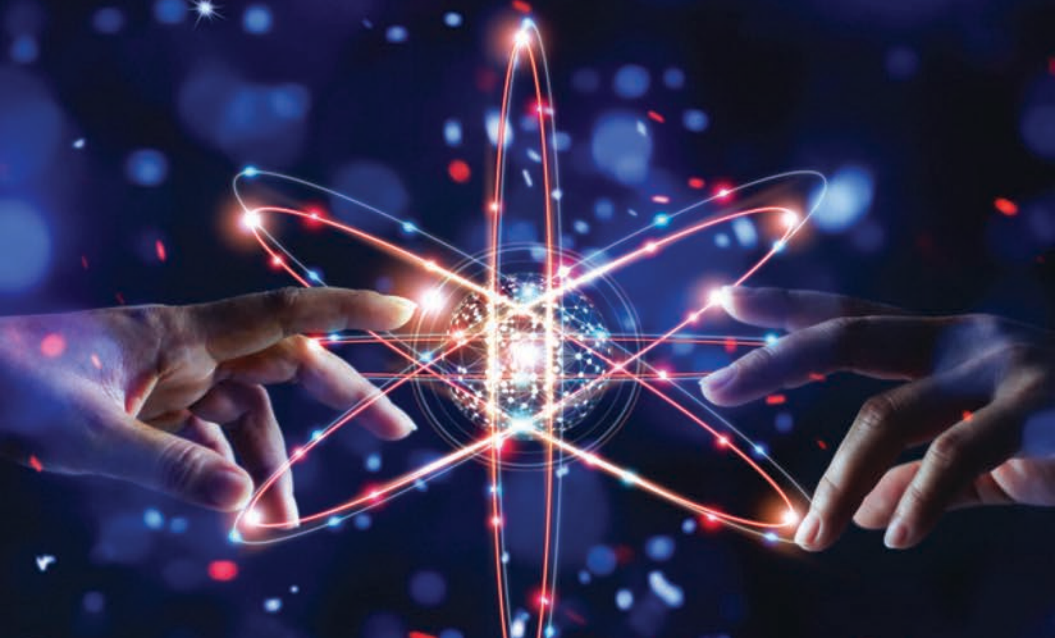
Secrets of the Universe



MATTER AND ENERGY

Principles of Modern Physics

By Paul Fleisher

illustrations by Patricia A. Keeler

Secrets of the Universe

Matter and Energy

Principles of Matter and Thermodynamics

by Paul Fleisher

illustrated by Patricia A. Keeler

LIVING BOOK PRESS

This book is dedicated to my students, past, present, and future.

ISBN: 978-1-925729-34-4

This edition published 2019 by Living Book Press
Website: **www.livingbookpress.com**

All editions are published by arrangement with Twenty-First Century Books, a division of Lerner Publishing Group, Inc., 24 l First Avenue North, Minneapolis, MN 55401 U. S. A.

The text for this book has been adapted from a single-volume work entitled Secrets of the Universe: Discovering the Universal Laws of Science, by Paul Fleisher, originally published by Atheneum in 1987. New back matter was developed by Lerner Publications Company.

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INTRODUCTION
What Is a Natural Law?

Everyone knows what a law is. It's a rule that tells people what they must or must not do. Laws tell us that we shouldn't drive faster than the legal speed limit, that we must not take someone else's property, that we must pay taxes on our income each year.

Where do these laws come from? In the United States and other democratic countries, laws are created by elected representatives. These men and women discuss ideas they think would be fair and useful. Then they vote to decide which ones will actually become laws.

But there is another kind of law, a scientific law. You may have heard about the law of conservation of energy, for example. It says that energy—such as heat, light, motion, or electricity—can neither be created nor destroyed. Where did that law come from? Who made it, and what could we do if we decided to change it?

The law of conservation of energy is very different from a speed limit or a law that says you must pay your taxes. Speed limits are different in different places. On many interstate highways, drivers can travel 65 miles per hour. On crowded city streets, they must drive more slowly. But the law of conservation of energy works exactly the same way no matter where you are. In the country or the city, in France, Brazil, or the United States, you can't create energy out of nothing, or make it disappear either.

Sometimes people break laws. When speed limit signs say 55, people often drive 60 or even faster. But what happens when you try to break the law of conservation of energy? You can't. There are no magic words or special procedures you can use to make heat or light suddenly appear or to cause them to simply vanish.

The law of conservation of energy doesn't apply just to people, either. All things obey this law: plants, animals, water, stones, even planets and stars. And the law stays in effect whether people are watching or not.

The law of conservation of energy is a natural law, or a rule of nature. Scientists and philosophers have studied events in our world for a long time. They have made careful observations and done many experiments. And they have found that certain events happen over and over again in a regular, predictable way.

You have probably noticed some of the same things yourself. Conservation of energy is a good example. Heat and light don't just appear or disappear. You know that from your own experience. A magician might seem to light an electric bulb that isn't connected to any wires or other energy source. But we know it's a trick. What makes the trick interesting is that we know it's not really possible for him to have done it.

A scientific law is a statement that tells how things work in the universe. It describes the way things are, not the way we want them to be. That means a scientific law is not something that can be changed whenever we choose. We can change the speed limit or the tax rate if we think they're too high or too low. But no matter how much we want to make light magically appear or cause a distant object to move, conservation of energy remains in effect. We cannot change that fact; we can only describe what happens. A scientist's job is to describe the laws of nature as accurately and exactly as possible.

The laws you will read about in this book are universal laws. They are true not only here on earth, but also throughout the universe. The universe includes everything we know to exist: our planet, our solar system, our galaxy, all the other billions of stars and galaxies, and all the vast empty space in between. All the evidence scientists have gathered about the other planets and stars in our universe tells us that scientific laws in effect here on earth also apply in other parts of the universe as well.

In the history of science, some laws have been found through the brilliant discoveries of a single person. But ordinarily, scientific laws are discovered through the efforts of many scientists, each one building on what others have done earlier. When one scientist receives credit for discovering a law, it's important to remember that many other people also contributed to that discovery.

Scientific laws do change on rare occasions, but they don't change because we tell the universe to behave differently. Scientific laws change only if we have new information or more accurate observations. The law changes when scientists make new discoveries that show the old law doesn't describe the universe as well as it should. Whenever scientists agree to a change in the laws of nature, the new law describes events more completely, or more simply and clearly.

The law of conservation of energy is a good example of this. In the early twentieth century, Albert Einstein realized that matter (or mass) can be transformed into energy. The energy doesn't just appear from nowhere. It is actually matter changed to a different form.

Einstein also discovered that high levels of energy can add to an object's mass. As an object accelerates toward the speed of light, gaining energy as it does, it becomes more and more massive. So modern science no longer identifies separate laws of conservation of energy and conservation of mass. Instead, there is one law—the law of conservation of mass-energy.

Natural laws are often written in the language of mathematics. This allows scientists to be more exact in their descriptions of how things work. For example, you've probably heard of Einstein's equation: $E = mc^2$.

It's one of the most famous equations in science. But don't let the math fool you. It's simply a mathematical way of saying that mass (m) can be changed into energy (E). Writing it this way lets scientists compute the amount of energy contained in a certain amount of matter.

The science of matter and energy, and how they behave, is called physics. In the hundreds of years physicists have been studying our universe, they have discovered many natural laws. In this book, you'll read about several of these great discoveries. There will be some simple experiments you can do to see the laws in action. Read on, and share the fascinating stories of the laws that reveal the secrets of our universe.

Chapter 1

The Law of Conservation of Matter

Magicians love to make objects appear and disappear. Coins suddenly appear behind someone's ear, a rabbit pops out of an empty hat, or a beautiful woman vanishes into thin air. Almost every magician depends on mysterious appearances and disappearances for many tricks.

When we see a magician make something appear or disappear, we're fascinated. Why? We're amazed because we know that in real life objects don't simply appear or vanish. We know we can't turn something into nothing or nothing into something. Without realizing it, we're using the law of conservation of matter.

The law of conservation of matter is usually stated like this: Matter can neither be created nor destroyed. Matter, of course, is stuff. It is any kind of stuff—solid, liquid, or gas. The law of conservation of matter says that whatever anyone does to an object, the matter it is made of will continue to exist, in some form or another. This law is also known as the law of conservation of mass. Mass is the measurement of the *amount* of matter any object contains.

A rock is a piece of matter. Let's use it as an example. Suppose we hit our rock with a sledgehammer and break it into pieces. Is the rock still there? Of course. It has just changed form.

Let's grind our pieces of rock into a fine powder and toss it up into the wind. The powder blows away. Have we destroyed anything? No. The same amount of rock still exists, but now it has become tiny particles scattered far and wide.

Perhaps some of our rock powder falls into a farmer's field. A corn plant absorbs some of the minerals through its roots. The rock becomes part of the corn plant, but it still exists. If we eat the corn, the minerals become part of our body. Still nothing has been destroyed.

Suppose we wanted to try these experiments, but we didn't have a rock. No matter where we looked, we just couldn't find a rock! Could we create one? Could we say some sort of magic spell that would make a rock appear from nowhere? Of course not. It seems very clear that matter cannot be created, either.

But grinding a rock into powder is just a physical change. No matter how fine we grind the rock, it's still rock. In chemical reactions, totally new substances are formed. For example, when we mix vinegar and baking soda, carbon dioxide gas is formed. The gas wasn't there before the reaction took place. Has new matter been created? Has any of the vinegar or baking soda been destroyed?

Fire is another type of chemical reaction. Think

No matter how we change the form of a rock, the material the rock is made of will never disappear.

about what happens when you burn a piece of paper. You start out with a full-sized sheet of paper, but after the flames die out, all that's left is a little pile of ash. If you weigh the paper before and after you burn it, you'll discover that the paper weighs much more than the ashes that are left behind. It certainly *looks* as though matter was destroyed by fire. If you had been a scientist in the early 1700s, this would have been one of your biggest puzzles.

There's another side to this same problem. Scientists in the 1700s also knew that if you heated certain chemicals, such as iron powder or mercury, they would change appearance and get heavier! It seemed that new matter was being created as they heated the metal.

It took one of the world's great scientists, Antoine-

Laurent Lavoisier, to figure out what was happening. And it is the Frenchman Lavoisier who is given credit for first stating the law of conservation of matter.

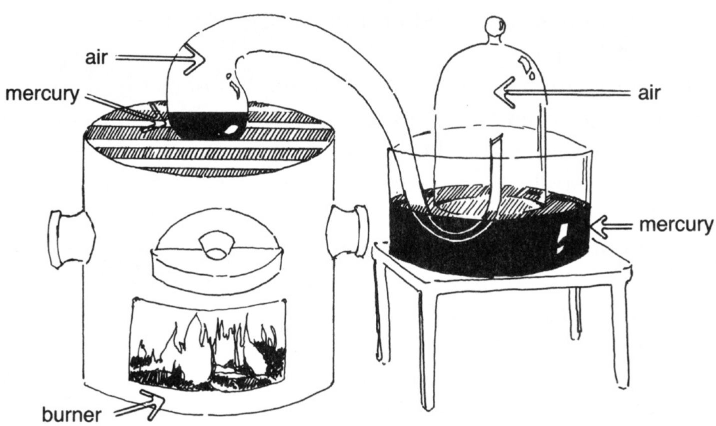
Before Lavoisier, scientists explained that objects lost weight when they burned because they combined with a substance in the air called *phlogiston*. Phlogiston was supposed to have negative weight, so a burning substance that combined with it would get lighter instead of heavier. Metals were supposed to give off phlogiston when heated, which explained why they got heavier. The trouble was, nobody had ever seen phlogiston or been able to collect it in a laboratory.

Lavoisier realized that the reason no one could find phlogiston was because it wasn't there. He discovered that when things burn, they combine with oxygen, a gas in the air. Sometimes this burning creates other gases. The gases blow away, leaving only a little bit of ash. It might look as though matter has been destroyed, but it has actually changed form, become a gas, and entered the atmosphere. If you carefully trapped and weighed all the gases produced when a sheet of paper burned, you would find that all the matter from that paper still existed.

Lavoisier heated measured amounts of mercury and iron in closed containers and noted that they changed to rust-like substances. These reddish substances (oxides) weighed more than the original metals. But there was also less air inside the closed containers. The amount of air that had been used up was equal to the amount of weight that the metals had gained. Lavoisier realized that no new matter had been created. Instead, the metals had combined with a portion of the air, which Lavoisier called oxygen. After many experiments, Lavoisier was sure that, while substances might change form or combine with other substances, matter could not be created or destroyed in ordinary chemical reactions.

So when you mix vinegar and baking soda, nothing is created or destroyed. The two chemicals react with each other and form other substances, including carbon dioxide gas. The same amount of material is still there. It has simply changed form.

Why was the law of conservation of matter so important? If scientists knew matter couldn't be created or destroyed, they could weigh their chemicals carefully, conduct their experiments, and figure out how elements combine to form various compounds. Only after Lavoisier and others realized that matter couldn't



Lavoisier heated mercury in a sealed container to prove that matter is neither created nor destroyed.

be created or destroyed could chemistry become an exact science. For this and other great contributions, Lavoisier is usually known as the founder of modern chemistry.