Secrets of the Universe

WAVES

Principles of Light, Electricity and Magnetism

By Paul Fleisher

illustrations by Patricia A. Keeler

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For Vanessa

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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 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. For example, you'll read about Coulomb's law later in this book. Coulomb's law tells us that the electrical force between any two objects depends on two things: the amount of electrical charge of each object, and the distance between the objects. Where did Coulomb's law come from, and what could we do if we decided to change it?

Coulomb's law 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 electrical force works exactly the same way no matter where you are—in the country or the city, in France, Brazil, or the United States, or even the moon.

Sometimes people break laws. When the speed limit is 90 kph (55 mph), people often drive 95 kph or even faster. But what happens if you try to break Coulomb's law? You can't. If you test one thousand electrically charged objects, you'll find that each and every one follows the rule described in Coulomb's law. All objects obey this law. And we know that the law stays in effect whether people are watching or not.

Coulomb's law 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 these patterns in our world yourself.

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. So 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 might want electrical forces to work differently, Coulomb's law 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 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, a few 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—like Charles-Augustin de Coulomb—receives credit for discovering a law, it's important to remember that many other people also contributed to that discovery. Almost every scientific discovery is based on problems and questions studied by many earlier scientists.

Scientific laws do change, on rare occasions. 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 laws that describe electricity and magnetism provide a good example of this. Scientists once thought electricity and magnetism were two separate and different things. But new discoveries and improved measurements helped a great scientist, James Clerk Maxwell, rewrite the laws that describe how electricity and magnetism work. Maxwell realized electricity and magnetism are two different forms of the same force. You will read about Maxwell's discoveries later in this book.

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, Coulomb's law is actually written like this:

$$F = K \times \frac{q(1) \times q(2)}{d^2}$$

Don't let the math fool you. It's the same law describing how electrical charges interact. Writing it this way lets scientists accurately compute the actual electrical forces 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
Optics: The Laws of Light

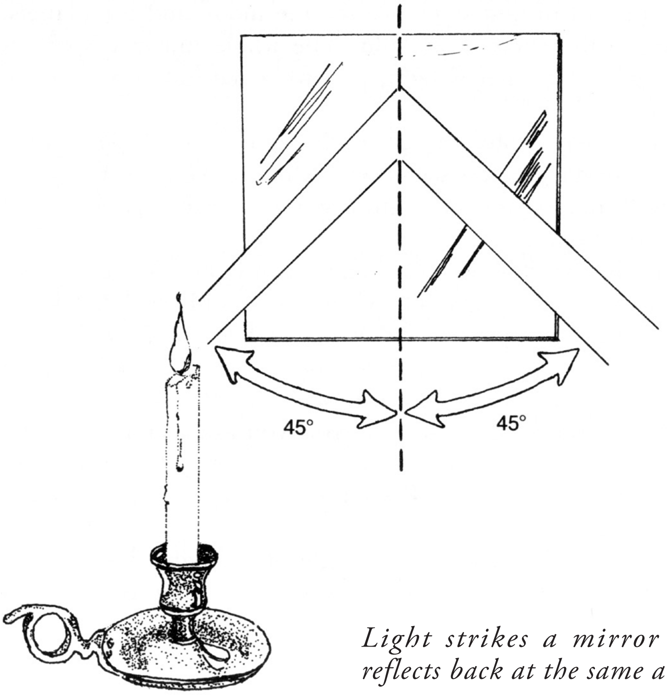
When we look into the sky at night, we see the light from thousands of different stars. We see the Moon and the planets, shining with reflected sunlight. The whole universe sparkles with light. But what is light, and what natural laws describe its behavior?

The branch of physics that studies light is called *optics*. Some of the world's greatest scientists, including Newton, Huygens, Maxwell, and Einstein, have studied optics, trying to understand the laws of light.

One law that describes the behavior of light has been known for two thousand years. The Greek philosophers didn't know what light was, but they did know that it travels in straight lines. The *law of reflection* depends on this fact. When light bounces off a mirror or other surface, this called *reflection*. When you see yourself in a mirror, you are seeing light that has reflected from your face to the mirror and then back to your eyes. The law of reflection says: The angle of incidence is equal to the angle of reflection.

The *angle of incidence* is the angle of the light shining onto the reflector. The *angle of reflection* is the angle of the light bouncing off the reflector. The law of reflection says that those two angles are always equal. If a light shines on a mirror at a 45-degree angle, it will bounce off the mirror at that same angle. This is true no matter at what angle the light is shining.

You can easily see the effects of this law by using a small mirror, a flashlight, some cardboard and tape, and a little bit of chalk dust or flour. (This demonstration works even better with a laser pointer.) Draw a straight line down the center of a square piece of cardboard. Then fold the cardboard in half along this line. On a second piece of cardboard, trace around the lens end of your flashlight. Cut along your traced line, then poke

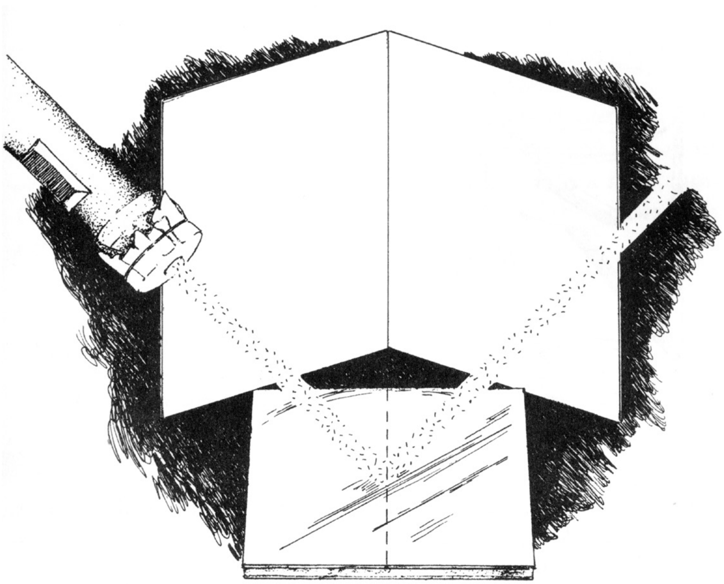


Light strikes a mirror and reflects back at the same angle.

a small hole in the center of the cutout shape. Cover the lens of the flashlight with it, taping it securely in place. That will give you a narrow beam of light when you turn on the flashlight.

Place the mirror on a table. Stand the folded piece of cardboard on the table, centered behind the mirror. This will give you a vertical line to use to compare the angles of the light beam. Shake a very small amount of the chalk dust or flour into the air, to make the beam of the flashlight visible. Darken the room and shine the light onto the center of the mirror.

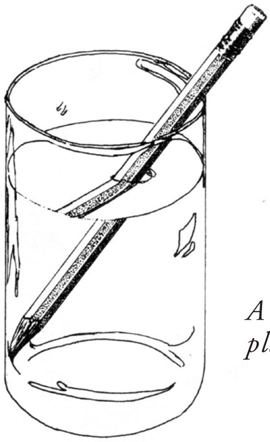
Notice that the beam of light bounces off the mirror at the same angle that it hits the mirror. It doesn't matter at what angle you hold the flashlight beam. The



You can see the path of light reflections by shaking fine powder into the air.

angle of the light reflected from the mirror will always match it exactly.

Light travels in straight lines. But light also bends when it travels from one kind of transparent material to another. If you stick a pencil into a glass of water, the pencil will appear to bend where it enters the water.



A pencil appears to bend when it is placed in water.

Of course, the pencil doesn't actually bend. It *looks* bent because the light traveling through the water bends. This bending of light is called *refraction*. Notice that the pencil seems to bend only at the surface of the water, where the water and air meet. Refraction takes place only at the boundary between two transparent materials.

Each transparent substance bends light at certain predictable angles. Refraction occurs because light travels at different speeds in different substances. The amount of refraction depends on the difference in the speed of light in the two materials. The bigger the difference in the speed of light between the two materials, the more the light will bend as it passes between them.

Light travels faster in air than it does in water. When light moves from air to water, it slows down. And as it does, it also refracts, or bends. Light travels even more slowly in glass. When light moves from air to glass, it bends even more. A pencil placed partly behind a thick piece of glass would seem to bend even more than the pencil in water.

One scientist who studied optics was Isaac Newton. Newton knew that when sunlight is refracted in a glass prism, the white light breaks up into a rainbow of colors, called a *spectrum*. Newton proved that sunlight is actually composed of all the colors of the rainbow.

Many years later, the astronomer William Herschel discovered the existence of another kind of light—light

Herschel discovered a surprising rise in temperature caused by invisible infrared light.