Chapter 1 – A Universe of Life?

What are We Searching For?

- **Extraterrestrial life** We are looking for any sign of life, be it simple, complex, or intelligent
- We are rapidly developing the spacecraft technology needed to search for microbes on other worlds of our solar system and the telescope technology needed to look for signs of life among the stars

1.2 The Scientific Context of the Search

- 3 particular disciplines play a role; astronomy, planetary science, and biology

How does astronomy help us understand the possibilities for extraterrestrial life?

- **Geocentric model** Belief that the Earth was in the middle of the universe.
- We now know that Earth is but one tiny world orbiting one rather ordinary star in a vast cosmos, and this fact opens up countless possibilities for life on other worlds

How does Planetary Science Help Us Understand the Possibilities of Extraterrestrial Life?

- Planetary science includes the study of planets themselves, and the study of moons orbiting planets, how planets form, and other objects that may form in association with planets
- 1. How planets form; and how common these are
- **Extrasolar planets** Planets orbiting stars other than our sun
- 2. How planets work
- **Habitable worlds** Worlds that contain the basic necessities for life
  - Whether it offers environmental conditions under which life could arise or survive, not whether it actually harbors life

How does biology help us understand the possibilities for extraterrestrial life?

- Basic laws of physics that we've discovered on Earth also hold throughout the universe
- Similarly confident that the laws of chemistry are also the same
  - Interstellar gas clouds contain many of the same molecules
- Chemical constituents found on the early Earth would have combined readily into complex organic (carbon based) molecules including many of the building blocks of life

Biology may be Common in the Universe

- Evidence that life can survive under a wide range of conditions
- Evidence that life appeared early in the history of Earth
- Evidence that organic molecules form easily and naturally

1.3 Places to Search

Where should we search for life in the universe?

Searching Our Own Solar System

- Ours is the only planet with oceans of liquid water
- Water is crucial to all terrestrial life
- Mars is the most promising candidate for life; strong evidence it once had flowing water
- At least 6 moons are possible candidates for life, with the best candidate being Jupiters moon, Europa because it has deep ocean of liquid water under its crust
- Two other moons of Jupiter; Ganymede and Callisto also show some evidence
- Saturns moon Titan; only moon in the solar system with a substantial atmosphere
- Saturn's moons Enceladus and Neptune's moon Triton also show possibility

Searching Among the Stars

- Journey to the nearest star would take 100,000 years

Could Aliens Be Searching for us?

- **Search for extraterrestrial intelligence (SETI)** A satellite that is available for signals from alien civilizations

1.4 The New Science of Astrobiology

- **Astrobiology** Combination of astronomy (study of the universe), and biology (the study of life), so astrobiology literally means the study of life in the universe

How do we study the possibility of life beyond Earth?

- NASA Astrobiology Institute, a collaboration involving scientists from NASA and more than a dozen other research institutions
- Most astrobiology is concentrated in the following ways
  1. Studying the conditions conducive to the origin and ongoing existence of life
  2. Looking for such conditions on other planets in our solar system and around other stars
  3. Looking for the actual occurrence of life elsewhere
- Seeks to reveal the connections between living organisms and the places where they reside

Chapter 2 – The Science of Life in the Universe

2.1 The Ancient Debate About Life Beyond Earth

How did attempts to understand the sky start us on the road to science?

- Ancient Chinese kept detailed records of astronomical observations 5000 years ago

Early Greek Science

- Thales was the first person known to have addressed the question "what is the universe made of" without resorting to supernatural explanations
  - Fundamentally consisted of water and Earth was a flat disk
- Plato and his student Aristotle also began searching but the Greeks tended to rely on pure thought and intuition than on observations or experimental tests
- Greek philosophers developed a tradition of trying to understand nature without resorting to supernatural explanations
- They worked communally, debating and testing proposals
- Developed mathematics in the form of geometry
- Understood that an explanation about the world could not be right if it disagreed with observed facts, which allowed them to discard explanations that don't work.

The Geocentric Model

- A scientific model is a conceptual representation whose purpose is to explain and predict observed phenomenon.
- Anaximander suggested that the heavens must form a complete sphere – the **celestial sphere** around Earth
  - Realized that Earth's surface must be curved; initially thought Earth was a cylinder
- Pythagoras and his followers adopted the idea of a spherical Earth for philosophical reasons
- Greek philosophers adopted a **geocentric model** of the universe
- Earth's circumference was first measured (fairly accurately) in about 240 B.C. by Erathosthenes

The Mystery of Planetary Motion

- The sun and Moon each move steadily through the constellations, with the Sun completing a circuit around the celestial sphere each year and the Moon completing each circuit in about a month
- Not only that the speed and brightness vary considerably, but the direction of motion sometimes also changes
- While the planets usually move Eastward relative to the constellations, something they reverse course and go backward **Apparent retrograde motion**
  - This was not easy to explain
- The Greeks believed that the heavens were perfect and everything moved in a perfect circle… opposite to the retrograde, therefore they came up with the Ptolemaic model
- **Ptolemaic model** Planets move around Earth on small circles that turned around larger circles
  - A planet following this circle on circle motion traces a loop as seen from Earth with the backwards portion of the loop mimicking apparent retrograde motion

- His model would correctly forecast future planetary positions to within a few degrees of the arc

An Alternative Model

- Aristarchus suggested Earth goes around the Sun
- He recognized that a Sun centered system offers a much more natural explanation for apparent retrograde motion
- Distant planets orbit the sun more slowly
- Mars never actually changes direction, it only appears to change direction from our perspective on Earth
- As Earth orbits the sun, we look at particular stars from slightly different positions at different times of the year, causing the positions or nearby stars to shift slightly relative to more distant stars
- **Stellar Parallax** Annual shifts in stellar position

Why did the Greek argue about the possibility of life beyond Earth?

- Greeks generally considered the "world" to include both Earth and the heavenly spheres
- Anaximander suggested that all material things arose and returned to the apeiron, which allowed him to imagine that worlds might be born and die repeatedly through time
- Believed the world was built from 4 elements; fire, water, earth, and air
- 2 distinct schools of thought emerged concerning nature
  1. **Atomists:** Held that both Earth and the heavens were made from an infinite number of indivisible atoms of each of the 4 elements. It was natural to assume that the same processed that created our world also could have created others
  2. **Aristotelians:** Held that the 4 elements were confined to the realm of Earth, while the heavens were made of a distinct fifth element; aether or quintessence
- Aristotle had a different view; believed that each of the 4 elements had its own natural motion and place and concluded the Earth is unique

2.2 The Copernican Revolution

How did the Copernican Revolution Further the Development of Science?

- **Copernican Revolution** radical suggestion of a sun centered solar system with mathematical detail

Copernicus – The Revolution Begins

- Copernicus discovered simple geometric relationships that allowed him to calculate each planet's orbital period around the Sun and its relative distance from the Sun in terms of Earth-Sun distance
- Theory didn't work that well, primary problem was the ancient belief that the heavenly motion must occur in perfect circles
- In the end, the complete model was no more accurate and no less complex than the Ptolemaic model
- Tycho Brache invented the telescope

Kepler – A Successful Model of Planetary Motion

- Was very religious and believed they should be perfect circles, and found a set of circular orbits that matched most of Tycho's observations quite well; but found discrepancies
- Small discrepancies finally led Kepler to abandon the idea of circular orbits – and find the correct solution to the ancient riddle of planetary motion
- Planetary orbits take the shapes of the special types of ovals known as ellipses
- **Keplers law of planetary motion**
  1. **Kepler's First Law:** The orbit of each planet about the Sun is an ellipse with the Sun at one focus. This tells us that a planet's distance from the Sun varies during its orbit
     - It is closest at the point called **perihelion**
     - It is farthest at the point **aphelion**
     - The average of a planets perihelion and aphelion distances is the length of its **semimajor axis**
  2. **Kepler's Second Law:** As a planet moves around its orbit, it sweeps out equal areas in equal times
     - It moves faster when it is nearer to the Sun, and slower when it is farther from the sun

3. **Kepler's Third Law:** More distant planets orbit the sun at slower average speeds, obeying the precise mathematical relationship.
    - One **astronomical unit (AU)** is defined as Earth's average distance from the Sun = 149.6 million kilometers

Galileo – Answering the Remaining Objections

- 3 basic objections
  1. Aristotle had held that Earth could not be moving because it is did, objects like birds would be left behind as Earth moved
  2. The idea of noncircular orbits contradicted the view that the heavens must be perfect and unchanging
  3. No one had detected the stellar parallax that should occur if Earth orbits the sun
- If heavens were not perfect, then the idea of elliptical orbits (as opposed to perfect circles) was not so difficult to accept
- Saw with his telescope that the Milky Way resolved into countless individual stars.
  - Helped him argue that the stars were far more numerous and more distant than Tycho believed
- Discovered 4 moons orbiting Jupiter, not earth
- Observed Venus going through phases that proved it orbited the sun
- Catholic church tried to make him take back what he said

Newton – The Revolution Concludes

- Precise mathematical descriptions of how motion works in general, ideas that we now describe as **Newton's laws of motions**
  1. An object moves at constant velocity unless a net force acts to change its speed or direction
  2. Force = mass x acceleration
  3. For any force, there is always an equal and opposite reaction force
- Used mathematics to prove that Kepler's laws are natural consequences of the laws of motion and gravity

Looking Back at Revolutionary Science

- Copernicus and his followers felt compelled to find models of nature that could actually reproduce what they observed
- By Newton's time, guessing was no longer good enough

How did the Copernican revolution alter the ancient debate on extraterrestrial life?

- The Copernican revolution proved Aristotle was wrong: Earth is not the center of the universe after all
- William Herschel assumed all the planets inhabited life
- Made it clear that the Moon and the planets really are other worlds, not mere lights in the sky

2.3 The Nature of Modern Science

How can we distinguish science from nonscience?

Approaches to Science

- **Hypothesis** An educated guess
- The scientific model can be a useful idealization, but real science rarely progresses in such an orderly way
- We learn about early life on Earth by piecing together its story from an examination of fossils and other evidence

Hallmarks of Science

- Three basic characteristics that are the hallmarks of science
  1. Modern science seeks explanations for observed phenomenon that rely solely on natural causes
  2. Science progresses through the creation and testing of models of nature that explain the observations as simply as possible
  3. A scientific model must make testable predictions about natural phenomenon that would force us to revise or abandon the model is the predictions do not agree with observations.

Occams Razor

- The idea that scientists should prefer the simpler of two models that agree equally as well with observations is called Occam's razor.

Verifiable Observations

- Observation against which a prediction can be tested
- Scientific study has never yet found the evidence to be strong enough to support the claim of alien spacecraft
- Because of its demonstrated unreliability, eyewitness testimony alone should never be used as evidence in science

Science, Nonscience, and Pseudoscience

- Can still use an observation, logic, and hypothesis testing
- Just because something is not science, doesn't make it wrong
- **Pseudoscience** Something that purports to be science and may appear scientific, but that does not adhere to the testing and verification requirements of the scientific method

Objectivity in Science

- All people should be able to find the same results
- Science is practiced by humans, and individuals bring their own personal biases
- Some valid ideas may not be considered by any scientist, because the ideas fall too far outside the general patterns of thought or **paradigm** at the time

What is a scientific theory?

- **Theory** A powerful yet simple model that explains a wide variety of observations in terms of just a few general principles, and has attained the status of a theory by surviving repeated and varied testing

The Meaning of the Theory

- Can never be proved true beyond all doubt, because ever more sophisticated observations may eventually disagree with predictions
- Can discard or replace a theory
- Einstein's theory as a broader theory of gravity than Newton, and some scientists today are looking for a theory beyond Einstein's.

2.4 The Fact and Theory of Gravity

- On a deeper level, stars and planets could never have been born without gravity
- Gravity is clearly a fact
- But scientifically, gravity is a theory because we use detailed, mathematical models of gravity to explain why things fall down and why planets orbit

What is Gravity?

- The first real breakthrough in human understanding of gravity came in 1666 when Newton saw an apply fall to Earth and suddenly realized that the gravity making the apple fall was the same force that held the moon in orbit around the Earth.
- Newton expressed the force of gravity mathematically with his **universal law of gravitation.**
- Three simple statements
  1. Every mass attracts every other mass through the force called gravity
  2. The strength of the gravitational force attracting any 2 objects is directly proportional to the product of their masses. For example, doubling the mass of one object, doubles the force of gravity between the two objects
  3. The strength of gravity between two objects decreases with the square of the distance between their centers. Follows an **inverse square law** – doubling the distance between two objects, weakens the force of gravity by a factor of 2^2 or 4.
- G is gravitational constant
- Edmund Halley used the law to calculate the orbit of a comet that was seen in 1682. His calculations showed it would return in 1758 which was right
- Observations of Uranus showed its orbit to be slightly inconsistent with the orbit expected according to Newton's laws.
- However, Urbain Leverrier suggested that the inconsistency could be due to an eighth planet – which was found to be Neptune.

Do we really understand gravity?

- According to Newton's theory, every mass exerts a gravitational attraction on every other mass, no matter how far away it is.

- Spacetime - massive objects curve this spacetime, and other objects simply follow the curvature much like marbles following the contours of a bowl
- Instead, he showed that Newton's theory was only an approximation to a more exact theory of gravity - the general theory of relativity
- But in cases of strong gravity, Einstein's theory works and Newton's fails

Chapter 3 – The Universal Context of Life

3.1 The Universe and Life

What major lessons does modern astronomy teach us about our place in the universe?

- Three ideas are important
  1. The universe is vast and old; plenty of time for more to evolve
  2. The elements of life are widespread
  3. The same physical laws that operate on Earth operate throughout the universe

3.2 The Structure, Scale, and History of the Universe

What does modern science tell us about the structure of the universe?

Our Cosmic Address

- Earth is a planet in our solar system which consists of the Sun and all the objects that orbit it: the planets and their moons, and countless smaller objects including rocky asteroids and icy comets
- The sun and all the stars we can see with the naked eye make up only a small part of a huge disk shaped collection of stars called **Milky Way Galaxy**
- **Galaxy** A great island of stars in space containing from a few hundred million to a trillion stars held together by gravity
- Our solar system is located about halfway through the disk of the galaxy, where it orbits the galactic center once every 230 years
- The **universe** is the sum of total matter and energy, encompassing the superclusters and voids and everything within them

The Scale of the Solar System

- The voyage scale model solar system in Washington D.C.
- The entire Earth could be swallowed by the storm on Jupiter known as the Great Red Spot.
- Trip to Mars is 200 times farther than the Moon

Distances to Stars

- **Light years** 1 light year is the distance light can travel in 1 year, which is about 10 trillion kilometers
- The nearest star to us is 4.4 light years away
- Voyageur 2 flew by Jupiter in 1979, Saturn in 1981 … and is not bound for the stars at a speed of close to 50,000 km per hour; would still take about 100,000 years to reach Alpha Centauri
- 4.4 light years – looking 4.4 years into the past

The Content of the Universe

- Stars orbit the center of the Milky Way Galaxy;
  - The more massive the galaxy, the stronger its gravity and the faster the stars should be orbiting
- Most of the mass in space lies unseen in much larger, spherical halo that surrounds the disk
  - **Dark matter** Matter that we infer to exist from its gravitational effects but from which we have not detected any light; dark matter apparently dominates the total mass of the universe
    - Most of the universe is made of this
  - **Dark energy** Energy that could potentially be the cause of the universe expansion to accelerate

What does modern science tell us about the history of the Universe?

The Big Bang and the Expanding Universe

- Entire universe is expanding which implies that galaxies must have been closer together in the past
- We call this beginning the **big bang** and conclude it happened around 14 billion years ago
  1. Detected a radiation left over from the big bang

- The universe must have been much hotter and denser if it was smaller in the past
- As the universe expanded and cooled with time, it should have left behind a faint "glow" of radiation that we could detect with radio telescopes – cosmic microwave background

2. Overall chemicals of the environment
   - The chemical composition of the universe after the Big Bang should be about ¾ hydrogen and ¼ helium
   - The early universe lacked the elements that make life on Earth

- Smaller scale: the force of gravity has drawn matter closer together
  - As the universe as a whole continues to expand, individual galaxies and galaxy clusters do not expand

Stellar Lives and Galactic Recycling

- A star is born when gravity compresses the material in a cloud to the point where the center becomes dense enough and hot enough to generate energy by **nuclear fusion** the process in which lightweight atomic nuclei smash together and stick or fuse to make heavier nuclei
- The natural pin of a contracting interstellar cloud keeps some of its gas spread away from its center while shaping it into a flattened disk
- Once a star is born, it shines with energy released by the nuclear fusion in its core
- It takes 4 hydrogen nuclei to make one helium nucleus: energy is released because a helium nucleus has slightly less mass than the 4 hydrogen nuclei
- More massive stars, with much denser and hotter cores, burn through their fuel at far greater rates than smaller stars.
  - Most massive stars live a few million years while stars like our sun live 10 billion years
- Massive stars die in titanic explosions called **supernovae**
  - The returned matter mixes with other matter floating between the stars in the galaxy, eventually becoming part of new clouds of gas and dust from which new generations of stars can be born

We Are Star Stuff

- Evidence shows that these elements were manufactured by stars
- Stars spend most of their lives generating energy by fusing hydrogen into helium
- Towards the end of their lives, stars like our Sun can fuse helium into carbon: Fusing 3 helium nuclei together makes one carbon nucleus
- The oldest star are made of nearly pure hydrogen and helium
- Younger stars are made of masses that are heavier than helium and hydrogen
- The theory of nuclear fusion in massive stars makes specific predictions about relative abundances
- Explosion and death of stars allow us to calculate the makeup of them
  - Without it, our universe would not contain the chemical elements of which we are made.
- The cloud that gave birth to our solar system was made of about 98% hydrogen and helium and 2% of everything else

Implications for Life in the Universe

- We expect the chemical composition of many other stars to be quite similar to that of our own

The Scale of Time

- On the cosmic calendar, the Big Bang is at January 1st
- Each month of the year represents just over a billion years; each day 400 million years, and each second 400 years
- Early February: Milky Way
- Early September: Our solar system and our planet formed
- Late September: Life on earth was flourishing; mostly microscopic
- Mid-December: Animals
- 26 December: Dinosaurs
- 9pm on December 31, early hominids

How big is the Universe?

- We have no idea how large it is

The Observable Planet

- When we look to great distances, we are also looking far into the past
- Nearest Galaxy – Andromeda; 2.5 million light years away
- We can't see anything that is 14 billion light years away
- Our **observable universe** – the portion of the entire universe that we can potentially observe – consists only of objects that lie within 14 billion years of Earth
    1. The fact that we cannot observe anything more than 14 billion light years away does not mean that nothing exists at such distances
    2. We are at the center of our own observable universe, since it is defined by a light travel distance in all directions of us

Worlds Beyond Imagination

- We can estimate the number of galaxies in the observable universe by counting the number that we can see in pictures made with powerful telescopes
- Astronomers estimate that the observable universe contains about 100 billion galaxies
- The total number of worlds - by which we mean any reasonably large bodies in space, such as planets, moons, or even large asteroids – may be even greater
- Confine our searches inside the Milky Way

Fine Tuned Universe

- Anthropic principle We are here to study the universe and basic principles, but if any of those properties were much different, we wouldn't be here today
- The expansion rate had to be "just right" for galaxies to form, a fact that looks even more remarkable when you take into account the acceleration, expansion, which also has to be the right value so it would have accelerated neither too much nor too little by now

3.3 The Nature of Worlds

- Inner planets are bunched much more closer together than the outer planets
- All planets orbit the sun in the same direction, and plane with nearly circular orbits, and most rotate on their axes in the same direction as well
- The Sun rotates in the same direction as well; as well as most moons

How do other worlds in our solar system compare to Earth

- Categorize planets
- Today we know that no other world in our solar system is much like Earth, at least on the Surface

Two Major Types of Planets

- **Terrestrial Planets**
    - Four inner planets; Mercury, Venus, Earth, Mars: are much smaller
    - Made almost entirely of metal and rock
    - Big densities
- **Jovian Planets**
    - Jupiter, Saturn, Uranus, and Neptune
    - Jupiter is the largest so they are called Jovian planets
    - Largely made of hydrogen, helium, and **hydrogen compounds** such as water (H20), methane (CH4) and ammonia (NH3)
    - Have at least 165 moons among them
    - Also have rings made up of countless small particles orbiting them
    - Uranus and Neptune contain much higher proportions of metal, rock, and hydrogen than Jupiter and Saturn, which are mostly made from helium and hydrogen

Asteroids, Comets, and Dwarf Planets

- Pluto, Eris, ad other objects large enough for their own gravity to have made them round are now considered dwarf planets

- The rest of the small bodies have traditionally been categorized into two groups
  - **Asteroids** Made mostly of metal and rocks
  - **Comets** Made mostly of ice and rock
- Most asteroids orbit in the region called the **asteroid belt** which lies between the orbits of Mars and Jupiter
- Comets come from two vast "reservoirs"
  1. **Kuiper Belt:** Occupies the region of the solar system beyond Neptune and in which we find both Pluto and Eris
  2. **Oort Cloud:** Distant, spherically shaped region. As many as trillion
- Pluto and Eris are members of the Kuiper belt
- Pluto and its cousins "as comets" and prefer the general term **Kuiper Belt objects,** adding that they are dwarf planets if they are round

Moons

- Pluto for example, is orbited by 3 moons
- Most moons are very small and would be considered asteroids or comets if they orbited the sun independently.
- Relatively large moons are planet like in almost every way except for their orbit
- Moons of the jovian planets generally contain large amounts of ice

Why do worlds come in different types?

- **Nebular theory** Starts with the idea that our solar system was born from the gravitational collapse of an interstellar cloud or nebula of gas and dust
- This particular cloud that gave birth to our solar system is called the **solar nebular**

Contraction and Disk Formation

- Once the collapse began, the laws of physics ensured that the solar nebula would heat up, spin faster, and flatten into a disk as it shrank in size
- The heating occurred because gas particles tend to move faster as they fall inward under gravity
- The particles in the solar nebula collided with each other as they fell inward, transforming their energy of motion into heat
- The cloud became hottest in the center, where the sun formed
  - The heating was a consequence of **the law of conversation of energy;** energy can be neither created nor destroyed, but only transformed from one form to another
- The spin of the cloud was a result of another physical law, known as **conservation of angular momentum;** state that the total amount of circling motion of an object must be conserved
  - Shrinking cloud of gas spins faster as it contracts
- As particles collide in a spinning cloud, they tend to add to each others motion when they are moving in the direction of the rotation, but to cancel each other motion in other directions

Seeds of Planet Formation

- Material had to begin clumping in some other way and to grow in size until gravity could start pulling it together into planets
- When the temperature is low enough, some atoms or molecules in a gas may bond together and solidify
- Condensation The formation of solid or liquid particles in a gas
- In the inner solar system (high temperatures) only rock and metal could condense, hydrogen compounds remained gas
- In the outer solar system (cooler temperatures), hydrogen compounds could condense to make solid bits of ice
- Small particles thereby began to combine into larger ones
- One the particles grew to sizes of a kilometer or more, gravity began to aid the process of their sticking together; accelerating their growth
- **Accretion** General process by which particles stick together and grow larger
  - We refer to the particles that grew to the size of mountains or larger as **planetestimals**

Two Types of Planets

- Inner solar system
  - Ended up being made of metal and rock because they could only condense into solid particles
  - Grew rapidly at first, but then became more difficult once they got bigger because collisions between planetestimals occurred at higher speeds and was destructive

  - Produced fragmentation more often than accretion
- Outer solar system
  - Because ice is more abundant than rock, they grew to larger sizes
  - With the large sizes, their gravity became strong to hold onto and capture hydrogen and helium gas that made up the majority of the surrounding solar nebular

Moons

- Each Jovian planet came to be surrounded by its own disk of gas, spinning in the same direction as the planet
- Moons could accrete from icy planetesimals within these disks, which probably explains the formation of most of the larger moons of the jovian planets
- Smaller moons are more likely to be asteroids or comets
- Predict that the moons appeared early because they have to be traveling slow enough to enter the orbit
- Captures were far less likely since the terrestrial planets were not surrounded by large disks of gas that could slow down the objects, and there was no place for large moons to accrete

Asteroids and Comets

- Asteroids are the leftover rocky planetestimals of the inner solar system, while comets are the leftover icy planetestimals of the outer solar system
- Kuiper belt comets reside in the same general region they were formed; relatively low density
- The Oort cloud comets are now thought to have originated in regions where they crossed the orbits of the jovian planets… gravity flings objects away
- For Jupiter and a comet, Jupiters loss (or gain) of energy would be unnoticeable because it is so much larger, while the comets gain (or loss) would completely change its orbit

Clearing the Nebula

- What happened to the majority of hydrogen and helium from the solar nebula?
  - Cleared away by a combination of energetic light from the young Sun, and the **solar wind:** a stream of charged particles continually blown outward in all directions from the Sun.
  - refer to figure 3.22 on page 79

Should we expect habitable worlds to be common?

- Based on our solar system, we would expect to find many other planetary systems with terrestrial and jovian planets laid out in the same way
- But the reality appears to be more complex

3.4 A Universe of Matter and Energy

What are the building blocks of matter?

Atomic Struture

- Atoms come in different types, and each type corresponds to a different chemical **element**
  - Hydrogen, helium, carbon etc.
- Atoms are made of particles that we call **protons, neutrons, and electrons**
  - Neutrons – Particles with no electrical charge found in the atom nuclei
  - Protons – Particles with a positive charge found in the atomic nuclei
  - Electron – Particles with negative electric charge; distribution of electrons gives the atom its size
- Most atoms mass resides in its nucleus
- **Electrical charge** in its nucleus; an objects electrical charge is a measure of how strongly it will interact with other charged particles
- An atom is held together by the attraction between the positive charged protons in the nucleus, and the negatively charged electrons that surround the nucleus
- Atoms often lose or gain electrons, in which case they obtain a net electrical charge
  - We call these atoms **ions**
    - **Positive ion –** Atom that has lost one or more electron so it has more positive charge
    - **Negative ion –** Atom that has gained one or more electron so it has a more negative charge.

Atomic Terminology

- **Atomic number** How may protons in the nucleus
- Complete set of the more than 100 known elements is listed in the **periodic table of the elements**
- The combined number or protons and neutrons in an atom is called the **atomic mass number**
- Every atom of a given element contains exactly the same number of protons, but the number of neutrons can vary. These are called **isotopes**

Molecules

- Atoms can be combined to form **molecules**
- Substances composed of molecules with two or more different types of atoms are called **compounds** (water is a compound; H20)
- Life is based on the complex chemistry of molecules (compounds) containing carbon, which are called **organic molecules/ organic compounds.**

Phases of Matter

- **Chemical bond:** Interactions between the electrons that hold the atoms in a molecule together
  - o **Gas:** Atoms or molecules move essentially unconstrained
  - o **Liquid:** Atoms or molecules remain together but move freely
  - o **Solid:** Atoms or molecules are held tightly in place
- Phase changes occur when one type of bond is broke and replaced by another
- Higher temperature means greater vibrations
- **Melting point** is the temperature at which the water molecules finally break the solid bonds of ice
- Adjacent molecules in liquid water are still held together by a type of bond, it is just much looser
- Above the **boiling point** all the bonds between adjacent molecules are broken, so that the water can only exist as a gas.
- A few molecules will always move fast enough to break free of their neighbours and enter the gas phase
- **Sublimation** the process by which molecules escape from a solid
- **Evaporation** the process by which molecules escape from a liquid
- Higher temperatures = more sublimation/evaporation

What is energy?

- What makes matter move
  - o **Kinetic Energy:** Energy of motion… falling rocks, orbiting planets, and molecules moving around us
  - o **Radiative Energy:** Energy carried by light. All light carries energy… example; light can alter molecules in our eyes
  - o **Potential Energy:** Stored energy that later might be converted into kinetic or radiative energy… a rock waiting to fall
- It is possible for energy to change from one form to another
- While energy can change from one form to another, it can not be created or destroyed; law of conservation of energy
- In most cases, there is no viable way for life to extract energy for its own use

What is Light?
Basic Properties of Light

- Light is characterized by rapidly changing electric and magnetic fields – **electromagnetic wave**
- **Wavelength:** the distance between adjacent peaks (or troughs) of a wave
- **Frequency:** the rate at which peaks of a wave pass by a point, measured in units of 1/s often called cycles per second or hertz
- Light comes in distinct pieces called **photons** that can exert pressure, knock electrons out of atoms, or cause molecules to start vibrating and rotating
- Wavelength x frequency = speed of light
- Longer wavelength means lower frequency and shorter wavelength means longer frequency

The ElectroMagnetic Spectrum

- Complete range of possibilities

- **Visible light** that we see with our eyes is only a tiny portion of the complete spectrum, with wavelengths from about 400nm at the blue end of the rainbow, to about 700nm at the red end
- Light with wavelengths somewhat longer than red light is called **infrared** because it lies beyond the red end of a rainbow
- **Radio waves** are the longest wavelength light
- The region near the border between infrared and radio waves representing wavelengths from micrometers to centimeters is sometimes called **microwaves**
- On the other side of the spectrum, light with wavelengths somewhat shorter than blue light is called **ultraviolet,** because it lies beyond the blue (or violet) end of the rainbow
- Light with even shorter wavelength is called **x-rays** and the shortest is called **gamma rays**

Learning From Light

- **Spectroscopy:** Involves collecting light through a telescope, then dispersing it into a spectrum in much the same way a prism disperses white light into a rainbow of colour
  - **Continuous spectrum:** The light bulb produces light of all visible wavelengths
  - **Emission Line spectrum:** The cloud also emits its own light but only at specific wavelengths determined by its composition
  - **Absorption line spectrum:** The cloud absorbs light at specific wavelengths determined by its composition
- Any dense object emits continuous light that is characteristic of the objects surface temperature are called **thermal radiation**
- A star like Sun emits more strongly in visible light than at any other wavelength, while a typical planet emits infrared light but no visible light at all.
- Careful study of a spectrum can allow us to determine the chemical composition of distant objects

3.5 Changing Ideas About the Formation of the Solar System

How did the nebular theory win out over competing models?

- German philosopher Immanuel Kant proposed that our solar system formed from the gravitational collapse of an interstellar cloud of gas
- Important difference from their hypothesis and the truth today
  - There was little evidence back then, and we have detail

Observations that a Formation Theory must Address

- 4 major features
  1. Orderly of large bodies – The theory should explain the organized patterns that we see in the orbits and rotations of the larger objects of our solar system
  2. Two types of planets – Need to explain why the planets divide into 2 clear groups
  3. Small bodies – Planets are outnumbered by asteroids and comets
  4. Exceptions to the rules
- We have not yet discovered the exceptions to the rules, but the belief is that they are leftovers from collisions

The Fall and Rise of the Nebular Model

- Scientists imagined a near collision between the Sun and another star.
- According to this close encounter hypothesis the planets formed from blobs of gas that had been gravitationally pulled out of the Sun during the near encounter
- BUT, this was probably not the case because it could not be applied to the observed orbital motions of the planets or the neat division of the planets
- The chance that 2 stars would pass so closely is also very rare

Why isn't the nebular model set in stone?

- New discoveries that are forcing reconsideration of the nebular theory fall into 2 major categories
  1. There are extrasolar planets with their surprising orbits
  2. There are new observations of young star systems made possible by increasingly powerful telescopes that allow us to see the phenomena that accompany stellar birth
- Observations of star forming clouds and young star systems have made scientists increasingly confident in the basic idea that stars and planets form from collapsing clouds of gas
- Births are quite violent

Chapter 4 – The Habitability of the Earth

Geology and Life

How is geology crucial to our existence?

- **Geology** is the study of our earth, but we extend the meaning to any world with a solid surface
- Long term evolution of life into complex forms that include us
- 3 aspects are particularly important
  1. **Volcanism:** Volcanic activity releases gasses trapped in Earth's interior, and these gases were the original source of Earth's atmosphere and oceans. It also releases heat and creates chemical environments that lead to life on our planet
  2. **Plate Tectonics:** Gradually rearranging the continents. But mostly responsibly for the long term climate stability that has allowed life to evolve and thrive for 4 billion years
  3. **Earths Magnetic Field:** Shields Earths atmosphere from the energetic particles of the solar wind

4.2 Reconstructing the History of Earth and Life

- History is recorded in rocks and **fossils** – relics of organisms that lived and died long ago that preserve clues we can unravel to learn about the past

What can we learn from rocks and fossils?

- Atoms and molecules are essentially locked in place in a solid, so they preserve information about the time at which they first came locked together

Types of Rocks

1. **Igneous rock** is made from molten rock that cools and solidifies
2. **Metamorphic rock** is rock that has been structurally or chemically transformed by high pressure or heat that was not quite high enough to melt it
3. **Sedimentary rock** is made by the gradual compression of sediments, such as san and silt at the bottom of seas and swamps

- Rock's can change from one form to another
- Each individual crystal represents a **mineral** – crystal of a particular chemical composition and structure
- All minerals contain substantial amounts of silicon and oxygen are called silicates
- Large amounts of carbon and oxygen are carbonates
- Type: how it was made, mineral: where it was made
- Igneous rocks
  - **Basalt:** Dark igneous rock commonly produced by undersea volcanoes rich in iron and magnesium
  - **Granite:** Lighter in colour and less dense, common in mountain areas

Sedimentary Strata

- Most fossils are found in sedimentary rock
- Records of time
- Remains of living organisms are buried along with the sediments
- Sedimentary rocks tend to be marked by distinct layers or **strata**
- Inner layers = older

Rock Analysis

- Three types
  1. **Mineralogical analysis:** Identifying the minerals present in a rock
     a. Tells us about the temperature and pressure conditions
  2. **Chemical analysis:** Determining the elemental or molecular composition of a rock or mineral
  3. **Isotopic analysis:** Determining the ratio of different isotopes of element of a rock, tell us the relative amounts of the three oxygen isotopes in a rock

a. Some end up being **radioactive:** their nuclei are unstable and tend to change over time into other isotopes

How do we learn the age of a rock or fossil?

- **Radiometric dating –** careful measurements of an objects proportions of various atoms and isotopes
- **Radioactive isotope –** has a nucleus that can undergo spontaneous change or **radioactive decay** suck as breaking apart or having one of its protons turn into a neutron
- When a radioactive nucleus undergoes decay, we say that the original nucleus before decay is the parent nucleus and the changed nucleus is the daughter nucleus
    - Daughter has a lower atomic mass
- Radioactive decay occurs when a nucleus spontaneously emits or absorbs an electron, causing one of its neutrons to turn into a proton, or a proton to turn into a neutron
- Radioactive decay always occurs at a specific and measurable rate that is different for every radioactive parent – daughter pair.

The Probabilistic Nature of Radioactive Decay

- Likelihood of a single nucleus decaying within a specific amount of time
- Results from the past do not affect results for the future

The Concept of a Half Life

- The decay rate by the substance's **half life –** the time that it would take for half the atoms in a sample of the substance to decay

The Essence of Radiometric Dating

- **Radiometric dating** The process of determining the age of a rock by comparing the amount of present radioactive substance to the amount of the decay process
- We must have some way of knowing how much of the daughter was originally present
- It works only for dating solids that have not undergone significant change since they formed
- Metamorphic rocks are more challenging
- A sedimentary rock cannot be dated as a whole because it is a compressed mix of rock grains containing minerals of different ages

The Reliability of Radiometric Ages

- Highly reliable
- Some ancient Egyptian artifacts have dates printed on them, and we can confirm by comparing them to ages that we can obtain from tree ring data
- Overall uncertainty in radiometric age dates is usually less than 1-2%

What does the geological record show?

- Earth's surface undergoes continual change through volcanism, plate tectonics, and erosion, making older rocks comparatively rarer than newer ones.

Fossil Formation

- When an organism dies and gets buried in sediments, minerals dissolved in groundwater gradually replace organic material
- Mineral rich portions of organisms such as bone, teeth, and shells may be left behind, becoming fossils like dinosaur bones
- Organisms sometimes themselves might decay, but in doing so leave an empty mold that fills with minerals dissolved in water
- Rarely, some of the organic material from a dead organism may be preserved well enough to allow at least some study
- Even rarer, organisms may be preserved in tree resin, or frozen in ice
- Coprolites are rocks that consist of petrified excrement, which can allow us to learn about an animals diet.
- Even bones and teeth decay quite rapidly after death
- Fossils can suffer the same fates as rocks, so older fossils are more likely to have been destroyed over time by volcanism, erosion, or other geological processes
- Large plants and animals – which make the most easily discovered fossils are relatively recent arrivals

The Geological Time Scale

- Distinct intervals make up the **geological time scale**
- 4 eons
  1. Hadean – hellish conditions during the early time
  2. Archean – 2.5 to 3.85 billion years ago – discovery of fossils from the first half of Earth's history
  3. Proterozoic – 542 million to about 2.5 billion years ago – fossils of single celled organisms that lived before the Phanerzoic era
  4. Phanerozoic – 542 million years ago; presence of fossils visible to the naked eye
- Phanerozoic eon is divided into 4 major **eras:** the Palezoic, Mesozoic, Cenozoic
- Three era's are further divided into **periods:** Cambrian, Jurassic, and Teritary

The Age of Earth

- The oldest known is about 4.02 billion years old
- How do we know the age of the planet?
  - Studies of tiny minerals grains of zirconium silicate; shows that some solidified about 4.38 billion years ago
  - Formed at a time when liquid water was present and continents had already begun to form, suggesting that Earth's crust had separated before about 4.4 billion years ago
- Can set a maximum age by dating the formation of the solar system as a whole by studying **meteorites –** rocks that have fallen to Earth from space
  - Some meteorites have a chemical structure that suggests they were among the first pieces of solid material to condense in the early history of the solar system
- Our planet accreted quickly in the early solar system, and the giant impact that formed the moon happened quite early as well

4.3 The Hadean Earth and Dawn of Life

How did Earth get an atmosphere and oceans?

- Our planet was probably too small and warm to capture significant amounts of hydrogen and helium has as it accreted within the solar nebula
- How then, did Earth obtain the water and gases that make up our oceans and atmospheres?
  - Earth formed primarily from "local" planetestimals of rock and metal, and other planetestimals that were swung in place by gravity.
  - As they became part of the Earth, their gaseous content became trapped on our within our planet
- **Outgassing –** When molten rock erupts, the release of pressure violently traps the gas, which probably released most of the water vapour that condensed to form our oceans and the gas that formed our atmosphere
- Volcanism is a major source of outgassing… Primary gasses that are released are
  - Water vapour, carbon dioxide, nitrogen, sulfur bearing gasses, and hydrogen
- Earth may have had early continents, oceans, and an atmosphere within only about 100 million years after the planet first formed
- Early atmosphere was probably dominated by nitrogen, and contains only trace amounts of carbon dioxide

Could life have existed during earths early history?

- Earth may have been habitable within 10 million years after its formation

The Heavy Bombardment

- Vast majority of these collisions occurred in the first few hundred years of our solar system's history, during the period we call the **heavy bombardment**
- On planets and moons with solid surfaces, such collisions leave behind **impact craters** as visible scars
- The most heavily cratered regions are the **lunar highlands,** where craters are so abundant that we see overlapping crater boundaries and craters on top of other craters
  - Many formed more than 4 billion years ago
- **Lunar maria –** see relatively few craters, likely because they were covered by molten lava, from about 3.9 and 3 billion years go
  - The craters we now see within the maria, must be the result of impacts that occurred after the lava flow

- **Late heavy bombardment –** a brief spike of impacts beginning around 4.1 billion years ago and ending roughly 3.8 billion years ago; may have been responsible for many of the Moons craters
  - Scientists believe this may have been due to a planetary migration
- Surfaces with fewer craters must be correspondingly younger, indicating that their original craters have been erased in some way

Large Impacts and Early Life

- Hadean Earth must have endured impacts at a rate much higher than Earth has experienced since
- Question is whether life on Earth survived this
- **Sterilizing impacts –** would have killed off any life on earth at the time; however, microscopic life living underground and in some deep ocean environments could have survived

4.4 Geology and Habitability

- Earth's surface has been shaped by 3 processes

What is Earth like on the inside?

- 6400 kilometers to Earth's center
- **Seismic waves** Waves that propagate much like sound waves both through Earth's interior, and along its surface after an earthquake
- After an Earthquake, geologists record the arrival times and the strengths of seismic waves at stations distributed all around the world

Earth's Interior Structure

- **Core**
  - The highest density material
  - Nickel and iron in the central core
  - **Inner core –** solid
  - **Outer core –** liquid molten
- **Mantle**
  - Rocky material of moderate density – mostly silicate minerals rich in silicon and oxygen – forms the thick mantle that surround the core and makes up most of Earth's volume
- **Crust**
  - Lowest density rock, including igneous rocks such as granite and basalt, forms the thin crust that is Earth's outer skin
- Vast majority of Earth's interior is solid rock
- **Lithosphere –** Earth's outer layer as the relatively cool and rigid rock that floats on warmer, softer rock underneath
- Beneath the lithosphere, the higher temperatures allow rock to deform and to flow much more easily
- The mantle rock flows with a characteristic patter called **convection** in which hot materials expands and rises while cooler materials contract and fall

Differentiation and Internal Heat

- **Differentiation –** Materials separate according to their density
- Our planet must have been molten or nearly molten throughout its interior
- The heat that caused tock to melt came from 3 main sources
  1. Impacts of accretion caused heat that melted the outer layers of the young Earth
  2. As denser materials sank through the molten, their gravitational potential energy was converted into thermal energy
  3. Heat continually released by the radioactive decay of elements within earth
- All the terrestrial worlds in our solar system underwent similar melting and differentiation
- 2 factors determine a cooling rate:
  1. Size – larger worlds tend to retain their internal heat much longer than do smaller worlds
  2. Heat deposition – if a world has a source of ongoing internal heat, it will tend to cool more slowly

How does plate tectonics shape Earths surface?

Meaning of Plate Tectonics

- Result of the slow motions of plates – fractured pieces of the lithosphere – driven by the underlying convection of the mantle

Evidence for Plate Tectonics

- Rest on 3 additional significant evidence
  1. Past continental arrangements
  2. Plates spread apart on seafloors
  3. Difference between the nature of Earths crust on the seafloors and continents
- Continental drift – the idea that continents gradually drift across the surface of Earth
- Mantle material erupts onto the ocean floor along ridges, while the existing seafloor spreads outward to either side
- **Seafloor spreading** helps to explain how the continents could move apart with time
- Earth's surface has 2 different types of Crusts
  1. **Seafloor crust** is made of high density igneous basalt and is 5-10 km thick and quite young
  2. **Continental crust** is lower density, granite and is about 20-70 km thick
- New seafloor crust continually emerges at sites of seafloor spreading

The Mechanism of Plate Tectonics

- Act like a conveyer belt for the lithosphere
- Seafloor spreading occurs at mid ocean ridges because they are places where mantle material rise upwards towards the surface. As it gets close to the surface, the lower pressure allows it to partly melt; and the molten material erupts to the surface, cooling and contracting
- **Subduction** occurs when one plate slides under another
- Two continental plates crashing into each other can push each other upwards and create mountains
- Where they pull apart creates rift valleys
- Places where plates slip sideways relative to each other are called **faults**
- Volcanic activity may occur any place where a plume of hot mantle material rises up to make a **hot spot**
- Plate tectonics gradually carry the Pacific plate over the hot spot, forming a chain of volcanic islands as different parts of the plate lie directly above the hot spot at different times

Plate Tectonics Through Time

- Note that all present day continents were once all stuck together in a single supercontinent sometimes called Pangaea
- The continents have slammed together, pulled apart, spun around, and changed places on the globe
- Suggests that plate tectonics began shortly after the birth of Earth

Cause and Effect of Plate Tectonics

- Their small size has allowed interiors to cool much more than Earths interior, their lithospheres have thickened
- Venus's high surface temperature has probably baked out water from its crust and upper mantle. This may have strengthened and thickened Venus's lithosphere
  1. Heat driven mantle convection
  2. Lithosphere thin and brittle enough to be fractured

Why does Earth have a protective magnetic field

- First, gas molecules move fast enough that they exceed their worlds escape velocity and can simply "take off" into space **thermal escape**
- Lightweight molecules such as hydrogen tend to move faster than heavier molecules such as oxygen which is why none of the terrestrial world have any significant amounts of hydrogen gas
- Impacts can also blast atmospheric gas into space, and smaller worlds are more prone because of their lower escape velocities
- Gas can be lost through a mechanism known as **solar wind stripping** which occurs when particles from the solar wind effect sweep atmospheric gas particles into space

Requirements for a Global Magnetic Field

- **A magnetic field** can affect charged particles or magnetized objects in its vicinity
- Arises as a battery forces charged particles to move along a coiled wire
  - o Charged particles move with the molten metals in its liquid outer core

- 3 basic requirements
  1. An interior region of electrically conducted fluid (liquid or gas) such as molten metal
  2. Convection in that layer of fluid
  3. At least moderately rapid rotation of the planet

The Magnetosphere and the Solar Wind

- The magnetic field protects Earth's surface and atmosphere from most of the energetic particles of solar wind because it creates a magnetosphere that acts like a protective bubble surrounding our planet
- We can map the presence with devices

4.5 Climate Regulation and Change

- 3 crucial ingredients to Earth's long term habitability have been volcanism, plate tectonics, and the magnetic field
- Stars gradually brighten with age
- The sun today is 30% brighter it was when Earth was formed which means the young Earth received a lot less solar warmth and light than it does today

How does the greenhouse effect make Earth habitable?

- The global average temperature for the entire planet would be -16, but it is now +15
- **Greenhouse effect** works by temporarily trapping some of the infrared light slowing its return to space; this trapping occurs because some atmospheric gases can absorb the infrared light
- Gasses that are particularly good are water vapour, carbon dioxide, and methane
- Human activity adds more to greenhouse gasses
- While greenhouse gasses make Earth livable, it is also responsible for the hot temperature of Venus

What Regulates Earths Climate

- Most of Earth's carbon dioxide is locked up in **carbonate rocks –** sedimentary rocks, such as limestone, that are rich in carbon and oxygen
- Venus lacks carbonate so all of its carbon dioxide remain in its atmosphere

The Carbon Dioxide Cycle

- Mechanism by which carbon dioxide has been removed from Earth's atmosphere and by which the current small amount of atmospheric carbon dioxide remains stable is called the inorganic **carbon dioxide cycle** or the **C02**
  - Atmospheric carbon dioxide dissolves in rainwater, creating a mild acid
  - The mildly acidic rainfall erodes rocks on Earth's continents, and rivers carry the broken down minerals to the oceans
  - In the oceans, calcium from the broken down minerals combines with dissolved carbon dioxide and falls to the ocean floor, making carbonate rocks
  - Over millions of year, the conveyer belt of plate tectonics carries the carbonate rocks to subduction zones, where they are carried down into the mantle
  - As they are pushed deeper into the mantle, some of the subducted carbonate rock heats up and releases its carbon dioxides which then outgasses back into the atmosphere through volcanoes
- Earth has so little carbon dioxide in its atmosphere is that most of the carbon dioxide was dissolved in the oceans

The C02 Cycle as a Thermostat

- The CO2 cycle acts as a thermostat for Earth
- **Feedback processes** – processes in which a change in one property amplifies (positive feedback) or counteracts (negative feedback) the behaviour of the rest of the system
- The C02 cycle has a built in form of negative feedback that returns Earth's temperature toward "normal" whenever it warms up or cools down
- The higher the temperature, the higher the rate at which carbon dioxide is removed
- The warmer temperature = more evaporation and rainfall, pulling more C02 to leave making it cooler

How does Earth's climate change over long periods of time?

Ice Ages

- **Ice ages** occur when the global average temperature drops by a few degrees.
- Slightly lower temperatures lead to increased snowfall, which may cover continents with ice down to fairly low latitudes
- Ice ages appear to have been strongly influenced by small, cyclical changes in Earth's rotation and orbit; Milankovitch cycles
- Greater tilt means more extreme seasons
- Smaller tilt means less extreme seasons that tend to keep polar regions colder and darker on average

Snowball Earth

- Increase of global ice would have set up a positive feedback process that would that would have cooled Earth even further
- Our planet may have entered periods we call the **snowball earth**
- It seems that Earth was far colder during these periods than in more recent years
- Interior would have still remained hot, so increase of volcanism to add C02 to atmosphere and it wouldn't have been able to be absorbed by the oceans, therefore being released into the atmosphere
  - In a few centuries, we went from a snowball phase to a hothouse
- Must have had serious consequences for life on Earth

Earth's Long Term Habitability

- Volcanic outgassing released most of the gasses that made the atmosphere
- Magnetic field has protected atmospheric gases from being stripped away from solar winds
- Greenhouse effect warms our planet enough for water to be liquid
- Maintained through c02 and plate tectonics
- The climate still goes through changes influenced by variations in Earth's axis tilt
- C02 cycle ultimately brings the climate back into balance

4.6 Formation of the Moon

How did the giant impact model win out over competing models?

- Three competing models
  1. Moon formed along with the Earth through the same process of accretion
  2. Moon had been an independent planet orbiting the sun that was somehow captured to Earths orbit
  3. Young molten earth had been spinning so fast, it split into 2 pieces
- Moon rocks differed significantly
- The moon contained virtually no **volatile** or easily vaporized ingredients

The Giant Impact Model

- 2 key pieces of evidence
  1. The moons average density is much smaller than Earths, and it lacks a large iron core like the earth
  2. The rock composition suggested that the Moon was built from mantle like material that had been strongly heated before it collected to form the moon
- The idea was that it was made from mantle material would explain the Moons resemblance to earth's mantle, and the violence of being blasted out would explain the heat necessary to have allowed volatiles to vaporize and exit.
- Current planets are the survivors of the shattering collisions that must have occurred
- A mars sized object blasted into the young Earth, and it shattered and melted our planet, splashing out molten debris from the mantle
- Counts as science because we can test it and it is natural.

Chapter 5 – The Nature of Life on Earth

5.1 Defining Life

What are the general properties of Life on Earth?

1. **Order:** All living things will show order in their internal structure

2. **Reproduction:** Reproduce or are products of reproduction

3. **Growth and Development:** Living organisms grow and develop in patterns directed at least in part by **heredity** traits passed on to an organism from its parents

4. **Energy Utilization:** Use energy to create, and maintain patterns of order within their cells to reproduce and to grow; life without it is not possible. The **second law of thermodynamics** states that when left alone, the energy in a system undergoes conversions that lead to increasing disorder. To maintain order and survive, a living organism must have a continual source of energy that it can use to counter the tendency for disorder to take over

5. **Response to the Environment:** All living organisms interact with their surroundings and actively respond in at least some ways to environmental changes

6. **Evolutionary Adaption:** Life evolves as a result of the interactions between organisms and their environments, leading over time to evolutionary adaptions that make species better suited for environments

- Species are groups of organisms that are genetically distinct from other groups, through the precise border between one species and another is not always clear

What is the role of evolution in defining life?
- Modern understanding of the capacity for evolutionary adaption is described by the **theory of evolution**

An Ancient Idea
- Jean Baptiste Lamarack suggested that life forms evolve by gradually adapting to perform successfully in their environments
- Called inheritance of acquired characteristics; organisms develop new characteristics during their lives and then pass these characteristics on to their offspring
- Has not stood the time of science scrutiny
- Replaced by Charles Darwin

The Mechanism of Evolution
- Darwin laid out the case for evolution in 2 ways; described and showed how
- Two undeniable facts
  1. Overproduction and competition for survival; this overproduction leads to a competition for survival among the individuals of the population
  2. Individual variation; some individuals possess traits that make them better able to compete for good and other vital sources
- Inescapable conclusion: Unequal reproductive success; those individuals whose traits best enable them to survive and reproduce will
- **Natural selection:** Over time, advantageous traits will naturally win out over less advantageous traits and pass them down to generations

Evidence for Evolution by Natural Selection
- Finches of the Galapagos Islands
- Fact that larger changes can occur over longer periods of time, with the result that entire species can become extinct
- Artificial selection – selective breeding
- On a microbial level, natural selection is what allows a population of bacteria to become resistant to specific antibiotics

Molecular Basis of Evolution
- Organisms are built from instructions contained in a molecule called **DNA**
- No credible scientific alternative to this model has been created

5.2 Cells: The Basic Units of Life
What are Living Cells?
- All living organisms are made up of **cells** – microscopic units in which the living matter inside is separated from the outside world by a barrier called a **membrane**
- While life elsewhere might also be composed of cells, we should not expect those to have the same biochemistry
- All life on Earth is related to every other one because all evolved over billions of years from the same origins of life

Earth Life is Carbon Based

- Life on Earth is made from more than 20 different chemical elements, however just 4 of these elements; oxygen, hydrogen, nitrogen, and carbon make up 96% of the mass of typical living cells
- We say that life is carbon based
  - Carbon can combine with other elements to make complex molecules
- We refer to carbon molecules as generically **organic molecules**

Non Carbon Based Life

- Silicon is the only element besides carbon that can have 4 bonds at a time BUT
  - The bonds formed are weaker
  - Doesn't normally form double bonds
  - Can be mobile in the environment in the form of gaseous carbon dioxide is a solid that offers no similar mobility

What are the molecular components of cells

- The large molecular components of cells fall into 4 main classes; carbohydrates, lipids, proteins, and nucleic acids

Carbohydrates

- **Carbohydrates –** Source of food energy
- Important cellular structures

Lipids

- Store energy for cells
- Commonly known as fats
- Major ingredients of cell membranes
- Can form in membranes in water and probably did so in early Earth

Proteins: Key Evidence for a Common Ancestor of Life

- Molecules called **proteins** are the workhorses of cells, because they have so many functions
- Some serve as structural elements in cells
- **Enzymes** are crucial to nearly all the important biochemical reaction that occur within cells – including the copying of DNA.
- A **catalyst** is any substance that facilitates or accelerates a chemical reaction that would otherwise occur much more slowly
- All proteins are large molecules built from large chains of smaller molecules **amino acids**
  - Identified more than 70 amino acids but we only see 20
- Naturally occurring amino acids come in 2 slightly different forms, distinguished by their **handedness**
  - The left handed and right handed are mirror images; living cells are only left handed

Nucleic Acids

- DNA is the basic hereditary material of all life
- RNA helps carry out the instructions contained in DNA

What are the major groupings of life on Earth?

- Anton Van Leeuwenhoek was the first to realize that drops of pond water are teeming with microorganisms

Microscopic Life

- Microbes are by far more dominant in mass and volume
- Most microbes are harmless to people and many are crucial to our survival
- Other microbes play a crucial role in cycling carbon and other vital chemical elements between organic matter and the social and atmosphere

Three Domains of Life

- Cells with nuclei are called eukaryotes, and whose without are called prokaryotes.
- 3 broad superkingdoms or **domains** known as
  - Bacteria - microbes

  - Archaea - microbes
  - Eukarya – humans, plants

Tree of Life

- Greater similarity in these molecules, the more closely related
  1. All large, multicellular organisms – meaning all plants, animals, and fungi represent three small branches of one domain (eukarya)
  2. True diversity of life on Earth is therefore found almost entirely within the microscopic realm
  3. Branch lengths in the tree represent the genetic difference between species. The closer we get to the root, the closer we get to a common ancestor

5.3 Metabolism: The Chemistry of Life

- **Metabolism** is the term that refers to the many chemical reactions that occur in living organisms and are involved in providing energy or nutrients to cells

What are the basic metabolic needs of life?

- Biomechanical manufacturing process requires 2 things
  1. A source of raw materials with which to build new products
  2. A source of energy to fuel the metabolic processes that break down old molecules and manufacture new ones
- Cells have the ability to build incredible variety from a limited set of starting materials

The Role of ATP

- Every living cell uses the same molecule **ATP** to store and release energy for nearly all of its chemical manufacturing
- It simplifies the manufacturing process
- Each time a cell draws energy from a molecule of ATP, it leaves a closely related by product called ADP
- The fact that all life uses the same molecule ATP for energy storage, offers further evidence for a common origin of life

How do we classify life by it metabolic sources?

- 4 major categories

Carbon Sources: Autotrophs and Heterotrophs

1. **Heterotroph –** Any organism that gets its carbon from eating
2. **Autotroph –** Some cells get carbon from the environment; self feeding

Energy Sources: Light or Chemicals

- The energy that a living cell uses to make ATP can come from one of 3 sources
  1. Photosynthesis – some cells get it directly from the sunlight
  2. Chemo – Eat it and use it for their own ATP
  3. Inorganic – do not contain carbon

The 4 Metabolic Classifications

- **Photoautotrophs:** Get energy from the sunlight, and their carbon dioxide in the environment
- **Chemoautotroph:** Obtain energy from chemical reactions and carbon from the environment
- **Photoheterotropoh:** Get energy from the sunlight, and get carbon from eating other organisms
- **Chemoheterotroph:** Obtain energy from chemical reactions, and get carbon from eating other organisms

Metabolism, Water, and the Search for Life

- This leaves us with one final ingredient to consider in metabolism: Water plays 3 roles
  1. Metabolism requires that organic chemicals be readily available for reactions
  2. Requires a means of transporting chemicals to and within cells and transporting waste away
  3. Metabolic reactions within cells
- Liquid water is one thing that no organism can survive without.

5.4 DNA and Heredity
- Organisms heredity
- Operating instructions – DNA

How does the structure of DNA allow for replication?
- Zipper teeth that links the 2 strands represent molecular components called **DNA bases**
- Adenine & Thymine
- Guanine & Cytosine
- The process in which DNA is copied is **DNA replication**
  1. Dna double helix
  2. Strands separate
  3. Each strand serves as a template for a new complementary strand
  4. Two identical daughter DNA molecules
- Believe DNA evolved from RNA

How is heredity encoded in DNA?
Genes and Genomes
- Instructions representing any individual function – such as the instructions for building a single protein make up **gene**
  - A gene is the basic functional unit of an organisms heredity
- **Noncoding DNA** makes up more than 95% of the total DNA in human beings and similarly large fractions of the DNA of many other Eukaryotes
- Complete sequence of DNA bases in an organism is the **genome**
- We humans have a genome of about 20,000 – 25,000
- These differences in genes of individuals explain why we are not all identical, and they are also the source of variation that underlies in evolution

The Genetic Code
- Set of rules of reading DNA is called the **genetic code**
- 64 in total
- Genetic code once depended only on 2 base words rather than 3 based words

The Role of RNA
- A molecule of RNA is quite similar in structure to a single strand of DNA, except that is has a slightly different backbone and one of its four bases is different from one of the DNA bases
  - Uses U instead of T

How does life evolve?
Mutation
- DNA replication proceeds with remarkable speed and accuracy
- Any change in the base sequence of an organisms DNA is called a **mutation**
- Sickle cell disease kills more than 100,000 people per year can be traced to one single mutation in the gene that makes hemoglobin where A changed to T
- Mutations that add or delete a base within a gene tend to have the most dramatic effects on protein structure
- It is this process of mutation that leads to variation among individuals in a species
- Mutations provide the basis for evolution
- A random mutation can become the normal
- Organisms can transfer entire genes to other organisms, a process called lateral gene transfer
- Primary ways that bacteria gain resistance to antibiotics
- Genetic engineering is when we take a gene from one organism and insert it into another

5.5 Life at Extreme
What kinds of conditions can life survive?

- Thriving in the extremely hot water around black smokers and other vents
- **(Hyper)Thermophiles** Extremely hot water
- Organisms that live in extreme environments of any kinds are called **extremophiles**
- Many extremophiles are anaerobic, meaning they don't need oxygen
- Even in the dry valleys, these spaces contain water from the rare rain or snowfall
- **Psychrophiles** Extremely cold places
- Microbes called endoliths can live several kilometers below the surface of the water
  - o These organisms are chemoautotrophs that get their energy for metabolism from chemical reactions and nutrients from the rock itself
- **Endospores** Allow the organism that creates them to be the dormant, neither growing nor dying in extremely inhospitable conditions

5.6 Evolution as Science

Is evolution a fact or a theory?

- Nearly all scientists consider it to be a fact, but we use theory of evolution to explain how and why these changes occur
- Some believed it is punctuated; with periods of rapid change, while others believe that it is steady
- Darwins theory has also been modified over time

Are there scientific alternatives to evolution?

- Science seeks explanations for observed phenomenon that rely solely on natural causes
- Science progresses through the creation and testing of models
  - o We can expect further refinements to the theory in the future
- We can make testable predictions
- Some people (intelligent design) believe that organisms are too complex to be explained by natural selection
  - o Doesn't offer testable results