Formation of the Solar System

K. J. Meech
Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822

Imagine . . .

Fig. 1.—View from inside a spherical space colony which would hold 10,000 people.

You and your classmates are heading out for gym class, but this class has some really far out activities! You live on the inside of a spherical space colony orbiting high above the Earth’s atmosphere (Figure 1), where the Earth’s gravity is very low. Healthy bones, muscles and blood flow all require the pull of gravity on our body. The best we can do in our space colony is to create an “artificial gravity” by slowly spinning the colony. This isn’t really gravity, but it produces a force or pull on our bodies which keeps us healthy. This is the same force that a ball attached to a string would feel as you whirl it around. The strength of the force depends on how fast the ball spins around and how long the string is. A longer string or a faster spin means a bigger force.

Our colony’s artificial gravity works the same way. Today, the class is heading toward the rotation axis of the sphere where the pull on our bodies drops to zero! Partway there, our class practices human-powered flight in the low gravity. Running at the track takes on a new meaning. On days when you want to get a really good workout, just run in the direction of the sphere’s rotation. Your running speed is added to the rotation speed which means a bigger pull and you will feel heavier. Of course, you could always run the opposite direction to get lighter! Things will get really interesting when you start weight lifting. Weight is a measure of the gravitational force on an object. If you lift a weight off the floor, you will be lifting it closer to the center of the spherical colony. The more you lift, the lighter it will get because our imaginary string is getting shorter! Just be careful someone doesn’t hand you something heavy to put down on the floor!

In this chapter we will explore how gravity along with pressure are the forces controlling the birth of our solar system, energy production in the Sun and the shape and structure of the Earth.

What Do You Think?

In your Science Log, try to answer the following questions based on what you already know:

1. What is the stuff that exists between the stars? This will be the building material for a new solar system.
2. Why does the Sun shine?
3. How does the Sun affect life on Earth?
4. What keeps the planets in their orbits?
5. Why is the Earth round?
6. Where did the Earth’s atmosphere and oceans come from?
7. What effect did the appearance of life have on Earth’s atmosphere?

Investigate!

Strange Gravity — Over two thousand years ago, early Greek philosophers, or “lovers of wisdom” formed new ideas only by making assumptions. They didn’t see any value in testing their ideas with experiments. This changed in the late Middle Ages (1600s) when the Italian scientist Galileo started performing all types of clever and popular experiments to try to figure out how the world worked. Galileo’s experiments helped later scientists understand how gravity works. In this activity you will experiment with how different objects behave under the
pull of Earth’s gravity.

Crumple a piece of notebook paper into a ball. Drop the crumpled paper to the floor at the same time and from the same height as an uncrumpled piece of notebook paper. Which falls to the floor first? Do the two pieces of paper have the same mass? If the pull of gravity depends only on mass and distance as you learned in chapter [X – the Nature of Matter], how do you explain this result? Record your observations in your ScienceLog.

Now find something with the same mass as the paper (a dime is a good choice). Drop the dime and the crumpled paper to the floor. What do you observe? Why is this result different? Record your observations in your ScienceLog and share your ideas with your classmates.

1. A Solar System is Born

Objectives

• Learn the basic process of planet formation and what the “initial ingredients” were for the Solar System.

• Understand why the inner and outer planets have different characteristics.

• Describe the difference between rotation and revolution.

• Understand the shape of the orbits of the planets, what keeps them in their orbits and how fast they move around the Sun.

• Discover how we know about planet formation.

1.1. The Solar Nebula

All the ingredients for building planets are found in the vast seemingly empty regions between the stars. These regions are not really empty. The “stuff between the stars”, also known as the interstellar medium contains a mixture of gas and dust. The dust is made up of common chemicals – mostly carbon. The gas is mostly hydrogen and helium. The dust and gas group together in huge clouds in space which are so big that light takes many years to cross them (Figure 2)! The clouds are cold (only 10 degrees above absolute zero) and dark, slowly spinning for millions of years. During this time, starlight from distant stars interacts with the dust and gas, and many new chemicals are formed. Exotic chemicals such as alcohols, and bits and pieces of complex molecules that look like the pieces necessary for life are eventually formed deep within these clouds. These clouds are the first ingredient for building a new planetary system.

Brain Food — The space between the stars is very empty. On Earth, if we took a cube of air at sea level that was a meter in size along each side, its mass would be 1 kg. Each molecule of air would be separated by only a billionth of a meter. Scientists sometimes try to create vacuums in the laboratory for their work. A vacuum means the absence of matter. The best we can do, is to reduce the number of air molecules by a factor of 1 billion. In a “vacuum” on Earth, the molecules are now only 1 millionth of a meter apart — but there are still a lot of them. In a region where planets will form the amount of material in a cube a meter in size is smaller by a factor of 1 billion than the best vacuum we can make on Earth. In young stellar nurseries, the gas molecules are only 1 millimeter apart! This is still 10 billion times more material than exists in the space between the galaxies.....

Because these clouds consist of matter, they have mass and this matter experiences gravitation. The clouds are so large that the attraction that the dust and gas feels
for each other is very small. If there were enough mass, then the attraction might be strong enough to pull everything close together into the center of the cloud. Even the clouds with a large mass don’t collapse towards the center because of the gravitational attraction. This is because there is another effect or force, which pushes in the opposite direction of gravity. Temperature is a measurement of how fast the gas molecules in the cloud move around. If they move very slowly, the temperature is very cold, and if they move fast the temperature is high. Because the cloud has a temperature which is above absolute zero, the gas is moving. There is no particular structure in the cloud (other than its slow spinning). Gas molecules can move in all directions, and sometimes they crash into each other (Figure 3). This creates a push, or pressure away from the other gas. It is the pressure which balances the gravity and keeps the cloud from collapsing.

![Diagram showing the balance between gravity and pressure](image)

Fig. 3.— The balance between gravity and pressure.

Sometimes, something happens which upsets this balance. Two clouds can crash into each other, or a nearby star might explode and material from the star can crash into the cloud. This will give a big push in the same direction as gravity. The attraction of gravity will win the battle over pressure, and the cloud will start to collapse towards its center, and a new star and solar system will be on its way to being born.

**Self Check**

If the interstellar material were at a temperature of absolute zero (no random motion in the molecules), would the cloud collapse on its own? **Ans:** No, because there would be no pressure to balance gravity.

### 1.2. Planetesimals and Protoplanets

Once the cloud starts to collapse, things happen quickly according to cosmic timescales. As the dark cloud collapses matter in the cloud gets closer and closer together (Figure 4). This makes the attraction even stronger, since gravity is stronger when things are closer together. The stronger attraction pulls the cloud together at a faster and faster rate. This increases the temperature at the center. At first this is very slow, but as more and more matter falls to the center this speeds up and the temperature climbs.

![Image of a young solar system](image)

Fig. 4.— A young solar system just beginning to lose the battle with gravity and start to collapse.

The matter in the cloud begins to crash into other molecules and dust as things begin to get crowded near the center of the cloud. Eventually much of the dust and gas stops moving around in random directions as it gets pulled toward the center. The matter also starts to flow
Fig. 5.— The solar nebula begins to flatten and get warmer near its center.

In the same direction of the spin of the cloud (otherwise it keeps crashing into too much other matter as the cloud gets crowded). This causes the cloud to start to flatten into a spinning disk, with a center that continues to get warmer and warmer (Figure 5).

Once the temperatures at the center of the cloud climb over a few thousand degrees, it is so hot that all the dust is vaporized into gas. Farther out in the cloud or nebula, the temperatures are cooler because the increasing amount of dust and gas near the center acts like a blanket to hold the heat in. Once things are circling the center of the cloud in the same direction, due to the cloud’s spin and all the collisions, sometimes bits of dust will stick together when they collide. More and more begin to stick together and grow in size, forming the tiny building blocks of the planets – the planetesimals (Figure 7). Within a few hundred thousand years, the planetesimals grow from microscopic sizes to boulder-sized, and eventually kilometer-sized. At this point, the collisions are faster and more violent. The biggest planetesimal in each orbit starts to win out sweeping up most of the debris in its path along the orbit – and it will eventually become a planet (Figure 8, Figure 9).

In the final stages of planet formation the largest planets either sweep up the last of the planetesimal debris (Figure 10), or because of a “gravity slingshot” toss the debris toward the outer regions of the solar system, or inwards toward the Sun. Meanwhile, the central part of the solar nebula has gotten so much mass and has become so hot, reaching temperatures of 10 million degrees, that hydrogen fusion begins (see section 2). This creates so much pressure inside the young star, that it wins over gravity and the star stops collapsing. As the star is born, the left-over gas and dust gets blown out of the system by a strong wind from the star (Figure 6), and a new solar system is formed. This takes less than 10 million years after the cloud first started to collapse. Our own Solar System is about 4.55 billion years old.

How do we know that our ideas of star and planet formation are correct? Even though this is a fast process on the cosmic timescale, it is slow for us (Figure 11). Also, the thick cloud of gas and dust usually prevents us from seeing inside the cloud. Powerful telescopes such as the Hubble Space Telescope are now able to show us some of the fine details inside some of the clouds (Figure 12). For the first time scientists can see evidence of disks of dust around stars which are in the process of forming (Figure 13).

Self Check
When the star’s wind starts to blow dust and gas away from the nebula as the planets form, why does it shoot out the top and bottom (as shown in Figure 6), rather
than flow out in all directions? **Ans:** The dust in the disk is so thick it makes it hard for the wind to blow in out the sides.

**Life Science Connection**
Some of the complex molecules created in the cold dark clouds which eventually form stars consist of fragments of amino acids. Amino acids are the building blocks of proteins and life. Scientists wonder if some of this material survives in the planetesimals which formed far from the Sun — the comets. Could comet impacts have brought life-forming molecules to Earth?

1.3. **Review**

1. What is normally balanced in a cold molecular cloud? **Ans:** gravitational attraction and pressure.

2. Why are the gas giants giant? **Ans:** They formed far out in the solar nebula where it was cold and there was more solid material (dust and ices) for the planets to grow.

3. Why is the composition of the gas giant planets and the terrestrial planets different? **Ans:** Close to the Sun it was too hot to make the planets out of anything except rocky (dust) material.

4. **Question for thought** — Why do all the planets go around the Sun in the same direction and why do the planets all lie in a flat plane? **Ans:** Because of all the collisions, the dust and gas settle down into a flat disk which moves in the same direction as the spin of the cloud.

**Fig. 7.** Formation of the planetesimals.

**Fig. 8.** View of the inner solar nebula as the planets start to form. The giant planets, such as Jupiter, Saturn, Uranus and Neptune get so large because there is more dust in the cooler outer nebula. Once they get big enough, gravity becomes strong enough to attract the nebula gases too — the hydrogen and helium. This makes the planet grow to giant sizes in comparison to the Earth. This also explains why the giant planets have a different composition from the terrestrial or Earth-like planets. Close to the Sun, where the terrestrial planets formed, it was too hot for anything except for a few of the dust grains to remain, so these planets are made of rocky material. Far from the Sun it was cool enough for ices too, in addition to the gases the planets collected.
Fig. 9.— Planetesimal collision and planet growth. Toward the end of the planet formation, the collisions became violent, leaving many craters on the worlds. We see evidence of this today on the Moon, Mercury and other planets and moons without thick atmospheres.

Fig. 10.— In the final steps of planet formation, the remaining planetesimals crash down upon the planets, or get thrown to the outer edge of the solar nebula by Jupiter — where they float in cold storage until nowadays when something sends them journeying into the vicinity of the Sun. If the planetesimal was icy, we will see this visitor as a new comet.

Fig. 11.— Cosmic timeline showing the formation of the universe, the solar system, and important events discussed in this chapter.

Fig. 12.— Cloud of gas and dust seen by the Hubble Space Telescope which is a nursery for young, newly forming stars.

Fig. 13.— Regions in the Orion nebula which show dust disks just beginning to form around young stars.
1.4. Planetary Motion

1.4.1. Rotation and Revolution

Have you ever wondered why we have day and night? This is the result of the Earth spinning or rotating about its axis. Only one side of the Earth faces the Sun at any one time. As the Earth rotates, different parts receive sunlight (where it is daytime). But, why does the Earth rotate in the first place? The Earth’s rotation is just leftover from its dusty birth in the solar nebula. Because the nebula rotated, the dust and gas eventually moved in the same direction as the rotation. Once the dust and matter began to settle down to a flattened disk, with everything moving in the same direction, collisions of planetesimals tended to be on the same side of larger bodies. This kept the bodies spinning in the same direction as the rotation of the nebula.

The planets also traveled in the same direction around the Sun. This motion of one body around another is called revolution, and the path that the travelling body makes is called an orbit.

QuickLab . . .

Going in Circles

Many people get confused between the terms rotation and revolution. For example, the Earth’s Moon always keeps the same side facing the Earth. Does it rotate? Does it revolve?

You Find Out . . .

1. Take 2 styrofoam balls – a larger one to represent the Earth and a smaller one to represent the Moon.
2. With a marker pen, write on one side of the Moon (to tell it apart from the other side.)
3. Stick a pencil through both the Moon and the Earth to simulate the rotation axes.
4. Have your partner hold the Earth, while you move the Moon around the Earth in its orbit.
5. As the Moon orbits the Earth, keep the marked side always facing the Earth.
6. Does the Moon revolve? Does it rotate? How can you tell?

1.4.2. Planetary Orbits

Another curiosity about the planets is why do they continue to revolve around the Sun? Does something hold them there? Why doesn’t gravity pull the planet towards the Sun? To answer these questions, we need to go back in time to look at the discoveries made by the brilliant philosophers of the 1500’s and 1600’s.

Curiosity about predicting the motions of the planets among the stars made the Danish nobleman, Tycho Brahe, carefully observe the positions of the planets for over a quarter of a century. When Brahe died in 1601, his young assistant, Johannes Kepler inherited all of his observations. Kepler set out to understand the motions of the planets and to make a simple description of the solar system with the planets moving around the Sun.

1.4.3. Kepler’s Laws of Motion

Kepler’s first discovery, or first law of motion, came from his careful study of the movement of the planet Mars. He discovered that the planet did not move in a circle around the Sun, but in an elongated circle called an ellipse. An ellipse is a closed curve where the sum of the distances from the edge of the curve to two points (called foci) inside the ellipse is always the same (Figure 14). The maximum length of an ellipse is called its major axis, and half of this is the semimajor axis. This is usually the number that is used to give the size of an ellipse. The semimajor axis of the Earth’s orbit is 150 million kilometers. This distance is called an astronomical unit, or an AU. The Earth is not always 1 AU from the Sun because the orbit is not circular. The amount of flattening is called the eccentricity of the ellipse.

Fig. 14.— Figure of an ellipse.

Kepler also discovered that the planets seemed to move faster whenever they were closest to the Sun, and slower when they were far away. If the planet is imagined as being attached to the Sun (which sits at one focus of
the ellipse) by a string, the string will sweep out the same area in equal amounts of time. This is Kepler’s second law.

In 1619, after nearly 18 years of studying the observations that Brahe made, Kepler discovered his most important law. Kepler’s third law says that the square of the periods of revolution in years is equal to the cube of the semimajor axis in AU. This means that

$$ P \times P = a \times a \times a $$

(1)

Written in terms of exponents (To learn more about exponents, turn to page M25 in the Math Refresher), Kepler’s third law is:

$$ P^2 = a^3 $$

(2)

Here $P$ represents the period, and $a$ represents the semimajor axis.

**Explore**

An ellipse is easy to draw. Take a short piece of string (about 5 inches long) and pin the string to a piece of paper with two thumb tacks. Keeping the string stretched tight at all times, use a pencil to trace out the path of an ellipse. Change the distance between the thumb tacks to change the shape of the ellipse. How does the position of the thumb tacks (foci) change the appearance of the ellipse?

**MATHBREAK**

**PROVING KEPLER RIGHT**

It is easy to prove that Kepler’s third law really works. Fill out the table for several of the planets to see for yourself if Kepler was right. Round your numbers to two significant figures. [Note to Ed: Last 2 columns should be blank - I filled in answers.]

<table>
<thead>
<tr>
<th>Planet</th>
<th>Period</th>
<th>$a$</th>
<th>Period$^2$</th>
<th>$a^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venus</td>
<td>0.6</td>
<td>0.7</td>
<td>0.36</td>
<td>0.34</td>
</tr>
<tr>
<td>Earth</td>
<td>1.0</td>
<td>1.0</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Mars</td>
<td>1.9</td>
<td>1.5</td>
<td>3.61</td>
<td>3.38</td>
</tr>
<tr>
<td>Jupiter</td>
<td>11.9</td>
<td>5.2</td>
<td>141.61</td>
<td>140.61</td>
</tr>
</tbody>
</table>

Notes: Periods, $P$, are measured in years, and the semimajor axis, $a$, in AU.

1.4.4. **Newton’s Law of Gravity**

Kepler wondered if there was a reason that the planets closest to the Sun moved faster than the planets farther away. Did the same property of the Sun cause this? Before this time, people believed the Sun only brought light to the planets.

The discoveries of the great philosophers of the Middle Ages were the building blocks of an understanding of how the planets and the Sun interacted. It was the genius of Sir Isaac Newton (1642-1727) who put the puzzle together to create the idea of gravity. Newton didn’t understand why gravity worked, or what caused it. Even today, modern scientists do not understand this. However, he was able to combine the natural laws of those before him to explain how the force of attraction between matter works.

Fig. 15.— The fall of the Moon toward the Earth and the explanation for orbital motion.

Newton got his idea by watching an apple fall to the Earth. He reasoned that it fell because it was attracted to the center of the Earth by gravity. The Earth was also attracted to the apple. The amount of attraction depends on how much matter there is in both the Earth and the apple. Because the Earth has so much more matter than the apple, only the apple appeared to fall. Newton extended his idea to realize that the Moon was also falling towards the Earth. The Moon is much farther away from the Earth, so the effect is much smaller. He discovered that the effect of gravity decreases as the
square of the distance. For example, if two objects are moved twice as far apart, then the gravitational attraction they feel will decrease by a factor of $2 \times 2 = 4$. If the objects are moved ten times as far apart, then the gravitational attraction will decrease by a factor of $10 \times 10 = 100$. Gravity depends on mass and distance.

**Self Check**
If the mass of the Earth was twice as much as it is presently, by how much would the gravity increase on a satellite in Earth orbit? If the satellite in Earth orbit were suddenly moved 3 times farther away, would the gravity it feels from Earth increase or decrease? By how much? **Ans:** gravity is directly related to mass, so increasing the mass by a factor of 2 increases the gravity by a factor of 2. Moving the satellite 3 times farther away will decrease the gravity it feels by a factor of $3 \times 3 = 9$.

How did Newton use gravity to explain the orbit of the Moon around the Earth, and the orbits of the planets around the Sun? If the moon were not moving, then it would fall toward the Earth as expected. However, the moon is moving and we have to consider both its forward motion and its fall toward Earth. **Figure 15** shows what is happening. If the moon were moving in a straight line, after 1 second of time it would move a certain distance past the Earth. However, during this same second it also falls toward the Earth because of gravity. If we add these two motions together, we see that the Moon’s path is curved into an orbit. It is the gravitational attraction of the bodies which keeps them in orbit!

**Apply**
When the space shuttle goes into orbit we see the astronauts floating around as they work. Many people talk about this as a “zero-g” environment, meaning no gravity. Is this correct? Are they affected by gravity? **Ans:** This is incorrect, the astronauts are affected by gravity, it is just less gravity because they are farther from Earth.

1.5. **Review**
1. What properties does the amount of gravity depend on? **Ans:** mass and distance.

2. What characteristics describe the shape and size of an orbit? **Ans:** eccentricity and semi-major axis.

3. **Question for Thought** – Will a planet or comet be moving fastest in its orbit when it is farthest or closest to the Sun? **Ans:** According to Kepler’s second law, a planet sweeps out equal areas in equal times. When the planet is close to the Sun, it must travel a longer distance along the orbit to sweep out a big area. Since speed is distance traveled per amount of time, it will travel faster when it is close to the Sun.

2. **The Sun: Our Very Own Star**

**Objectives**
- Learn the basic structure and composition of the Sun.
- Understand how the Sun produces energy.
- Describe how changes in the Sun’s energy output affects life on Earth.

There is nothing special about our Sun, other than the fact that it is close enough to the Earth to give us light and warmth. Otherwise, the Sun is just like all of the other stars in our galaxy. It is basically a large ball of gas, made mostly of hydrogen and helium.

![Fig. 16.— Structure of the Sun and its atmosphere.](image-url)
2.1. The Structure of the Sun

Although it may look like the Sun has a solid surface, it does not. When we see a picture of the Sun, we are really looking through the Sun’s outer atmosphere, down to the point where the gas is so thick we cannot see through it anymore. The part of the Sun that we see is called the **photosphere** (Figure 16). The photosphere has a temperature of about 5500°C. Just above the photosphere is a thin region in the Sun’s atmosphere called the **chromosphere**. This is slightly cooler than the photosphere, and usually it is transparent and we don’t see it at all. During a solar eclipse, however, we can get a glimpse of the red chromosphere. During one eclipse in 1868, a scientist measured a new chemical element in the chromosphere which was not known on Earth. He named it after the Greek word for the Sun – *helios* – or helium. Helium was not discovered on Earth until the late 1800s.

Sun. During an eclipse, however, it may shine as bright as the full moon. The corona can extend outwards as many as 10-12 times the size of the Sun (Figure 17).

The photosphere marks the visible edge of the Sun at a radius of almost 700,000 km. Beneath the photosphere is a region about 200,000 km thick called the **convection zone**. In this region hot gases float up from deeper in the interior, and cooler, heavy gases at the surface sink back down because of the pull of gravity. This brings the Sun’s energy to the surface like bubbles rising to the top of a pot of boiling water. Below the convection zone lies a 300,000 km thick layer called the **radiative zone**. In this zone the atoms are so closely packed together that light takes a long time to get out. At the center of the Sun lies the **core** where all of the Sun’s energy is produced. The core has a radius of about 200,000 km and a temperature near 15 million degrees C.

2.2. Energy Production in the Sun

2.2.1. Historical ideas

The Sun has been shining on the Earth for about 4.55 billion years. How can it stay hot for so long? The first ideas about the source of the Sun’s energy are seen more than 2000 years ago with some of the earliest philosophers. The Sun is bright and hot, so many believed that it was burning to create the heat. When something burns the bonds holding together the molecules are broken. This releases heat and light. The amount of energy that is released is not enough to power the Sun. If all of the matter in the Sun were burned, it would last for only 10,000 years.

A more powerful source of energy could be provided by gravity. Most people realize that it takes energy to go against the pull of gravity. When you jump up you are using your energy to get farther from the center of the Earth (if you do this many times, you will believe it takes a lot of energy!). When a rocket launches, a lot of rocket fuel is burned to give the rocket energy to leave the Earth’s surface. What happens now if something is dropped from a large height? It does not require any effort, and in fact as it falls, attracted to the Earth by gravity, it releases energy.

When it was clear that burning wouldn’t last long enough to keep the Sun shining, people thought that maybe the Sun was collapsing. As it collapsed energy would be released and this would heat the Sun. The release of gravitational energy is much more powerful than
burning, but it is still not enough to power the Sun. If all of the Sun’s gravitational energy were released, it would last for only 45 million years. This is only 1/100th the present age of the Sun. Something even more powerful was needed. This source of power is nuclear energy – first suggested in 1899.

Self Check
Why does the solar nebula get warm in the middle as it collapses? Ans: As the nebula collapses, gravitational energy is released and this heats the gas and dust.

2.2.2. Nuclear Fusion

Life Science Connection
Scientists might have discovered the source of the Sun’s power half a century earlier if Darwin’s theory of evolution had not been so controversial. People who were upset with the idea that we could have evolved from lesser animals over billions of years argued that this was not possible because the Sun could not shine for that long. If they had accepted Darwin’s theory, then they would have had to discover new ideas for powering the Sun!

At the beginning of the 20th century, Einstein demonstrated that matter and energy are interchangeable. Matter can be converted to energy according to his famous formula:

\[ E = mc^2 \]

where \( E \) is the energy, \( m \) is mass and \( c \) is the speed of light. Because the speed of light is so large, even a small amount of matter can create a large amount of energy. Nuclear fusion of hydrogen fusion is the process of combining the nuclei of two hydrogen atoms together. This converts them to helium, with a little bit of matter left over which gets converted to pure energy.

Brain Food — The energy released during the hydrogen fusion of 1 gram of hydrogen is equal to about 100 metric tons of TNT!

Atoms are the smallest building blocks of matter which keep their chemical identity. An atom consists of a nucleus which is surrounded by one or more electrons which have a negative charge. A nucleus can have two types of smaller particles: a proton with a positive charge and a neutron with no charge. The protons in the nucleus are balanced by an equal number of negatively charged electrons. It is the number of protons and electrons which give the atom its chemical identity.

Under normal conditions, the nuclei of hydrogen atoms would never get close enough to combine together because they are positively charged and like charges repel each other. In the center of the Sun, however, the temperatures are very high because of the pressure created by the huge amount of matter sitting on the core. This gives the hydrogen nuclei enough energy to overcome their dislike of getting close together — allowing the conversion of hydrogen to helium. The conversion to helium occurs in 3 steps. First two hydrogen nuclei combine to produce a heavy form of hydrogen called deuterium. This combines with another hydrogen to form a variety of helium. Two of these helium atoms then combine to form ordinary helium. In the process lots of other exotic particles are created, and a large amount of energy is released (Figure 18).

![Fig. 18.— Fusion of hydrogen in the Sun](image)

The energy in the core of the Sun takes approximately 10 million years to reach the surface. In the radiative zone just outside the core, the matter is so crowded that the light and energy keeps getting blocked and sent off in different random directions. Eventually it will reach the less crowded region of the convection zone where the hot gases carry it up to the photosphere relatively quickly.

Self Check
If nuclear fusion in the Sun suddenly stopped right now, would we notice the sky get dark in the daytime? Ans:
No. It would take about 10 million years for the last energy made in the core to reach the surface of the Sun.

**Brain Food — Each second, the Sun converts about 5 million tons of matter into pure energy.**

### 2.3. Solar Activity

The Sun obviously plays a very important role for us on Earth through the day and night cycle. From sunlight we get warmth and energy for growing plants. Without sunlight, the Earth’s temperatures would drop, plunging the Earth into an ice age. Eventually, without the energy from the Sun, gases in the Earth’s atmosphere would freeze.

![Aurora](image)

**Fig. 19.** Aurorae as seen from space.

Have you ever wondered what causes the winds to blow, ocean currents to travel across the ocean, why we get rain? All of these effects are caused by the Sun’s energy. Let’s imagine that we have atmosphere that was completely calm — no wind. Sunlight would heat up certain regions on the surface of the Earth more than others. Warm air is less dense than cold air (this is because the molecules are moving much faster and they spread out into a bigger volume). The warmer, less dense air floats upwards. Cooler air from nearby regions on the ground will flow in to take the place of the air that floated upwards and wind will be created. Wind flows can occur on global scales as hot air from the equators rises and the colder air from the poles flows down to replace the air. On Earth it is a little more complicated than this because the Earth’s rotation causes the winds to flow in spiral patterns. Also, the Earth’s surface is not smooth, and rough features like mountains can interfere with the simple flow of the wind. Likewise, heat from the Sun causes water to evaporate into the atmosphere. In cooler regions the water will fall out as rain. The basic source of energy to cause our weather, however, is from the Sun.

The Sun’s activity also exerts more subtle, less well understood effects on the Earth. Giant storms on the surface of the Sun, called solar flares send out a huge stream of particles from the Sun. These interact with the Earth’s upper atmosphere to give us spectacular aurorae ([Figure 19](image)). During a flare, radio communication on Earth is also affected.

There may be an even more interesting connection between the Earth’s long-term climate and the Sun’s magnetic cycle. Sunspots (cooler dark spots on the Sun) are related to the changes in the magnetic properties of the Sun. The number of sunspots and location on the Sun changes on a timescale of 11 and 22 years. Records of numbers of sunspots have been kept ever since the invention of the telescope in the 1600s. In [Figure 20](image) the cycle of sunspot numbers is clearly seen with the exception of the years 1645-1715. During these years there weren’t any sunspots seen. These years marked a much colder than average period for Europe, and have been called the “Little Ice Age”. Scientists don’t fully understand how the connection between sunspots and the Sun’s magnetic field affect the Earth’s climate. This is an exciting area for more study.

![Sunspots](image)

**Fig. 20.** Number of sunspots each year since Galileo’s first observations in 1610.

### 2.4. Review

1. What is the source of the Sun’s energy? **Ans:** hydrogen fusion.

2. How does the Sun’s activity affect Earth? **Ans:** weather, solar storms, aurorae, climate variation.
3. Apply Concepts – If the Sun is just a massive ball of gas, why doesn’t it collapse under its own weight because of gravity? Ans: The Sun does not collapse because the energy being produced in the core creates a pressure which pushes outward and balances the force of gravity.

3. The Earth Takes Shape

Objectives

• Be able to describe the shape and structure of the Earth.

• Understand how the Earth got its layered structure. Understand how this process affects the surface appearance of Earth.

• Learn how the Earth got is atmosphere and what the influence of early life was on the atmosphere.

• Learn how the Earth got its oceans.

3.1. The Solid Earth Takes Form

Understanding the earliest childhood of the Earth is not easy because we cannot study it directly. When we try to understand how the solar system formed, astronomers at least are starting to get evidence from other stars where planets are forming. In this way, we can see if our ideas are correct. Figuring out what the early Earth was like is like having a huge jigsaw puzzle where most of the pieces are missing. We develop ideas about what happened based on our knowledge of chemistry, biology, physics, geology and other sciences. When new pieces of information come in, we may have to re-arrange our puzzle to make the pieces fit.

What information do we have from the earliest years?

• The oldest rocks left on Earth date from 3.8 billion years ago. Many of these rocks are sedimentary, so we know that the oceans existed then.

• The Sun was cooler shortly after the Earth formed. We know this from the study of how the hydrogen fusion reactions work.

• The Earth must have had a thick atmosphere with greenhouse gases early in its life, or it would have been too cold to have liquid oceans.

• The oldest fossils of primitive life, the blue green algae called stromatolites formed between 3.7-3.4 billion years ago. Life must have started before this (sometime between 4.5-3.7 billion years ago), because stromatolites were more advanced than the first life must have been. The blue green algae used photosynthesis to get energy from sunlight.

• Oxygen in Earth’s atmosphere started to appear between 2.5-2.0 billion years ago. This is seen from minerals in the rock record.

• Careful measurements of gases that don’t react chemically with anything (such as helium, argon, neon etc.) show that most of the material that made up the Earth was similar to that seen in meteorites. The material did not match the gases seen in the solar nebula.

Fig. 21.—The process of differentiation begins when the inside of the planet begins to melt.

3.1.1. The Shape and Structure of the Earth

The Earth formed by the continuing impacts from planetesimals which kept it growing until it reached its present size. This happened within the first 10 million years of the collapse of our solar nebula. While a young planet is still quite small, it can have any irregular shape. Bits can get broken off during collisions, and new material doesn’t always collect on the infant world evenly. Once the planet gets bigger than a certain size, however, it will change to a spherical shape. This is because of gravity. As more and more matter heaps on to the young planet the gravity increases, and the weight of the material pushing down toward the center of the planet gets heavier and heavier. For a rocky world, like Earth, this pressure is greater than the strength of the rocks in the center when it is about 350 km in size. At this point the planet starts to become spherical in shape as the rocks in the center get crushed.
We have the same situation as we did with the collapse of the solar nebula and the energy production in the Sun. As planet-building material falls to the Earth, feeling the Earth’s attraction, it gives up energy and this makes the Earth get warmer. Once the Earth gets big, it cannot cool off as fast as the temperature rises, and the rocky material inside begins to melt. The original material making up the Earth was similar to the meteorites—combinations of different minerals and elements, some heavy, and some lighter.

Have you ever dropped some pebbles into water? Have you ever tried mixing oil and water and watched what happened? The heavier material (either liquid or solid) sinks, and the lighter material floats up to the top. This is because of gravity. The material with more matter, or a higher density, experiences a stronger attraction. The same thing happened in the young Earth. As it melted, the heavy elements, such as nickel and iron sank into the center of the Earth—forming what we call the core, leaving other lighter materials to float to the surface. This process of separating the light from the heavy elements is called differentiation (Figure 21).

Self Check
One motivation for constructing low-gravity space stations in Earth orbit is for manufacturing. Some products require mixing 2 liquids of very different densities. Why does getting into Earth orbit help? Ans: This gives the opposite situation of differentiation. It will be easier to mix the 2 liquids in zero-gravity because the heavier or denser liquid will not sink to the bottom.

The formation of the core started while the Earth was growing and the energy came from the falling of material onto the Earth. A second source of energy for heating the Earth was from radioactive material which was present in the solar nebula. Radioactive material radiates energy, and as this collected within the Earth, it also heated things up.

3.1.2. The Earth’s Crust

The Earth is divided into 3 distinct layers. These layers exist because of the size of the Earth which allowed it to melt on the inside. Geologists can map the interior of the Earth by measuring how sound waves pass through the planet during earthquakes and man-made explosions. The core at the center, contains the heaviest material (nickel and iron) and extends from about 2886 km below the surface to the center of the Earth, 6371 km below the surface. Above the core, is the mantle, extending from about 20 km below the surface to 2886 km. The mantle has lighter rocks than the core. These rocks are rich in silicates. Finally, on top of the mantle is the outermost layer of the Earth, called the crust.

Fig. 22.—Cross section of the Earth showing its layered interior.

Because we don’t have a record of the earliest period on Earth, we can only form ideas about when the crust formed. Some geologists believe that it formed between the Earth’s formation 4.55 billion years ago and the earliest rocks – 3.8 billion years ago. The crust may be differentiated material from the mantle—the lightest material which floated to the top. The early Earth was much warmer than it is now, so the crust may not have formed right after the Earth was born. Just like in the outer layer of the Sun where the hot gases float to the surface – this happened in the Earth’s mantle. On Earth, however, it was not hot gases that could rise to the surface, but hot rocky material. Even solid rock can have this convection motion which lets heat come up to the surface and escape. Of course this will be much slower than if it is a gas or a liquid. The movement in solid rocks may only be mm or cm per year, but it is enough to let heat escape. On the early Earth the movement was much faster because it was hotter, and at first this would have made it difficult to form a solid crust.

Self Check
Jupiter formed just like the Earth did—but farther from the Sun. Icy planetesimals formed a large part of Jupiter, and it captured gases from the solar nebula. Where on
Jupiter is any rocky material that it formed with? **Ans:** The rocky material must be in the core. When Jupiter differentiated, it would have sunk to the core.

### 3.1.3. Review

1. Why is the Earth spherical in shape, but most asteroids and comets are not? **Ans:** Because Earth is large enough that the rocks inside get crushed by gravity.

2. Why did the Earth separate into distinct layers? **Ans:** Melting inside the Earth allowed the heavy material to sink to the center.

3. **Apply Concepts** — recent photos released by NASA from the SOHO solar satellite show that 2 comets plunged into the Sun on June 1 and June 2, 1998. Did this require gravitational energy or was gravitational energy released? **Ans:** It was released.

### 3.2. The Atmosphere Evolves

#### 3.2.1. Earth Lost its First Atmosphere

Earth has an abundance of life. Other than the presence of life, one of the biggest differences between the Earth of today and the Earth of 4.5 billion years ago is the character of its atmosphere. Earth’s atmosphere today is composed of 21% oxygen, 79% nitrogen and about 1% argon (with tiny amounts of many other molecules). The early atmosphere was very different. Laboratory experiments have shown that we can easily make amino acids and other complex organic molecules which are the building blocks of life under certain conditions. These conditions include the presence of an atmosphere rich with hydrogen in gases such as methane, ammonia and water along with a source of energy (the Sun). The early solar nebula was rich in hydrogen, so most people believed that Earth in the beginning had a first atmosphere which was hydrogen rich.

New evidence is changing how we think about the Earth’s first atmosphere. One of our “puzzle” pieces finally is fitting into the puzzle. The puzzle piece suggests that most (about 85%) of the Earth’s material came from material similar to the meteorites. The other 15% came from something else. Measurements of non-reacting chemicals in our atmosphere suggest that this additional material was icy from the outer solar system – cometary planetesimals.

**Chemistry Connection**

The Cassini Mission to Saturn (launched in November 1997) will study the chemistry of Saturn’s moon, Titan. Titan has an atmosphere composed of mostly nitrogen, like Earth, but with many hydrogen rich compounds. Scientists want to study the chemistry of how molecules essential to life are formed in this atmosphere.

If the early atmosphere of the Earth was not hydrogen rich – what was it made of and how do we know? During the final stages of formation, the Earth was hit many times by impacts, and the surface was very hot, perhaps molten in places. The Earth would have been venting a large amount of gas released from the heated minerals. Measurements of meteorites tell us that much of that gas would have been water and carbon dioxide. These are also two very common gases released during volcanic eruptions when the rocks melt. Earth’s first atmosphere was probably a steamy atmosphere made of water and carbon dioxide (Figure 23).

![Fig. 23.— Possible view of Earth’s surface shortly after formation.](image)

This didn’t create our oceans right away, however. Even though impacts may help release gases from the Earth, they can also help knock some of the atmosphere back into space. This is because the planetesimal is coming so fast, that it can speed up molecules in the atmosphere fast enough for them to overcome gravity and leave the Earth. In the beginning, too, while heavier elements such as iron were on the surface of the Earth, water would react chemically with them – producing lots of hydrogen. Hydrogen is the lightest element – and because the early Earth was so warm, it had enough speed to escape.
Many of the cometary impacts arrived later in the formation – because it took longer for them to come in from the outer regions in the nebula. These planetesimals brought in a range of elements, but most common was carbon, hydrogen, oxygen and nitrogen, as well as water (Figure 24).

Fig. 24.— Possible picture of comets bringing ocean water to the early Earth.

After the Earth cooled off, and the core formed – taking the iron and nickel with it, it was possible to start to have our second atmosphere take shape. This atmosphere had a cometary contribution, and a large contribution from the gases released from volcanos (Figure 25). Eruptions from Hawaiian volcanos show that a large amount of water (H2O) is produced, along with carbon dioxide (CO2), chlorine (Cl2), nitrogen (N2) and sulfur (S2). How do we know that these ideas are right? Although we are starting to see evidence of planet formation, we cannot look at any of these planets in detail to study them.

One of our other puzzle pieces gives us a clue. Earth was warm for a long time after it formed, even though the early Sun was not as hot. A thick atmosphere must have helped keep the heat trapped. Carbon dioxide is a very good greenhouse gas – one that traps heat. Scientists can estimate how much carbon dioxide the Earth had in its atmosphere in order to keep it warm. Carbon dioxide gets dissolved in rain water then reacts with the minerals on Earth to create calcium carbonate – limestone. Nowadays this process is helped along by ocean plankton who use this to make their shells, but in the past it was done chemically. Most of the Earth’s carbon dioxide is therefore tied up in the rocks and minerals. If we could heat them up and release it all, it would make an atmosphere of carbon dioxide 60 times as thick as our present atmosphere.

Fig. 25.— Eruption of a volcano in Hawaii.

3.2.2. Evolution and Organisms

How did this early atmosphere change to become the atmosphere we know today? Ironically, with the help of solar ultraviolet radiation – the very thing that we worry about today for its destruction of cells (and cancer-causing ability). Solar ultraviolet is dangerous because it has a lot of energy, and can break apart molecules. Today, we are shielded from most of it by Earth’s protective layer of ozone (O3). Earth’s early atmosphere had no ozone. Many molecules were broken apart in the atmosphere, and many got washed out into shallow seas and tide pools by rain. After awhile, a rich supply of these
pieces of molecules collected in protected areas, forming a rich organic "primordial soup" (Figure 26).

Fig. 26. — "Primordial Soup".

![Image of primordial soup]

Although there was no ozone, a layer of water can protect from the effects of ultraviolet radiation. In these sheltered pools of water complex molecules were given the chance to form. Sometime between 4.5 and 3.8 billion years ago the spark of life began. By 3.7 to 3.4 billion years ago life had evolved to the simple blue-green algae - a type of cyanobacteria (Figure 27 and 28) which was able to photosynthesize energy from sunlight and produce oxygen.

Oxygen didn’t build up for awhile because it combined so readily with the minerals on the surface of the Earth. Eventually, between 2.5 and 2.0 billion years ago, oxygen started to increase greatly - reaching about 20% the amount of oxygen we have today. The bacteria also played a role in helping keep the nitrogen in the atmosphere. Nitrogen liked to combine with the surface rocks, but bacteria kept releasing it back into the atmosphere. It was the emergence of life which completely changed our atmosphere into the one we see today. Ironically, if the early Earth had had lots of oxygen in its atmosphere, the chemical processes which gave rise to life probably would not have occurred!

Astronomy Connection
Oxygen combines very quickly with other chemicals. Therefore we do not expect to ever see oxygen in an atmosphere unless there were life to keep making it. Discovery of oxygen in the atmosphere of a planet around another star would be the discovery of life!

![Image of stromatolites]

Fig. 27.— Stromatolites – mats of primitive bacteria similar to the first fossil life on Earth.

![Image of prokaryotic bacteria]

Fig. 28.— Prokaryotic bacteria – blue green photosynthetic algae.

3.3. The Oceans and Continents

It is hard to say exactly when the first oceans appeared on Earth, but they probably formed early, as soon as the Earth was cool enough for rain to fall. We know that Earth’s secondary atmosphere had plenty of water. Millions of years of rain began to cover the Earth with water, and we certainly had an ocean by 4 billion years ago, and an atmosphere that was very different from the present one. Was this a giant global ocean, or were there continents? When did the continents form? Our best estimates show that for the first few hundred million years of the Earth’s history there were no continents.

To understand the changes occurring in the atmosphere, the oceans and on the surface of the Earth, we have to look at the whole picture because they were all related. Continental crust material is very light compared to material in the mantle, and the chemistry of the granite and rocks making up the continents tells geologists that the rock was melted and cooled many times. Each time the rocks were melted, the heavy elements sank and the scum that floated to the surface became more and more like continental material. The slow “boiling” mo-
tion in the Earth’s mantle (convection) was the engine that caused this to happen. Hot molten rocks rose to the surface, erupting in volcanoes, and the cooler material which was denser, sank because of gravity. The sinking rocks melted to start the process over again. After awhile, some of the rocks were light enough that they didn’t sink and began to pile up material on the surface – these were the beginnings of the earliest continents. After gradual thickening, they might have risen above the level of the seas.

These randomly distributed young continents didn’t stay in the same place because the slow convection in the mantle pushed the continents around. By about 3.5 billion years ago, only 5 to 10% of the continents were made, but around 2.5 billion years ago, continents really started to grow large. At 1.5 billion years, the upper mantle had cooled enough and become denser and heavier, so it was easier for the colder parts of it to sink – and the real continental action or plate tectonics began.

Fig. 29 — Early super-continents on Earth about 300 million years ago.

Plate tectonics is the name for the movement of the large continents. They move driven by heat rising from deep within the mantle – causing the convection. By about 250-300 million years ago, there was one large supercontinent, called Pangaea meaning “all land” surrounded by a super-ocean called Panthalassa (“all-ocean”) (Figure 29). This super-continent formed from the collision of 2 smaller continents – Laurasia in the north and Gondwanaland in the south, separated by the Tethys sea. After only 50 million years or so, the ever-present mantle motions caused by convection, pulled the continent apart into pieces which look more like the familiar continents we have now.

3.4. Review

1. Where did the Earth’s primary and secondary atmospheres come from? **Ans:** First atmosphere came from degassing of the Earth as it heated from collapse and during impacts. The secondary atmosphere came from volcanic eruptions and from cometary impacts.

2. How did the Earth’s second atmosphere change composition to today’s nitrogen and oxygen atmosphere? **Ans:** Solar energy created new chemicals which created life. Bacteria greatly changed the composition of the atmosphere.

3. Apply Concept — If the Earth were not hot inside, would we have moving continents (plate tectonics)? **Ans:** No. It is the convection in the mantle which causes crustal movement and pushes the continents around.

4. Lab and Activity Highlights

[Note to Holt: Although not required, here are some suggested lab activities.]

4.1. The Swirling Planetary Nebula

This simple experiment shows how the dust and gas in the spinning solar nebula settles into a disk shape. [Requires: beaker, water, glitter, overhead projector. In this experiment you put glitter in the water and stir it vigorously. Place the beaker on the overhead and students can see a random "cloud" of particles spinning. Slowly the cloud will condense in the center looking very much like a solar nebula]

4.2. Centripetal Force

This experiment will illustrate how centripetal force can simulate gravity. Take a small plastic pail and fill it with water. Have the students (outside) swing the bucket in an arc overhead and note that the water stays in. A variant is to have a small weight (e.g. a washer)
tied to the end of a string. Tie the other end to a pencil and whirl the weight around the pencil. Watch how the velocity of the rotation speeds up as the string gets shortened.

4.3. Pressure and Temperature

This is a fun demo to show how atmospheric pressure really works. Take an aluminum can and heat some water (a small amount) in it on a hot plate. After heating, immediately turn the can upside down into a shallow pan of cold water (i.e. in a jelly roll pan. The steam in the can will rapidly condense, dropping the pressure inside the can. Because the atmospheric pressure is high outside the can, and the can is not very strong, it should be crushed.

5. Chapter Highlights

5.1. Vocabulary

The following terms are used in this chapter. If you are not sure what they mean, turn back to the page listed and reread the information. If you’re still uncertain, discuss the term with your teacher or your classmates.

- astronomical unit (p. 7)
- aurorae (p. 12)
- chromosphere (p. 10)
- convection (p. 10)
- core (p. 10,14)
- corona (p. 10)
- crust (p. 14)
- cyanobacteria (p. 17)
- differentiation (p. 14)
- eccentricity (p. 7)
- electrons (p. 11)
- ellipse (p. 7)
- foci (p. 7)
- force (p. 1)
- greenhouse gas (p. 16)
- hydrogen fusion (p. 4, 11)
- interstellar medium (p. 2)
- mantle (p. 14)
- nebula (p. 4)
- neutron (p. 11)
- nucleus (p. 11)
- nuclear fusion (p. 11)
- orbit (p. 7)
- Pangaea (p. 18)
- Panthalassa (p. 18)
- photosphere (p. 10)
- planetesimal (p. 4)
- plate tectonics (p. 18)
- pressure (p. 3)
- proton (p. 11)
- radiative zone (p. 10)
- revolution (p. 7)
- rotation (p. 7)
- semimajor axis (p. 7)
- solar flares (p. 12)
- solar nebula (p. 4)
- stromatolites (p. 13)
- temperature (p. 3)
- vacuum (p. 2)

5.2. Chapter Notes

Section 1

- The solar system formed out of a vast cloud of cold gas and dust.
- Gravity and pressure balanced—keeping the cloud at the same size until something upset the balance. Then the cloud began to collapse.
- Collapse of the cloud caused heating in the center.
- As material crowded closer together, planetesimals started to form.
- Planetesimals were made only of rocky materials close to the center of the solar nebula. Farther out they were also made of ices.
- One planetesimal in each orbit got large and became a planet.
- Left over material got thrown onto the planets, or into the outer solar system as comets and asteroids.
- Solar System formation was fast on cosmic timescales—less than 10 million years.
- The orbit of one body around another has the shape of an ellipse.
- Planets move faster in their orbits when they are closer to the Sun.
- The square of the period of revolution of the planet is equal to the cube of the semi-major axis.
- Gravity depends on the mass of the body divided by the square of the distance.

Section 2

- The Sun is a gaseous sphere 700,000 km in radius. It is made of hydrogen and helium.
- The Sun produces energy in its core by a process called hydrogen fusion.
- Energy takes a long time to leave the center of the Sun—10 million years.
• The Sun is 4.55 billion years old. This is about halfway through its lifetime.
• The Sun’s energy drives wind, ocean currents, weather and affects Earth’s climate.

Section 3

• The Earth has differentiated into 3 main layers: core, mantle and crust.
• Differentiation occurred because of melting inside Earth. Heavy elements sank to the center because of Earth’s gravity.
• Earth’s original atmosphere formed from release of gases during differentiation.
• Earth’s second atmosphere arose from late cometary impacts and volcanic eruptions. The composition was largely water and carbon dioxide.
• The presence of life dramatically changed Earth’s atmosphere.
• Oxygen first appeared about 2.5-2.0 billion years ago.
• Earth’s oceans formed shortly after Earth did – after Earth cooled off enough for rain to fall.
• Small continents started to form after the first few hundred million years. Large supercontinents existed about 300 million years ago.

6. Chapter Review

6.1. Using Vocabulary

For each pair of terms, explain the difference in their meanings.

1. rotation, revolution
2. ellipse, circle
3. differentiation, collapse
4. planetesimal, planet
5. temperature, pressure
6. photosphere, corona

To complete the following sentences, choose the correct term from each pair of terms below.

7. Which region inside Earth has matter with the lowest density ________ (core, mantle, crust)?
8. (Convection, Radiation) ________ is the fastest way to get energy from the Sun’s core to the surface of the Sun.
9. (Rotation, Revolution) ________ of the Earth causes our night and day.
10. What is the absence of matter called? ________ (vacuum, interstellar medium)
11. What is the cloud surrounding a young star and forming planets called? ________ (interstellar medium, solar nebula)

6.2. Understanding Concepts

6.2.1. Multiple Choice

13. Impacts in the early solar system do what? (a) bring new materials to a planet; (b) release energy; (c) knock materials off a planet; (d) dig craters; (e) all of the above. Ans: (e)
14. Which type of planet will have a higher density – one that forms (a) close to the Sun or (b) far from the Sun. Ans: (a)
15. Which process releases the most energy? (a) hydrogen fusion, (b) burning, (c) collapse due to gravity. Ans: (a)
16. Which planet has a shorter period of revolution? (a) Pluto; (b) Earth; (c) Mercury. Ans: (c)
17. Which gas in Earth’s atmosphere tells us that there is life on Earth? (a) hydrogen; (b) oxygen; (c) water; (d) carbon dioxide; (e) nitrogen. Ans: (b)
18. Which matter in Earth has the lowest density? (a) core material; (b) mantle material; (c) crustal material. Ans: (c)
19. How old is the solar system? (a) 10 million years; (b) 4.55 billion years; (c) 4.55 million years Ans: (b)
20. What is the term for the speed of gas molecules (a) temperature; (b) pressure; (c) gravity; (d) force. Ans: (a)
21. Which of the following properties of Earth are not directly related to changes in the Sun’s energy input to Earth? (a) weather, (b) wind; (c) ocean currents; (d) Earth’s rotation; (e) aurorae; (f) long term climate changes. Ans: (d)
22. Which of the following objects is not likely to have a spherical shape? (a) comet; (b) Venus; (c) the Sun; (d) Jupiter Ans: (a)

6.2.2. Short Answer

23. How do we understand things about the early Earth when there are no fossil records? Ans: We have many clues, such as chemical composition of Earth’s atmosphere – especially the heavy elements which don’t interact with other chemicals. We have evidence that oceans were present early on Earth, and when continents must have formed. We also have models of how we think the
solar system worked.

24. How is the period of revolution related to the semimajor axis of an orbit? Draw an ellipse and label the semimajor axis. **Ans:** The square of the period of revolution is equal to the cube of the semimajor axis: \( P \times P = a \times a \times a \).

25. Why does the solar nebula begin to collapse to form a star and planets if the forces of pressure and gravity are balanced? **Ans:** Some external force pushes inward on the cloud and overcomes gravity. This can be caused by 2 clouds colliding or a nearby explosion.

### 6.3. Concept Mapping

26. Create a concept map using the following terms: gravity, plate tectonics, Sun, hydrogen fusion, Earth, differentiation, solar nebula.

27. Create a concept map using the following terms: outgassing, volcanoes, accretion, solar UV, life, comet impact, escape, oxygen.

### 6.4. Critical Thinking AND Problem Solving

29. Explain why hydrogen fusion works inside the Sun but not inside Jupiter which is also made mostly of hydrogen and helium. The mass of Jupiter is about 1000 times less than that of the Sun. **Ans:** The mass of Jupiter is too small. Not enough pressure is created in the center (core) to get temperatures high enough to start hydrogen fusion. This requires temperatures of 10 million degrees, and masses about 100 times bigger than Jupiter.

30. Why is it cheaper (esier – needing less rocket fuel) to launch a spacecraft built on the international space station in Earth orbit rather than the same spacecraft from Earth? **Ans:** On the space station you are farther from Earth’s center, so gravity is less and it will take less fuel to escape from Earth.

31. Early in the formation of the Universe, there was only hydrogen and helium. Heavier elements (things such as carbon, silicates, and all the matter that makes up the heavier minerals and rocks) were made in the atmospheres of the first generation of stars in their death throes. Do you think these first generation of stars had any planets like the Earth, Venus, Mercury and Mars? **Ans:** No. The terrestrial planets formed mostly from rocky material. The only type of planets that these early stars could have formed would have been the gas giants.

### 6.5. Math in Science

32. Suppose astronomers discover a new planet orbiting our Sun. The orbit has a semimajor axis of 2.924 AU. What is the planet’s period of revolution? If this planet is twice as massive as the Earth, but has the same size, how much would a person who weighs 100 kg on Earth weigh on this planet? **Ans:** We need to use Kepler’s 3rd law for the first part of the question:

\[
P \times P = a \times a \times a
\]

We know that \( a = 2.924 \). The right side of the equation equals \( 2.924 \times 2.924 \times 2.924 = 24.999 \), which rounds to 25. Since \( 5 \times 5 = 25 \), the period of revolution must be 5 years. The force of gravity depends directly on the mass of the planet. The planet is twice as massive as the Earth, so the person would weight twice as much – 200 kg.

### 6.6. Interpreting Graphics

Examine the artwork below and answer the following questions.

![Fig. 30.— Vista from an imaginary world.](image)

33. Do you think this is a terrestrial (rocky) planet or a gas giant? **Ans:** This is a rocky planet.

34. Did this planet form close to the star or far from the star? **Ans:** This planet probably formed close to the star. First it is rocky, and secondly the sky looks quite
bright, so there must be a lot of sunlight – in other words it must be fairly close to the star.

35. Does this planet have an atmosphere? Ans. Yes. But the atmosphere must be a different composition from the Earth’s atmosphere. You can tell this because the color of the sky is very different. The gases in the atmosphere interact differently with the sunlight than do the gases in Earth’s atmosphere.

Now What Do You Think?
Take a minute to review your answers to the questions found at the top of page 1. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

REFERENCES


