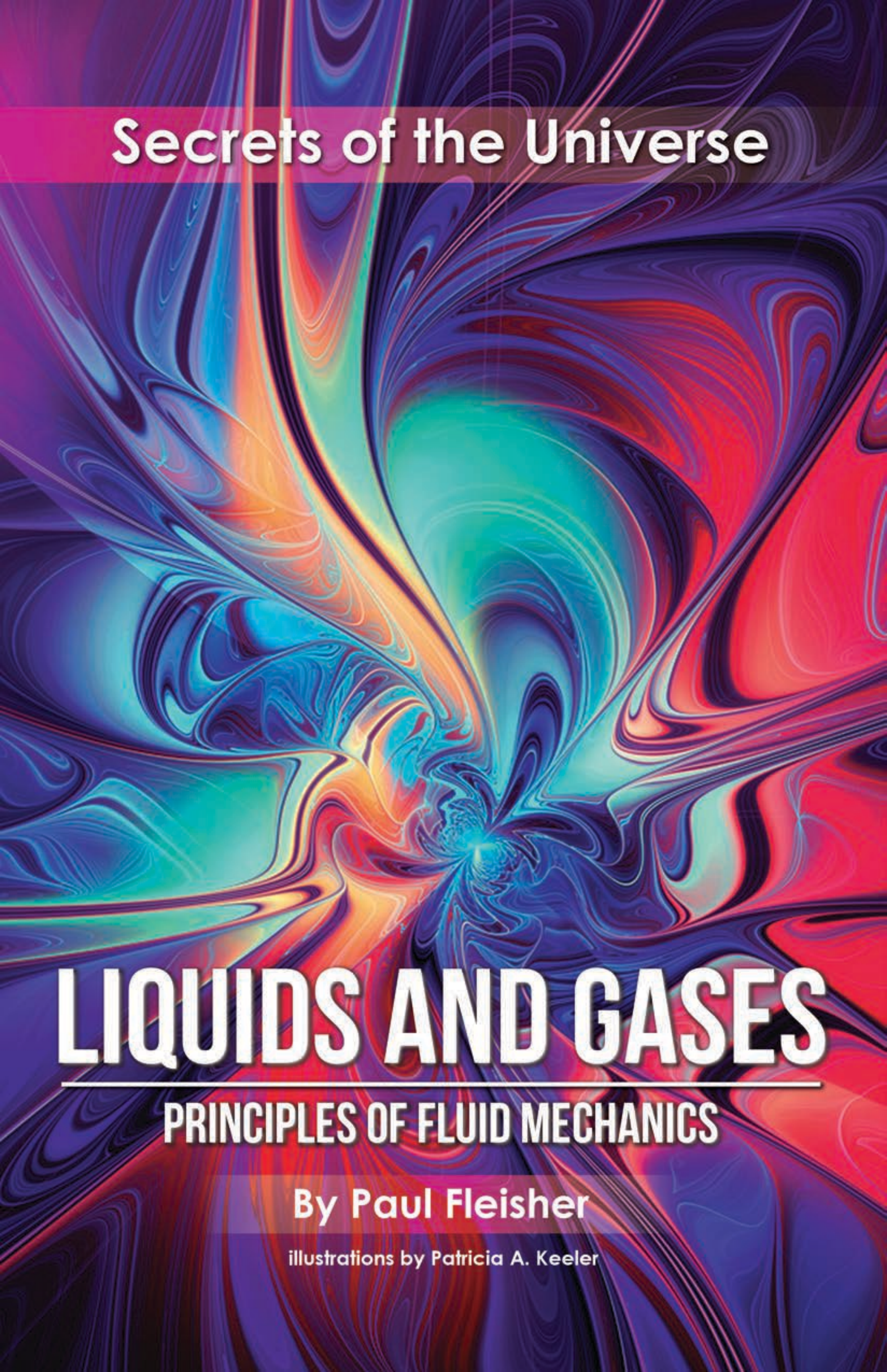

Secrets of the Universe

LIQUIDS AND GASES

PRINCIPLES OF FLUID MECHANICS

By Paul Fleisher

illustrations by Patricia A. Keeler

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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 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 which 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 Archimedes' principle, for example. It is a scientific law that tells us a floating object displaces (pushes aside) an amount of water equal to its own weight. If the object is too heavy and dense to push aside enough water, it will sink. Where did that law come from and what could we do if we decided to change it?

Archimedes' principle 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 105 kilometers (65 miles) per hour. On crowded city streets, they must drive more slowly. But Archimedes' principle works exactly the same way no matter where you are. In the country or the city, in France, Brazil, or the United States, a floating object displaces its own weight.

Sometimes people break laws. When the speed limit is 90 kph (about 55 mph), people often drive 100 kph (60 mph) or even faster. But what happens when you try to "break" Archimedes' principle? You can't. Here on Earth, if you float one thousand different objects, each one will push aside an amount of water exactly equal to its weight.

All objects obey this law: plants, animals, water, stones, and even people. And we know that Archimedes' principle stays in effect whether people are watching or not. Archimedes' principle 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. Archimedes' principle is a good example. When you put an object in water, it will float or sink. Objects that are denser than water will sink. You know that from experience.

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 an object to float instead of sink, Archimedes' principle remains in effect. We cannot change it; 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. That means they are true not only here on Earth, but elsewhere throughout the universe too. The universe includes everything we know to exist: our planet, our solar system, our galaxy, all the other billions of stars and galaxies, and the vast empty space in between. All the evidence that scientists have gathered about the other planets and stars in our universe tells us that scientific laws that apply here on Earth also apply everywhere else.

In the history of science, some laws have been found through the brilliant discoveries of a single person. Archimedes' principle, for example, is the result of the Greek philosopher Archimedes' great flash of individual understanding. But ordinarily, scientific laws are discovered through the efforts of many scientists, each one building on what others did earlier. When one scientist receives credit for discovering a law, it's important to remember that many other people also contributed to the 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 does not 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.

For example, Aristotle—one of the founders of scientific thought—believed that air had no weight. Early scientists held that belief for almost two thousand years. Finally in the mid-1600s, the Italian scientist Evangelista Torricelli created the world's first barometer. Scientists then realized the air at sea level does have weight—enough weight to support a column of mercury 76 centimeters (30 inches) high. Several years later, the French scientist Blaise Pascal showed that the weight of the air decreases as you climb higher and higher.

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, the ideal gas law, which we'll learn about later in this book, is actually written like this:

$$\text{V (volume)} = \text{R (gas constant)} \times \frac{\text{T (temperature)}}{\text{P (pressure)}}$$

Don't let the math fool you. It describes the actions of air and other gases you are familiar with in everyday life. Writing it this way lets scientists accurately compute the actual volume, temperature, or pressure of a gas in many different situations here on Earth and elsewhere in the universe.

The science of matter and energy and how they behave is called physics. In the hundreds of years that physicists have been studying our universe, they have discovered many natural laws. In this book, you'll read about some 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

Archimedes' Principle

An oceangoing ship weighs hundreds or even thousands of tons. Yet it can float on water. How is that possible? The answer begins with one of the oldest and most famous stories in the history of science.

Let's imagine an experiment. You decide to take a bath, so you turn on the water and fill the tub to the very top. Then, with the tub filled just to overflowing, you step in and sit down.

You already know exactly what will happen. In fact, you'd better not try it, unless you want to do a lot of mopping up afterward! When you get into the tub, gallons of water will pour onto the floor.

According to an ancient story, this is just what happened to the Greek scientist Archimedes more than 2,200 years ago. Archimedes sat down in an overly full bathtub, and water flooded over the sides. Seeing the water overflow gave Archimedes a brilliant idea. He was so excited about his new idea that he jumped out of the tub. Forgetting to put on his clothes, he ran through the streets shouting “Eureka!” (*“I found it!”*)

Archimedes had been thinking about why some things float while others sink. It couldn’t just be a matter of weight. Greek ships were very heavy, and yet they floated. But even a tiny pebble sinks right to the bottom of the sea. What Archimedes realized in his bathtub was the law of buoyancy. In modern times, this is usually known as Archimedes’ principle in his honor. Archimedes’ principle says: Any floating object pushes aside, or *displaces*, an amount of water equal to its own weight. If a boat weighs 250 kilograms (550 pounds), it must displace 250 kilograms of water in order to float.

Imagine a boat pushing a “hole” into the water. If you measured the amount of water it would take to fill that hole, it would weigh as much as the boat itself. A boat that weighs 100 metric tons (110 tons) must push aside 100 metric tons of water to float.

If you measure carefully, you will be able to see this law at work in the following demonstration. Place an aluminum pie plate on a sensitive scale. Weigh it and record its weight. Next, find an object that will float—like a block of wood— weigh it, and write down its weight.

Put the pie plate back on the scale. Place an empty can or wide-mouthed jar in the center of the plate. Carefully fill the jar with water to the very top. The water should be ready to overflow if you add just one more drop.

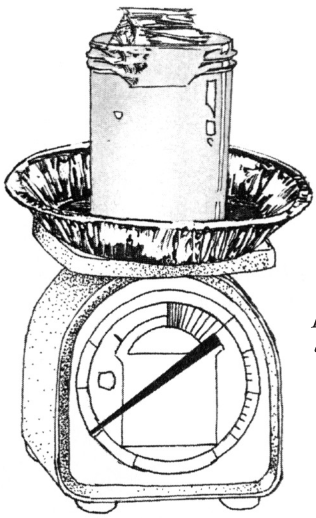
Gently lower the block of wood into the water until it floats by itself. Some of the water will overflow as the block pushes it out of the jar. That's exactly what should happen.

After the wood is floating in the jar, carefully lift it, with the wood and the water, out of the pie plate. Pick up the jar very gently so that you don't spill any more water out of it.

Weigh the pie plate with the overflow water in it. Subtract the weight of the pie plate itself. That will give you the weight of the water that the block of wood pushed out of the jar.

$$\begin{array}{rl} & \text{Total weight of water and pan} \\ - & \underline{\text{Weight of pan}\qquad\qquad\qquad} \\ & \text{Weight of water in pan} \end{array}$$

Compare the weight of the water in the pan to the weight of the block of wood. They should be equal. The water that the floating object displaces weighs just as much as the object itself. That's Archimedes' principle.



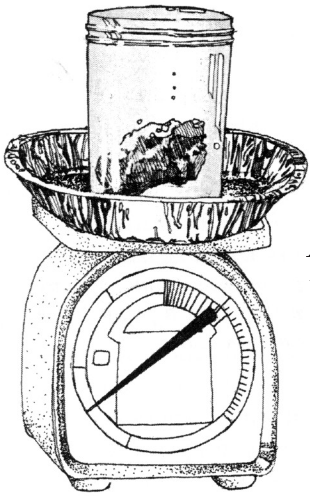
You can demonstrate Archimedes' principle using a jar, a pie plate, and a small scale.

Archimedes' principle is true for any object, in any situation. That's why it's considered a law. If an object can displace its own weight in water, it will float. If it's too heavy or dense to displace its own weight, it will sink.

Try the same experiment using a rock instead of a block of wood. The rock will sink to the bottom. As it does, it will push some of the water out of the jar and into the pie plate. Compare the weight of the rock to the weight of the water it displaced. You should discover that the rock weighs more than the water in the pan. The rock wasn't able to displace its own weight in water, so it sank.

Archimedes' principle can be described in another way: If an object is less dense than water, it will float. If it is denser than water, it will sink.

Two different objects can be exactly the same size (or volume), but one can be much heavier than the other. A brick and a block of plastic foam may be exactly the

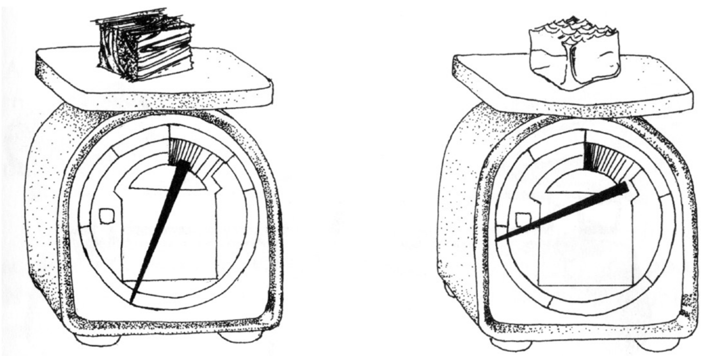


A rock doesn't displace enough water to be able to float.

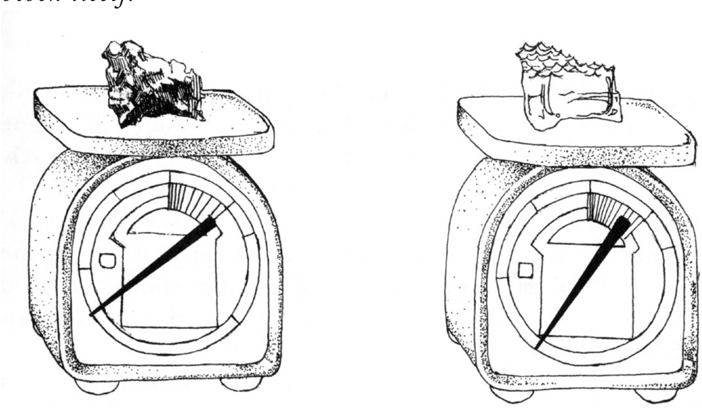
same size. But when you compare their weights, the brick is much heavier. The brick has much greater density.

The density of an object is calculated by comparing its volume with its weight. The more mass (the amount of matter or substance an object is made of) that is packed into the same amount of space, the greater the density.

Imagine comparing the weight of our block of wood with the weight of a "chunk" of water exactly the same size and shape as the wood. If we could weigh the block



A wood-block-sized "chunk" of water weighs more than the block itself.



A rock-sized "chunk" of water weighs less than the rock itself.

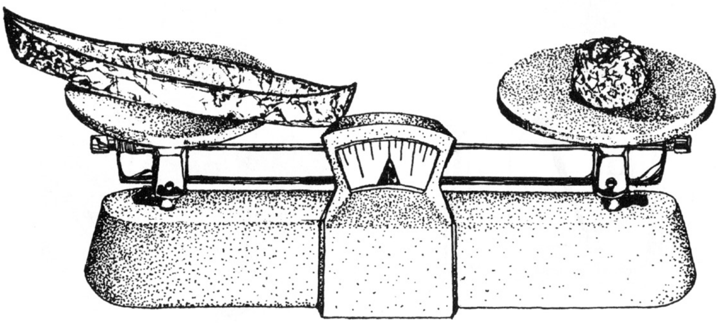
of wood and the "block" of water, the water would weigh more. That means the wood is less dense than the water, so it will float.

If we weighed a "chunk" of water the same size as our rock, we would get a different result. The rock would weigh more than the chunk of water. The rock is denser than the water, and so it sinks.

The material an object is made of has a lot to do with whether or not it will float. But as you might guess from the way boats are designed, so does the object's shape. Here's another experiment to show how true that is.

Tear off two equally sized sheets of aluminum foil. Form one into the shape of a canoe. Fold and crush the other one into a small ball, squeezing it as tightly as you can.

Place both pieces of foil in a container of water. The ball sinks right to the bottom. As long as it doesn't fill with water, the foil canoe will float. Because of its shape, the canoe can displace its own weight of water, and so it floats. The densely packed ball cannot displace enough water, and so it sinks.

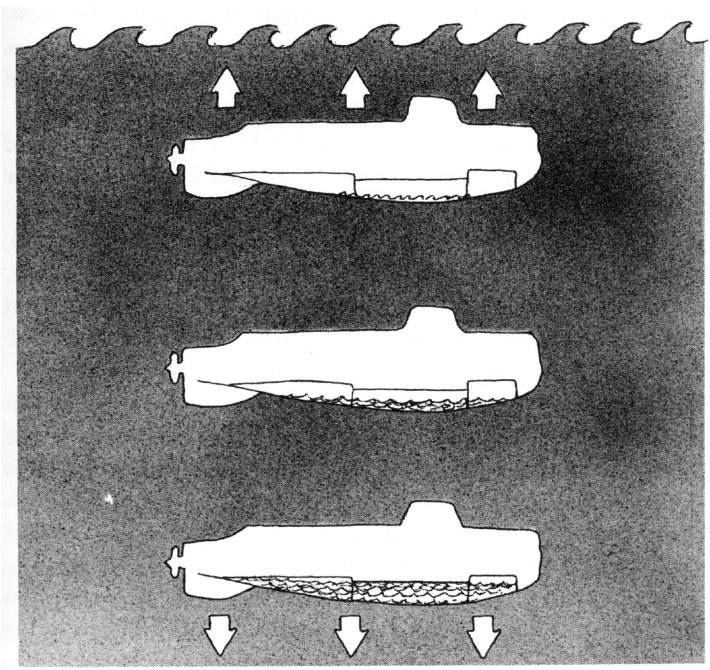


The same amount of foil can be made into a floating canoe or a tight ball that will sink.

A submarine is a special kind of boat. It uses Archimedes' principle very precisely to either sink or float. A submarine has several ballast tanks in its hull. When these tanks are filled with water, the submarine weighs more than the water it displaces. It sinks toward the bottom.

When the captain wants to float to the surface, he uses compressed air to force water out of the tanks. This makes the submarine lighter. It then displaces more than its own weight of water, and it rises toward the surface.

To keep the submarine at a certain depth, the captain allows just enough water in the tanks to give



A submarine changes its buoyancy by adjustments to the amount of water in its tanks.

the submarine *neutral buoyancy*. The ship weighs exactly as much as the water it displaces. So it stays just where it is, neither rising nor sinking.

Archimedes' principle doesn't apply just to objects floating in water. It's true for any liquid or gas.

Helium is less dense than air. A helium-filled balloon rises in the air because it displaces more air than its own weight. A balloon filled with the heavy gas xenon will quickly sink to the ground. It weighs much more than an equal volume of air. And a heavy steel bar will float gently on the surface of a pool of mercury, an even denser liquid metal.

Archimedes made many other contributions to science and technology. He invented a new type of water pump. He began the science of mechanics, the study of how objects move. He explained how to use levers to move heavy loads. Although he hated war, he invented new weapons to help the Greeks defend themselves against their enemies. But the contribution for which he is best remembered still bears his name. Eureka!