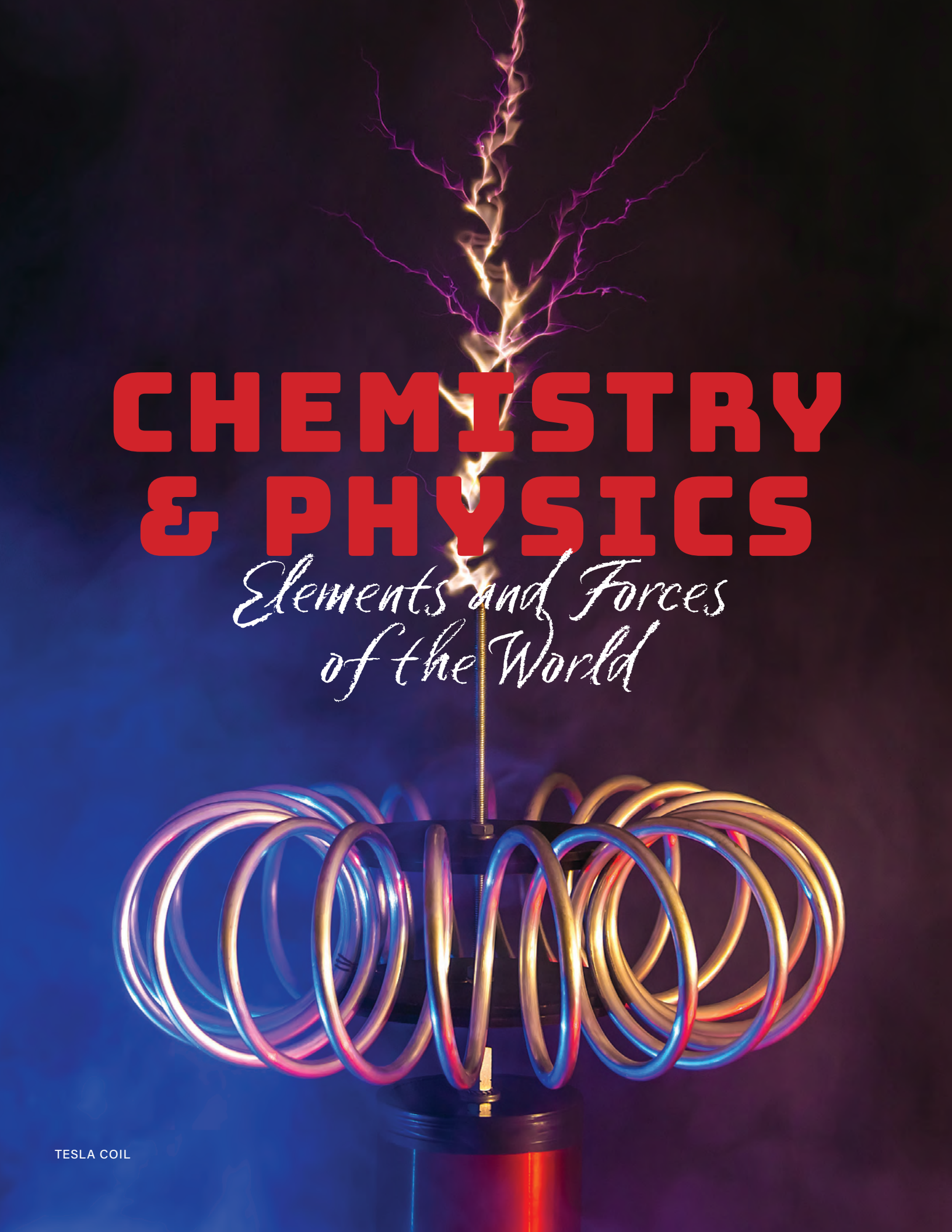
CHEMISTRY & PHYSICS

Elements and Forces of the World



TESLA COIL

Mr. Adolfo Ayala is an Assistant Professor of Chemistry in the department of Biology and Biochemistry at Belmont Abbey College. He has been teaching high school science and math in some capacity for the past six years. He is a gifted teacher and makes learning math and science understandable and enjoyable. He has also taught courses in Chemistry and Engineering at various small colleges throughout the country. Mr. Ayala earned his MS in Chemical Engineering at the University of Notre Dame after completing his BS in Chemical Engineering at the University of Arkansas. He has a hobby of collecting math instruction books, both old and new, so he has a familiarity with a variety of teaching methods and believes that the older methods provide a better foundation for proficiency in the mathematical arts. Mr. Ayala assists his wife in homeschooling their four children. When he has free time, Mr. Ayala enjoys playing tennis, cooking, gardening, and practicing his woodworking skills. You can often find him reading a book on philosophy or theology and drinking a cup of his freshly roasted coffee.

CHEMISTRY EXPERIMENT IN A LABORATORY

CHEMISTRY & PHYSICS

Elements and Forces of the World

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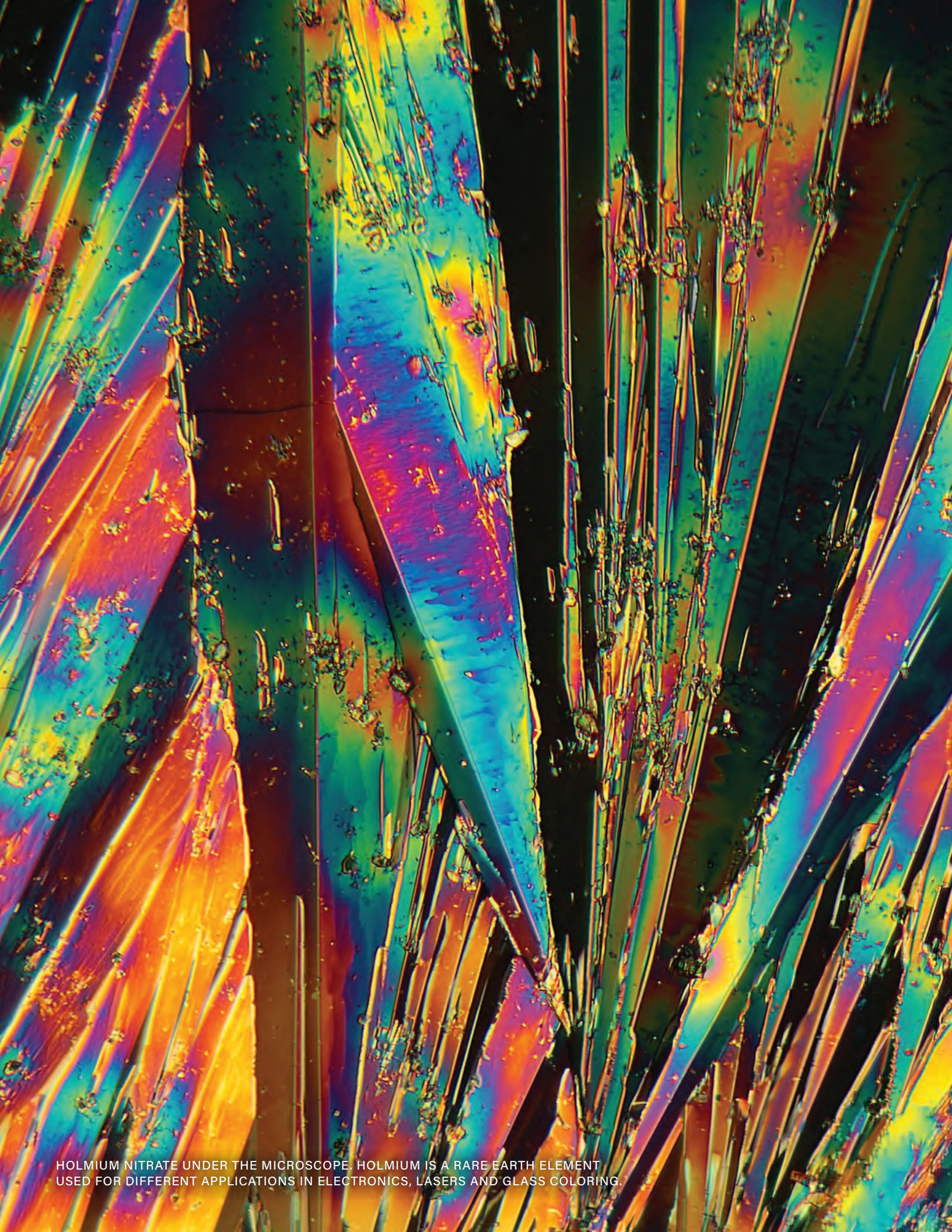
"Where were you when I laid the foundation of the earth?"

–Job 38:4



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CONTENTS

PREFACE

When I think about the scientific study of the natural world, two phrases from the writings of Pope St. John Paul II come to mind:

(1) a rigorous pursuit of truth and

(2) a love of learning.

The first—a rigorous pursuit of truth—describes science and its processes. Scientists make careful observations, design experiments, and collect data to learn more about how the world works. Too often, though, science may seem like something you do in a big research facility with a lab coat.

But we are all scientists!

Anyone can study the living world in a scientific way. From an early age, everyone has a curiosity to understand the world. Think of a baby repeatedly dropping something onto the floor; he is discovering how gravity works! It is this basic curiosity that drives science.

The second piece—a love of learning—also describes what science should inspire. Sometimes science is depicted as a dry, boring set of facts, but nothing could be further from the truth. The world is a fascinating place. I have been interested in the natural world my whole life. This love of nature led me to obtain undergraduate and postgraduate degrees that have allowed me to teach biology classes every day for a living, and yet I am still constantly amazed by the wonders of our world.

There is always something new to learn within the natural and physical sciences. This unit discusses the sciences of chemistry and physics. As a biologist, I know that these concepts have a profound role in understanding biological organisms and systems. There are so many fascinating things to learn about these sciences, and how they affect the world around us.

For example, did you know:

- the reason it is more difficult to walk through water than on dry land is because of a force known as hydrodynamic drag?
- we can see lightning before we hear the clap of thunder because light moves at an astonishing 300,000,000 $^{m}/_{s}$, while sound only travels at 340 $^{m}/_{s}$?
- echoes work better when they bounce off a hard surface instead of a soft one?

What an amazing world we live in! This text, written by friend and colleague, Adolfo Ayala, will introduce you to chemistry and physics and some of the rules and laws written into the physical world around us.

"[Science and faith] each can draw the other into a wider world, a world in which both can flourish."

–Pope St. John Paul II in *Physics, Philosophy and Theology*

Finally, it is too often assumed in our society today that faith and science act in opposition to one another, that somehow if we learn enough about the world, it would disprove the existence of God. But it is important for each of us to be confident in our Faith and the fact that truth cannot be in opposition with itself.

We read in the *Catechism of the Catholic Church*: "Methodical research in all branches of knowledge, provided it is carried out in a truly scientific manner and does not override moral laws, can never conflict with the faith, because the things of the world and the things of faith derive from the same God. The humble and persevering investigator of the secrets of nature is being led, as it were, by the hand of God in spite of himself, for it is God, the conserver of all things, who made them what they are" (*CCC* 159).

Holy Mother Church teaches us that we can pursue scientific knowledge unafraid. It is my hope that *The Foundations of Science* series will not simply give your family some facts about the world but also instill a curiosity and love of learning in you that you can apply across all the disciplines of your life, both scientific and otherwise.

Timothy Polnaszek, PhD


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INTRODUCTION

Most of you have probably heard of the scientific studies of chemistry and physics. But do you really know what they are? Do you know what chemists and physicists study? Well, you are about to find out, because you are about to become junior chemists and physicists!

Chemistry and physics are natural sciences in that they study characteristics of the world. In a sense, we can say they study everything around us. For example, as you got ready to sit down to read this, you probably turned on a light so you could see and shut your bedroom door to block out the sound in your house so you could concentrate. You may have taken a deep breath before cracking open the front cover or brought a snack with you to eat to give you some energy. Believe it or not, with all these actions, you were mixed up in the world of chemistry and physics!

Though these two sciences surround us every day, they are somewhat different from the other topics you have studied in *The Foundations of Science* series because much of what takes place in chemistry and physics happens "below the surface." We don't consciously notice or think about all the ways chemistry and physics are present in our lives like we do when we are studying animals or plants. And yet, every second of our day depends upon the objects of these two natural sciences.

At their core, these sciences are the study of different aspects of *matter* and *energy* (those are two words you are going to hear a lot over the next twelve chapters). Chemistry is the study of the structure of different types of matter, the transformation of one kind of substance into another kind of substance, and the energy changes occurring in these transformations. Physics, meanwhile, studies the way in which matter can be moved in space and the energy changes involved in those movements. This includes the study of sound, light, electricity, and other areas of life that will be familiar to you, only you will understand them on a deeper level when our journey concludes. So without any further delay, let's dive into this fascinating world!

Any study of chemistry and physics must begin with an in depth look at matter.

CHAPTER 1

WHAT IS MATTER?

UNDERSTANDING THE BASICS

A good place to start our study of chemistry and physics would be by defining some of the terms that we use in these branches of science. An interesting thing you will notice as we go through this book is that many of the terms that are used are taken from everyday language, but they are given special scientific definitions. This was done a long time ago as early physical scientists took everyday words and gave them a technical definition when they used them in their work.

Chemistry and physics are the study of matter. With that definition, we introduced two words—*study* and *matter*—that may be familiar, but when talking about these sciences, we won't be using them quite like you are used to. Let's look at each of these terms in turn, starting with matter.

Physics fun fact: *A bowling ball and a balloon can have approximately the same volume but have wildly different densities.*

Everything in the material world is made up of matter. In the simplest terms, **matter** is anything that takes up space and can be weighed, which means matter has volume and mass, or density. We've introduced even more terms here so we will need to define those too.

Volume refers to the amount of space something occupies (you can think of it like the size of something, as in your dad's volume is more than yours), while **mass** is the quantity of matter (how much matter) in an object. **Density** meanwhile describes *a relationship between volume and mass*—it is the amount of mass packed into a given unit of volume. Think about it this way: density can be used as a descriptor of how "heavy" an object is. A dense object will feel heavy for the amount of space it occupies. Consider a balloon filled with air and a bowling ball. Even though they are approximately the same size

(the same volume), we know the bowling ball is much heavier (has more mass packed into that volume). Therefore, the bowling ball is the denser object. In another book of this series, we used a different analogy to understand density, comparing two suitcases of the same size: one with three T-shirts packed in it, and another with thirty T-shirts. Though the suitcases have the same volume (they are the same size), the one with thirty T-shirts has a higher density (and therefore weighs more) because there is more mass (more T-shirts) packed into that given volume.

Another way to define mass is by saying it is the volume, or space, of the given matter multiplied by the density of the object (this is Isaac Newton's definition—we will talk more about him in chapter 4). Notice that we have now added a mathematical operation into the definition. This mathematical understanding is one of the defining characteristics of the study of matter in chemistry and physics, but we will come back to this in the next chapter.

Before moving on, let's review what we have learned so far:

- **Matter**: Anything that takes up space (volume) and can be weighed (density/mass).
- **Volume**: The space an object occupies or takes up.
- **Mass**: The quantity (amount) of matter in an object.
- **Density**: The relationship between volume and mass; the amount of mass packed into a given unit of volume; a descriptor of how "heavy" an object is.

SENSING MATTER AND ITS PROPERTIES

Another way to think about material things, or matter, is that they can be detected using our senses, meaning we can hear, taste, see, smell, or feel matter. However, this does not mean that we can use *all* five senses *all* the time. Some things you can smell but you cannot see, or we can feel air when it is blowing, but our eyes do not see it. Still, matter is discernable by our senses, even if not by all of them. We use our senses to describe objects and to share the experiences with others. We can distinguish a heavier object from a lighter object by holding them at the same time. We can see who runs faster in a race by using our sight to see who crosses the finish line first. Sometimes we use machines to help our senses, as when we use a microscope to see very small things or a telescope to see things that are very far away.

Experience of the natural world through our senses gives us an expectation of how objects will normally behave. If you drop a rock, or a rabbit, or a bucket of water from a bridge into a pond, you know that all three will fall into the water because of gravity. The rock will sink because it is heavy, the rabbit will get wet, and the water in the bucket will mix with the water of the pond. Speaking of water, we know that it can turn into ice if it gets very cold, or steam if it gets very hot. You can differentiate plain water from a drink like tea by looking at it, because the color is different. You can even tell which is which while blindfolded because they taste so different.

Different substances have different tastes, textures, and colors. They also have different densities, different

Beyond Matter

This is a book about matter, its structure and its changes. But as Catholics, we know that not all that exists is *material* (meaning physical). Yes, we know that all matter, including ourselves, is created by God, yet we humans are not simply material beings. God created us in His image and likeness (see Gn 1:26–27)—this means we are more than just physical creatures. The faculty we have to take the information from our senses and consider higher thoughts with it points to our intellect and to our soul being spiritual and immortal. It is the spiritual nature of our soul that allows us to think beyond the particular material objects present to us. It allows us to abstract from the many tables we have seen what a table is, and allows us to judge what makes a table "good." It allows us to define what matter is and gives us the faculty to judge the different types of matter and categorize it. Cardinal Joseph Ratzinger (later Pope Benedict XVI) wrote that the scientist is not creating anything in carrying out scientific studies but "rethinking" that which has been thought before. In this sense, the scientist is trying to go beyond matter to understand the mind of God.

temperatures at which they freeze or boil, and they differ in how easily they get hot or how quickly they cool off. We call all these descriptors of a substance the **properties** of that given substance; they are like different characteristics, just like you might have certain physical characteristics (tall or short, brown or blond hair, etc.). Everything you have studied in the *Foundations* series is made of matter, from the largest star to the smallest bacteria, from a blue whale to a grain of sand. Each of these things has certain properties.



The properties of a given substance are like its characteristics. One characteristic of water is that it can be found in three separate states of matter (liquid, solid, gas) depending on what its temperature is.

BREAKING DOWN MATTER

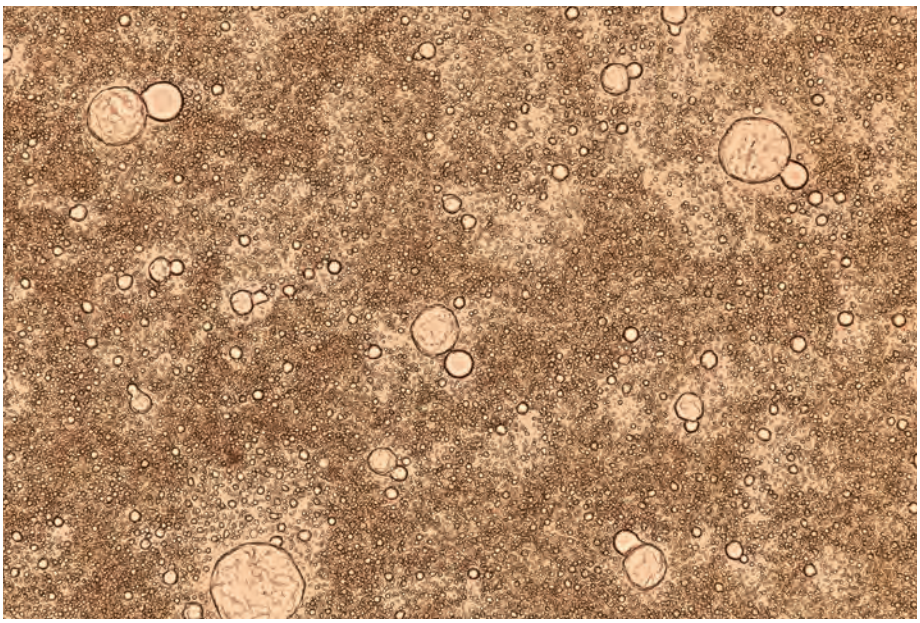
If everything in the physical world is made of matter, then could we say that chemistry and physics are the sciences of *everything*? In a way, yes! Some scientists would say that it is possible to treat everything as basic physics and/or chemistry. But, of course, we must further break down things in order to truly study them.

When we look at all the things made of matter, we can make distinctions by characterizing them as either *living* or *nonliving*. Things that have life (animals, plants) are the subject matter of **biological sciences**. Chemistry and physics, meanwhile, look at the material world from the perspective of nonliving matter. This does not mean that chemistry has nothing to say about what happens to the matter in the cells of an organism, but still, we cannot treat the organism as simply a series of chemical reactions. Even when looking at a living organism, chemistry and physics treat the matter in the organism in the same way they treat that matter in a laboratory.

After establishing the limits of chemistry and physics to nonliving matter, we can ask the question: Is all nonliving matter the same? As you might expect, the answer is no. Scientists characterize matter into either *mixtures* or *pure substances*. Let's look at mixtures first.

A **mixture** is something that is made from at least two or more pure substances. There are two different kinds of mixtures: heterogeneous mixtures and homogeneous mixtures. A **heterogeneous mixture** is one in which we can observe the different components of the mixture. Think of a tossed salad with lettuce, tomatoes, cheese, and nuts. The salad is a mixture of all those

components, and you can easily see the individual components. Another example would be chocolate chip cookie dough. You clearly see the chocolate chips scattered throughout the buttery dough. But not all heterogeneous mixtures are this easy to identify. Sometimes we need a microscope to see the different components of a mixture. The milk people buy at the store looks like it is all the same throughout, but if you were to put a drop of it under the microscope, you would see little bubbles of fat floating in the watery whey of the milk.



Under a microscope milk doesn't look quite as delicious! Milk is an example of a heterogenous mixture because we can observe different components within the mixture.

A **homogeneous mixture** is one in which the different substances that are mixed together *cannot* be observed separately. This mixture may look like a pure substance but is not. The vanilla extract in your pantry is an example of a homogeneous solution with a lot of different substances present. The extract will have water, vanillin, maybe alcohol, maybe sugar, and other possible substances in it. When you pour it into a teaspoon, you do not see the different components, as they are all dissolved by the water in the extract (it just looks like one substance despite being a combination of many).

Both homogeneous and heterogeneous mixtures can be separated into their pure substances (the "whole" can be divided into "parts") using techniques called physical changes. A **physical change** is one that changes the given substance but does not change *the kind of* substance you have. For example, if you had a glass of sugar-water, we can get the sugar out of the mixture by boiling off all the water. Though we have changed the sugar-water, the evaporated water is still water (now in a gas form) and the sugar that remains is still sugar.

Let's now pivot to talking about the other kind of matter: pure substances. **Pure substances** are those that cannot be separated from other substances using physical changes. A pure substance can be changed into other pure substances through what scientists call chemical changes, or chemical reactions (we will discuss these more in a later chapter). There are two types of pure

WHAT IS MATTER?

MATTER

LIVING THINGS

NON-LIVING THINGS

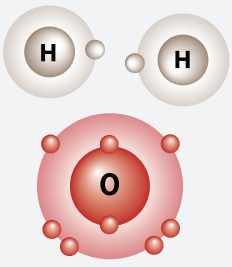
MIXTURES

HETEROGENEOUS MIXTURE

HOMOGENEOUS MIXTURE

PURE SUBSTANCES

ELEMENTS



COMPOUNDS

substances: elements and compounds. A **compound** is a chemical substance made up of multiple elements, which can be broken up or joined through a chemical reaction, while an **element** is a substance that cannot be broken into any other type of substance by using chemical reactions. For example, we can take hydrogen gas and combine it with oxygen gas to make water (H_2O). Hydrogen and oxygen are elements, and water is a compound. Water can also be broken back into oxygen and hydrogen. The fact that we can break water into elements means it is a compound. We will add a layer to this understanding when we discuss atoms later in the book.

At the beginning of this chapter, we said that chemistry and physics are the study of matter. Now that you have a general understanding of the term matter, we can discuss the method scientists have used and continue to use to study the material world.

Physics fun fact:
Everything in the world is made of matter. Everything!

FOUNDATIONS REVIEW

- ✓ Chemistry and physics are the study of matter. Matter is anything that takes up space and can be weighed, which means matter has volume and mass, or density. Volume refers to the amount of space something occupies, while mass is the quantity of matter (how much matter) in an object. Density, meanwhile, describes a relationship between volume and mass—it is the amount of mass packed into a given unit of volume. Density can be used as a descriptor of how "heavy" an object is. A dense object will feel heavy for the amount of space it occupies.
- ✓ We can detect matter and understand it (understand how it will behave) using our senses. We do this by observing its properties, which describe its characteristics, things like how it tastes, what it feels like, or what color it is. Different types of matter can also have different densities, different temperatures at which they freeze or boil, and they can differ in how easily they get hot or how quickly they cool off.
- ✓ Matter can be broken down into two categories: living and nonliving things. Chemistry and physics, for the most part, study nonliving things. Nonliving things can be further broken down into pure substances (elements and compounds) and mixtures (heterogeneous and homogeneous). A mixture is something that is made from at least two or more pure substances.

Understanding Matter: Form and Accidents

When you see a marble statue, is the fact that the statue is made from marble the only thing that is important about it? Is that what makes it a statue? Or is the shape it has been formed into more important?

Usually, you determine it is a statue because it has been shaped by a craftsman. You can see the features of it and his intention, maybe even the tool marks that show his agency. We can say that the lump of matter (the marble), through the hands of the craftsman, has received a *form*. The lump of matter in the hands of a well-trained artist can be transformed into a beautiful work of art by the agency of the artist (by agency we mean through the free action and intention of the artist—his ability to act for himself and make decisions). We can say that the lump of matter had the potential to be actualized into a statue by the artist who had the ability to do so.

A full understanding of an object must take into account that it is made of the union of matter and form. The matter is what it is made of (marble), and the form is that which makes it to be what it is (a statue). The bench I sit on as I write this is made of wood, but it may just as well have been made of plastic, stone, or metal. In each case, no matter what it was made from, because it has the form of a bench, you would be able to recognize it as a bench.

Similarly, when you look at a dog, you know it is a dog because its matter is "united" to the form of dog. The adjectives that describe a dog (big, small, white, black, etc.), its "properties", in a theological sense, are called the *contingent accidents.* What makes a Labrador Retriever different from a Saint Bernard? The differences between the dogs come from their differences in size, color, musculature, etc.—they have different contingent accidents. They are both clearly dogs, as they have the characteristics of a dog. We would say these characteristics are *essential accidents,* those things that if changed would make it no longer a dog.

If someone asks you what a table is, you would use the *essential accidents* to describe a general table. If you were asked to describe your dining table, you would then give all the *contingent accidents* that are particular to your table. For example, my dining table is made of oak, has a light finish, and has a burn mark right in the middle where my wife's roommate burned it before we got married! In a sense, the essential accidents are general qualities about a thing,

while the contingent accidents are the specific qualities.

We humans all share the same form. The individual differences among us are not differences in our substance, but in the matter that makes us all individuals sharing the same form. What is the best definition of "man"? Aristotle and St. Thomas define man by saying we are rational animals. The rational part includes our will and our intellect, which we get from our soul. The animal part corresponds to the material life, including our senses and ability to move. All differences in skin tone, athletic ability, mathematical ability, etc., are contingent accidents. This demonstrates that all humans are children of God made in His image and likeness. Like a Divine Sculptor, He has formed us into images of Himself.

As we discuss the physics and chemistry of the material world, we will often overlook that the matter has a form and generalize to how matter behaves under our investigation. This does not mean that the form is not important, but we are simplifying things to better understand the matter's behavior.