U3 Terrestrial Planets

Intro

- Division of terrestrial and gas/ice giants based on density

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- Material common to all terrestrial planets is Si, O, Al, Mg, S, and Fe
    - Most abundant rock type is basalt (common to all) -> Basalt is an igneous rock which is the primary product of volcanic lava, fine grained, dark grey to black
- (**basalt**: an igneous rock, the primary product of volcanic lava, fine grained, dark grey to black

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Chapter 6
Collision

Learn the different models of the Moon's origin and why one is favoured:

- Moon is unusual compared to other natural planet satellites:
    - Very large relative to the planet it orbits
    - Abnormally low density for an object associated with a terrestrial planet
    - Core that amounts to 2-4% of its total mass compared to 30% for Earth's core
    - Abnormally high angular momentum
- Prior 1970's 3 hypotheses were tossed around and little hard evidence to support any one of them:
    1. **Fission Hypothesis:**
        - George Darwin proposed 100 years ago
        - Moon broke off from rapidly spinning Earth
        - Hypothesis rejected as this would require that Earth rotated every 2,5 hours rather than every 24 hours which is difficult to reconcile with current roational rate
    2. **Condensation Hypothesis :**
        - Earth and Moon formed contemporaneously from the same material
        - Hypothesis rejected as they both do not have the same chemical composition
            - Moon has tiny metallic core compared to earth
            - Also moon and earth don't orbit exactly on an equatorial plane
    3. **Capture Hypothesis:**
        - Moon formed as an independent planetary body that was captured by Earth during a close pass
        - Hypothesis rejected because it is astronomically unlikely that there was exact gravitational and dynamic conditions needed for an object the size of Moon to fall into orbit about Earth
            - Some chemicals were so similar between Earth and moon that there needed to be some close genetic relationship
            - Every single attempt to model this hypothesis via computer program failed

Giant impact Hypothesis:

- Preferred mechanism to explain the formation of the moon:
    - Collisions and melting of melting of both bodies
    - Glancing blows gave an increased angular momentum to Earth
    - Metal core of the empactorseparated and dropped into earth giving it large metalcore
    - The molten mantle material of both bodies mixed and formed debris in space just above earth
        - Most of it collected into a single mass to become a moon

<u>Challenges to this model:</u>

- How do you explain the similarity of lunar samples with rocks found on Earth?

- Tungsten isotope tells us moon started life 30 million years ago
- Oldest Moon rocks were formed when magma ocean cooled so Moon must have started out with large enough input energy
- Isotopes of oxygen in lunar samples have almost exactly the same proportions as rocks -> quite confident that Earth and Theia must have been well mixed
    - So this means that an impact event is required for the formation of the Moon

Different Viewpoints of Model:

- Much larger impact than what was previously though -> the only way to get a match for Earth and Moon's composition is to make Theia nearly as massive as Earth
- Or there must have been a high velocity impact with a much smaller body:
    - Earth has to be spinning really fast (combo of fission hypothesis and Giant Impact) -> mechanism to slow down rapid spinning of earth is tidal interaction with the sun
- Or earth had 2 moons
- SO THIS IS STILL AN AREA THAT IS BEING RESEARCHED

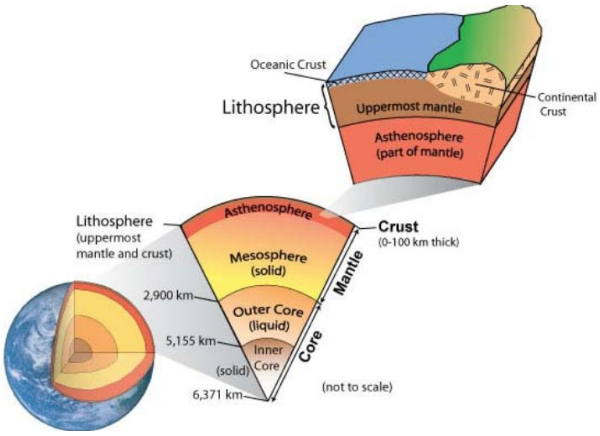
Chapter 7
Earth

- 5th largest planet
- Densest **major** body in the solar system (5.5)
- One permanent natural satellite the moon
- Plane of orbit is only 7 degrees from sun's equatorial plane
- Orbital path circular -> angle of obliquity is 23 degrees is responsible for seasons -> called **obliquity or tilt angle**
- Earth rotates, rotational axis moes making a cone like pattern -> precession -> positions of celestial poles change
    - Ancient Egypt -> North Pole Star was Thuban
    - Today North Pole star is Polaris (constellation Ursa Minor)
    - In 12000 it will be Vega (in Lyra)
- strong magnetic field generated by electrical currents in iron rich core
    - Mercury weaker
    - Venus none
    - And Mars extremely weak
- Earth Consists of **78% nitrogen, 21% oxygen**
    - Other 1% trace elements
- Planet grew by **accretion**
    - Accumulation of smaller bodies, dust and gas
    - As it was grewing the planet was very hot -> top was melted from impactor **kinetic energy** being transformed to heat
- Fe, O, Mg, Si, S account for 95% of earth's composition
    - Iron significant component of early earth and its impactors
    - Iron Catastrophe:
        - Iron is heaviest -> hot liquid iron from top layer would sink to the core -> released more energy causing the whole planet to melt
        - Remove much of iron from outer layer to form a liquid core of 100% metal

- Pressure as earth grew core turned into solid
- Lighter elements such as Si, Al, and O at surface

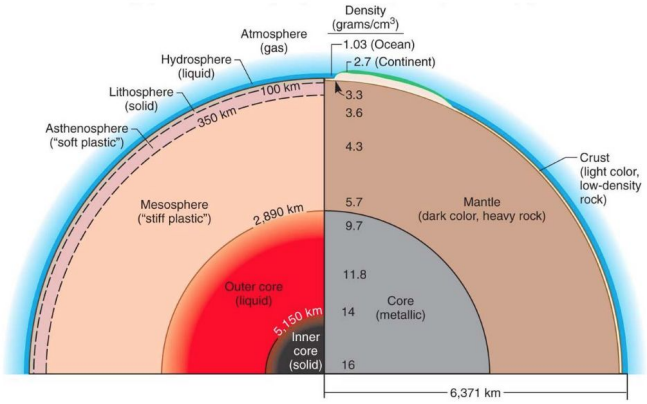
Differentiated Earth:

- **Differentiation**: process of chemical zonation from core to surface



First classification:
- Crust
- Mantle
- Core

Newer classification:
- Lithosphere
- Asthenosphere
- Mesosphere
- Outer Core
- Inner Core



- Left are physical properties
- Right are chemical properties
- **Pressure and Temperature and density** increase from surface to core

- Lithosphere: Outermost layer of mantle
  - Rocky, solid, strong
- Asthenosphere: under Lithosphere
  - Heat softened
  - Weak
  - Slow flowing rock
  - Within lithosphere and asthenosphere -> mountain building, volcanism, earthquake activity and creation of ocean basins originate
- Mesosphere:
  - High pressure
  - Rock is solid
  - High temp: material acts like stiff plastic
- Core:
  - Outer and Inner Core
  - Nearly pure metal
  - Temp of inner core is hotter than sun's surface
  - Inner core is solid

- Outer core liquid

Magnets and Magnetism:

- Dipoles
- Dynamo: most practical mechanism generate magnetic field
  - Mechanical device converts physical to electrical energy
  - Anywhere that electrical energy flows -> magnetic field surrounding it
- Rotation speed is gradually slowing
  - Inner core spins faster than earth
  - The liquid around makes it respond slower to outside forces
- Normal: what the Earth's Magnetic Field is now
- Reverse: north and south poles switch sometimes
- Currently Earth;s magnetic north pole is not coincident with Earth's geographic North Pole -> constantly changing

Plate Tectonics:

- Lithosphere divided into **plates**
  - Move due to **tectonics** that occur between them
  - Plate boundaries mark regions of interaction -> most of world's earthquakes and volcanic eruption
  - **North American Plate** -> London Ontario located on
- Can't find distinct tectonics on other planets

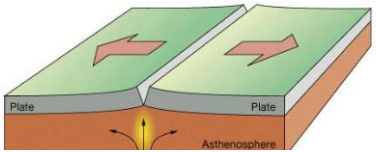
Continental Drift

- **Leonardo Da vinci (1508):**
  - Some fossils collected from top mountain were remains of seashells
  - This means that they once had to be on the seafloor
  - Realized seafloor had uplifted as seashells are not found everywhere on land
- **Charles Darwin (1830):**
  - Part of coastline of chile raised up due to earthquake
  - Vertical movement (up lift and down drop)
- **Alfred Wegner:**
  - Introduced idea of continental drift
  - Features of earth can be connected across gap of oceans
  - Sometime in past Atlantic Ocean did not exist
  - North and South America joined with europe and Africa as enormous continent called **Pangaea**
  - Pangaea broke apart through **continental drift** -> couldn't explain how though

Rock Magnetic Pattern:

- Magnetometers were introduced in WWII to help detect submarines, however they also helped detect magnetic patterns of Earth's crust that rapidly revived Wegener's hypothesis
- The study of magnetic properties of rocks is called **paleomagnetism**
- The most common rock on Earth is **basalt,** which is the most dominant rock of ocean floors, it is also abundant in magnetite, which in its solid state in basalt would have kept a record of what the magnetic field would be at the moment it was frozen
- The pattern that was present in the record of magnetite in basalt on the ocean floor showed that in specific locations a ridge could be defined to prove the spreading of plates

Plate Margins



- Since new seafloor is being created at the spreading centers, areas of the earth must be being destroyed in other areas, this phenomenon can be explained by expanding to three types of plate tectonics
- **Divergent margins:** characterized by plates moving apart, commonly called spreading centres
- **Convergent margins:** characterized by plates moving towards each other such that the edge of one plate sinks beneath the edge of the second plate (subduction)
- **Transform Fault margins:** boundaries where two plates slide past each other, with no significant vertical motion, sometimes the faults that make up the margin are called strike-slip faults
- Most volcanic eruptions occur along divergent and convergent margins
    - Most earthquakes occur along any of the three types of plate margins

<u>Convection and subduction</u>

- **Convection**, through Earth's radioactive decay, provides a tremendous driving force to move material around
- Convection currents cause material to be able to rise from the bottom to the top of the mesosphere
- **Seismic tomography** uses seismic waves to detect temperature of materials in the lithosphere

<u>Mantle plumes</u>

- Due to the high temperatures surrounding the mesosphere, occasionally large pockets of hot, less dense material starts to rise through the layer above it, once it eventually pushes through the lithosphere it can cause volcanoes

Dating Rocks; Earth's Geological Time Scale

- **Relative age dating**
    - Using relative relationships to determine the age of a sequence of rock formations
    - Arranging sequences like this from North America, they can be matched with others around the world to put together a **geological time scale**
    - **Proterozoic** (545 million years ago): soft-bodied lifeforms
    - **Phanerozoic** (Cambrian Period until present)
        - **Paleozoic** (early life)
        - **Mesozoic** (middle life)
        - **Cenozoic** (recent life)
- **Absolute Age Dates**
    - Discovery of radioactivity (1896)
    - What we need to determine the age of most rocks
        - The rate of radioactive decay **(half-life)**
        - The amount of the isotope that is in the process of breaking down **(parent)**
        - The amount of the isotope produced by the breakdown **(daughter)**
    - Most common radioactive elements used are **uranium** and **thorium**
    - **Carbon** dating can only work for something no older than 100,000 years
    - Oldest surviving rock is about 4 billion years old
    - Oldest thing in the ocean is about 250 million years old

Earth's Atmosphere, Hydrosphere and the Beginning of Life

- The Ancient Atmosphere
    - Other planets have atmospheres but none has an atmosphere that nurtures a biosphere
    - earth's original atmosphere was primarily hydrogen and helium
    - When Earth's surface solidified it switched to a dominant composition of carbon dioxide (~96%) and Nitrogen (~2%)

- **Venus** and **Mars**, have atmospheres composed of approximately 96% carbon dioxide (CO2), about 2-3% nitrogen (N2)
- Today **nitrogen** (78%) dominates with **oxygen** second (21%) and the remaining made up of argon and traces of carbon dioxide
- Earth's atmosphere (1 bar), Mars (0.07) and Venus (90 bars)
- Water on Earth dissolves carbon dioxide, almost completely removing it from Earth's atmosphere, regulating the temperature and allowing for life
- Beginnings of today's atmosphere were volcanic glasses, spewing water vapor and carbon dioxide, this early atmosphere was devoid of oxygen

- Add the Hydrosphere and Biosphere
  - Sometime between 4 and 4.5 billion years ago, Earth was pummelled by comets and asteroids, each containing small quantities of water
  - Earth's hot surface temperature turned this water into vapour but when the surface of Earth had cooled sufficiently, the water vapour in the atmosphere condensed and rain began, creating the hydrosphere
  - Fossil evidence of sea life 3.5 billion years ago, chemical evidence that life was present 3.8 billion years ago
  - **Photosynthesis (co2 + h2o = O2)** allowed for the addition of oxygen to the atmosphere
  - The biosphere lowered the carbon dioxide content severely, lowering the temperature
- The Rise of Oxygen - The Fall of Carbon Dioxide
  - **Anaerobic** environment - containing no free oxygen
  - Most ancient fossils found to date (3.5 billion years) are single celled organisms called prokaryotes
  - Prokaryotes could produce oxygen through photosynthesis, but as an anaerobic organism, oxygen was poisonous
  - Abundant ion in the ancient oceans absorbed the oxygen, allowing for some of these organisms to continue to survive
  - After 2 billion years this cycle used up all of the available iron in the water,finally causing free oxygen to appear
  - This led to new multi-cellular organisms called **eukaryotes**
    - Used oxygen for respiration
    - Grew rapidly in very large colonies
    - Were truly photosynthetic
    - Thus contributed a great amount of oxygen to the atmosphere and rapidly changed the biosphere of Earth

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Chapter 8
Moon

- Only nearby object other than the sun we can actually resolve features on, with our eyes
- Tidal coupling: phenomenon in which a larger body's gravitational influence imposes its rotational and orbital period onto a smaller body

<u>The View from Earth</u>

- Even from earth we can tell the Moon is airless, due to its size it must have a low escape velocity
- Harsh shadows also show that there is no air to soften them

- Near side of the moon (faces us) is divided into light areas called lunar highlands (composed of anorthosite) and darker areas called maria (seas, filled with dark basalt lava)
- Volcanically dead for 3 billion years
- Relative ages, maria must have been formed after the highlands
- Lava cut channels known as sinuous rilles
- Almost no marias on the far side of the moon

Crates to Learn By

- **Meteoroid:** sand size to 100m diameter
- **Asteroid:** >100m diameter to 1000km
- Most of the large impacts to the moon must have been during the solar system's youth
- Meteoroids and asteroids typically strike planets at 10 or more km/s
- A crater will be roughly 15-20 times the size of the impactor, 50 times for the moon due to lack of atmosphere

Lunar Exploration

- July 20, 1969: Neil Armstrong became the first human to set foot on the Moon **(Apollo 11)**
- Soviet Luna 1 was the first spacecraft to reach the Moon (1959)
- Firsts in lunar exploration
    - First successful US mission toward the moon was **Pioneer 4**
    - **Ranger** series took a stack of excellent photos
    - Soviet **Luna 9** in 1966 was the first ever Earth ship to soft-land on another planetary body
    - Months later US also made a soft landing with S**urveyor**
    - **Zond 5** in 1968 collected samples with Earth organisms
    - **Apollo 8** in late 1968 was the first manned lunar orbital mission, A**pollo 10** was a dry run

Moon Rocks

- Rock samples from Apollo found that **every single solid rock on the Moon's surface was igneous in origin**
- Moon rocks are extremely dry
- Lunar maria contains dense dark **basalts**, some of which are **vesicular** (contain holes caused by bubbles of gas)
- Mare basalts can be dated from their radioactive atoms, ages range from 3.1 to 3.8 billion years
- highlands are composed of **anorthosite:** low-density rock containing calcium, aluminum and oxygen rich minerals (4 to 4.5 billion years old)
- A large fraction of the lunar rocks are **breccias**: rocks that are made up of fragments of earlier rocks cemented together by heat and pressure
- **Regolith:** powdered rock and crushed fragments covering the highlands and lowlands
    - 10m deep on the maria but over 100m deep in certain places in the highlands
    - 1% meteorite fragments

Seismic Activity

- **Seismology:** study of motions in the ground
- Moon is 100 million times seismically quieter
- Moon has a small core (2-4% of its mass) (Earth's is 30%) that is hot and perhaps is still partially molten

Geologic History of the Moon

- US probe **Clementine** completely mapped the surface of the Moon
- Four-stage history of the Moon

- **Stage 1:** The Apollo Moon rocks show that the Moon must have formed in a molten state, high density materials sunk to the core creating a very low- density surface (3.30 g/cm3) (surface solidified 4.6 to 4.1 billion years ago)
- **Stage 2:** Period of heavy bombardment, crust was shattered to a depth of 10 km and the largest impacts formed giant multi-ringed crater basins hundreds of km in diameter such as Mare Orientale
- **Stage 3:** Intense cratering led to lava flowing which flooded the craters creating the maria and filling it with dark basalts (3.8 to 3.2 billion years ago)
    - 4 billion years ago, an asteroid the size of Rhode Island struck the Moon, the impact was so violent the ejecta blanketed 16 percent of the Moon's surface
    - Impacted surface on the opposite side of the Moon (jumbled terrain)
    - Largest impact basin is the south-pole Aitken Basin (2500 km in diameter, deeper as 13 km in some places)
- **Stage 4:** Final period of slow evolution, changes occur very slowly due to the lack of liquid water

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Chapter 9
Mercury

- Always stays in the same region of the sky as the Sun
- Never gets closer the Earth than about 80 million km
- **Mariner 10** was the closest spacecraft to approach Mercury providing almost all of our knowledge at that point (1974)
- Much of our current understanding is based on data from the **MESSENGER** mission (2004)
    - Took 7 years to reach Mercury's orbit, eventually did so on March 18, 2011
    - Succeeded in mapping out the entire surface of Mercury
    - Crashed into the planet's surface on April 30, 2015

Planet Facts

- Diameter: 4878 km (this is roughly about one and one-half that of the Moon).
- Density: 5.4 g/cc
- Mean surface temperature: 350°C day; -170°C night.
- Rotation period: 58.65 days (compared to 24 hours for Earth)
- Orbital period: 88 days (compared to 365 days for Earth).
- Orbital speed: 47.87 km/s (that would be 172,332 km/h – which is really moving!)
- Orbital eccentricity: most eccentric of all terrestrial planets.
- Orbital inclination: 7 degrees to the plane of Earth's orbit (the ecliptic)
- Axial tilt: almost too small to measure
- Magnetic field: present (at about 1.1% the strength of Earth's field)

Orbital Chaos

- During the 1880s an Italian astronomer hypothesised that Mercury was **tidally couple**d to the Sun, which was correct
- Tidal coupling is 3:2 spin-orbit with the Sun (1.5 rotations for every orbit)
- Mercury year is 88 Earth days and a **solar day** 176 Earth days (one full Mercury day is two Mercury years long, in theory)

Mercury's Surface

U3 Terrestrial Planets

- Surface temperature
    - **Perihelio**n (point in orbit when it is closest to the Sun), Mercury is only 46 million km away from the Sun
    - **Aphelion** (furthest from the Sun) it is 70 million km away
    - 427C at full sunshine, -173C at night
- Atmosphere
    - Very thin atmosphere which is blasted off its surface by solar winds, constantly replenishing it (**exosphere**)
- Craters and Plains, Cliffs and Hollows
    - enormous cliffs, hundreds of km longs
    - Also has smooth plains (volcanic deposits) which cover approximately 40% of the surface, some appearing to the result of explosive eruptions
    - Largest basin is called the **Caloris Basin**, 1300 km in diameter, concentric mountain rings up to 3 km high, impact threw ejected 600 to 800 km across the planet -> same structure as **Imbrium Basin** on moon
    - Mercury lacks the mare's filled with dark material
    - There are less heavily cratered areas called **intercrater** plains marked by small craters (less than 15 km in diameter) cites that lava flow partially buried old craters
    - Smaller regions called **smooth plain**s appear to be even younger
    - Mercury is not as reflective as the Moon, having a lower **albedo** (portion of light reflected by planetary body) of 0.1
    - No evidence of plate tectonics, escarpments believed to have formed due to shrinkage during Mercury's cooling

<u>The Interior of Mercury</u>

- Mercury is denser than any other planet except Earth
- Mercury has a large core (75-85% of total mass) surrounded by a solid shell of iron and sulphur
- Mercury has a magnetic field of .5-1% of the strength of Earth's meaning the core is still molten, despite its small size

<u>History of Mercury</u>

- **Stage 1**: Mercury formed in the innermost part of the solar nebula, a giant impact may have robbe it of some of its lower density rock and left it a small, dense world with a large metallic core
- **Stage 2:** Like the Moon, Mercury suffered heavy cratering by debris in the young Solar System, probably similar bombardment period as the Moon, however ejecta would have travelled 65% the distance due to heavier gravity
- **Stage 3:** Flooding began with lava flows filling some lowlands, Caloris impact may have been so big it fracture the crust and triggered still more outpourings of molten lava, forming smooth plains
- **Stage 4:** Slow surface evolution from micrometeorites

<u>Surface Composition</u>

- Much more sulphur, 10 times as much as Earth
- Surface rocks high in magnesium citing high temperatures at the time of eruption, also have a high abundance of p**yroxene, feldspar and sulfide minerals**
- MESSENGER found existence of water-ice, 10-30cm thick on the North Pole which is in fact never exposed to the Sun

Future Missions

- **BepiColumbo** (2017, 2024 arrival), Bepi was the Italian mathematician who figured out the 3:2 spin ratio

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Chapter 10
Venus

- Often called the evening or the morning star (normally seen 3 hours after sunset or 3 hours before sunrise)
- Hard to see Venus even from telescopes due to the heavy top layer of cloud which never clears
- 0.95 times the diameter of Earth, very similar density, known as Earth's twin
- 23 spacecraft have flown past or orbited Venus, over a dozen have landed on its surface
- Surface is incredibly dry
- USSR had 15 successful missions, 10 landings
- Venera 9, 10, 13 and 14 even managed to transmit images
- US' **Magellan** was the first space probe to be launched from a space shuttle (1989), landed on the surface in 1994

Planet Facts

- Diameter: 12,104 km
- Density: 5.24 g/cc
- Mean surface temperature: 462°C
- Rotation period: 243.01 Earth days (apparent retrograde)
- Rotational speed: 6.52 km/h (you could easily run faster!)
- Orbital period: 224.68 days (so 1 day is longer than 1 year!)
- Orbital speed: 35 km/s
- Orbital eccentricity: 0.0068 (most nearly circular of all the planets)
- Orbital inclination: 3.23° to Earth ecliptic
- Axial tilt: 177.36° (zero or 180 would be vertical)
- Satellites: none

Orbit and Rotation

- .72 AU, second closest planet to the Sun
- Orbital path lies almost in the same plane as Earth's, differing by slightly less than 3.4 degrees
- Venus rotates clockwise unlike most planets (only shared by Uranus and Pluto) this is called r**etrograde motion**, found in 1962
- It's the **slowest** spinning object in the known universe
- Completes a rotation every 243 days
- One Venusian day is 117 Earth days due to this slow **rotation** and its 225 day **revolution** around the Sun

Atmosphere and Greenhouse

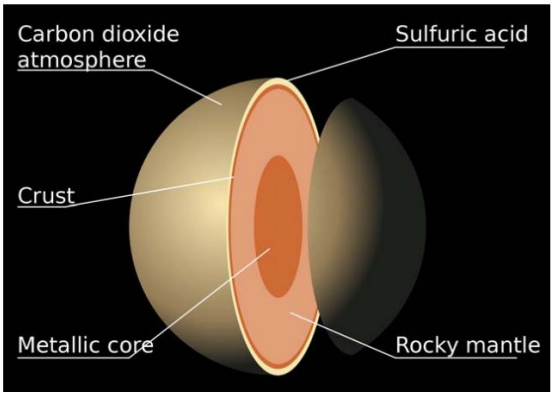
- Venus is completely covered with a thick blanket of clouds (droplets of liquid/solid sulfur and droplets of sulfuric acid)
- Its thick atmosphere is composed mainly of carbon dioxide (96.5%), nitrogen (3.5%), 0.1% to 0.4% water vapour, 130ppm sulfur dioxide and 60 ppm of free oxygen
- **There is about as much carbon dioxide found in the rocks and oceans of Earth as there is in the Venusian atmosphere**
- Venus loses a large volume of its atmosphere due to the stream of electrons coming from the Sun
- Venus' carbon dioxide rich atmosphere creates a very harsh greenhouse effect, resulting in surface temperatures of about 462C
    - CO_2 is transparent to **incoming light energy** -> opaque to **outgoing infrared energy**
- Evidence that Venus once had an abundance of liquid water to make a planet wide ocean up to 25 meters deep, due to evidence of hydrogen isotopes
- **runaway greenhouse effect** has made the surface so hot that even sulfur, chlorine, and fluorine have baked out of the rock and formed sulfuric, hydrochloric, and hydrofluoric acid vapours
- Soviet **Venera** spacecraft, equipped with searchlights for illuminating the surface, found no need for artificial lighting

<u>Geology</u>

- The Surface of Venus
    - Very few impact craters, largely due to its dense atmosphere which would **burn up smaller objects through friction**
    - Surface craters seem to indicate that Venus is about 500 million years old, however we know it is closer to 4.5 billion years meaning some large scale global resurfacing must have happened at that time
    - Huge dome surrounded by concentric fractures: **coronae**
    - Deep volcanic crater, result of one of the coronae blowing its top: **caldera**
    - Hundreds of thousands or even millions of volcanoes, some flattened **(pancake volcanoes)**
    - Venus and Earth should have similar interiors, but without **plate tectonics (on earth allow for heat to escape)**, heat is not periodically expelled meaning that Venus' heat occasionally "boils over" in the form of volcanic eruptions
    - The theory is that 300-500 years ago, the whole planet was resurfaced by basaltic lava flows; they erupted for thousands to millions of years
    - Venus has extremely sharp, uneroded mountain ridges and cliffs, this is due to extremely dry conditions and a lack of water

<u>The Interior of Venus</u>

- Must be a mix of rock and metal, much like Earth
- Interior must be hot, perhaps on par with Earth
- Venus has a very weak magnetic field due to the interactions of solar wind and its atmosphere



Chapter 11
Mars

- Less than a century ago The Guzman Prize was offered in France to the first person to establish contact with beings from another world - **Mars was excluded for being too easy**
- G.V. Schiaparelli (1877) drew a relatively good image of Mars, identifying so called desert regions, calling them canali (channels), they were eventually mistranslated leading to the "canals of Mars," believed constructed waterways
- In 1907 Percival Lowell created an observatory, promoting the idea of a planet-wide irrigation system so much so that the Wall Street Journal suggested that **"the proof by astronomical observations that conscious, intelligent human life exists upon the planet Mars**"

Planet Facts

- Distance from Sun: 1.52 AU
- Diameter: 6792 km (about 0.53 of Earth)
- Density: 3.934 g/cc (Earth = 5.515)
- Surface temperature: -87°C to -5°C
- Rotational period: 1.026 days
- Equatorial rotational speed: 868.22 km/h (Earth's is 1670 km/h)
- Orbital period: 686.97 days
- Orbital speed: 24 km/s
- Orbital eccentricity: 0.0933
- Orbital inclination: 1.850°
- Axial tilt: 25.19°
- Satellites: two (Phobos and Deimos)

Orbit and Rotation

- A day on Mars is 24 hours and 30 minutes, martian year last 1.88 Earth years
- Mars is tipped 25 degrees, Earth is 23.5

Mission to Mars

- **Functioning spacecraft currently orbiting Mars**
    - Mars Reconnaissance Orbiter (2005, USA)
    - Mars Express (2003, European Space Agency)
    - Mars Odyssey (2001, USA)
    - MAVEN (2013, USA)
    - Mars Orbiter Mission (MOM), also called Mangalyaan (2013, India)
    - 5 non-functioning, a dozen crashed spacecraft
- **Functioning spacecraft currently on Mars' surface**
    - Mars Curiosity (2011, USA)
    - Mars Opportunity (2003, USA)
- Between May 25, 2008 and November 10, 2008 there was also the stationary Phoenix Mars Lander, building upon Viking 1 and 2 (1975) and Pathfinder (1996)
- The twin rovers Spirit and Opportunity, completed a 90 day lifespan in 2004, 12 years later their discoveries of martian geology are still extremely important to research
    - Spirit is stuck in a sand trap, no communication

    - Opportunity is driving around the Endeavour Crater looking for evidence of clay materials
- Mars Curiosity
    - Launched on November 26, 2011, landed on Aeolis Palus crater August 6, 2012, a site now called Bradbury Landing
    - Primary objectives for Curiosity are:
        - To investigate whether Mars could or has ever held microbial life
        - To explore the presence of water on Mars
        - To explore martian climate
        - To explore martian geology

Atmosphere and Greenhouse

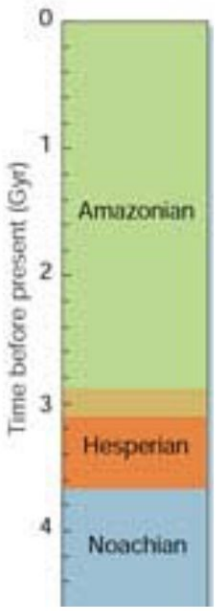
- Air on Mars
    - 96% carbon dioxide
    - 2% nitrogen
    - 2% argon
- The air contains miniscule traces of **water vapour and oxygen**
- Density at the surface of the planet (1% that of Earth's atmosphere) does not provide enough pressure to prevent liquid water from boiling into vapour
- Use to have **Primitive atmosphere** of hydrogen helium, bit of argon, neon, methane and some Ammonia
- After solar system started to take shape it was replaced by **Secondary atmosphere** of volcanically emitted gasses (similar to that of Venus and Earth)
- Mars escape velocity is only 5 km/s, less than half of Earth's meaning **gas atoms can escape more easily**
- **Lower-mass gasses and some whole molecules (broken down) have been lost**
- During winter, frozen carbon dioxide creates a **polar hood**, carbon dioxide clouds and haze hanging over the polar regions
- Stronger wind can pick up larger grains, enabling them to hop erratically over the surface, a process called **saltation**
- **Dune** fields, or large masses of wind-sculpted dunes, are common on both Mars and Earth
- **Current atmospheric pressure is too low to find liquid water,** however many geological features were certainly formed by moving water with significant amounts of water hidden in the crust
- Evidence in 2006 of a water burst smoothing and carrying materials down a crater
- Water flowing at low temperatures due to salts called perchlorates
- What water is left?
    - Ice in caps at north and south poles
    - Ice as permafrost just below surface
    - Water chemically bound to other elements in the structures of minerals and rocks
    - Tiny amounts of water vapour which, during local winter, forms frost and thin temporary ice deposits
- North polar cap is nearly all water ice, southern pole is a mix of carbon dioxide and water ice, 200 to 1000 meters in diameter, 8 meters thick
- Magma from which the rocks solidified must have contained up to 1.8% water
- Enough evidence to support there being a 20m deep planet wide ocean

U3 Terrestrial Planets

Geology

- Mariner 9 (1971) mapped the whole planet in detail for the first time
- Mars is a one plate planet (similar to Venus) also includes some of the largest volcanoes in the Solar system
- Atmosphere of Mars is thin but protects it from micrometeorites
- Southern highlands are heavily cratered (2-3 billion years old)
- Northern lowlands are smooth to the point in which it must have been resurfaced roughly a billion years ago
- Martian volcanoes are shield volcanoes (shape like an inverted warrior shield)
- Largest volcano in the solar system is Olympus Mons on Mars, larger than Mauna Loa on Earth which has sunk through the crust but Olympus Mons has not sunk under the crust on Mars, citing a thicker martian crust
- Valles Marineris is a canyon deeper than the Grand Canyon which would strength from Toronto to Vancouver, citing there was once activity in the crust
- Tharsis Rise, 10km above the mean elevation of the planet

- **Noachian Era:** Earliest period of martian history,
  - thicker early atmosphere
  - high rates of cratering, heat flow, volcanism, fluvial activity, and probable glacial activity It lasted from planet formation 4.5 billion years ago until about 3.5 billion years ago
- **Hesperian Era**:
  - Era of transition from **Noachian** conditions to modern **Amazonian** conditions
  - major outflow channels,
  - The last water flows and erosion episodes probably dated from this period
- **Amazonian Era**:
  - The modern, dry, dusty, mostly frozen era
  - active geology (lava flows, water release) in this era



Deimos and Phobos illustrate three principles:

- Some satellites are probably captured asteroids.
- Small satellites tend to be irregular in shape and heavily cratered.
- Tidal forces can affect small moons and gradually change their orbits
  - We find even stronger tidal effects in Jupiter's satellite system.