WAVES

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In the last chapter, we looked at how things move back and forth on their own. Now, let's think about what happens when a bunch of those things are together, like in a group. Imagine a bunch of objects stuck together, like in a piece of material. These objects can push and pull on each other, so when one moves, it affects the others.

For example, if you drop a small stone into a calm pond, the water's surface gets wavy. Those waves don't stay in one spot; they spread out in a circle from where the stone landed. If you keep dropping stones, you'll see these circles moving out from the center. It might seem like the water is flowing outward, but if you put some pieces of cork on the wavy water, they go up and down but stay in the middle. This shows that the water itself doesn't move out; it's just that a moving disturbance is created in the water.

Similarly, when we talk or make a sound, the sound spreads out from us, but there's no actual flow of air from one place to another. These patterns that move without moving the whole thing are called "waves." In this chapter, we'll learn more about these waves.

Waves are like carriers of energy, and they carry patterns of information from one place to another. Almost all our ways of talking to each other rely on sending signals through waves. When we speak, we create sound waves in the air, and when we listen, we pick up those sound waves. In many cases, communication uses various types of waves. For instance, sound waves can be turned into an electric signal, which can then create an electromagnetic wave that travels through an optical cable or a satellite. When someone receives the signal, they usually go through these steps in reverse to understand the original message.

Not every wave needs something to travel through. Take light waves, for example. They can move even in a vacuum, which is like empty space. Think about the light coming from faraway stars, hundreds of light years away. It reaches us even though there's hardly anything in space between us and those stars.

The most common waves, like those in strings, water, sound, or earthquakes, are called mechanical waves. These waves need something to move through, they can't go through empty space (vacuum). They happen because the particles in the material move back and forth and depend on how the material can stretch and bounce back.

Now, electromagnetic waves, a different kind of wave. They don't always need a material to travel through; they can move through empty space just fine. Examples of electromagnetic waves include light, radio waves, and X-rays. In empty space, all electromagnetic waves travel at the same speed, which is called c, whose value is:

$c = 299,792,458 \ \mathrm{ms}^{-1}$

There's another type of wave called "Matter waves." These waves are linked to tiny parts of matter, like electrons, protons, neutrons, atoms, and molecules. You'll dive into this concept more when you study quantum mechanics later. While it's a bit more abstract to think about than mechanical or electromagnetic waves, we already use these matter waves in some important technology. For example, we use matter waves associated with electrons in electron microscopes, which are really helpful tools in science and technology.

People have been inspired by waves in art and literature for a long time. But the scientific study of waves started in the 17th century. Some famous scientists who worked on wave physics include Christiaan Huygens, Robert Hooke, and Isaac Newton. Understanding waves in physics followed the study of things that swing back and forth, like masses on springs and pendulums. Waves in materials that can stretch or bounce, like strings, springs, and air, are linked to these kinds of oscillations.

We shall illustrate this connection through simple examples. Consider a collection of springs connected to one another. If the spring at one end is pulled suddenly and released, the disturbance travels to the other end.

What's going on here? Imagine the first spring gets stretched or squished. Since its connected to the second spring, it also gets stretched or squished, and so on. The disturbance travels from one end to the other, but each spring only wiggles a little around its normal position. Think about a stationary train at a station. The train cars are connected by springs. When an engine pushes one car that push moves through the springs to the other cars without moving the whole train.

Let's think about how sound waves move through the air. When a sound wave passes through the air, it squeezes or spreads out a small part of the air. This change in air density, called $\delta\rho$, also causes a change in pressure, δp, in that area. Pressure is like the force per space, similar to how a spring stretches or compresses. Here, the change in density is like what happens with a spring.

If an area gets compressed, the air molecules in that area get close together, and they try to move into the nearby area, which increases the density or squeezes the air in the nearby area. This causes a "crowding" in the first area. If an area becomes less crowded (rarefied), the surrounding air will rush in to fill that space, making the area less crowded, and this "less crowded" effect moves to the nearby area. So, by this process of squeezing and spreading out, the disturbance can move through the air, which is how sound travels.

When we look at solids, we can apply similar ideas. In a solid, like a crystal, the atoms or groups of atoms are neatly arranged in a repeating pattern. Each atom or group is in a balanced state because of the forces from nearby atoms. If we push or pull one atom while the others stay still, it will experience a force that tries to bring it back, just like a spring. So, you can imagine these atoms in the solid as endpoints connected by springs.