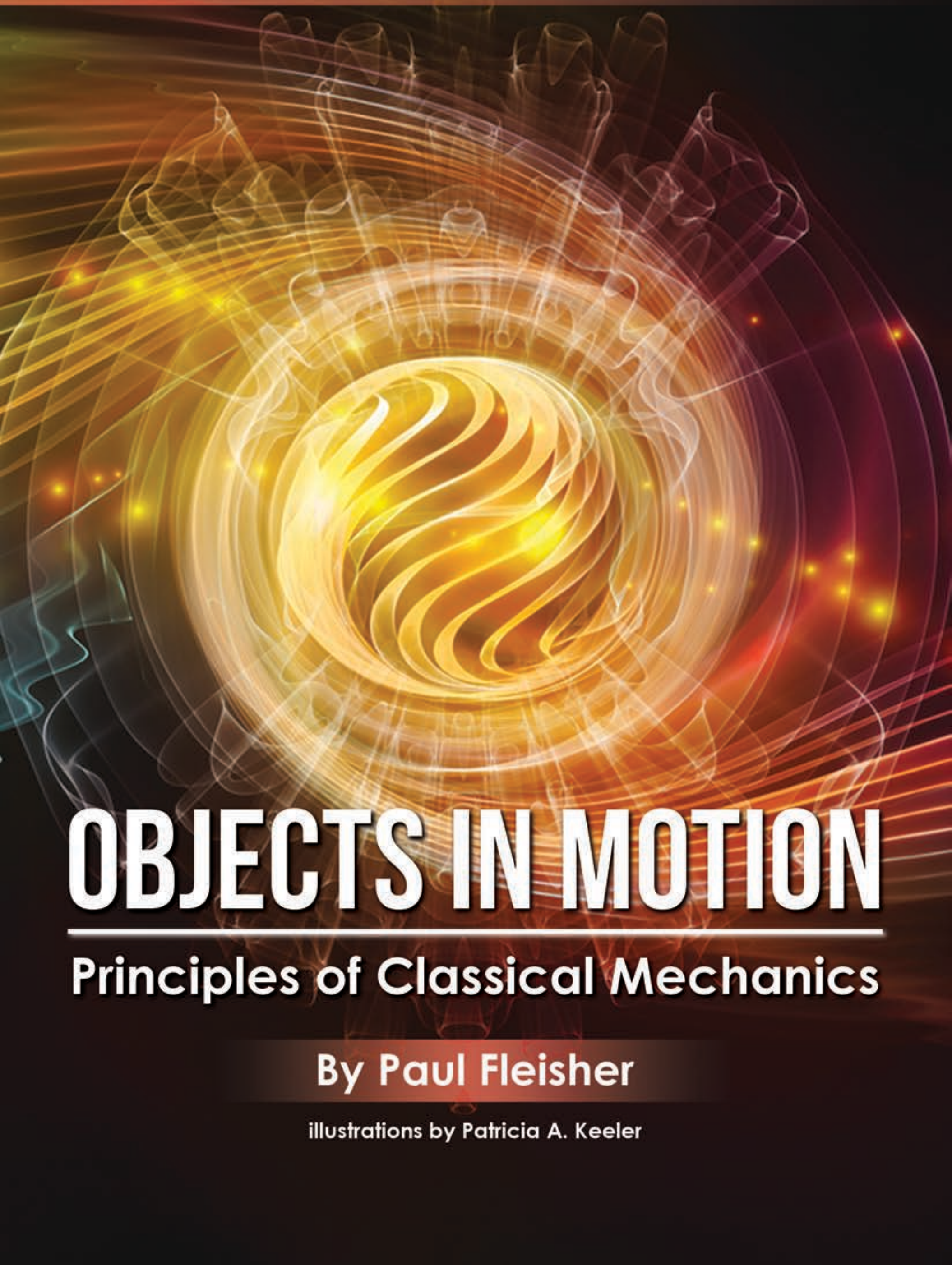
Secrets of the Universe



OBJECTS IN MOTION

Principles of Classical 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 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 what 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 probably have heard about the law of gravity, for example. Where did that law come from? Who made it, and what could we do if we decided to change it?

The law of gravity 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 the law of gravity works exactly the same way no matter where you are. In the country or the city, in France, Brazil, or the United States, when you drop a ball, it will fall down. And it will always fall at the same rate.

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 the law of gravity? You can't. Here on Earth, if you drop a ball a thousand times, it will fall down at the same rate of speed every time. It will never fall up or sideways, or just float in place.

The law of gravity doesn't apply just to people, either. All objects obey this law—plants, animals, water, stones, and even entire planets and stars. And we know that gravity stays in effect whether people are watching or not.

The law of gravity 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. Gravity is a good example. When you let an object go, it will drop. Objects on Earth don't just float away. You know that from experience. Would you bet your life savings that a baseball tossed up into the air will fall back down again? It would be a safe bet. You'd be certain to win.

A scientific law is a statement that explains 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 float instead of fall, gravity 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 all 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 the 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. The law of universal gravitation, for example, is the result of Sir Isaac Newton's great flash of individual understanding. 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. Even Newton's discovery was based on problems and questions studied by many earlier scientists.

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. A 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 laws that describe how planets move around the Sun are good examples of this. Astronomers once thought the planets, the Sun, and the Moon all orbited the Earth in perfect circles. But new discoveries and improved measurements of the planets' paths forced two great scientists, Copernicus and Kepler, to rewrite the laws that describe the planets' motion. They realized the Sun doesn't revolve around the Earth after all, they realized. The Earth and the other planets revolve around the Sun! Once scientists realized this, they had to rewrite the laws that described the motion of the planets.

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, Newton's law of universal gravitation is actually written like this:

$$F = G \times \frac{m(1) \times m(2)}{d^2}$$

Don't let the math fool you. It's still the same gravity you experience with every step. Writing it this way lets scientists compute the actual gravitational force accurately 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 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

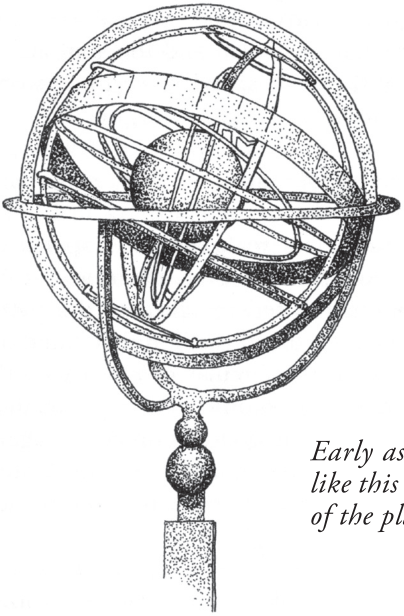
PLANETARY MOTION

Every morning the Sun rises in the east. It travels across the sky in a great arched path. Every evening it sets in the west. The Moon follows a similar path. So do the stars. It looks as though these objects must be traveling in great circles around the Earth.

People have watched the sky and kept track of the paths of the Sun, Moon, and the stars since the earliest times. And for thousands of years, astronomers thought all those heavenly lights circled around us while the Earth stood still. After all, we can see the stars moving in the sky. Standing here on the Earth, we don't seem to be moving at all. Almost everyone agreed that the Earth was the center of the universe and all other heavenly objects revolved around it in perfect circles.

But there was a problem. A few objects in the sky didn't fit into the pattern. Sometimes these objects seemed to stop, move backward for a while, stop again, and then resume their paths across the sky. Because these heavenly objects didn't follow a regular path like the stars, Sun, and Moon did, they were called planets, which means “wanderers” in Greek.

Astronomers plotted more and more complicated maps to keep track of the planets’ strange wanderings. They drew maps with circles on circles on circles. But these complex arrangements still didn’t solve the problem. The rules of science tell us that the simplest explanation is usually the best. It seemed unlikely that the heavens followed such a complicated pattern. Astronomers began to realize that the whole system didn’t make sense. They needed a simpler explanation for the movements of the stars and planets.



Early astronomers used devices like this to follow the movements of the planets.

In 1543, the astronomer Nicolaus Copernicus published a new explanation. Copernicus believed that the Earth was also a planet. He said the Earth and the other planets revolved in circles around the Sun. Many people found this new idea very disturbing. Human beings thought of themselves as being at the center of the universe. But Copernicus's theory said the Earth was just one of several travelers around the Sun. It made the Earth seem less special.

Another reason many astronomers disagreed with Copernicus at first was that the Earth doesn't seem to move at all. It feels as if the Earth is standing perfectly still. However, others realized everything on our planet moves right along with the planet itself. The Italian scientist Galileo Galilei used a moving ship as an example of this. If a sailor at the top of a mast drops an object while the ship is moving smoothly, the object falls right to the base of the mast. The ship doesn't move out from under the object while it is falling. The sailor, the falling object, and the ship are all moving forward together at the same speed. Everything works just as if they were all standing still. Galileo argued that the same thing happens with the Earth as a whole. Everything is moving together at the same speed, and so we don't experience any motion at all.

After a while, most astronomers realized that Copernicus's new idea was better than the old one. However, there was still a big problem. When astronomers tried to calculate the paths, or orbits, of the planets, their predictions still didn't come out right. The planets didn't circle the sun exactly the way astronomers thought they should. To improve their predictions, astronomers began adding circles on circles again. And once again their maps became much too complicated. There still had to be a simpler explanation for how the planets moved.

In 1609, the Austrian astronomer Johannes Kepler finally found the explanation. Kepler's discoveries are known as the laws of planetary motion.

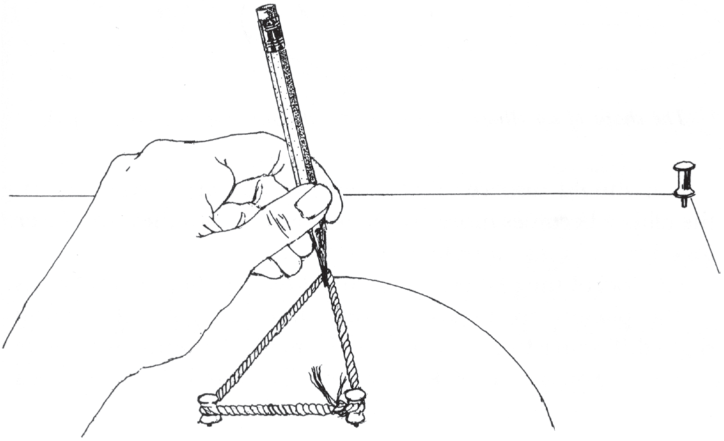
Johannes Kepler loved geometry. He believed the circle was the most perfect of all shapes. Because he believed that the universe was God's perfect creation, he thought the planets must travel in perfect circles around the Sun. He was determined to prove that the planets traveled in circular orbits. Kepler spent year after year making careful calculations of the orbits of the planets. He used the very best astronomical information available. The information had been gathered by his teacher and employer, Tycho Brahe. Brahe was the most accurate astronomical observer of his day. There were no better measurements than his.

For years Kepler tried to make Brahe's measurements fit into a pattern of circles. But no matter how hard he tried, he just couldn't make them fit.

Kepler finally realized that the planets didn't move in circles after all. They traveled in ellipses, or oval-shaped orbits. The more he studied his information, the more confident he was. In 1609, he published his first law of planetary motion: Planets travel around the Sun in elliptical orbits, with the Sun at one focus of the ellipse.

Unfortunately, we can't do a simple experiment to show this law in action. Experimenting with planets would be difficult. But we can experiment with drawing ellipses.

An ellipse is like a circle that has been stretched out in one direction. A circle has one center point. An ellipse has two. Each of the two points is called a focus (plural: foci, pronounced "FOH-sy"). To draw an ellipse, you will need a pencil, six pushpins, a piece of white paper, a piece of cardboard, and a piece of string about 30 centimeters (12 inches) long.

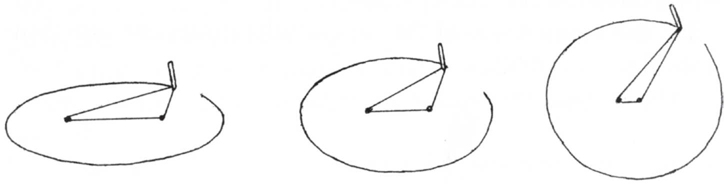


Use two pushpins and a string to draw an ellipse.

Pin the four corners of the paper to the cardboard with four of the pins to hold it down. Push the other two pins into the center of the paper, about 5 centimeters (2 inches) apart. Tie the two ends of the string together to form a closed loop. Slip the loop over both pins and stretch it out as far as it will go with the pencil. Next, draw with the pencil, keeping the string tight as you move it in an arc. Draw half of the ellipse this way. Then move the pencil and string to the other side of the pins and draw the other half of the ellipse.

Look at the ellipse you have just drawn. If it were the orbit of a planet, the outer oval shape would be the planet's path. The two center pinholes would be the foci. One of the two pinholes would represent the location of the Sun.

What happens when you change the distance between the two foci (the center pushpins)? How does the shape of the ellipse change when they are closer together or farther apart? Try it. Move the pins and draw different ellipses with several different distances between the foci.

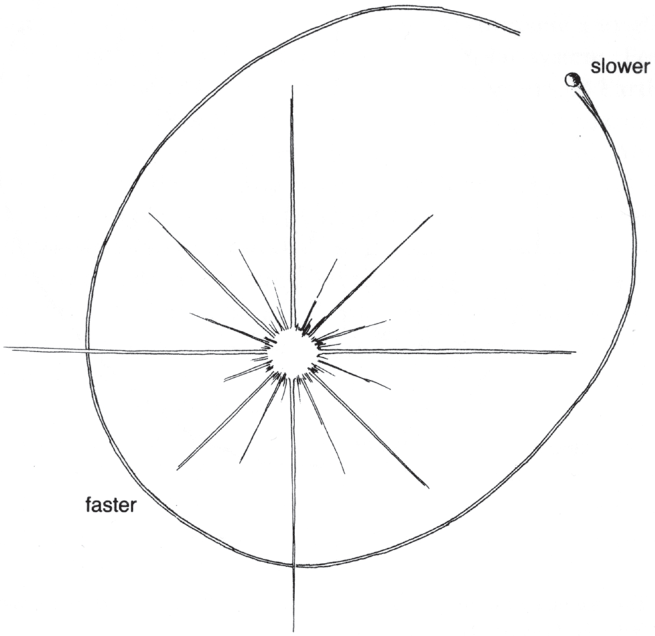


The shape of an ellipse depends on the distance between the two foci.

You'll discover that when the foci are farther apart, the ellipse becomes more stretched out. When they are closer together, it looks more like a circle.

The two foci of each planet's orbit are close together. So the orbits of the planets are almost circular, but not quite. It was this slight difference from a perfect circle that had given astronomers so much trouble. Once Kepler discovered the orbits were oval in shape, tracking the planets' movements became much simpler.

Because their orbits are elliptical, planets are closer to the Sun at some times and farther away at others. Planets' speeds also vary as they orbit the Sun. When they are closer to the Sun in their orbit, they move faster. When they are farther away, they move more slowly. Kepler wondered if there was a law that would describe this difference in speed.

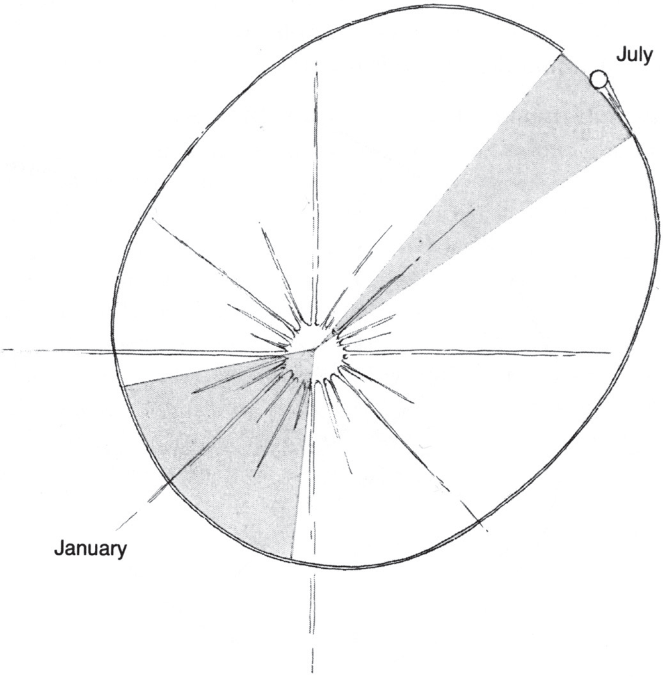


Planets move faster when they are closer to the sun and more slowly when they are father away.

After more study and calculation, Kepler finally found it. It is known as the second law of planetary motion: A planet sweeps out sections of equal area in equal amounts of time as it travels along its orbit.

That may sound complicated. What does Kepler's second law mean? Suppose we mark Earth's position in its orbit on January 1 and again thirty days later on January 31.

We could then draw straight lines from those positions to the Sun, forming a pie-shaped wedge like this:



The two shaded sections have equal areas, even though the planet moves faster in January than it does in July. This drawing is exaggerated. Earth's orbit is much more circular, and the Sun and Earth are not drawn to scale.

That gives us an elliptical section of Earth's orbit.

We could then mark another two positions, thirty days apart, on Earth's orbit. Let's say we mark July 1 to July 31. Again we can draw straight lines and form another wedge.

It happens that Earth is closer to the Sun during January that it is during July. Earth also moves faster in its orbit during January than during July. So the