reflects)
 3. Dark objects near the Sun are hot: shiny objects far from the Sun are cold
- The **equilibrium temperature** of an object heated by the Sun (given without proof):

$$T_{eq} = 278K \frac{(1-A)^{1/4}}{\sqrt{d}}$$

- d = distance from Sun (in AU)
- A = albedo (1 = perfectly reflective, 0 = absolutely black)

- **Examples:**
 - **Moon** (dark rocky surface)
 - a) A = 0.12
 - b) d = 1 AU
 - c) $T_{eq} = 269$ K
 - **Enceladus** (icy surface)
 - a) A = 0.99
 - b) d = 9.54 AU
 - c) $T_{eq} = 28$ K
- Wild card: an atmosphere with a greenhouse effect would increase these temperatures
- Wild card: **Thermophiles** on Earth remind us that the Sun isn't the only source of energy
- Life around deep-sea volcanic vents and in hot springs is powered by **geothermal** energy
- **A liquid solvent of some kind is probably necessary**
 - Water is called the "**universal solvent**"; it dissolves more substances than other liquids do
 - Water stays liquid over a wider range of temperature than other liquids do
- **Wild card: there are other possible solvents**
 - **Water** (H₂O): liquid from 0 to 100°C (100°C range)
 - **Ammonia** (NH₃): liquid from -78 to -33°C (45°C range)