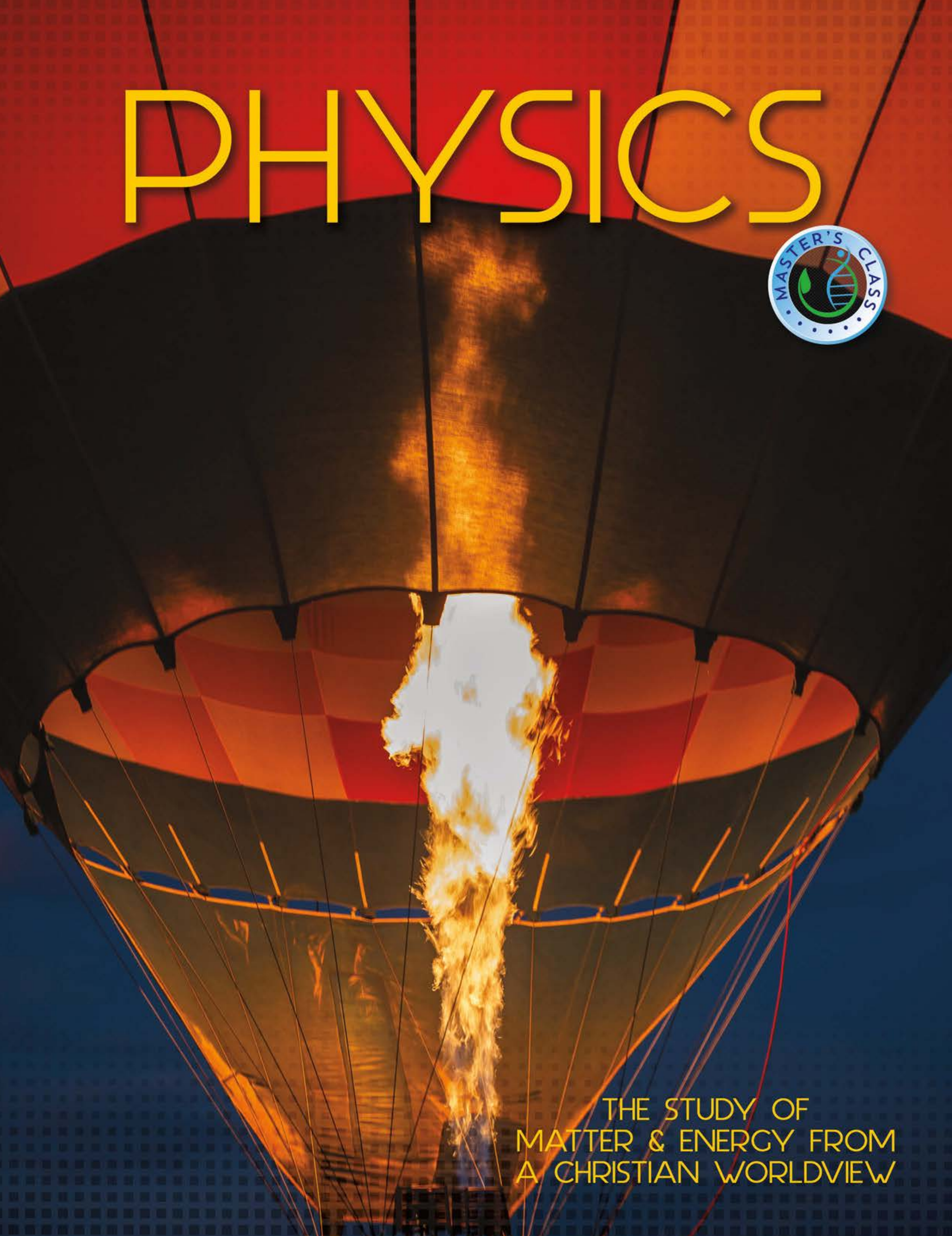
PHYSICS

MASTER'S CLASS



THE STUDY OF
MATTER & ENERGY FROM
A CHRISTIAN WORLDVIEW

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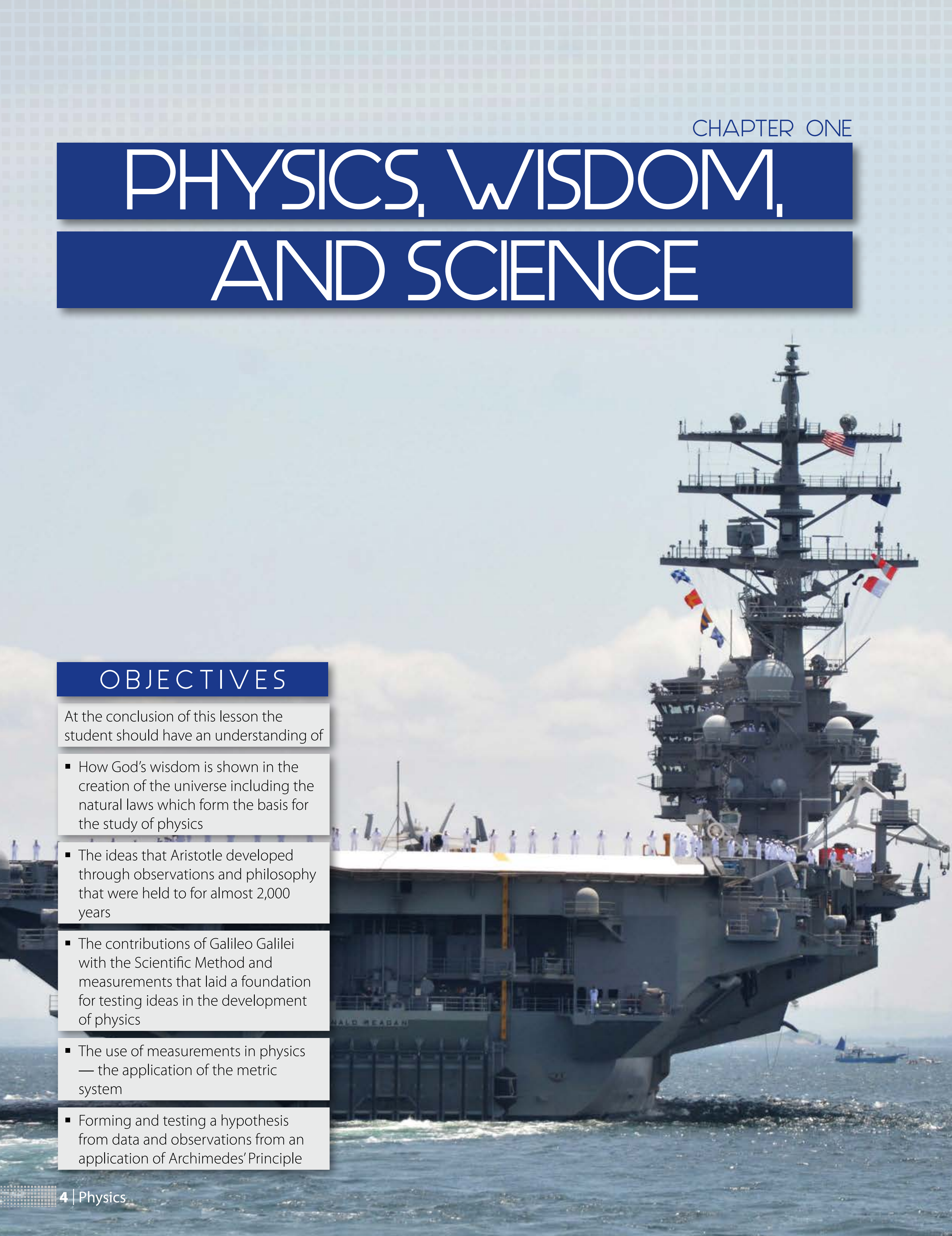
CHAPTER ONE

PHYSICS, WISDOM, AND SCIENCE



OBJECTIVES

At the conclusion of this lesson the student should have an understanding of

- How God's wisdom is shown in the creation of the universe including the natural laws which form the basis for the study of physics
- The ideas that Aristotle developed through observations and philosophy that were held to for almost 2,000 years
- The contributions of Galileo Galilei with the Scientific Method and measurements that laid a foundation for testing ideas in the development of physics
- The use of measurements in physics — the application of the metric system
- Forming and testing a hypothesis from data and observations from an application of Archimedes' Principle

Curiosity and the Natural World

Have you ever wondered how a fully loaded aircraft carrier can float, but a rock cannot? Have you ever wondered how a plane with hundreds of people can fly? How does food become energy that moves your muscles? When you were first born you probably did not wonder much. But you have made up for it since. Sometimes while growing up we are told not to ask so many questions, though that does not stop us from wondering. To be alive and appreciate God's bountiful creation, we need to keep asking those questions. We are made to be curious and to try to answer our questions. Hopefully, this study will answer some of those questions you have always wondered about and cause you to ask more. Why do you feel colder when wet but warmer after you dry off?

God and Physics

Physics is a study of the natural laws, such as the Law of Gravity, which we live by every waking moment of our lives. In our dreams we may soar above treetops and fly with the birds — but not when we are awake. Don't try it. People knew of the natural laws long before they understood them. Have you ever wondered where they came from or what life would be like without them? Most feel that they are just there as part of the world in which we live. They operate the same way all the time. The law of gravity functions the same way on earth and Mars.

Our universe is not just stuff. We also have gravity, light, electric forces, magnetic forces, nuclear forces, and on and on. They are all measurable and follow exact patterns all the time. The only exceptions are miracles. This is the only reason we can study physics. If the natural laws changed, physics would have to be reinvented every time.

"In the beginning God created the heavens and the earth." Genesis 1:1 states that God spoke the universe into being from nothing. This included the natural laws because the universe had to work from the very beginning. Gravity had to determine the orbits of the planets in the solar system and the stars in galaxies and the galaxies in families of galaxies. The sun, moon, and stars were created on the fourth day of creation, so God created light four days before the sun. The light consisted of electromagnetic radiation, so laws controlling electrical forces and magnetic forces had to be there as well from the beginning.

By His wisdom, God created the universe. Proverbs 8:22–23 states, "The Lord possessed me [wisdom] at the beginning of His way, before His works of old. I have been established from everlasting, from the beginning, before there ever was an earth." God (Father, Son, and Holy Spirit) created by His wisdom a fully functioning universe at the beginning. There was light, gravity, and the other functions that are studied in physics at the moment God gave birth to the universe. From the time of Adam and Eve, we have been trying to understand this fascinating universe in which we live. Can you imagine what the new heavens and earth will be like — even greater and without sin?

Biblical wisdom is often referred to as moral and spiritual wisdom. But in Proverbs 8:22–31, God's wisdom is directed at the creation of the physical universe — putting together the physical aspects of the universe. Physics shows us the results of the physical aspects of God's biblical wisdom. It is true that some of man's ideas do not reflect biblical wisdom, but an objective study of the universe itself can show God's wisdom that He put into His creative work.

A natural law is a description of observations made many times that do not vary. For example, gravity is always the same everywhere. Your weight is the pull of gravity from the earth on your mass. Your weight changes as your mass changes or you move closer or farther from the center of the earth. As you move closer to the center of the earth, earth exerts a stronger force of gravity on you and as you move farther from the center of the earth, you weigh less because the force of gravity from the earth on your mass is less. When Jesus walked on water, He altered the force of gravity so that it would not pull Him below the water. As God, the **laws of nature** only affected Jesus as He submitted to them. When He hung on the Cross, He could have altered gravity so that his weight would not have pulled Him down onto the nails tearing into the flesh of His hands and feet. But He chose not to so that He could suffer, paying the ultimate price for our sin.

Natural laws cannot be altered or disobeyed (except by God and whom He allows); they are applicable throughout the universe and are mathematically precise every time. They point to the wisdom and character of God. Therefore, Albert Einstein stated that the existence of God cannot be denied. It has been said that there are no true atheists — just bitter people.

Even as Christians, we often think and act as if the natural laws came about and operate on their own and the only evidence for God are miracles. This is what the Jewish rulers were saying when they told Jesus to give them a sign (perform a miracle). Even when He raised the dead, they did not accept His divine control over creation.

The role of God in creating and maintaining the natural laws is critical to your understanding of physics. You are not studying things made up by a lot of people, but the very handiwork of God Himself.

> **All things were created through him [Jesus] and for him. And he is before all things, and in him all things consist (Colossians 1:16b–17).**

Early Physics — Aristotle

The Greek philosopher Aristotle (384–322 B.C.) studied the motion of objects using observations and logic. He concluded that motion was caused by force — the push and pull on an object. He wondered why a thrown ball kept moving when it left someone's hand. When it left a person's hand there was no longer a force on the ball. He concluded that when the ball moved through the air, the ball pushed the air causing it to go behind the ball and push it. Today we know that momentum and inertia also play a role. Measurement and experiments were not part of his study; this came later. He also concluded that a heavier object will fall faster than a lighter object — it just seemed to make sense. But later measurements and experiments demonstrated that they will fall at the same rate unless they hit air resistance. Therefore, a parachute falls more slowly than a rock — good thing. Aristotle's teachings were accepted as common sense for almost 2,000 years.

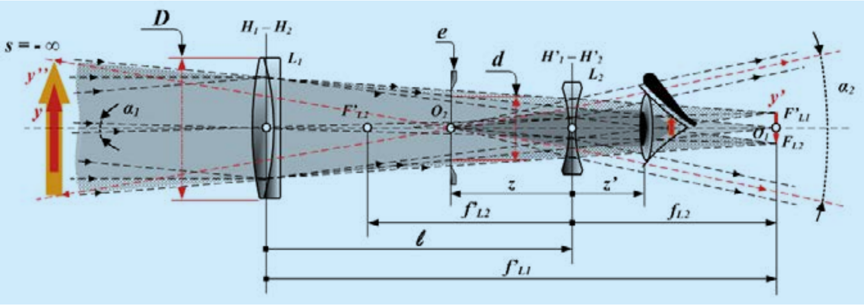
School of Aristotle

It is interesting to note that Aristotle tutored Alexander the Great, who conquered most of the Mediterranean civilization and part of Europe. Daniel 7:6 tells that Daniel had a vision while in exile in Babylon of a leopard that had four heads. The leopard was symbolic of Alexander the Great, and the four heads were four generals that would divide his kingdom after his death. History is "His Story" where all the puzzle pieces are part of a larger whole of God moving through time. While studying physics, you are not just studying a bunch of isolated ideas and equations that only a few people care about. They came to be described by many people over centuries as God worked in their lives.

Measurements and Experiments — Galileo Galilei

The Italian scientist Galileo Galilei (1564–1642) was the first to experimentally study the **acceleration of gravity** (the rate that an object speeds up as it is falling). He did not have a timing device, so he used his pulse rate (which did vary). When he dropped heavier and lighter objects of the same shape, they fell at the same rate.

After Huygens developed lenses, Galileo put them together and made a refracting telescope. Refracting refers to using lenses to bend light rays. It was assumed that objects outside of earth were perfectly shaped because they were closer to heaven. With his telescope, Galileo saw craters on the **moon**, four moons around Jupiter, and sun spots. He saw phases of Venus (like the phases of the moon) indicating that Venus orbited around the sun. These sound like great discoveries, but they went against the teachings of the Catholic Church at that time. The doctrine of the Church was that earth was the center of God's attention; therefore, it was at the center of the universe, and the planets and the sun orbited around earth. Galileo was declared a heretic and judged by the Inquisition court. The penalty was death, but because of the persuasion of close friends, he was placed under house arrest. Before Galileo, Copernicus supported the idea of planets orbiting the sun. This led to the idea of a conflict between the Church and science. A major problem was that these doctrines were not biblical doctrines, but ideas developed from philosophy. A safeguard is to use chapter and verse from the Bible where a doctrine is stated in clear terms, which has the authority of God in Scripture.

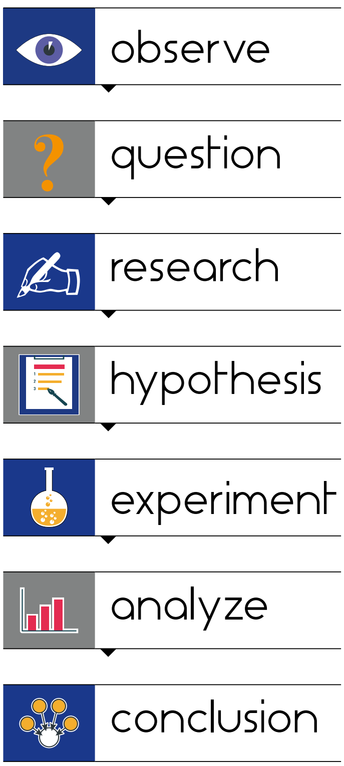


Galilean telescope

In 1638, Galileo published his life work in a book entitled *Discourses and Mathematical Demonstrations Concerning Two New Sciences.* It is usually referred to as *Two New Sciences.* The two sciences were the science of moving objects (velocity, acceleration, momentum, etc.) and the science of non-moving objects. It was smuggled out of Italy because of the conflict with the Church in Rome and published in Leiden, Netherlands. This was considered to be the first modern scientific textbook because it described the universe using laws that could be understood by the human mind. Because of the conflict with the Church at that time and the idea that humans were able to understand the world around them, science became in the minds of many to be the highest source of knowledge. Many felt that they could understand all they needed to know without God. God has given us a tremendous ability to understand His creation because we are created in His image. There are many very intelligent people today who feel they have no need for God in their lives. This goes back to a choice to be independent of God. Galileo, however, believed in God and His role in creation and maintaining the universe. Because God has been so gracious to us by giving us the remarkable gift of intelligence, we still need to recognize our need for Him. You will meet many very intelligent people who reject Christ and worship science. Remember that their view is based upon a choice to exclude God and not upon evidence. I often wonder what science will be like in the new heavens and earth without sin and imperfection. Science is a gift from God, as Galileo recognized, to be used wisely, but our lives go even beyond that to appreciate the greater wisdom given by His Spirit through the Scriptures. Perhaps God can use you to reach many in the sciences to lead them to redemption in Christ. With the Holy Spirit, we can understand and enjoy physics much more.

Science has been a valuable gift from God. He created the natural laws and gave us the ability to use them to design many blessings such as our computers, modern medicine, automobiles, airplanes, etc. The greater gift He gave us was His Son whom He demonstrated as authentic by the miracles that Christ performed as was prophesied centuries before by the prophets. The miracles performed by the Apostles as well clearly demonstrated God's sovereignty over the natural laws that He created.

Galileo used what became known as the **scientific method.** This involves using experimentation to test ideas rather than accepting what seems reasonable. It seemed reasonable to Aristotle that heavier objects should fall faster than lighter objects, but it just is not so. Science begins with observations from which ideas (**hypotheses**) are developed. In observing objects falling, Galileo noticed that heavier objects did not fall as fast as he thought they should. From that he predicted that the heavier and lighter objects would fall at the same rate. Experiments had to be designed to test his prediction that dropped objects of the same shape (to avoid differences in air resistance) would fall at the same rate. His experiments supported his prediction. If the predictions did not work out as expected, the original idea would need to be altered or replaced. A well-supported hypothesis is called a **theory.**



To be able use the scientific method, experiments must be repeatable. Many consider science to be the most reliable way of discovering truth because it relies on repeatable experiments with measurements. It also involves peer review where others repeat the experiments to confirm the results. But a major limitation of science is that it is impossible to think of all possible explanations (hypotheses) for the observations, all the possible predictions from the hypotheses, and all the possible experiments to test the predictions. As new hypotheses, predictions, and experiments are devised, hypotheses and theories are always being replaced by better ones. When science is treated as the ultimate source of knowledge, the conclusion is that there are no absolutes (nothing can be known for certain). The critical point is that there is a greater source of knowledge — God and the Bible that He provided. The Bible must be handled correctly and not made to say things that it does not say. Galileo recognized this when he said that "God is known by nature in His works, and by doctrine in His revealed word."[1]

It was an error to make the earth the center of the universe doctrine because the Bible does not state that. Our knowledge from science grows and is constantly changing, but the truths of the Bible are the same. God is the greatest authority. One of our greatest limitations is that it is hard for us to grasp the idea of the infinite, omnipotent, omnipresent loving God. Some today compare the opposition that Copernicus and Galileo experienced to the opposition of creation against evolution. This is not a valid conclusion because these are different

1 "Letter to the Grand Duchess Christina of Tuscany, 1615"; *Discoveries and Opinions of Galileo: Including The Starry Messenger (1610), Letter to the Grand Duchess Christina (1615), and Excerpts from Letters on Sunspots (1613), The Assayer (1623).* Translated with an Introduction and Notes by Stillman Drake. NEW YORK: Anchor Books, 1957. Pg. 183. The quote is a shortened version of Tertullian's quote in the book *Adversus Marcionem.*

ideas, and creation is described in the Bible. Without the guidance of the Holy Spirit, it is impossible to realize that God's Word is greater than anything that we can propose. Over the years, I have noticed that as good, honest objective research is done in science, it does not contradict the Bible. The conflict lies in the opinions of some. It is true that the Bible is not a textbook of science, but where it overlaps with science it is true because it is based upon the integrity of God.

Measurements in Physics

Measurements are part of the wisdom of God that went into the original creation. Proverbs 16:11 states that "Honest weights and scales are the Lord's; All the weights in the bag are His work."

To test the hypothesis that heavier objects had the same acceleration of gravity as lighter objects, Galileo had to be able to measure the acceleration of gravity of many objects of differing weights.

Length is a fundamental measurement. In the English system, we use inches, feet, yards, and miles. In the metric system everything is divisible by 10, which is much easier to use, which is why it is used exclusively in science. The metric system was developed by Antoine Lavoisier. He was honored in France by being placed in charge of taxation right before the French Revolution. He was one of the first to lose his head to the guillotine. This does not mean that you will go to the guillotine if you use metrics.

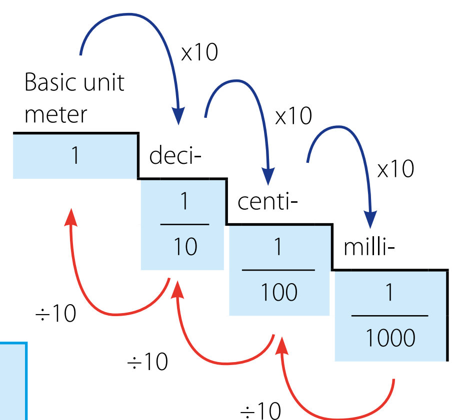
The basic unit in the metric system for length is the meter.

The prefix **deci-** means $\frac{1}{10}$;

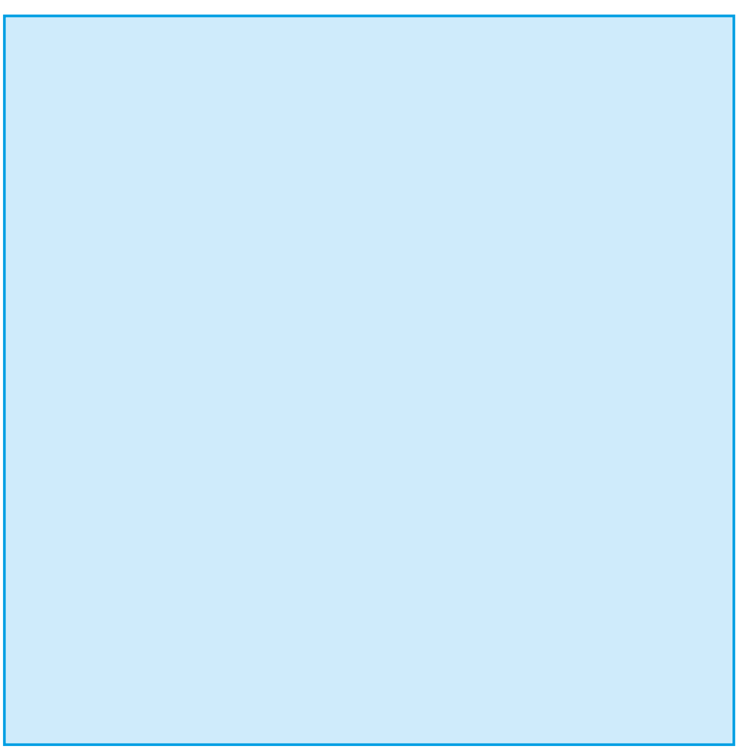
centi- means $\frac{1}{100}$;

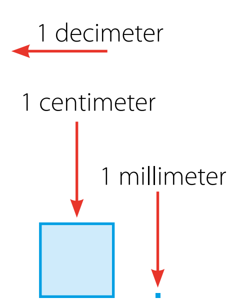
milli- means $\frac{1}{1000}$ and

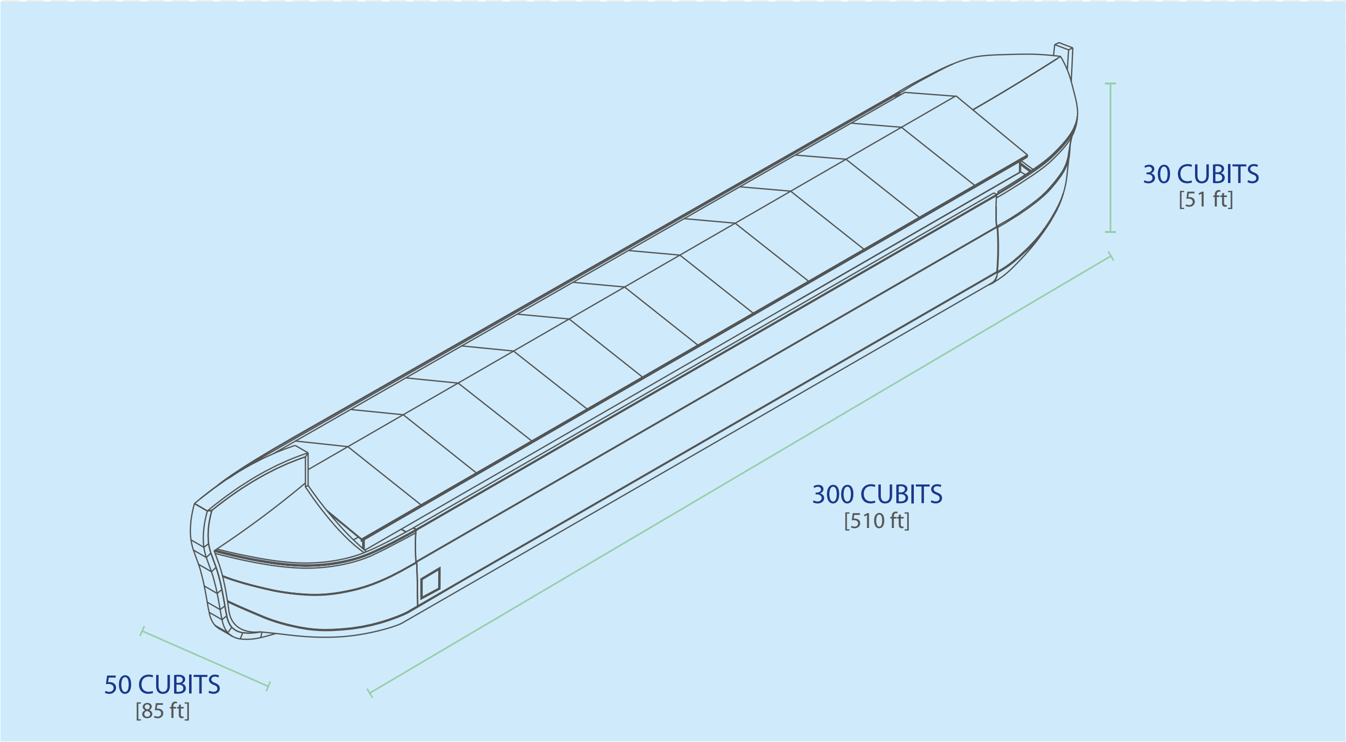
kilo- means $\times$ 1,000.



There are 10 decimeters in a meter; 100 centimeters in a meter; 1,000 millimeters in a meter and 1,000 meters in a kilometer.







Noah had a clear understanding of measurements because God gave him specific instructions in building the Ark. The instructions were in cubits, which was the unit of length used at that time. There are 1.7 feet in a cubit and 0.308 meter in a foot.

The Ark was 50 cubits wide.

$$50 \text{ cubits} \times \frac{1.7 \text{ feet}}{\text{cubit}} = 85 \text{ feet}$$

$$85 \text{ feet} \times \frac{0.308 \text{ meter}}{\text{foot}} = 26.2 \text{ m wide (m stands for meter)}$$

The Ark was 30 cubits high.

$$30 \text{ cubits} \times \frac{1.7 \text{ feet}}{\text{cubit}} = 51 \text{ feet}$$

$$51 \text{ feet} \times \frac{0.308 \text{ m}}{\text{foot}} = 15.7 \text{ m high}$$

The Ark was 300 cubits long.

$$300 \text{ cubits} \times \frac{1.7 \text{ feet}}{\text{cubit}} = 510 \text{ feet}$$

$$510 \text{ feet} \times \frac{0.308 \text{ m}}{\text{foot}} = 157.1 \text{ m long}$$

So, the volume of the Ark was 26.2 m $\times$ 15.7 m $\times$ 157.1 m = 64,621.5 m^3 (cubic meters), because you multiply length $\times$ width $\times$ height.

That was some boat!

If you get a chance, go see the Ark Encounter in Williamstown, Kentucky, which is a replica true to size of the ark built by Noah to the biblical dimensions.

Did you notice how cubits were converted to feet and meters? A cubit is 1.7 feet and 0.518 meter is the same length as a foot. In the expression cubits $\times \frac{\text{feet}}{\text{cubit}}$, cubits are divided by cubits which is 1 leaving 1 $\times$ feet. Another way to state it is to say that the cubits cancel each other. Do not get bothered if you do not understand why this is so, pay attention to the process. The understanding can come later in a math course. Right now, we are using it as a tool. It is like knowing how to use a computer without knowing how to program it.

The basic unit of mass in the metric system is the **gram** (g) and the basic unit of time is the second (s).

Density is defined as the mass of something divided by the volume. The average density of sea water is $\frac{1.027\text{ kg}}{\text{m}^3}$. To float, the Ark would need a density (ρ) just below that of sea water — so its density would have had to have been less than 1.027 $\frac{\text{kg}}{\text{m}^3}$. The volume ($V$) of the Ark would have been 64,621.5 m^3. For its density to be less than $\frac{1.027\text{ kg}}{\text{m}^3}$, its mass ($m$) would have to have been just under. . .

$$\rho = \frac{m}{V}$$

$$\frac{x\text{ kg}}{64{,}621.5\text{ m}^3} = \frac{1.027\text{ kg}}{\text{m}^3}$$

$$x\text{ kg} = \frac{1.027\text{ kg}}{\text{m}^3} \times 64{,}621.5\text{ m}^3 = 66{,}366\text{ kg}$$

A kg is 1,000 grams so 66,366 kg = 66,366,000 grams!

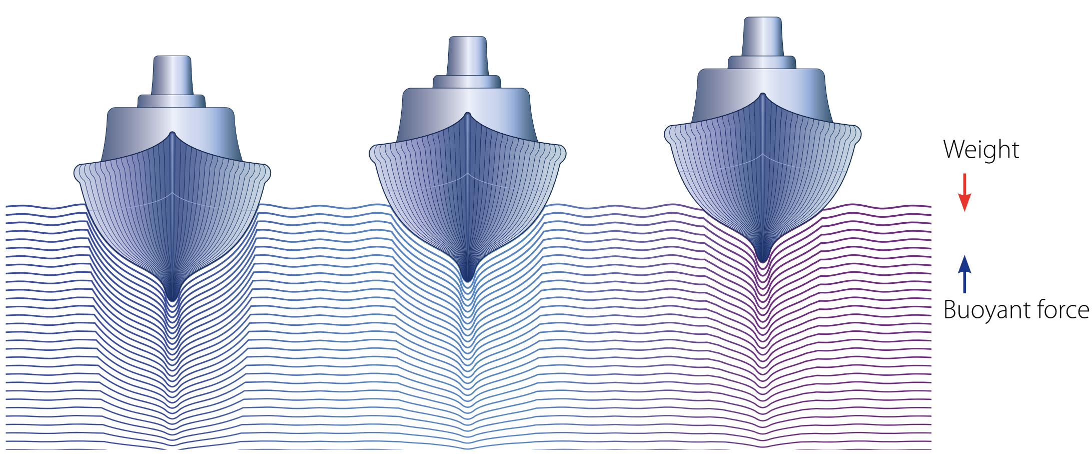
$\rho = \frac{m}{V}$

ρ = density

V = volume

m = mass

We have no way of measuring the mass of the Ark with all of the animals and Noah and his family on board, but we can find it with a little math. This is a method used often in physics. You can calculate things from what you can measure. Its validity lies in that it is based on what is measured and using a valid calculation procedure.



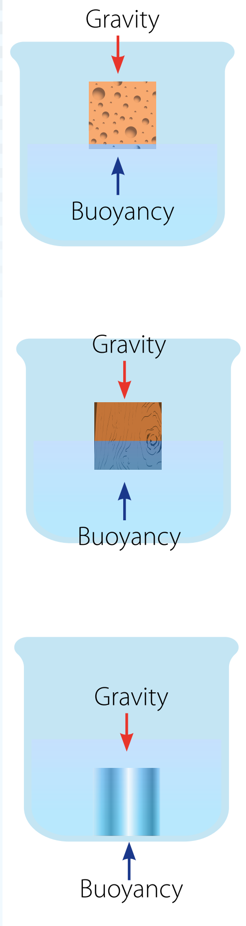
If math is not your friend, do not panic because all the math that you need will be explained. It also makes more sense when you can see how it is applied.

Answer the questions on the related worksheet for this chapter in the Teacher Guide. You may look at the answers to correct your work or if you get stumped. You can write your answers on a separate sheet of paper if you wish to go back and redo them as a review as you prepare for the quiz on this chapter and the later exam. After you have reviewed this chapter and mastered the questions in the worksheet, then take the chapter quiz which will be graded by your teacher.

Archimedes' Principle

REQUIRED MATERIALS

- Digital scale
- 12 cm × 12 cm piece of heavyweight aluminum foil
- Duct tape
- Metric ruler
- Package of at least 25 metal washers
- Fine tip permanent marker



Introduction

Science is based upon observations, hypotheses, predictions to test the hypotheses, and determining whether the experiments support or reject the hypotheses. In this exercise, you will make some observations, make a hypothesis, and test it. Archimedes (287–212 B.C.) made observations like yours in this exercise. He noticed that some objects that were heavier floated while others that were lighter sank. Therefore, weight was not the only factor in determining whether something floated or not. Have you ever wondered why an aircraft carrier floats and a rock sinks? You have been making observations since you were born but probably have not wondered why they happened that way or tested them.

Purpose

This exercise provides experience in making observations and forming and testing a hypothesis.

observe

1. Take a 12 cm × 12 cm (centimeter) piece of aluminum foil and mark it using the ruler as shown in the diagram. (*Diagram L1.1*)
2. Cut the aluminum foil as shown in the diagram below and fold up the sides so that the triangle-shaped pieces on the corners overlap. With pieces of duct tape, tape the overlapping corners so that you have a square shaped "boat" that is 4 cm × 4 cm at the base with the sides 4 cm tall. (*Diagram L1.2*)
3. Find the mass of your boat using the digital scale. Find the mass of a washer. The mass of each are in grams.

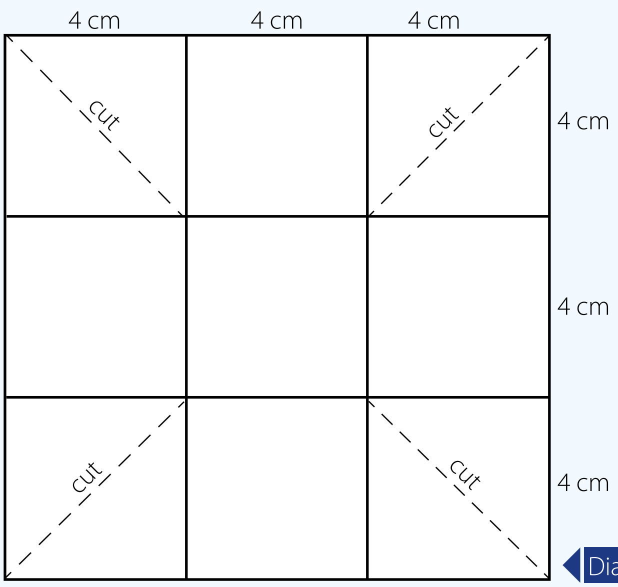


Diagram L1.1

4. Mark the side of the aluminum boat 1 cm up from the bottom. (*Diagram L1.3*)
5. Place the aluminum boat in a body of water such as a bath tub or sink. Check it for leaks to be sure that no water enters the boat.

question

6. Carefully add washers to the boat until it sinks down to the 1 cm mark but is still floating. Count the number of washers that you added and multiply that number by the mass of the washer found in step 3. Add the mass (grams) of the washers to the mass of the boat for the total mass. Find the density of the boat and washers by dividing the mass (grams) of the boat and washers by the volume of the boat. The volume of the boat is $4\ \text{cm} \times 4\ \text{cm} \times 4\ \text{cm} = 64\ \text{cm}^3$.

research

7. Add additional washers to the boat until it sinks. Count the number of washers you added and multiply that number by the mass of the washer found in step 3. Add the mass (grams) of all the washers to the mass of the boat for the total mass. Find the density of the boat and washers after the boat sank. Divide the total mass of the boat and the washers (that made the boat sink) by its volume ($64\ \text{cm}^3$).
8. Record your data and observations in your lab report.
9. The density of water is $\frac{1\ \text{gram}}{\text{cm}^3}$.

hypothesis

10. Look at your data and observations and form an explanation (hypothesis) as to why the boat floated in step 6 and sank in step 7. Write out your hypothesis and how you came up with it. In other words, propose a reason why the boat floated in step 6 and sank in step 7.

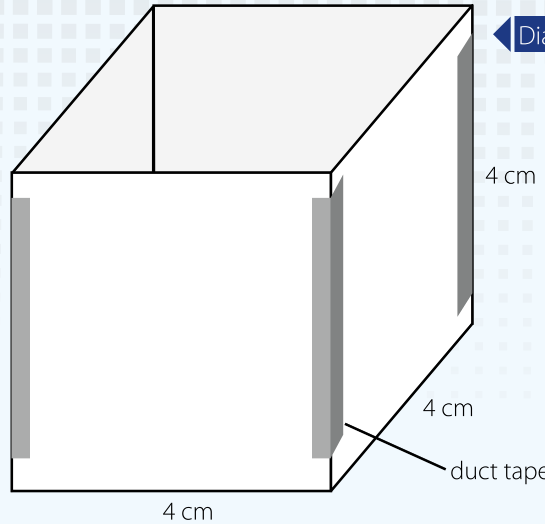


Diagram L1.2

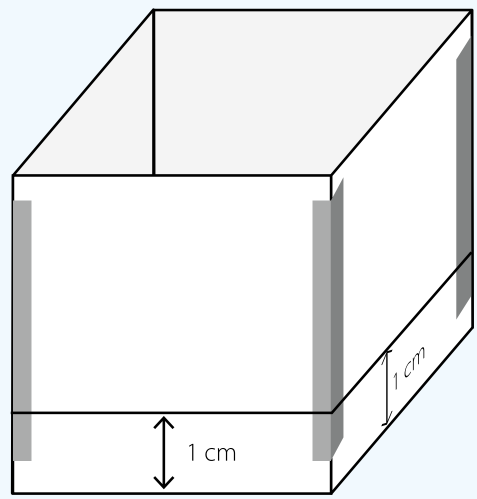


Diagram L1.3

experiment

11. Now you need to test your hypothesis. A suggestion would be to repeat step 7 but add 1 less washer than in step 7 and observe whether it floats or sinks. Then find the density of the boat with its washers (as in step 7).

analyze

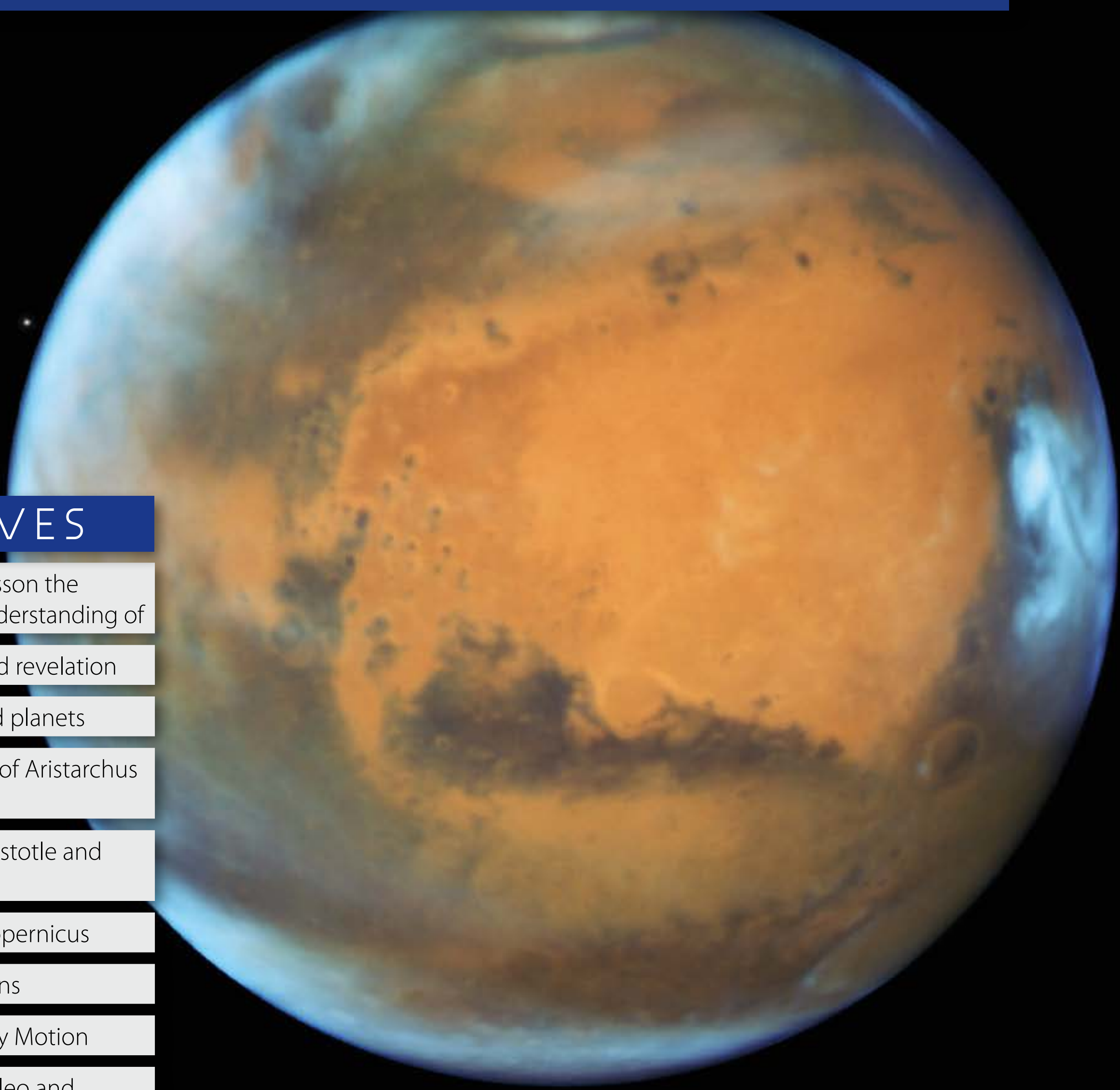
12. How would this support or reject your hypothesis? You can use your creative juices to come up with other ways to test your hypothesis.

conclusion

13. In your report, state how you tested your hypothesis and whether you supported it or rejected it and why.

CHAPTER TEN

KEPLER'S LAWS OF PLANETARY MOTION



OBJECTIVES

At the conclusion of this lesson the student should have an understanding of

- The nature of science and revelation
- Observations of stars and planets
- Early heliocentric model of Aristarchus of Samos
- Geocentric models of Aristotle and Ptolemy
- Heliocentric model of Copernicus
- Tycho Brahe's observations
- Kepler's Laws of Planetary Motion
- The contributions of Galileo and Newton accounting for the centripetal acceleration that keeps planets in orbit around the sun

The first nine chapters dealt with the area of physics called **mechanics**, which is the study of motion. This chapter is an application of those concepts. An important aspect of science is the purpose and limitation of science. This is not meant to be a negative statement. Consider all the blessings that we have gained from the many long years and hours that thousands of people have put in so that we could enjoy these blessings. The laptop that I am writing on is one of those blessings. I remember when I used a typewriter and could not just back up and correct it when I made a mistake. I could not go back and insert a sentence that I left out. Science, by nature, grows and never arrives at ultimate truth. That is what this chapter is all about. In Scripture, we have the inspiration of the Holy Spirit to give us truth in written form. Scripture has many prophecies that have been fulfilled later to the letter. We cannot do that in science. We can make reasonable conclusions — such as if you hit your thumb with a hammer, it is going to hurt. Prophecies are different. Prophets told many years before precisely where Christ would be born. Even the Roman officials that occupied Israel at the time recognized that. Science is a different type of tool than Scripture which is the inerrant Word of God. Each has its purpose and when you use the wrong tool for a task you have problems.

The heavens have always been a subject of curiosity. We are told that on the fourth day of creation "God made the two great lights; the greater light to rule the day, and the lesser light to rule the night. He made the stars also" (Genesis 1:16).

Stars and planets have always fascinated people. The Chaldeans, from which God called Abraham, named some of the prominent constellations. These are regions of the night sky recognized by groupings of brighter stars. God used stars in His promise to Abraham.

> **Then He brought him outside and said, "Look now toward heaven, and count the stars if you are able to number them." And He said to him, "So shall your descendants be." And he believed in the Lord, and He accounted it to him for righteousness (Genesis 15:5–6).**

Even though Abraham could only see the closest stars in our Milky Way **galaxy**, there were so many that Abraham could not count them all.

The word *planet* comes from the word "wanderer" in Greek. They noticed that stars always appeared grouped in the same constellations over the course of a human life span. They noticed other bright objects in the sky that appeared at different times in different constellations, so they called them wanderers in contrast to the stars. In Jude 13, the Greek word for wanderer was used for false teachers.

Throughout this chapter there are names of scientists with the years they lived or wrote. These dates are not given to be memorized but to show which ideas were developed before others and which were contemporaries and could have shared ideas with each other.

In 300 B.C., Aristarchus of Samos said that the sun was the center of the universe. This meant that all the heavenly bodies, including the planets, revolved around the sun. Even though we know today that the sun is not in the center of the universe, we know that planets revolve around the sun in our solar system. This idea was lost by the Greeks and only realized much later.

Geocentric model

Aristotle (384–322 B.C.) and Plato taught that earth was surrounded by four spheres. On the outer sphere were all the stars in their constellations. As this sphere rotated around earth, the stars appear to pass overhead across the night sky. Planets were on a smaller sphere inside the sphere of the stars. This was their explanation for why the planets appeared to wander apart from the stars. The sun and moon were also on separate spheres revolving around the earth. They thought of the spheres as ideal shapes appropriate to the heavens, as approaching perfection because they were closer to God.

In A.D. 150, Ptolemy published a work called the Almagest (The Greatest) where he described the earth as being the center of the solar system with the planets, sun, and moon revolving around the earth. This was a modified form of the teachings of the Greeks. Popular ideas at that time were common sense, just as they are today. This, along with the idea that earth was the center of the solar system, became part of the teachings of the Roman Catholic Church at that time. Later, in the time of the Renaissance, Reformation, and the Inquisition, to think otherwise was heresy and subject to the death penalty.

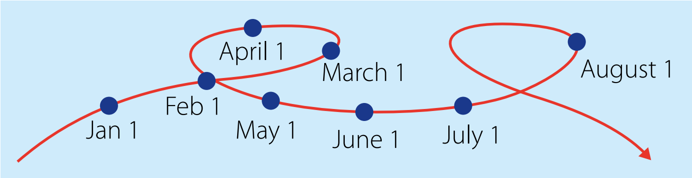


Diagram 10.1

Retrograde motion of an outer planet

The **geocentric** (earth-centered) idea proposed by Ptolemy did a pretty good job of predicting where and when the planets would appear in the night sky. There were some problems, however, including the changing brightness of planets and the retrograde motion of Mars, Jupiter, and Saturn. They had not discovered Uranus, Neptune, and Pluto yet. Retrograde motion means to go backward. As these planets move across the night sky on successive nights, they appear to go backward and then forward again (*Diagram 10.1*).

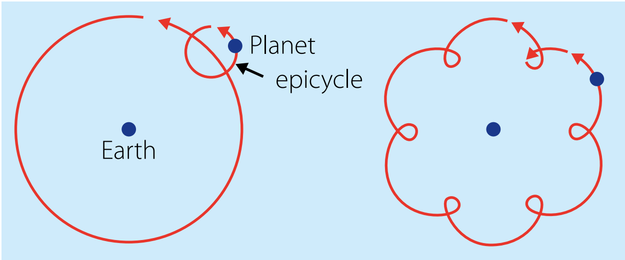


Diagram 10.2

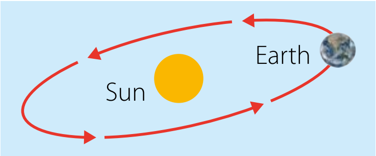
Orbit of a planet with epicycles

Ptolemy tried to explain this by having the planets go in smaller circles (called epicycles) as they gradually revolved around earth. This would make them appear to go backward and then forward again. But this still did not explain the changes in the brightness of the planets (*Diagram 10.2*).

Notice, as in this case, in the development of ideas in science, observations are made and must be accounted for in the proposed explanations.

Much later, the Polish astronomer Nicolaus Copernicus (1473–1543) published, while on his deathbed, a **heliocentric** (sun-centered) view. This was a radical departure from the long-held view described earlier by Ptolemy. He waited until they could not do anything to him, because others had been burned at the stake for lesser heresies.

Copernicus' ability to predict the positions of the planets in the night sky was about the same as that of Ptolemy. But he explained the retrograde motion of planets in a much simpler way. With the planets revolving around the sun, the planets closer to the sun would not have to go as far as the planets



Heliocentric model

farther away, so they would pass the outer planets and go around the sun sooner, making it appear that the outer planets went backward and forward again (*Diagram 10.3*).

He explained the changing brightness of the planets, because if they all revolved around the sun, sometimes they would be closer to earth and sometimes farther away.

Some argued against Copernicus' ideas stating that if earth revolved around the sun, it would be going about 1,000 miles an hour and we would feel it and blow off the earth because of the great wind it would produce. This was concluded because of their lack of understanding of gravity that came later with Galileo and Newton. It was later realized that we did not pass through air, but that our atmosphere was held to earth by gravity, so it traveled with us.

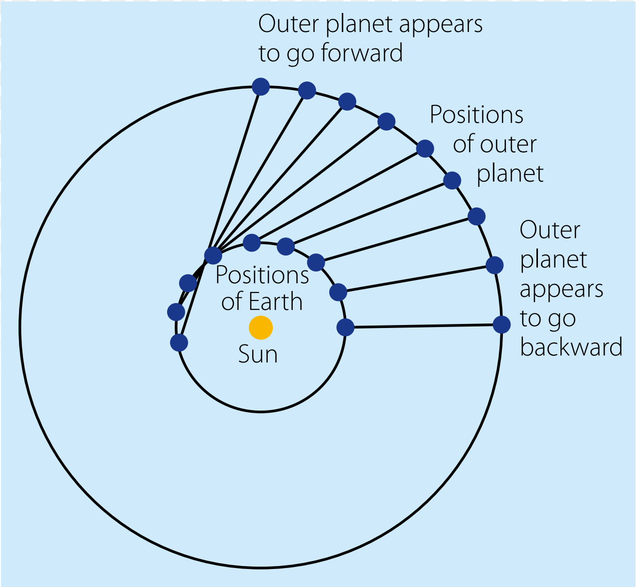


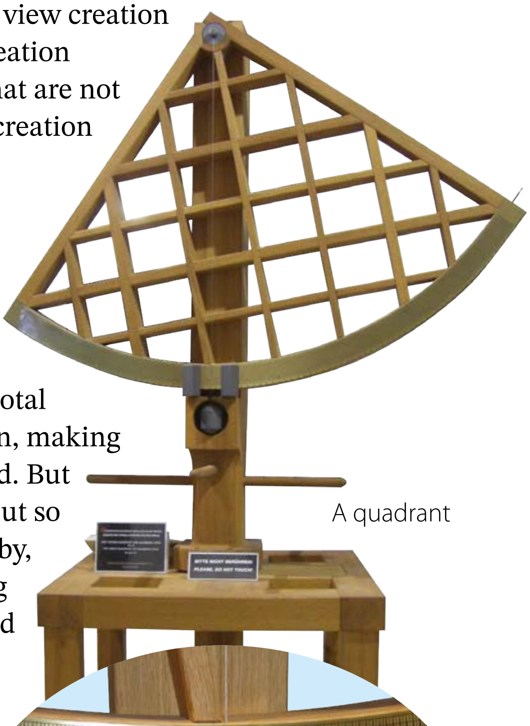
Diagram 10.3

Retrograde motion of outer planet with heliocentric model

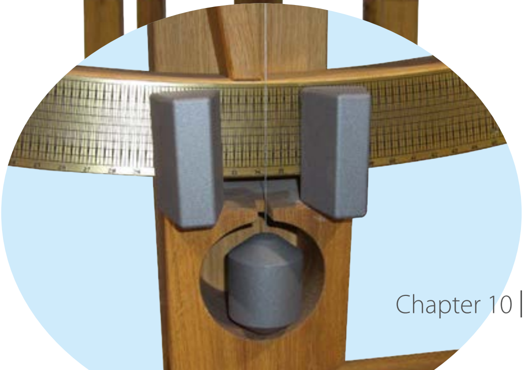
Much later the heliocentric model became more acceptable. Usually it takes about 100 years for a completely different idea to replace a common belief.

It is common today in astronomy classes to compare the church's treatment of Copernicus to the treatment of evolutionists today. The point is made that church dogma hindered reliable scientific observations and sound conclusions. They think of creation as church dogma and evolution as conclusions made from reliable observations. If doctrines, such as creation, were just opinions of church officials and not divine revelation, their claims would be valid. The problem is how the Scriptures are viewed. You more than likely will encounter such arguments. When you do, ask how they view the Scriptures. Many view creation as an idea where there are no changes at all in living forms. But creation acknowledges that limited changes do occur in living organisms that are not evolution, because they are restricted within the original kinds of creation and are controlled by DNA that had to be present in first life forms created.

Further detailed observations of the positions of stars and planets were made by the Danish astronomer Tycho Brahe (1546–1601) over the span of many years. As a teenager, Tycho Brahe noticed that the astronomers of his day (without telescopes, because they had not yet been invented) predicted the time and day that a total eclipse of the sun (the moon coming between the earth and the sun, making the sun go dark momentarily) and it occurred just as they predicted. But he also noticed that some of their other predictions did not come out so well. He developed a passion to make better predictions and, thereby, have a better understanding of the universe. As he became a young man, he had a bit of a combative spirit. Once, he got into a duel and got his nose blown off with a musket ball. The doctor made him a replacement nose out of brass. The king of Denmark, wanting to protect him, built him an observatory on an island off the coast of Denmark so that he would stay there out of harm's way. Brahe built a large instrument, called a quadrant, that look like half of a giant protractor. By looking past the quadrant with its markings to distant objects in the sky, he



A quadrant



could accurately identify their positions within $\frac{1}{60}$ of a degree. The sky from horizon to horizon is 180 degrees and $\frac{1}{60}$ of a degree is called a minute. This enabled him to make very accurate observations.

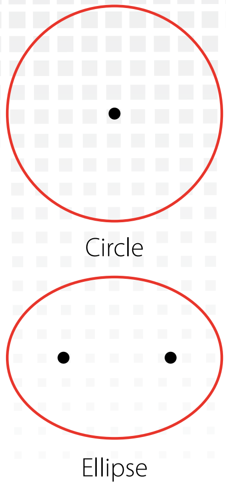
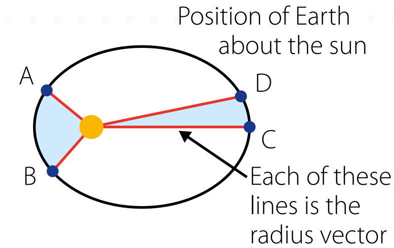


Diagram 10.4

Even though he kept very accurate records over many years, he was not well organized. He did not have a spread sheet to record his data. He had a model of the solar system where the planets revolved around the sun, but he had the sun and moon revolving around earth. To make better predictions, he had to be able to see general patterns from all his data. Johanne Kepler succeeded Brahe and was able to see several patterns from his data which became known as Kepler's Laws of Planetary Motion. At first, Kepler had the same limitations in predicting the positions of the planets as Ptolemy and Copernicus because he viewed the orbits of planets as being circles. Tradition has it that one day he said, "What a silly bird I have been." He tried placing the orbits of the planets in ellipses, instead of circles, and his predictions were much better. An ellipse has two points around which an object revolves instead of one as in a circle (*Diagram 10.4*).

Kepler's First Law of Planetary Motion was that planets orbit around the sun in ellipses instead of circles. It was a minor but significant improvement because the ellipses were almost circles.



The two shaded regions are equal in area. Earth goes from A → B in the same time it goes from C → D

Diagram 10.5

The Second Law of Planetary Motion was that planets go faster when they are closer to the sun and slower when they are farther from the Sun. Another way to state it is that the radius vector from the sun to a planet sweeps out equal areas in equal amounts of time. It is shown by this diagram (*Diagram 10.5*).

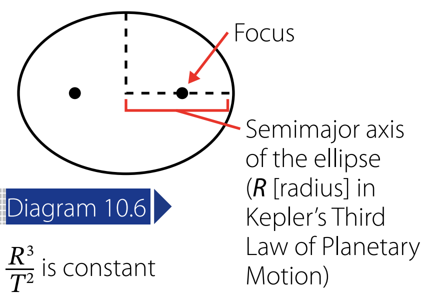


Diagram 10.6

$\frac{R^3}{T^2}$ is constant for planets in the solar system

The Third Law of Planetary Motion, sometimes called the law of harmonies, is that the radius of revolution of a planet cubed, divided by the period (T, the time it takes a planet the orbit the Sun) squared is the same for every planet except for Pluto (that had not been discovered yet) (*Diagram 10.6*).

These three laws of planetary motion together were much better at predicting the positions of planets than before. Tycho Brahe would have been thrilled if he could have lived to see the fruition of his work. Accurate predictions are evidence of design and numerical predictions are much greater evidence of design. Kepler gave God the glory for His creation of the heavens. Kepler had the earth revolving around the sun, and the moon revolving around earth.

In science, everyone's work is built upon the work of many others that have gone before. There will always be some unanswered questions. When planetary orbital patterns were better understood, the question that remained was, why do the planets keep changing direction to follow around the sun? What keeps them going around the sun? Why don't they just fly off into space? In chapter 8,

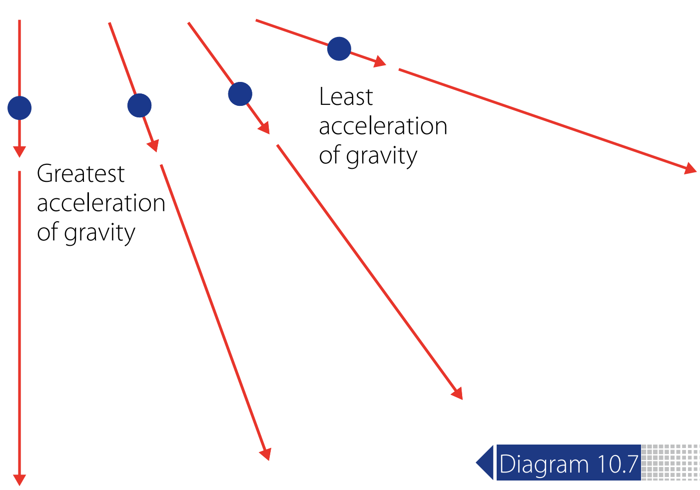


Diagram 10.7

The Galilean moons Io, Europa, Ganymede, and Callisto (in order of increasing distance from Jupiter)

we called this **centripetal acceleration**. Acceleration is a change in velocity, and planets must constantly change direction to keep going around the sun. Remember that centripetal means "center seeking." But what was the force causing the centripetal acceleration? Whenever you have an acceleration, it must be caused by a force. This led later for Galileo (1564–1642) to propose the idea of the acceleration of gravity. He demonstrated, using inclined planes, that the greater the slant of the plane, the less the acceleration. This meant that the greatest acceleration was straight down (*Diagram 10.7*).

Many believe that answers to questions like this mean that nature can function without God having to make it work. This is based on the belief that God is only involved when He must be — when there is no explanation other than a miracle. This is contrary to a biblical understanding of the very nature of God. Maybe that is why we are tempted to act as if God does not know what we are thinking and doing.

Galileo was the first to report observing the moon with its craters, sunspots, and four of the moons around Jupiter that became known as the Galilean moons. He was one of the first to use a refracting telescope, one that uses lenses. He ended up living out the rest of his life in house arrest because the round heavenly bodies represented steps toward holiness to many of the religious leaders of his day. Sunspots and moon craters were thought of as blemishes in what was considered holy. This illustrates how ideas that are not spelled out in Scripture can lead to very serious problems.

Later Isaac Newton (1642–1727) proposed the Universal Law of Gravity that provided the force for the centripetal acceleration of the planets. He said that if you launched a projectile from a high enough mountain fast enough, it would orbit the earth. He stated that gravity was the force that provided the centripetal acceleration that kept the planets in orbit.

It is fascinating that just over two centuries after Newton wrote of a projectile being launched into space and orbiting the earth in his work *A Treatise of the System of the World*, the first such rocket fulfilled his thought experiment. In October 4th of 1957, the USSR launched Sputnik 1, an unmanned craft that orbited Earth until it fell back down in January 4th of 1958. The first person in space was launched into a single orbit of Earth in 1931, also from the USSR, and the first people to go to the moon came from the United States just a few years after that, in 1969. The race for space was accelerating.

Kepler's laws of planetary motion describe and explain the shape and times of planetary revolutions around the Sun with the heliocentric model.

Elliptical Orbits And Moon Phases

REQUIRED MATERIALS

- $8\frac{1}{2}$" × 11" piece of cardboard
- Three $8\frac{1}{2}$" × 11" pieces of plain paper
- 2 tacks
- 10" long piece of string
- 2 helpers, a flashlight, and a darkened room

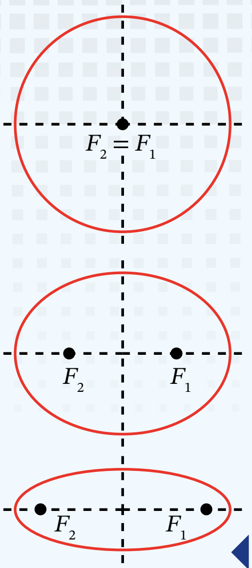


Diagram L10.1

Introduction

Planets and the moon reflect light from the sun and do not emit their own light. As the moon revolves around earth, the side illuminated by the sun is seen as bright. During a full moon, the earth is between the moon and the sun and we see light reflected to us showing the full surface of the moon. During a new moon, the moon is between us and the sun and the light from the sun hitting the moon reflects to the sun and we do not see it. During a first quarter moon (when the moon is a quarter of the way around earth), we see the right side of the moon illuminated because that is the side of the moon that the sun shines on. During a third (or last) quarter moon (when the moon is three quarters of the way around earth), we see the left side of the moon illuminated because that is the side of the moon the sun is shining on. As the moon revolves around earth, we are seeing light reflected from the part of the moon the sun shines on. While this is happening, the same side of the moon always faces us. This is because the moon revolves around earth at precisely the same rate that it rotates on its axis. If the rate of revolution and rotation were even slightly different, after a few thousand years we would be seeing a different part of the moon (*Diagram L10.2*).

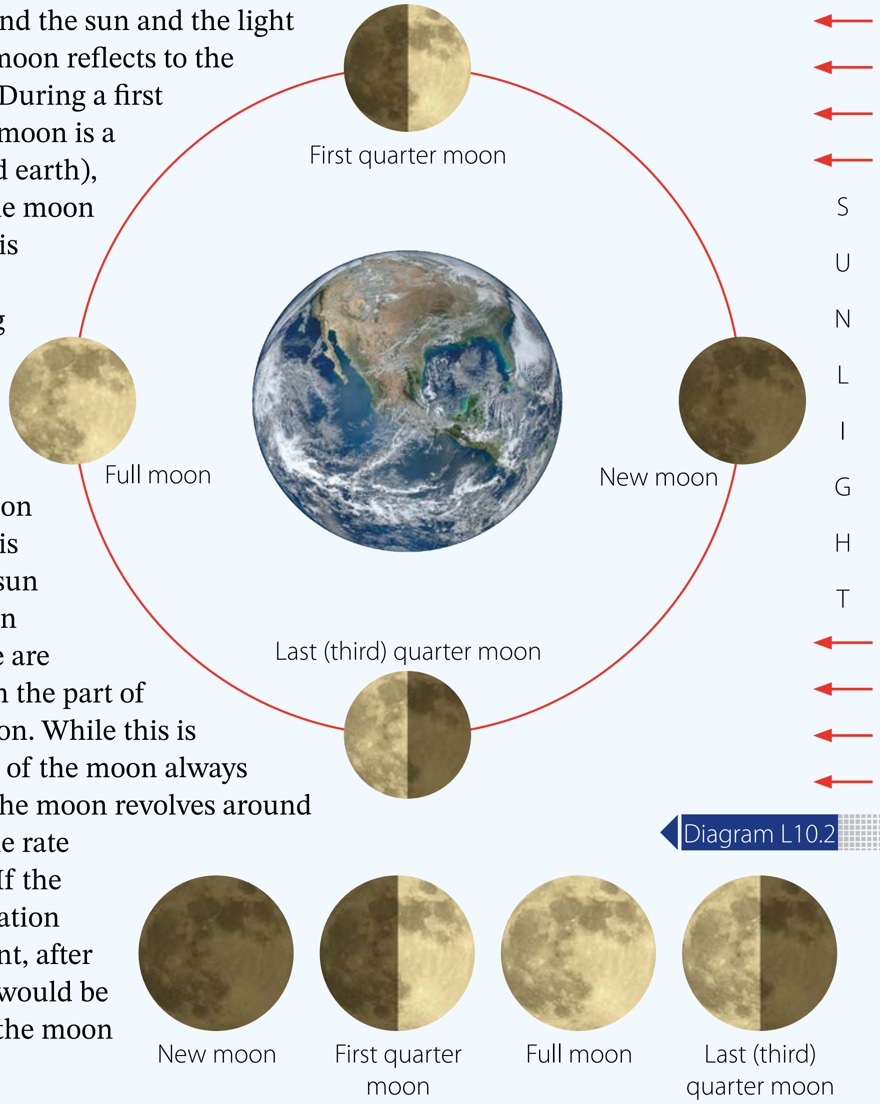


Diagram L10.2

Purpose

This exercise is to demonstrate the nature of an elliptical orbit and the phases of the moon.

Procedure

observe

1. Cut an $8\frac{1}{2}$“ × 11” piece of cardboard or stiff paper. Lay a piece of unlined paper onto the cardboard. Cut a piece of string 10” long. Place a tack in the middle of the paper. Tie the two ends of the string together to make a loop. Place the string loop over the tack and a pencil in the other end of the string loop. With the string loop attached to the tack, draw a circle around the tack by moving it around the tack.

2. Place another sheet of paper on the cardboard. Instead of the tack, place 2 tacks 1 inch apart in the middle of the paper. Place the string loop over the two tacks and draw a small ellipse around the tacks. This is like a planetary orbit around the sun, where the sun is represented by one of the tacks. Notice that your ellipse has a point closer to the "sun" and a point farther from it (*Diagram L10.3*).

question

3. Repeat step 2 except this time place the tacks 3 inches from each other. Draw out the ellipse around these foci. Notice that this a much narrower ellipse.

4. If you can, go outside tonight and see if you can see the moon. If the sky is relatively clear and the moon has not risen yet, check every night for a while until it is visible. As an alternative, you can go online and ask the question "What does the moon look like tonight?"

research

5. Describe and draw the moon as you see it. After a week, go out and describe and draw the moon again. Do this 2 more times. Describe the phase of the moon for each evening that you observe it. This part of the lab will take at least a month to complete.

hypothesis

6. The moon has phases which is evidence that it revolves around the earth. You can also see phases of the planet Venus if you use binoculars or a telescope. This is because Venus revolves around the sun closer to the sun.

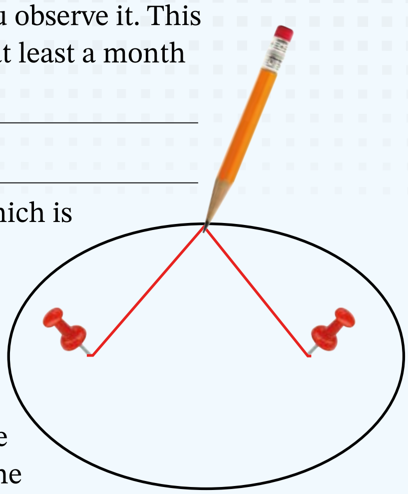


Diagram L10.3

experiment

7. Go into a dark room with 2 helpers. Stand in the middle of the room (you are earth). Have another person (the moon) walk in a circle around you, rotating so that the front of the person always faces you. The third person (the sun) is to stay on one side of the room and shine a flashlight on the person going around you. It is important that the light always come from the same direction. Have the rotating person go to new moon, first quarter moon, full moon, and third quarter moon position.

analyze

8. Describe how the light shines on the rotating person at each position.

conclusion

9. This is how the phases of the moon are produced.

CHAPTER TWENTY

ELECTRIC CIRCUITS 1

OBJECTIVES

At the conclusion of this lesson the student should have an understanding of

- Electric circuits
- Current, voltage, and resistance
- Open and closed circuits
- Circuit diagrams
- Direct and alternating currents
- Circuits in series
- Circuits in parallel
- Voltmeters and ammeters
- Electric power
- kWh

Do you remember the last time you rubbed your shoes across a carpet on a dry, warm summer day and got a shock when you touched a doorknob or sleeping cat? That was from a build up of negative charged electrons on your body. It is called static electricity — it accumulated on your body but was not flowing through a conductor, like a copper wire.

An electric **current** is the flow of electric charge. It can be the flow of positive charges like the movement of positive charged sodium ions (Na^+) in a solution or the flow of negative charges like the flow of electrons in a wire. The path that electrons take in a wire is called a **circuit**.

The direction of current flow is indicated as the direction of the movement of positive charges. When electron flow is involved, the current is said to flow in the direction opposite to that of negative charges, even though the overall movement of electrons is in the opposite direction. This allows the same equations to be used in all situations (when dealing with the movement of positive ions or negative electrons). The standard symbol for current is the letter I (*Diagram 20.1*).

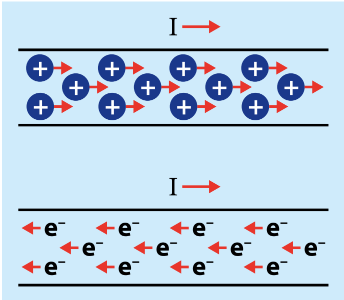
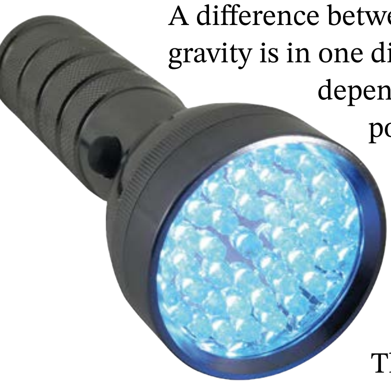


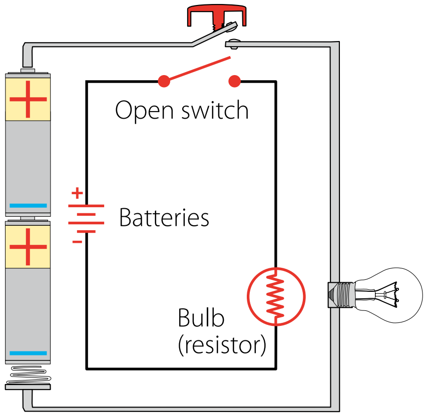
Diagram 20.1

Water flows down a river, rather than uphill, because of gravity. When a book is lifted and placed on a shelf at height h, its gravitational potential energy is mgh in units of joules. When the book falls, its potential energy becomes kinetic energy ($\frac{1}{2}mv^2$) until it hits the floor. Electric charges do not move because of gravity, but rather because of the attraction of opposite charges and the repulsion of like charges. Electric potential is measured in units of **volts**, which is joules per coulomb (a coulomb is the charge of 6.25×10^{18} electrons). Current is measures in units of amperes or amps, as it is usually called. One ampere is 1 $\frac{\text{coulomb}}{\text{second}}$.

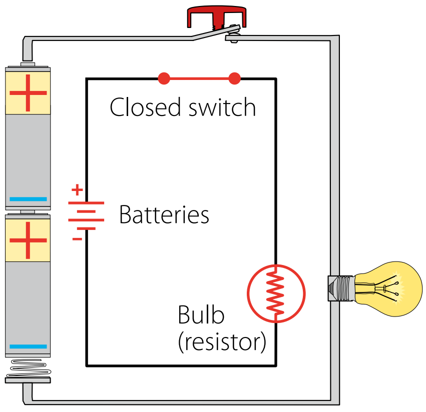


A difference between gravity and the attraction of charges is that gravity is in one direction, but electric potential can go either direction depending upon the charges. Charges move between two poles (positive and negative). The positive pole, like on a battery, is the source of positive charges and the negative pole attracts positive charges. Therefore, you must have a complete or **closed circuit**. Consider this circuit with a flashlight battery, a switch, and a bulb.

The symbols used in the following diagram are standard symbols. When the switch is down connecting everything together, the circuit is closed. If the switch is up so that the wires are not connected, it is an **open circuit** (the switch is open) and the wires are not all connected — the current cannot get from one pole on the battery to the other. When the circuit is closed and everything is connected, electrons move from the negative pole of the battery to the positive pole of the battery and the current is said to flow from the positive pole to the negative pole.



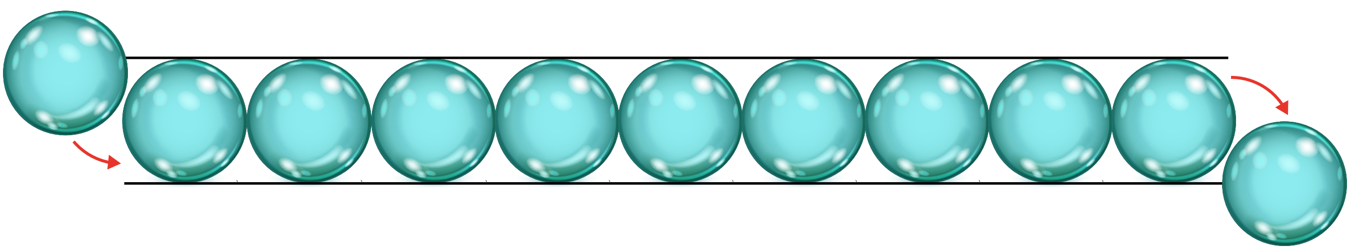
Open circuit



Closed circuit

The bulb is a source of **resistance** to the flow of electrons. A resistor is symbolized by the zig zag line and the circle represents a bulb. Resistance in an electric current is like friction to a sliding object. It resists movement and releases some energy as heat and possibly light. The alternating long and short lines represents the energy source (in this case a battery).

Have you wondered how the lights come on almost instantaneously when turn on a light switch? The electrons that leave the negative pole of the battery do not end up on the positive pole. They do not move through a wire like water flowing through a pipe. Metal atoms, which are usually good conductors of electricity, have a few of their outer electrons moving about between the atoms. Consider the analogy of a pipe packed with marbles single file from one end to the other. When you poke a marble in one end, one falls out the other end. When an electron leaves the negative pole of the battery and goes into the wire, one leaves the other end of the wire going onto the positive pole of the battery. Because some of the electrons in a metal wire are mobile, they can do this. Even so, they do not take a direct route but zig zag around a lot between the metal atoms.



In the circuit diagrammed on the previous page, most of the energy loss is at the bulb, which is why it is called a resistor. The wires and batteries do offer some resistance, but it is very small compared to the bulb. Longer wires have more resistance than shorter wires because more electrons must move through the length of the wire. Also, thicker wires offer less resistance that thinner wires because the electrons have more options to move around metal atoms than in thinner wires.

Electrical resistance is measured in units of **ohms** (symbolized by the Greek letter omega Ω). The opposite of resistance is conductance which is measured in units of mhos (who would have guessed?): $\frac{1}{\text{ohm}} = \text{mho}$.

In 1826, Georg Simon Ohm discovered the relationship that came to be known as **Ohm's Law**.

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} = \frac{\text{Volts}}{\text{Ohms}}$$

$$I = \frac{V}{R}$$

When the circuit is closed and current flows through the bulb, the bulb glows and gets hot. Producing light and heat takes energy. It is said that there is a **voltage drop** over the bulb. The amount of voltage lost as the current flow through the bulb is . . .

$$\Delta V = IR$$

The symbol Δ means "a change in" so ΔV means a change in voltage or the drop in voltage.

A battery supplies a **direct current** (DC) because the current flows in only one direction. Household currents are **alternating currents** (AC) because they go back and forth.

In some circuits, when more than one battery or resistor is used, they can be connected in **series**. If you use two batteries and two bulbs, the circuit looks like this (*Diagram 20.2*).

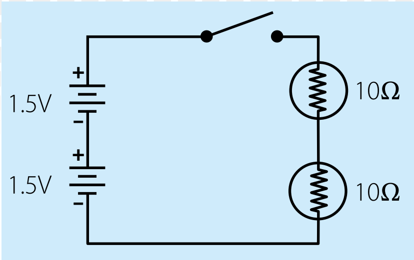


Diagram 20.2

The total voltage is the sum of the two batteries or 3V. if each bulb has a resistance of 10Ω, the total resistance is 20Ω. What is the current of this circuit?

$$I = \frac{V}{R} = \frac{3V}{20\Omega} = 0.15 \text{ A}$$

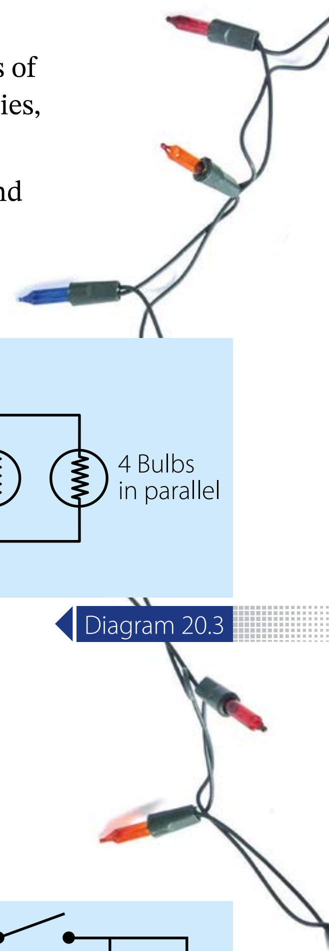
The more bulbs there are in a series, the dimmer each bulb will be because each bulb gets less energy.

If 1 bulb is used, what would be the current available to the 1 bulb?

$$I = \frac{V}{R} = \frac{3V}{10\Omega} = 0.30 \text{ A — which would produce a brighter bulb.}$$

The voltage drop of the 1 bulb is 3V. When the circuit is complete, the voltage drop equals the voltage provided by the power source. If 2 bulbs are used, the voltage drop across each bulb is $1\frac{1}{2}$ volts.

Another disadvantage of using bulbs in series is that if one bulb burns out, the circuit is open and all the bulbs go out. This is what used to happen with the older design of a series of lights that were hung on a Christmas tree or on the house. There were many bulbs in a series, so the burned-out bulb had to be found and replaced. That could be quite a job.



What if 2 batteries and 4 bulbs were used? The total voltage would be 1.5V + 1.5V or 3V and the total resistance would be 40Ω (10Ω + 10Ω + 10Ω + 10Ω). The current would be . . .

$$I = \frac{V}{R} = \frac{3V}{40\Omega} = 0.075 \text{ A}$$

Modern Christmas lights are wired in **parallel** instead of in series. This is why if one bulb burns out the others stay lit. If 2 batteries are wired with 4 bulbs in parallel, it would look like . . . (*Diagram 20.3*).

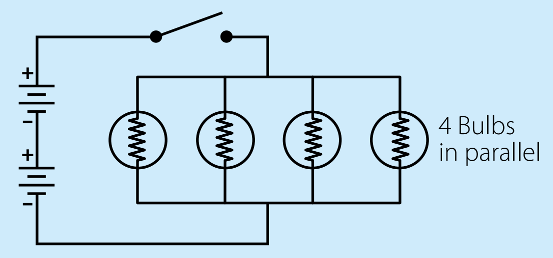


Diagram 20.3

The total voltage is 3V (1.5V + 1.5V) and the total resistance is found by . . .

$$\frac{1}{R_{\text{Total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega} = \frac{4}{10\Omega} = 0.4 = \frac{1}{R_{\text{Total}}}$$

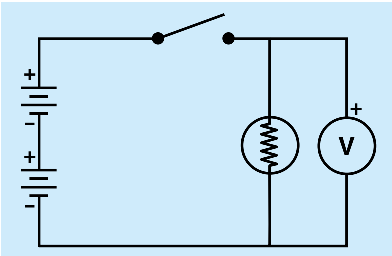
The total resistance of the four resistors is $\frac{1}{.4} = 2.5$ W.

What is the current of this circuit?

$$I = \frac{V}{R} = \frac{3V}{2.5\Omega} = 1.2 \text{ A}$$

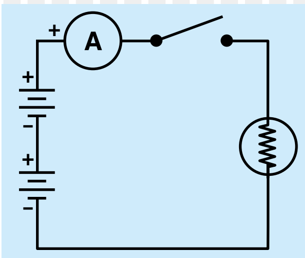
There is 1.2 A of current flowing through every bulb since the current has equal access to each bulb.

The voltage and current is measured with a multimeter. First set the dial on the function that you want to measure. To measure the voltage drop across a bulb place the leads of the meter in parallel with the bulb. Be sure that the positive lead from the meter is on the side of the bulb facing the positive pole of the battery. The voltmeter has a large resistance, otherwise the current would flow through the meter instead of the bulb. (*Diagram 20.4*).



Voltmeter parallel to bulb

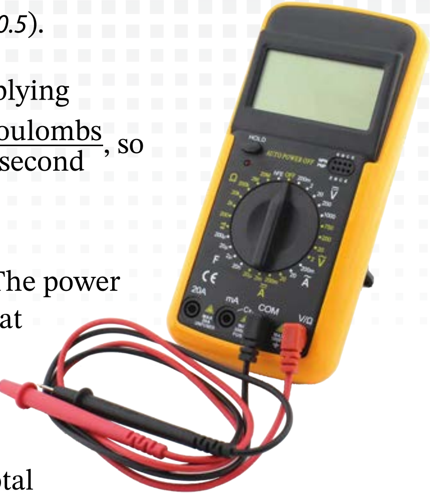
Diagram 20.4



Ammeter in series

Diagram 20.5

When measuring current, switch the dial on the multimeter to amperes in the proper range and it serves as an ammeter. If you wanted to measure the flow of water in a stream, you would place the flow meter in the stream. To measure electric current, place the ammeter meter in series in the circuit between the bulb and the positive pole of the battery (*Diagram 20.5*).



Electric power is $\frac{\text{joules}}{\text{second}}$ = **watts**. It is found by multiplying volts × amperes. Volts are $\frac{\text{joules}}{\text{coulomb}}$ and amperes are $\frac{\text{coulombs}}{\text{second}}$, so

$$\frac{\text{joules}}{\text{coulomb}} \times \frac{\text{coulombs}}{\text{second}} = \frac{\text{joules}}{\text{second}}$$

If P is power, $P = \Delta VI$ and by Ohm's Law $\Delta V = IR$, $IR \times I = I^2R$. The power input equals the power output which is another way of saying that the voltage supplied by the battery equals the sum of the voltage drops of the resistors.

What is the power used by 3 10Ω bulbs in series powered by 2 1.5V batteries? The total resistance of the bulbs is 30Ω and the total voltage is 3V.

$$I = \frac{DV}{R} = \frac{3V}{30\text{ W}} = 0.10\text{ A}$$

The power $P = \mathrm{I}^2\mathrm{R} = 0.10\mathrm{A}^2 30\Omega = 0.3$ watts.

What if you had 3 10Ω bulbs in parallel with 2 $1\frac{1}{2}$ batteries? What would the power usage be?

$$\frac{1}{R_{\text{Total}}} = \frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega} = \frac{3}{10\Omega} \text{ and } R = \frac{10}{3\Omega} = 3.3\Omega$$

$$I = \frac{DV}{R} = \frac{3V}{3.3W} = 0.9\text{ A}$$

$$P = I^2R = 0.9A^2 3.3\Omega = 2.67\text{ watts}$$

Utilities charge for electric power usage by the kWh or **kilowatt hour**. Light bulbs are labeled according to their power usage. If you had a 150-watt bulb on for 12 hours, how many kWh would that be?

$$(150\text{ watts})(12\text{ hours}) = 1800\text{ watt hr} = 1.8\text{ kWh}$$

If the power company charged 10 cents for each kWh, that would cost 1.8 × 10 = 18 cents. Usually, power companies have a staggered cost scale where a lower rate is paid up to a number of kWh and more for the kWh above that. Some companies have several layers in the fee structure.

What would it cost to run an electric clothes dryer for 4 hours that used 5400 watts of power, on a 220V circuit that would use 25A?

$$I = \frac{DV}{R} \text{ and } R = \frac{DV}{I} = \frac{220V}{25\text{A}} = 8.8\Omega$$

$$P = I^2R = (25\text{A})^2(8.8\text{W}) = 5{,}500 \text{ watts} = 5.5 \text{ kW}$$

$$(5.5 \text{ kW})(4 \text{ hr}) = 22 \text{ kWh}$$

$$(22 \text{ kWh})(4 \text{ hr}) = 88 \text{ kWh}$$

$$88 \text{ kWh} \times 10 \frac{\text{cents}}{\text{kWh}} = 880 \text{ cents}$$

or

8 dollars and 80 cents

This is more than the cost for using the light bulb.

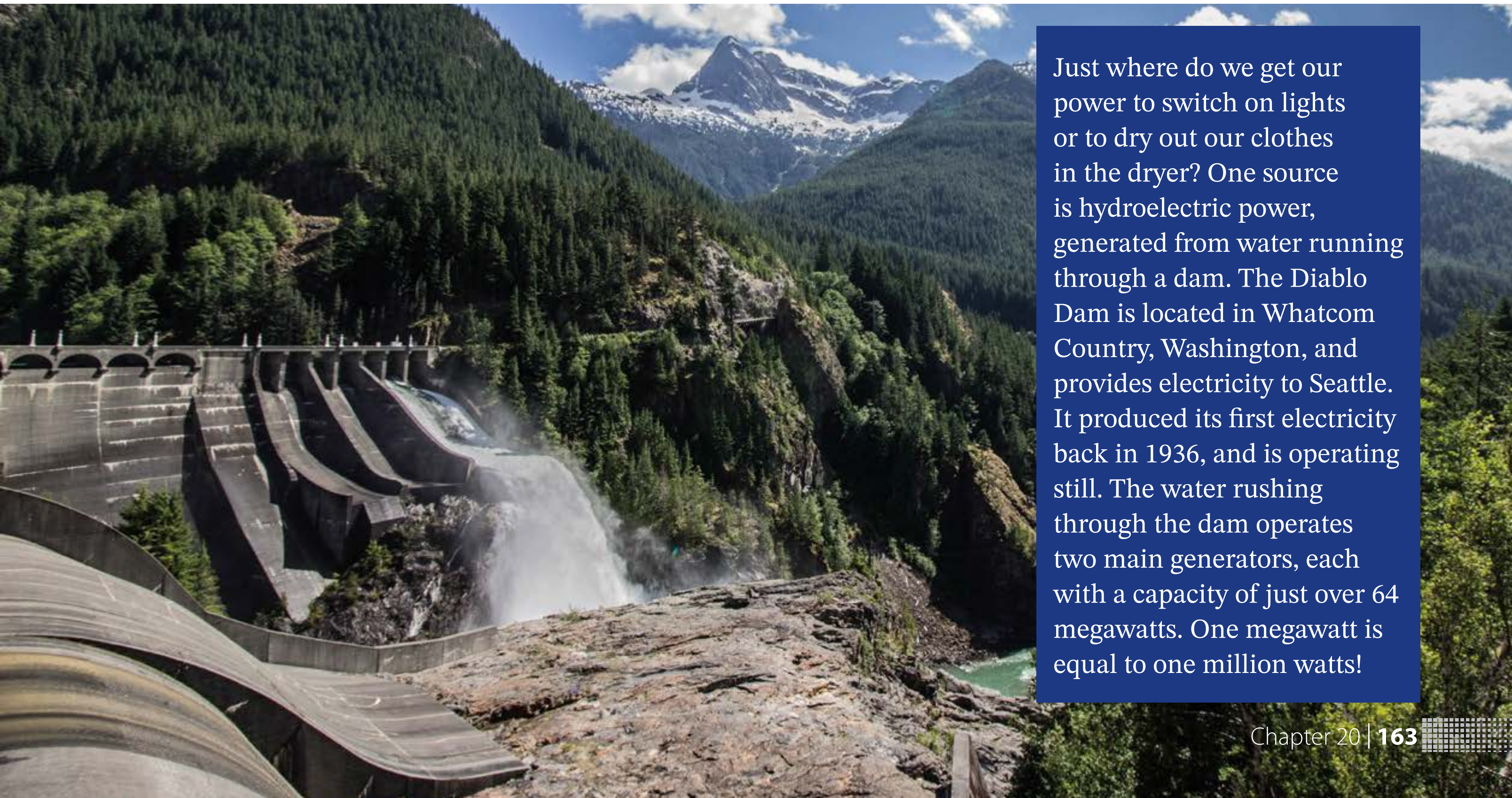
What if you had the dryer on a 110V circuit instead?

$$I = \frac{110V}{25\text{A}} = 4.4\Omega$$

$$P = (25\text{A})^2(4.4\text{W}) = 2{,}750 \text{ watts} = 2.75 \text{ kW}$$

Using about half the power, it would probably take twice as long to dry the clothes. Power is the rate that energy is being used, so if half the power is being used, it would take twice as long to use the same amount of energy.

Electricity can be a blessing and a curse. It can power machines and convey information rapidly over great distances. It is an example of how exact and efficient God's creation is in spite of the fall. It does not take much energy for an electric current to travel large distances. Think of how fast and efficiently information is carried over the internet. On the other hand, generating electricity can harm the environment and has also been the cause of several destructive fires.



Just where do we get our power to switch on lights or to dry out our clothes in the dryer? One source is hydroelectric power, generated from water running through a dam. The Diablo Dam is located in Whatcom Country, Washington, and provides electricity to Seattle. It produced its first electricity back in 1936, and is operating still. The water rushing through the dam operates two main generators, each with a capacity of just over 64 megawatts. One megawatt is equal to one million watts!

Electric Circuits

REQUIRED MATERIALS

- Insulated copper wire
- Switch
- 3.7 V bulbs (2)
- Bulb holder (2)
- AA battery holder
- AA batteries (2)
- Multimeter

Introduction

This lab exercise involves 2 AA batteries and one or two bulbs in a circuit which is controlled by a switch. When the switch is open, no current can flow through the circuit because there is a break in the connections. When the switch is closed, the current can flow through the circuit. The voltage is measured from one end of a bulb to the other. This is a **voltage drop** because some of the electrical potential energy is used by the bulb. It is like a book falling part way to the floor using part of its potential energy.

When measuring the voltage drop, a voltmeter is connected in parallel to the bulb because the difference in voltage between the two points is being measured. When measuring the current, the ammeter is placed in line with the current so that the current flows through it the same way that you would place a flow meter in a stream to measure the rate of water flow.

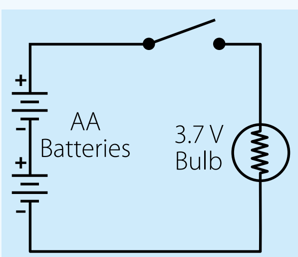


Diagram 20.1

If you are curious, you can measure the voltage across the batteries. If you measure it when the switch is open, you should get 3V ($1\frac{1}{2}$V + $1\frac{1}{2}$V). This is a property of the chemical reactions in the batteries. If you measure the voltage across the batteries when the switch is closed, it should read a bit less than 3V (maybe around $2\frac{1}{2}$V) because as the current flows through the batteries there is some internal resistance.

In any electrical circuit, the current flow is indicated from the positive pole of a battery to a negative pole of a battery. The flow of electrons, however, is in the opposite direction — from the negative pole (where there is an excess of negative electrons) of the battery to the positive pole.

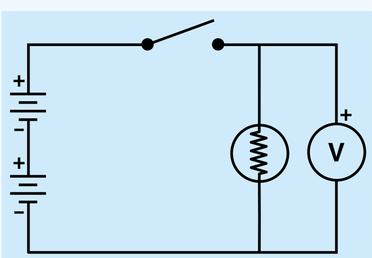


Diagram 20.2

Purpose

This lab exercise is to provide experience setting up an electrical circuit with bulbs in series and parallel and measuring their voltage drops and current.

Procedure

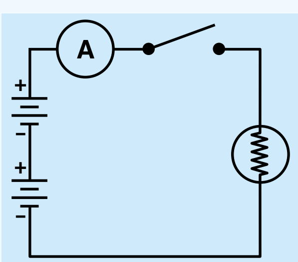


Diagram 20.3

observe

1. Using lengths of the insulated copper wire (at least 1 to 2 inches long per section), connect the battery holder with 2 AA batteries, the switch, and a bulb holder with a 3.7V bulb. Connect the wires to the screws on each of the different parts (*Diagram L20.1*).

   Test your circuit by closing the switch to be sure that the bulb shines. Then open the switch so that you do not drain the batteries.

For all of these procedures, attach the red wire of the multimeter to the outlet on the meter marked $V\Omega mA$, and the black wire to the outlet on the meter marked COM. When testing the circuit, the red lead from the meter is closest to the positive poles of the batteries.

question

2. As you work through this lab, describe what you are doing and your results to your teacher. Record your results in your report. Describe the direction of current flow and the direction of electron flow.

3. Disconnect the wire connected to the bulb holder and connect the red lead to the wire going to the battery holder and the black lead to the bulb holder. Set the dial on the meter to 200*m*A (the maximum reading on the meter is 200 *m*A or 0.2 A). If the reading on the meter exceeds 200 *m*A, set the dial to 10 A. This means that the maximum reading is 10 A. Close the switch and read the current from the meter. Record this value. Open the switch (*Diagram L20.2*).

research/hypothesis

4. Remove the multimeter from the circuit and restore the wire connections as before. Turn the dial on the multimeter to DCV 20 V. Place the red lead of the multimeter on the side of the bulb holder close to the positive poles of the batteries and the black lead on the opposite side of the bulb holder. Close the switch so that the bulb glows and read the voltage from the multimeter. Record this value. Open the switch (*Diagram L20.3*).

experiment

5. Add a second bulb holder with a bulb into the circuit in series with the first bulb as shown in this diagram (*Diagram L20.4*).

6. Repeat step 2 with 2 bulbs in series instead of 1 bulb. Record the value of the current with two bulbs (*Diagram L20.5*).

7. Repeat step 3 with 2 bulbs in series instead of 1 bulb. Measure the voltage drop of each bulb separately and together (*Diagram L20.6*).

8. Rewire the circuit so that you have 2 bulbs in parallel instead of series (*Diagram L20.7*).

9. Repeat step 2 with 2 bulbs in parallel instead of 1 bulb. Record the value of the current with two bulbs connected in parallel (*Diagram L20.8*).

10. Repeat step 3 with 2 bulbs in parallel instead of 1 bulb. Measure the voltage drop of each bulb separately (*Diagram L20.9*).

analyze

11. From the current and voltage of the circuit in step 2, calculate the resistance of the bulb. Use Ohm's Law $R = \frac{V}{I}$. Show your work in your report.

12. From your results in this lab exercise, describe the meaning of the terms *current*, *voltage*, and *resistance*. How did placing the bulbs in series affect the current?

conclusion

13. How did placing the bulbs in parallel affect the current?

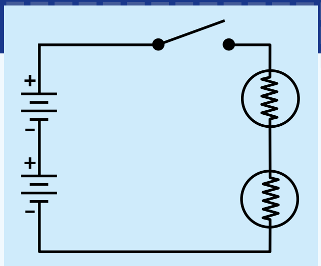


Diagram 20.4

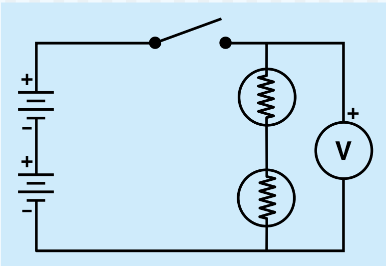


Diagram 20.5

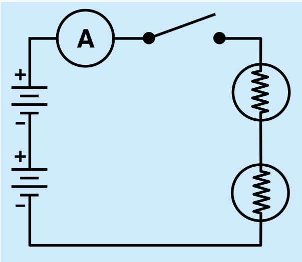


Diagram 20.6

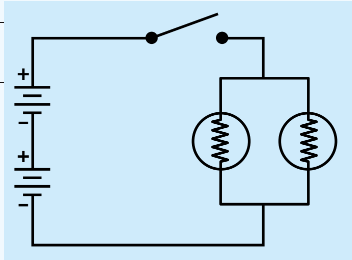


Diagram 20.7

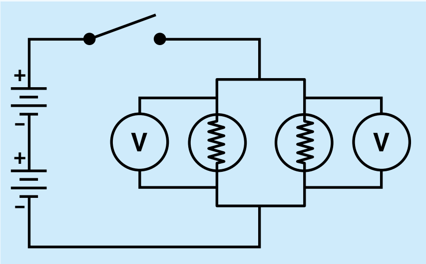


Diagram 20.8

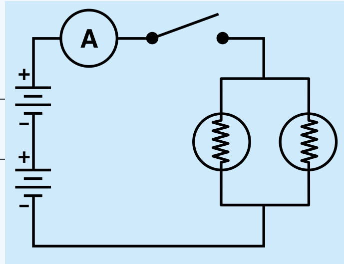


Diagram 20.9