ASTROPHYSICS: AN INTRODUCTION

The word astronomy comes from two Greek words — one that means "star" and the other that means "to arrange." Thus, very literally, the word astronomy means "to arrange the stars." Astronomy is a study of the planets, stars, comets, and other objects found throughout the universe. It measures positions, distances, luminosities, and nature of various objects in space.

This text focuses on what is known as astrophysics. Astrophysics considers what is learned in astronomy, yet goes a little deeper into how the universe began, how it works, and how things like black holes, dark matter, and gravity are used by God to sustain His creation. Astrophysics utilizes the information obtained from physics and chemistry to propose theories behind the origins of objects we know about and discover, as well as their purpose. In this study it will also include discussions on cosmology, which studies the chronology and nature of the universe as a whole.

The study of the planets and stars has a powerful purpose – its purpose is to bring us closer to God. Psalm 19:1 tells us that the heavens above declare God's glory. Psalm 8:2-8 goes further in pointing out that even though we are very tiny compared to the universe, we are very special in God's sight. Romans 1:18-20 builds upon this, arguing that the world around us demonstrates that God exists, and is very powerful so that men are without excuse.

Most people readily agree that there is much beauty in gazing into the night sky. In this course, you will learn a bit about how chemistry and physics play a part in astronomical studies. But if one's understanding ends there, then one has entirely missed the point. God has created a wondrous creation, but sin has tainted that world. The study of the universe ought to bring people to understand these facts and bring them to repentance and salvation through God's only Son, Jesus Christ.

The luminous, hot star Wolf-Rayet 124 (WR 124)

Introduction to Lesson 1

Many of you might think that facts and theories are opposites. It is important to realize facts and theories are two very different kinds of things. We use facts to support or oppose theories. We use theories in all areas of human endeavor. For instance, some schools offer a course in music theory. Music theory is the study of the basics of music, such as meter, timing, pitch, and dynamics. We use all these elements and more to create music. Far from being an untrue statement about music, music theory is a well-established way of studying music. Economists have different theories, or systems of belief, about how the economy works. Different theological systems or different methods of Bible study are theories. The most important aspect of all of these is that they work. A good theory should be useful. The same is true with scientific theories.

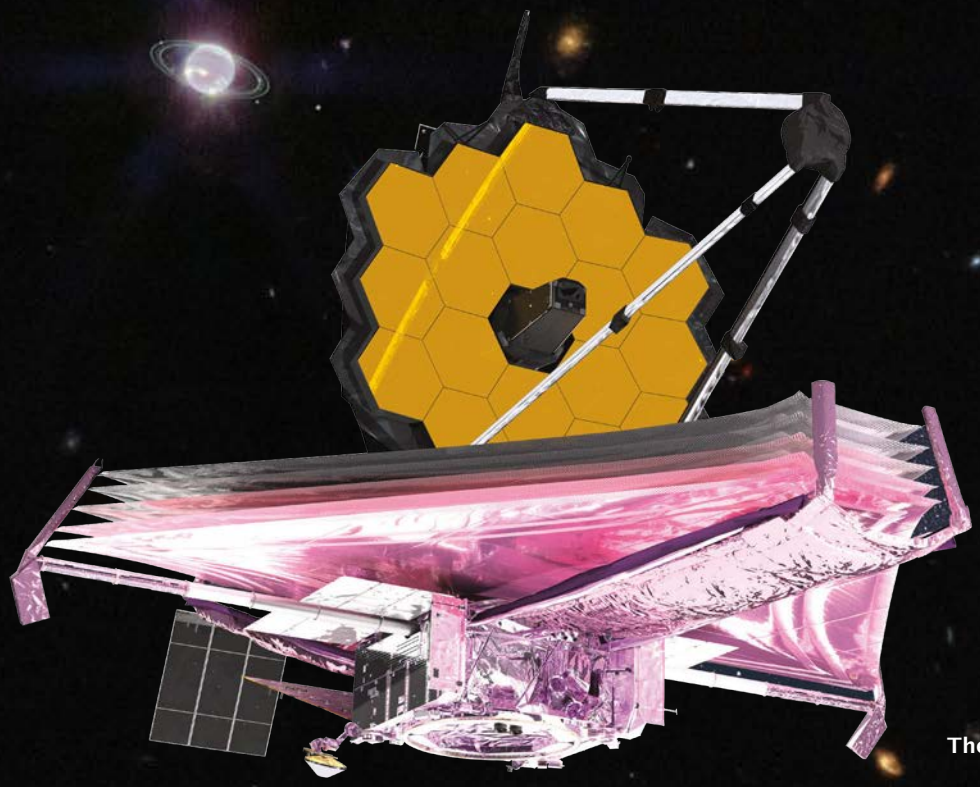
Since this course is intended for upper-level high school grades, you may have varying degrees of experience with science. You should have knowledge of the scientific method. If all of you have had previous science courses, then you may wish to refresh your memory quickly and then move on.

The same is true of scientific notation and significant figures. If you are well versed in these topics, then there is no need to spend much time on it. However, if you are weak in working with numbers scientifically, then you must take the time to cover these topics adequately. Since subsequent lessons do not include a lot of quantitative information and handling of numbers, these topics were relegated to a Feature. However, the lab book does use numbers extensively.

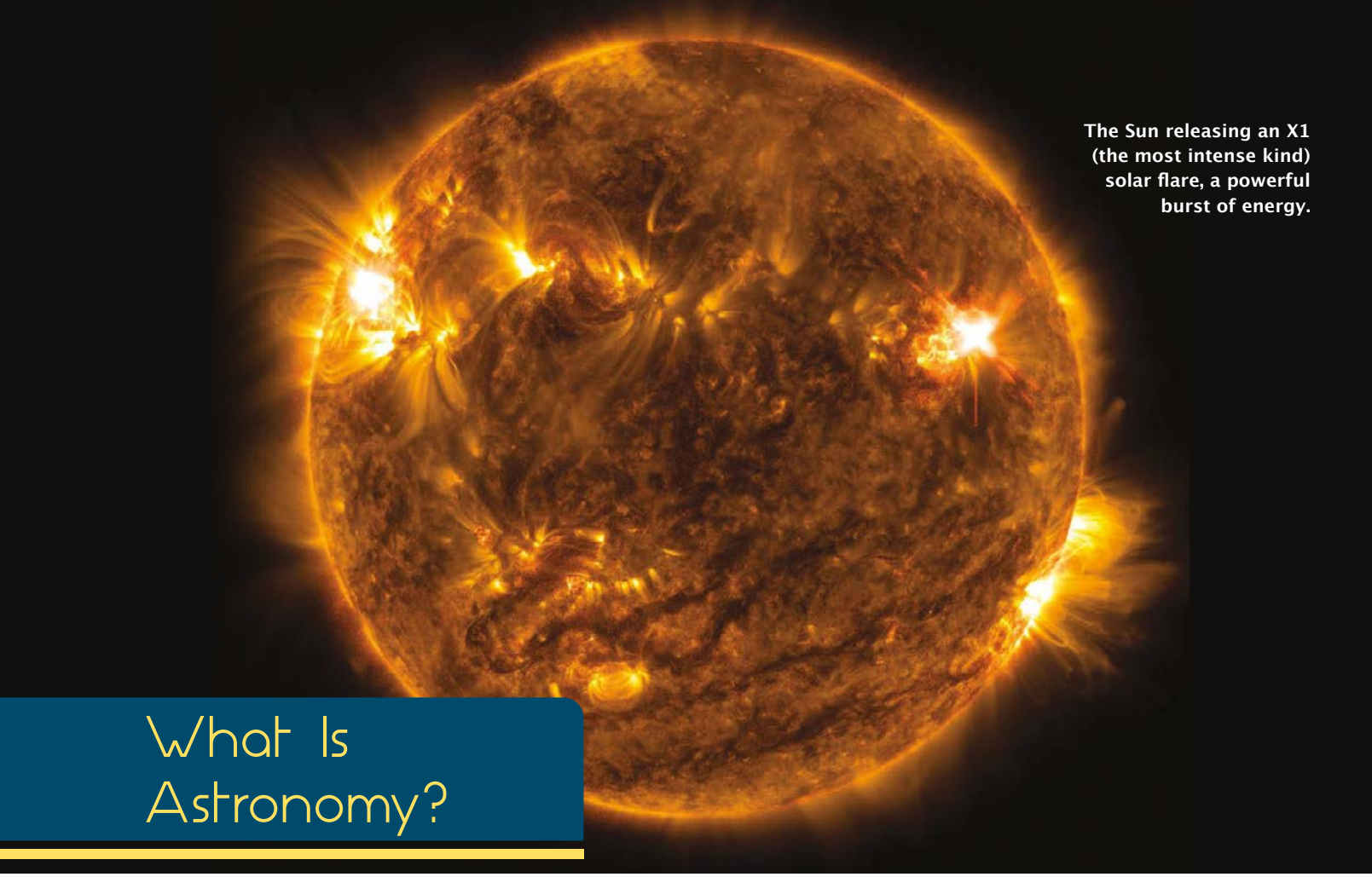
Be aware of what a bias is. Note that biases are not necessarily bad. We should not be ashamed of our biblical bias. Objectivity is not necessarily lost if we have a bias. It is more important that we acknowledge that we have a bias so that we can deal with it accordingly. Those who believe in evolution and naturalism generally deny that they have any bias. This does not allow them to be objective in certain matters.

Worldview: Through the Lens

CREATIONISTS	EVOLUTIONISTS
Hold certain foundational things to be eternally true and hence beyond debate	Hold that truth is relative and changeable by new information or new perspectives
There is a Creator, and He accomplished His creation in the not too-distant past	There is no creator, and the universe has been evolving for billions of years
The belief about origins is based on the Biblical record	The belief about origins is based on philosophical reasoning
Have a bias toward God and the supernatural	Have a bias against the possibility of the supernatural
Use a divine, supernatural explanation of how everything came to be	Use a purely physical, purely natural explanation of how everything came to be
Base understanding in the assumption that God exists and has revealed himself in Scripture	Base understanding in the assumption that the physical world is all that exists



The James Webb Telescope



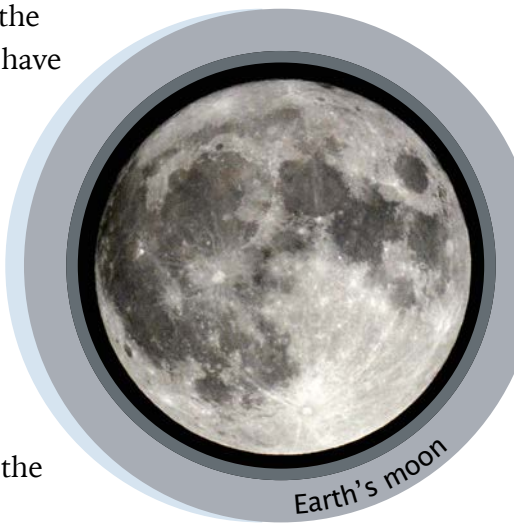
The Sun releasing an X1 (the most intense kind) solar flare, a powerful burst of energy.

What Is Astronomy?

Astronomy: The Oldest Science

The word **astronomy** comes from two Greek words — one that means "star" and the other that means "to arrange." Thus, very literally the word astronomy means "to arrange stars." The arrangement here refers to information about stars, and so more loosely, astronomy means the study of stars. Today we understand that astronomy is more than just the study of stars but includes the study of other objects beyond the earth, such as planets, comets, and asteroids as well.

Astronomy is perhaps the oldest of all sciences. Genesis 1:1 tells us that God created the heavens, along with the earth, in the beginning. God made the sun, moon, and stars on the fourth day of creation. According to Genesis 1:16, the greater light (the sun) was created to rule the day, and the lesser light (the moon) was created to rule the night. Besides being separators of night and day, Genesis 1:14–16 gives three other purposes for lights in the firmament (expanse). One purpose is to provide light upon the earth, another is to be for signs, and the third is to mark the passage of time and seasons. It is conceivable that just as Adam named the animals, he may have named some of the astronomical bodies as well.



The first purpose of the lights in the heavens, to provide light, is obvious. During the

day, we have the sun that allows us to see well enough to go about our daily lives. Historically, people have been less active at night because artificial means of light, such as candles, were not too bright. The invention of electric lights made it possible for us to produce well-lit conditions at night so that our activities need not cease after sundown. In the past, people relied more upon natural light. For instance, people often used a bright full moon to work after sunset. When we discuss the phases of the moon, we will learn that farmers used the harvest moon to help them gather their crops. A full moon at the first Passover allowed the Hebrews to travel at night. Even when the moon is not in the sky, the light of the stars can give enough light for us to see our way, albeit poorly. Unfortunately, with our many bright lights today, few people now ever get the opportunity to see the night sky in the splendor that our ancestors did.

Another purpose for heavenly bodies is the marking of seasons and time. Astronomical motions have always served as the definitions of time measurements. The day is the length of time that it takes the earth to spin. We define the month as the orbital period of the moon around the earth. The period that the earth requires to orbit the sun is the year. While modern definitions of time passage have changed from this, the astronomical basis is still there. If we watch the skies, the motions that are the bases of time measurement are obvious. For example, the stars that are visible at night vary by season. If we watch how the stars change, we can anticipate the coming of each season. This time reckoning is very important in determining when one should plant crops. Ancient societies were aware that sunlight, warmth, and, in some cases, seasonal rains were necessary to grow crops successfully. The ancients knew that not only did the sun return each day, but that the seasons returned each year at regular intervals. From careful observations, they realized that they could accurately anticipate these events.

The ancients also realized that they could predict other important events as well. An example of this was the annual flooding of the Nile River in Egypt. This was an important event to anticipate, because this was the time in which planting should occur. The Egyptians did not know that torrential rains far to the south caused

the flooding. However, they did learn that the annual first rising of the star Sirius with the sun in the morning always happened shortly before the Nile flooding occurred each year. They were able to use this observation to predict when the Nile would flood. Another name for Sirius is "the Dog Star," and so the ancient Egyptians came to call this time of year, "dog days," a custom continued even today.

However, in the past many people lost sight of the true purpose of the stars and began to worship the "creature more than the Creator" (Romans 1:25). As men forgot the true God, they substituted various pagan ones. Since most ancients did not know what caused the daily return of the sun or the yearly return of the seasons or the annual flooding of the Nile, we can understand why people began to believe that the signs of coming events were the causes of the events. If the signs in the sky were the cause of seasonal events, then it follows that people might be able to influence those events by appeasing those signs. Thus, the sun, the moon, the stars, and the wandering stars, or planets, became objects of worship and honor.

Psalm 19:1 reveals that a purpose for the heavens is that they declare God's glory.

Astrology

The ancient belief that astronomical bodies affect our lives and our destinies quickly developed into a religion called **astrology**. Astrology is a pagan religion that is opposed to Christianity, and there are biblical passages that warn against it (Deuteronomy 4:19, 17:3; Isaiah 47:13–14). Although people today do not seem to practice the religion of astrology, it is more prevalent than many realize. Most newspapers carry horoscopes, and many bookstores have larger sections on astrology and the occult than they do for science. Many gardeners plant by the "signs" published in farmers' almanacs, never realizing the astrological basis.

For most of history, astronomy and astrology were closely related, and in many cultures, they were one and the same. Having a lunar calendar, the Hebrews obviously made astronomical observations, so they would have had to take extraordinary steps to avoid lapsing into astrology. Other societies had no such scruples, and so they intertwined reckoning of time and of seasons with the casting of horoscopes and pagan worship.

With the rise of modern science in the 17th century, astronomy (a science) and astrology (a false religion) distinctly split. The word *astrology* comes from two Greek words, *aster* and *logos*. The first word means, "star," and the second literally means "word." We have loosened the word *logos* to mean "knowledge." Many other sciences use the same root. Examples include biology (the study of life) and geology (the study of the earth). The similarity of the word *astrology* to the names of other sciences such as *biology* and *geology* and its similarity to the word *astronomy* are most confusing. Even many educated people have difficulty remembering which is which, and probably every astronomer has been called an astrologer on more than one occasion. Many people enroll in astronomy courses expecting to learn about astrology. You should commit the difference to memory.

Scriptural Perspective

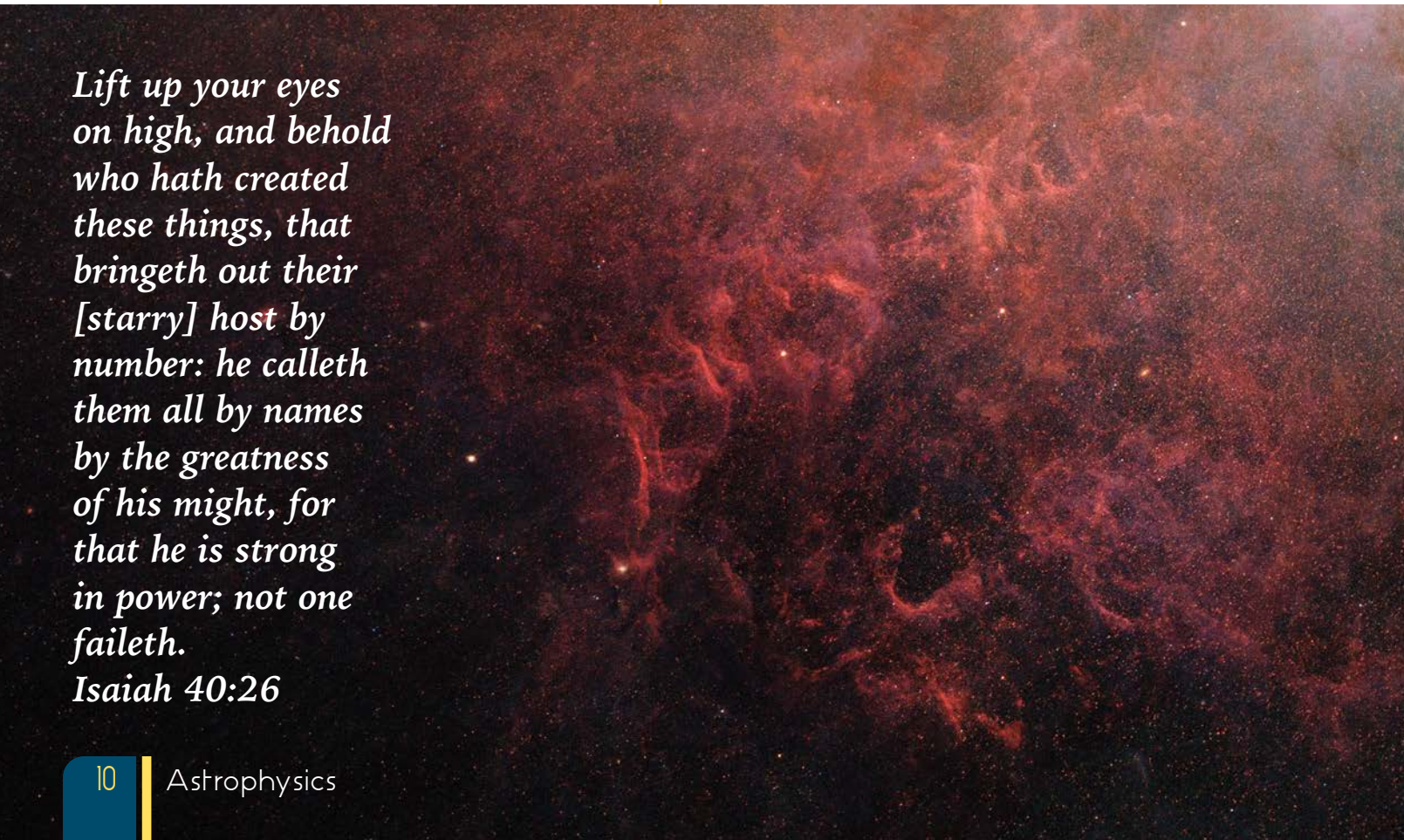
Astronomy is the science that the Bible most explicitly mentions. Psalm 19:1 reveals that a purpose for the heavens is that they declare God's

glory. Or consider Psalm 147:4, which states that God knows the number of the stars and calls them all by name. It is impossible for man to count the stars, but conservative estimates place their total at more than several hundred billion billion. It is obvious that only an omnipotent and omniscient God could create and then know how many stars there are, but on top of that, He has unique names for each one!

Isaiah 40:26 builds upon this information to challenge us, "Lift up your eyes on high, and behold who hath created these things, that bringeth out their [starry] host by number: he calleth them all by names by the greatness of his might, for that he is strong in power; not one faileth." This sentiment is echoed in Romans 1:19–20 where it declares that the creation itself reveals God's existence and power, so that sinful men are without excuse. With the tremendous advances we are making in astronomy today, the evidence of God's power in creation has never been clearer.

Natural revelation is the concept that the world shows that God exists. Sometimes we refer to natural revelation as general revelation. While most astronomers probably believe that there is a God, it is sad that few of them know the true God personally. This underscores the fact that natural revelation alone is inadequate to bring one to Jesus. All that Psalm 19:1–6 and Romans 1:19–20 tell us is that there is a God and that He is very powerful. This is very limited information about the Creator. All that natural revelation can do is cause us to search for more information. Of course, we find that additional information in the Bible. **Special revelation** is the revealed truth of the Bible (2 Timothy 3:16–17).

Some Christians teach the **dual revelation** theory. This is the belief that natural revelation and special revelation are parallel, nearly equal, ways of finding God's truth. Those who teach this argue that all truth is God's truth and as such all truth must agree. Another way to state the dual revelation theory is that the book of nature



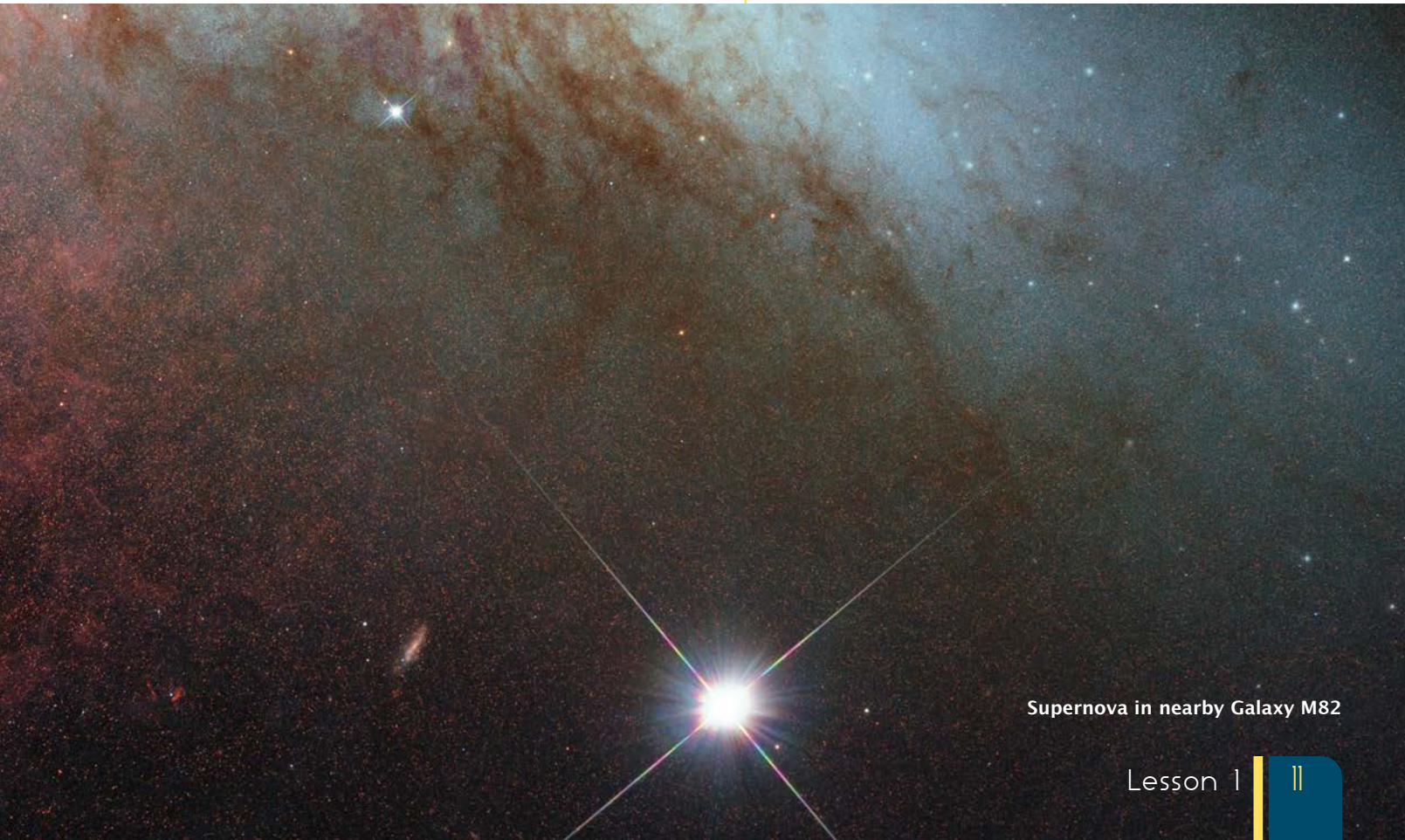
Lift up your eyes on high, and behold who hath created these things, that bringeth out their [starry] host by number: he calleth them all by names by the greatness of his might, for that he is strong in power; not one faileth.
Isaiah 40:26

and the Bible must agree. The danger here is in elevating natural revelation to the same level as the Bible. Romans 1:19–20 and other passages do not support this.

Proponents of the dual revelation theory often engage in a very subtle shift. They begin by talking about the book of nature, but then eventually substitute science for nature. Science is not nature, but instead it is the man-made method of studying the natural world. Since science is a man-made process practiced by humans, it is subject to the same failings that people have. Scientists frequently make errors in judgment. Scientists must entertain new ideas as we perform new experiments and new facts become known. Science is a very changeable thing, but the Word of God never changes.

Another problem with the dual revelation theory is that we know what the facts of the Bible are, but what are the facts of nature? The facts of the Bible are in its 66 books, and that information does not change. However, the facts of nature, as determined by science, do change. There are many things that scientists today believe to be true, but that does not make those things true. We can never be sure just what scientific facts will survive further scrutiny, but we can be sure that the Bible will not change.

By their actions, many of those who believe the dual revelation theory hold science in higher regard than the Bible. They frequently reinterpret the Bible to fit the latest ideas of science. This has it completely backward from a true Christian worldview. The Christian must hold to the truth of the Bible. We must reinterpret through Scripture any area of human endeavor that is contrary to what the Bible says. In this textbook, we will take the proper biblical approach, which will mean that this book will disagree with modern astronomy on some points.



Supernova in nearby Galaxy M82

What is Science, and How is Science Done?

Science is defined several different ways. The definition adopted by this textbook is science is the study of the natural world using the five senses. Many sources now say that science is the search for natural explanations. This definition may sound similar to the first definition, but it is very different. Hidden in this second definition is the assumption of **naturalism**, the belief that the natural world is all that exists. Therefore, this definition excludes consideration that there may be a God. A scientist need not believe in God, but a good scientist will at least hold out the existence of God as a possibility. Otherwise, the scientist eliminates from consideration a logical possibility before he even begins his work. This amounts to a bias.

The late secular astronomer, Carl Sagan

The late astronomer Carl Sagan expressed the assumption of naturalism very well. In 1980, Sagan hosted a popular PBS television series called "Cosmos: A Personal Journey," accompanied by a book with the shorter title *Cosmos*. Both the TV series and the book began with the statement, "The cosmos is all there is, all there ever was, and all there ever will be." Many people hearing or reading that statement think it was a profound scientific statement. However, that statement contains no science at all. Rather, it is a bold statement of Sagan's philosophy. The cosmos is another word for the universe, the totality of physical existence. Since God is not physical, then with this statement Sagan was denying God's existence.

Sagan could not make this statement with any certainty. How could Sagan have known that the cosmos is all there is? The only way Sagan could have known this would have been to get outside of the physical realm and seen that there is nothing outside the physical realm. How could Sagan have known the cosmos is all there ever was? He would have needed to have gotten outside the physical realm throughout all time past and seen that there was nothing there. How could Sagan have known that the cosmos is all there ever will be? He would have needed to have gotten outside the physical realm at all future times and seen that there was nothing there. If Sagan could have done all this, he would have been God. But Sagan's statement is a denial that God exists. Hence, Sagan's quote was not a scientific statement but rather an assertion of his philosophy.

In other science classes you have probably learned about "the **scientific method**." The first step in the scientific method is to define a problem or question to solve. Examples of possible questions might be "What is the source of the sun's energy?" or "What is the composition of the Jovian planets?" The next step in the scientific method is to do preliminary research of relevant literature to find if anyone else has already worked on the problem. You may find that the question has already been successfully answered, in which further investigation may not be necessary. On the other hand, you may find that we lack enough data or that the question is too complex for there to be an answer satisfactory to everyone. Any information that you gather could guide you to aspects of the problem that remain unsolved or help you avoid mistakes that others previously may have made.

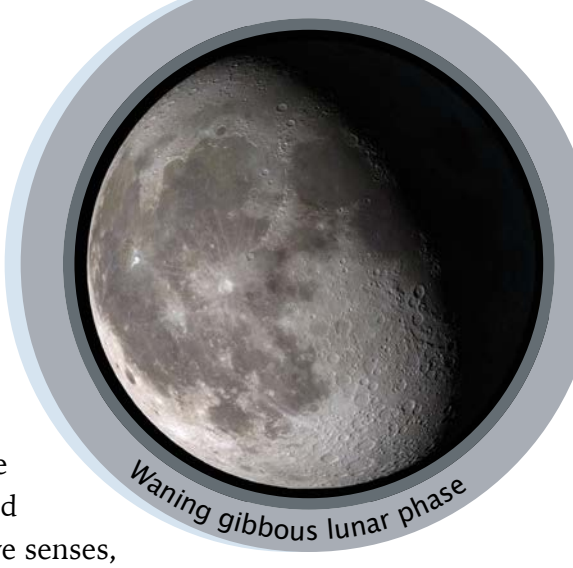
Once you think that you adequately understand the problem, you may formulate

a **hypothesis** to explain what you observe. Sometimes a hypothesis is defined as an educated guess. Notice that an educated guess is not a wild guess. You must have some information for your hypothesis to explain. Furthermore, your hypothesis must be reasonable.

Next, you must develop a strategy to collect data, or information, that will either verify or contradict your hypothesis. In most sciences, this means planning an experiment, but astronomy is different from other sciences in that it is largely an observational rather than an experimental science. Except for meteorites, rocks returned from the moon, or the probes on the surface of Mars, we have no astronomical bodies on which we can perform experiments. Given the large sizes and great distances of stars, how can we expect to do something like a dissection? Instead, we must position ourselves in a good location and wait for astronomical bodies to reveal themselves. This puts the astronomer at a disadvantage when compared to other scientists, but the rest of the basics of the scientific method hold.

Once we conduct an experiment or observation, we must organize and analyze the data to make sense of it. We may find that our hypothesis correctly predicted the outcome of the experiment or observation. If so, we say that we verified our hypothesis, and we have some confidence that our hypothesis is correct. However, we may find that our hypothesis or certain aspects of it may be incorrect, and so this is a time to refine the hypothesis. Then we can make new predictions and plan future experiments. As we test and improve our hypothesis through this repeated process, we have increased confidence that our hypothesis is true.

Unfortunately, this very basic cookbook approach to science is rarely followed by scientists. As it turns out, science is not that simple. Science is more about an empirical approach to studying the natural world. As we study the natural world using the five senses, we can draw inferences about how the natural world works. In this course, we will see how inferences are drawn to reach conclusions about how the astronomical world works, inferences that cannot be tested by the very simplified cookbook "scientific method" that is often taught in schools. Examples of this include the cause of lunar phases and the cause of eclipses. But this does not mean that the conclusions we reach in astronomy are not scientific. Again, in doing science, scientists rarely follow this very simplified "scientific method." Why do schools teach this very simplified approach to science? Much of what you learn in school is very simplified. Often the simplification is so great as to make it wrong.


Waning gibbous lunar phase

In your study of science, you certainly have encountered the term theory. Most people misunderstand what a theory is. Many people think that a theory is some untested idea, often in contrast to established facts. From time to time, someone may dismiss an idea by stating, "That's just a theory." An illustration of this thinking is from an apocryphal letter to the editor printed in *Superman* comic book many years ago. The supposed writer of the letter objected to a story in a previous issue in which Superman had flown at the speed of light or faster. The letter writer stated that according to Einstein's theory of relativity that was impossible. A response states, "What Einstein said was theory, what Superman flies is

fact." However, this is not what a theory is at all. A theory is a well-formulated statement of how some aspect of the world occurs which has been tested and refined in numerous experiments. Through the process of science, some clear picture (theory) begins to emerge, but it is always subject to refinement and to possible discarding. The history of science is littered with many discarded ideas, so one can never be sure from a scientific standpoint that any theory is "true."

This tentative and changing nature of science has caused critics of creation to argue that one cannot be a creationist and a scientist. This is because creationists hold certain things forever to be true and hence beyond debate. Among these assumptions is that there is a Creator and that He accomplished His creation in the not-too-distant past. Evolutionists sometimes ask if there is any evidence that they could present to dissuade the creationist from that view. Since the answer to that is no, creationists would appear to have closed minds on this issue and hence do not practice the tentative and changing nature that science is supposed to have.

However, we can turn this argument around. Is there any evidence that we could present that would convince an evolutionist that evolution is not true or that creation is true? The honest answer would be no, revealing that belief in evolution is no more or less scientific than belief in creation is. Consider the Carl Sagan statement that amounted to a denial of God's existence. The denial of God is just as much a non-negotiable position for many scientists. Sagan also addressed evolution, stating that evolution is a fact. It does not appear that Sagan changed his mind about this before his death. The personal tragedy is that this belief resulted in a Christ-less eternity for Sagan. In this world, it is sad that eminent scientists such as Sagan sometimes fall into the false dichotomy between fact and theory.

This line of reasoning just illustrates that the question of ultimate origins is not a scientific question at all. Science relies upon observation and experiment. The process by which the universe and the world came into existence happened in the past, and without a time machine, we cannot study it. Scientists may offer opinions on past and other non-repeatable processes, but we cannot base such opinions upon purely scientific principles. Thus, the study of origins is philosophical or religious, but it is not scientific.

But perhaps this criticism is too harsh. Many creationists now recognize that science is often used two ways now. The traditional way that science is done is sometimes called "operational science," or "experimental/observational science." This is the study of the natural world as it now exists. However, scientists, including creation scientists, often use scientific principles gleaned from the way the world now exists to speculate what might have happened in the past. This "historical science" or "origin science" has a different set of rules of evidence from operational science.

Investigator comparing shoe indentations with print left at the crime scene

One example of historical science is forensic science. Crime-scene investigators use principles of operational science to infer what might have happened in the past. One cannot directly observe or test what might have happened at the crime scene, but one can reach reasonable conclusions about what likely happened. Another example of historical science is historical geology. Geologists can use what we learn by observing natural processes today to infer what might have happened in the past. Creation geologists use knowledge of sedimentation and erosion to propose theories of how the rock layers of Grand Canyon may have formed and how the canyon may have been carved as a direct result of the flood.

The problem is that people often confuse these two very different ways of doing science. Critics of creationists sometimes say that doubting evolution is like doubting gravity. However, physicists often conduct experiments in the world today to test various theories of gravity. These are not tests of how gravity may have operated in the past, but how gravity works now. On the other hand, one cannot test in the present how evolution might have worked in the past. We must remember that the conclusions of historical/origin science are less certain that experimental/observational science.

Another fair question to ask is, "In constructing a theory or a model (another word for a theory) are we really concerned with 'truth'?" The **heliocentric** theory is the model that the sun is the center of motion and that the earth and the other planets orbit about it (**Figure 1.1**). The **geocentric** theory is the model that the earth is the center, and the sun and planets move around it (**Figure 1.2**). Nearly all people today believe that the heliocentric theory is true. Does that mean that the geocentric model is not useful? No. The terms "sunrise" and "sunset" which everyone uses, are geocentric. A planetarium is a geocentric model of the universe, and most navigation is based upon the geocentric model. Though we do not believe this model to be true, we still use it because it works. See **Feature 1.1** for more discussion about the geocentric theory.

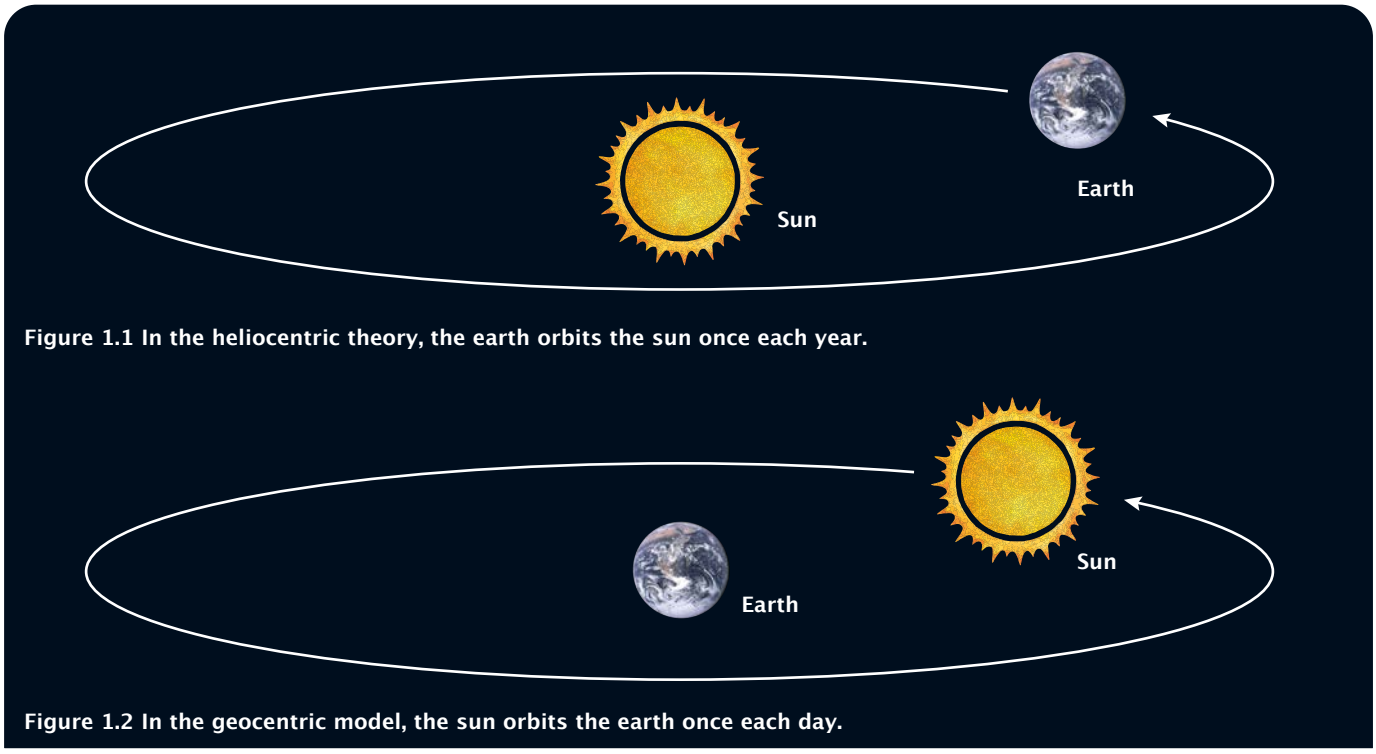


Figure 1.1 In the heliocentric theory, the earth orbits the sun once each year.

Figure 1.2 In the geocentric model, the sun orbits the earth once each day.

FEATURE 1.1

GEOCENTRISM AND CREATION

Until about four centuries ago, most people believed that the earth did not move. The motions that we see in astronomical bodies were explained by those bodies moving around the earth. We call this geocentrism, meaning the earth is the center of everything. Geocentrism reached its high point in the early second century A.D., with publication of the Ptolemaic model. The Ptolemaic model remained the dominant cosmology for 15 centuries. During the Middle Ages, the Roman Catholic Church came to interpret the Bible in terms of the Ptolemaic model. However, four centuries ago most people abandoned the Ptolemaic model in favor of the heliocentric theory, the belief that the earth is one of several planets that orbit the sun. The heliocentric model has been the dominant cosmology ever since. We will discuss this history of geocentrism and heliocentrism in more detail in lesson 3.

Despite the widespread acceptance of heliocentrism over the past four centuries, recent decades have seen a return to geocentrism among some Christians. However, the version of the geocentric theory that modern geocentrists believe is different from the Ptolemaic model, the theory that the ancients followed. We can trace the modern geocentric theory to a 16th century Danish astronomer named Tycho Brahe. In the Tychonic model most of the things in the universe orbit the sun, and the sun in turn orbits the earth each day.

Much of the support for the Tychonic model comes from a very literal interpretation of biblical passages. Examples include Joshua 10:12–13, which records that the sun (and not the earth) stood still, and Psalm 104:5, which states that the foundation of the earth shall not be moved. Most people would conclude that we ought to take the former passage in a phenomenological sense, that is, it is in the language of what we observe. Likewise, many people understand that the latter passage ought to be taken figuratively at least in part.

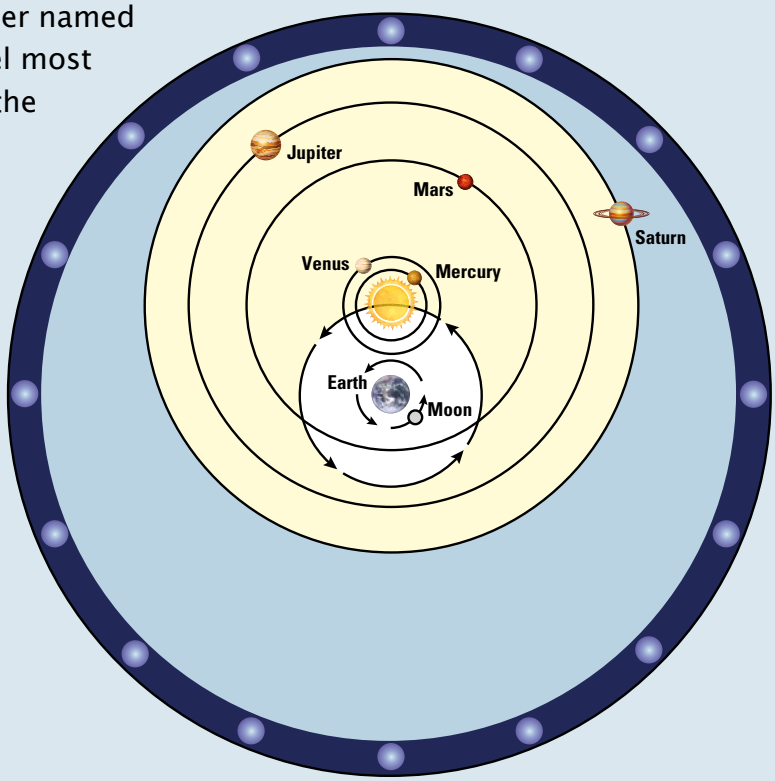
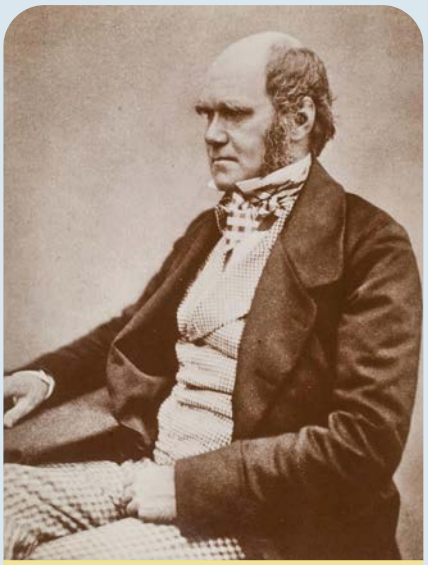


Diagram depicting the Tychonian geocentric system. The moon, sun, and the fixed stars revolve around the Earth, while Mercury, Venus, Mars, Jupiter, and Saturn revolve around the sun. The inferior planets (Mercury and Venus) orbit the sun more closely than the sun orbits the earth, so they always appear near the sun in the sky. The superior planets (Mars, Jupiter, and Saturn) orbit the sun farther than the sun orbits the earth, so they can appear anywhere in the sky.

Geocentricists will have no part of this, claiming that any who so interpret these passages are guilty of not taking the Bible seriously.



Charles Darwin

Geocentrists have found some obscure physics experiments to give scientific support for their theory. They correctly point out that the heliocentric theory gained nearly universal acceptance in the 17th century, despite that there was no direct experimental evidence of the theory until the 18th century. Of course, there has been additional evidence since then. Why did most people conclude that the heliocentric theory was true before there was direct evidence for it? The main reason that the heliocentric theory became accepted was that it offered a much simpler explanation than the competing theory of the day. As discussed in this lesson, it is a general rule in science and in logic that when given a choice between two otherwise equal theories, the simpler one is the correct one (Occam's razor).

Creationists believe that the theory of evolution is a great attack upon God's Word in that it brings into question the authority of Scripture in the first Chapters of Genesis. This attack is usually traced to the 19th century, particularly to the publication of Darwin's *Origin of Species* in 1859. But the roots go back a bit earlier. Prior to Darwin, geologists of the late 18th century had argued for geological evolution and millions of years. However, geocentrists believe that the root of the problem began much earlier with the adoption of the heliocentric theory. They argue that the acceptance of the heliocentric theory attacked scriptural integrity and laid the groundwork for the later assault of evolution.

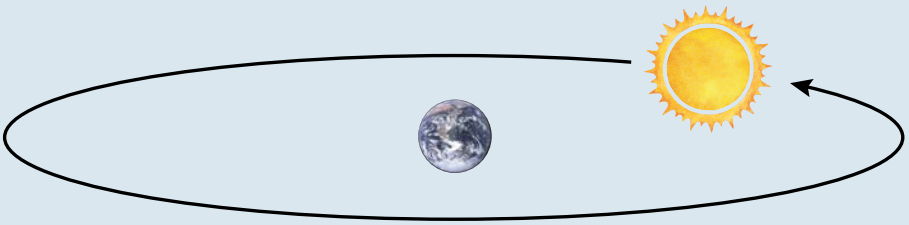


Diagram of the geocentric theory.

Those who support the geocentric theory insist that their theory should prevail unless others can prove the heliocentric theory to their satisfaction. Science does not work this way. As challengers to the accepted idea of the day, the geocentrists must make their case. While we may admire their commitment to scriptural integrity, their condescending attitude toward those who disagree with their extreme understanding of a few passages makes it difficult for others to work with these people.

It is the opinion of the author of this textbook that the heliocentric theory is correct and poses no danger to biblical Christianity. Therefore, throughout this textbook we will assume that the heliocentric theory is true.

Limitations of Science

In an earlier section, we saw that science is a product of human beings and so is subject to the same limitations that people have. One limitation is fallibility. That is, we make mistakes. We make errors in measurement, judgment, and reasoning. If this were not enough, science suffers from other problems as well. We have incomplete knowledge. We can never be sure whether we may find new data that contradicts our current theories.

Another problem stems from the way in which science works. In explaining some phenomenon, we select a hypothesis that fits the data. However, there could be many different hypotheses that could equally explain our observations, so how do we know that we have found the correct one? A good hypothesis will allow us to make predictions of the outcomes of experiments. As we conduct various experiments, either we gain confidence in our hypothesis or we replace or alter our hypothesis. As discussed earlier, this can lead to the development of a theory. We hope that the process of refinement through predictions and experimentation will lead us to the correct explanation. We must realize, however, that competing theories may equally explain the data. Usually, we will be aware of only one theory at a time, so it is entirely possible that we have concentrated on an incorrect theory while the correct one remains unknown to us. Therefore, repeated experimentation is very important. If we have developed an incorrect theory, we hope that some future experiment will tell us that we have.

Another limitation of science is that all people have biases. A bias is a preconception or prejudice. ... The bias of this textbook is that God exists, He created and interacts with this world, and that He has revealed himself through the Bible.

Another limitation of science is that all people have biases. A **bias** is a preconception or prejudice. One bias that all scientists have is that the natural world is understandable. If we believed that the natural world was not understandable, we would not spend any time studying it in order to make sense of it. Another bias that all scientists have is the assumption that the world is simple. When confronted with two competing explanations of some phenomenon, one simple and one complicated, we usually choose the simple one as the correct explanation. (This principle is known as Occam's razor, named for William of Ockham, an early 14th-century philosopher and theologian.)

William of Ockham (1285–1347)

Of course, it is impossible for a person to be unbiased. It is obvious that a bias can be harmful. If we close our minds to certain possibilities, then that could prevent us from considering the correct theory. However, not all biases are bad. The two biases just mentioned make science possible — without them science could not exist. It is important that we acknowledge that we have biases and deal with them accordingly. It is not a question of whether we have biases, but a question of what our biases are and if we are aware of our biases. If we are aware of our biases, there is some hope that we can compensate for them. But if we are blind to our biases, there is no possibility for making allowances for them.

One very powerful bias present in scientists today is the exclusion of the possibility of the supernatural. This is quite different from the situation when modern science arose four centuries ago. At that time, scientists such as Johannes Kepler pursued their work to the glory of God and freely wrote such opinions in their

Johannes Kepler (1571–1630)

Fossil trilobite imprint in the sediment

work. They viewed their study as thinking God's thoughts after Him. Today, evolution heavily influences science, and has done so for more than a century. Most scientists now assume that everything must have a material explanation, rather than assuming the world is a creation of God.

Astronomy has not escaped the influence of **evolution**. To most people, the mention of evolution brings to mind biological evolution. However, evolution is much broader than that, and it has become the single unifying theme of science to many scientists and science educators. To account for this broad approach of modern evolution, we ought to have a broad definition of evolution. The one that we will use is that evolution is a purely physical, purely natural explanation of how we and our world came to be. Notice that this definition fits biological evolution. It also fits geological, chemical, cosmic, and astronomical evolution.

If evolution were true, then there is no need for a Creator. This does not mean that one cannot believe in both evolution and God, for there are many people who do believe in both. However, belief in evolution ultimately causes one to dismiss God's existence and influence upon the world when developing scientific ideas. This leads to the assumption that the physical world is all that exists. As we have seen earlier, we call

this view of the world naturalism. This means that at its core evolution is an atheistic idea. I repeat that this does not necessarily mean that an evolutionist must be an atheist, or that an evolutionist cannot be a Christian. However, a Christian who believes in evolution fails to see the philosophical foundation of evolution.

The bias of this textbook is that God exists, He created and interacts with this world, and that He has revealed himself through the Bible. Of course, most scientists consider this to be out of the mainstream of modern science. However, for the Christian there can be no other starting point. We will assume that when the Bible and science disagree, it must be science that is in error. Therefore, we will interpret science in the light of Scripture. To do otherwise ultimately leads to science reinterpreting the Bible. This is very dangerous. After all, modern science confidently tells us that a virgin birth and the resurrection of a man who has been profoundly dead for three days are both impossible. If we give more credence to the pronouncements of science on the matter of how the world came to be, why should we not do likewise on these other important Christian doctrines?

Astronomy deals with some of the smallest things (atoms and subatomic particles) and some of the largest things (what is bigger than the universe itself?).

The Use of Numbers

All sciences involve measurements and numbers. However, different sciences use numbers to varying degrees. For instance, physics and chemistry are very quantitative. On the other hand, other sciences, such as the life sciences, are less quantitative. Astronomy is somewhere in between these two extremes. Astronomy deals with some of the smallest things (atoms and subatomic particles) and some of the largest things (what is bigger than the universe itself?). To express such a great range in dimensions it is usually necessary to use scientific notation. You probably are familiar with scientific notation already, but if you are not, you should review the material in **Feature 1.2**. Astronomers also define new units of measure such as the astronomical unit and parsec. We will define these units, as we need them.

Carina Nebula

FEATURE 1.2

SCIENTIFIC NOTATION AND SIGNIFICANT FIGURES

Scientific notation is useful for two reasons. First, in calculations without a calculator the work is much easier. Second, scientific notation lets everyone know how accurately we know the numbers. As an example of the first reason, let us find the distance to the sun in kilometers, given that it is 93,000,000 miles away. A mile is equal to 1.61 kilometers. Working with a piece of paper, many people would write

$$\begin{array}{r} 93{,}000{,}000 \\ \times \quad 1.61 \\ \hline \end{array}$$

and then proceed to include 18 zeroes in doing the long multiplication. Even with a calculator, numbers much larger than this may not fit into the display if the calculator does not have scientific notation.

A much easier way is to write 93,000,000 in scientific notation first. Scientific notation consists of two parts: a number between one and ten, and a multiplier of some power of ten. To get 93,000,000 between one and ten, we must move the decimal point to the left seven places. The movement of the decimal point tells us what power of ten the multiplier must be. So, we write 93,000,000 as 9.3×10^7. For a number less than one, we must move the decimal point to the right, and the power of the multiplier will be negative.

$93{,}000{,}000 \longrightarrow 9.3 \times 10^7$

$149{,}730{,}000 \longrightarrow 1.4973 \times 10^8$

Multiplying 9.3×10^7 by 1.61 is very easy. We could write the second number as 1.61×10^0, because this number was already between one and ten and we did not move the decimal point, and so the exponent of ten is zero. To multiply these two numbers, you multiply the numbers between one and ten, and then you multiply the powers of ten. Notice that you do these two products separately. Therefore, 9.3×1.61 equals 14.973, and $10^7 \times 10^0$ equals 10^7. Recall that when multiplying numbers with exponents, you add the exponents, and when dividing, we subtract the exponents. Therefore, the answer is 14.973×10^7. Notice that this is not in standard form, because 14.973 is greater than ten. We should move the decimal point one digit to the left and increase the exponent by one. Therefore, the final answer is 1.4973×10^8.

The answer 1.4973×10^8 brings up the second purpose of using scientific notation: precision or apparent accuracy. This answer tells us that the sun is 149,730,000 kilometers away, but this answer seems more accurate than the 93,000,000 miles that we started with. How accurate was the figure 93,000,000? Most people would assume that the number is closer to 93,000,000 than it is to 92,000,000 or 94,000,000. If that is the case, then we say that the number has two significant figures. In other words, the zeroes are not significant,

at least concerning the question of accuracy. However, what if we wanted to express the idea that the number is *exactly* 93,000,000? In that case, the zeroes would be significant, but there is no convenient way to express that in the way that we usually write numbers.

Scientific notation allows us unambiguously to convey the accuracy of numbers. All digits in scientific notation are significant. In the above calculation, we wrote 93,000,000 as 9.3×10^7, which has two significant figures. If we wished to indicate that all the zeroes were significant, we would have written the number as 9.3000000×10^7. The way that we wrote that number indicates that all the zeroes are significant, and we say that the number has eight significant figures. Therefore, we could have written the distance to the sun to any number of significant figures by including more or fewer zeroes after the decimal point.

You should see that it is very important how you write a number, because it tells how accurately we know the number. Let us return to our example. We determined that the answer was 1.4973×10^8. Is this written correctly? We multiplied two numbers, 9.3×10^7 and 1.61. The first number had two significant figures while the second had three. Our answer appears to have five significant figures. If this were permissible, it would seem to suggest that we could improve accuracy merely by multiplying numbers together. This is not possible, so we must have overstated the accuracy of our final answer. Since one of the numbers that we multiplied had only two significant figures, our final answer can have no more than that as well. Therefore, we ought to write our final answer as 1.5×10^8. To do this, we must round off our answer. Always make certain that you properly write your numbers to reflect the accuracy.

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