IN THIS CHAPTER

» Recognizing the physics in your world

» Understanding motion

» Handling the force and energy around you

» Warming up to thermodynamics

Chapter 1

Using Physics to Understand Your World

Physics is the study of the world and universe around you. Luckily, the behavior of matter and energy — the stuff of this universe — is not completely unruly. Instead, it strictly obeys laws that we can understand through the careful application of the *scientific method,* which relies on experimental evidence and rigorous reasoning. In this way, physicists have been uncovering more and more of the beauty that lies at the heart of the workings of the universe, from the infinitely small to the mind-bogglingly large.

Physics is an all-encompassing science. You can study various aspects of the natural world (in fact, the word *physics* is derived from the Greek word *physika,* which means "natural things"), and accordingly, you can study different fields in physics: The physics of objects in motion, of energy, of forces, of gases, of heat and temperature, and so on. This book exposes you to the study of all these topics and many more. In this chapter, we give you an overview of physics — what it is, what it deals with, and why mathematical calculations are important to it.

What Physics Is All About

Thinking about physics makes most of us a little nervous. The sheer number of equations, symbols, and other terms makes physics seem like a language in and of itself. Guess what? It is! And by reading this book, you can pick up the key to understanding this language. Physics exists to help you make sense of the world, and it's a human adventure — undertaken on behalf of everyone — into the way the universe works.

REMEMBER

At its root, physics is all about becoming aware of your world and using mental and mathematical models to explain it. The gist of physics is this: You start by making an observation, you create a model to simulate that situation, and then you add some math to fill it out — and voilà! You have the power to predict what will happen in the real world. All this math exists to help you see what happens and why.

In this section, we explain how real-world observations fit in with the math. The later sections take you on a brief tour of the key topics that comprise basic physics.

Observing the world

The complexity of today's world is an excellent starting point for observations of motion. Leaves are waving, the sun is shining, light bulbs are glowing, driverless cars are moving, 3-D printers are making objects, people are walking and riding bikes, streams are flowing, and so on. When you stop to examine these actions, your natural curiosity gives rise to endless questions such as these:

- Why do I slip when I try to climb that snowbank?
- How distant are other stars, and how long would it take to get there?
- How can a thermos flask keep hot things warm *and* keep cold things cool?
- Why does an enormous cruise ship float when a paper clip sinks?
- Why does water roll around when it boils?

Any law of physics comes from very close observation of the world, and any theory that a physicist comes up with has to stand up to experimental measurements. Physics goes beyond qualitative statements about physical actions — "If I push the child on the swing harder, then she swings higher," for example. With the laws of physics, you can predict precisely how much higher the child will swing.

Making predictions

Physics is simply about modeling the world (although an alternative viewpoint claims that physics actually uncovers the truth about the workings of the world; it doesn't just model it). You can use these *mental models* (abstract representations of physical phenomena) to describe how the world works: How blocks slide down ramps, how stars form and shine, how black holes trap light so it can't escape, what happens when cars collide, and so on.

Initially, physics models are relatively number-free; they focus on explaining and understanding scenarios at a high level. Here's an example: How are stars created? You could start by saying that stars are made up of this layer and then that layer, and as a result, this reaction takes place, followed by that one. And pow! — you have a star.

As time goes on, those models become more numerically inclined. Physics class would be a cinch if you could simply say, "That cart is going to roll down that hill, and as it gets toward the bottom, it's going to roll faster and faster." But the story is more involved than that: Not only can you say that the cart is going to go faster, but by exerting your grasp of the physical world, you can also say how much faster it'll go.

REMEMBER

Think about the power of physics this way: You can start with a qualitative, intuitive explanation of some physical phenomenon that just makes sense to you — such as the harder you throw a ball, the further it will go. Applying physics takes that intuitive understanding into a quantitative result: If you know the force with which you throw the ball, you can predict how far it will travel!

There's a delicate interplay between theory — formulated with math — and experimental measurements. Often experimental measurements not only verify theories but also suggest ideas for new theories, which in turn suggest new experiments. Theories and measurements feed off each other and lead to further discovery.

Many people approaching the technical side of physics may think of math as something tedious and overly abstract. However, in the context of physics, math comes to life. While quadratic equations may seem like something you'd rather skip over, don't rush to judgement — they're key to understanding concepts such as the correct angle to fire a rocket for the perfect trajectory. Chapter 2 explains all the math you need to know to perform basic physics calculations.

Reaping the rewards

So what do you get out of studying physics? If you want to pursue a career in physics or in a related field such as engineering, the answer is clear: You'll need this knowledge on an everyday basis. But even if you're not planning to embark on a physics-related career, you can get a lot out of studying the subject. You can apply much of what you discover in an introductory physics course to real life for these reasons:

- **In a sense, all other sciences are based upon physics.** For example, the structure and electrical properties of atoms determine chemical reactions; therefore, all of chemistry is governed by the laws of physics. In fact, you could argue that everything ultimately boils down to the laws of physics!
- **Physics does deal with some pretty cool phenomena.** Many videos of physical phenomena have gone viral on TikTok (or other social media); take a look for yourself. Do a search for "non-Newtonian fluid," and you can watch the creeping, oozing dance of a cornstarch/water mixture on a speaker cone.
- **The applications of physics arm you with problem-solving skills for approaching any kind of problem.** Physics problems train you to stand back, consider your options for attacking the issue, select your method, and then solve the problem in the easiest way possible.

Observing Objects in Motion

Some of the most fundamental questions you may have about the world deal with objects in motion. Will that boulder rolling toward you slow down? How fast do you have to move to get out of its way? (Grab your calculator . . .) Evaluating motion was one of the earliest explorations of physics.

When you take a look around, you see that the motion of objects changes all the time. You see a motorcycle coming to a halt at a stop sign. You see a leaf falling and then stopping when it hits the ground, only to be picked up again by the wind. You see a pool ball hitting other balls in just the wrong way so that they all move without going where they should. Part 1 of this book handles objects in motion — from balls to railroad cars and most objects in between. In this section, we introduce motion in a straight line, rotational motion, and the cyclical motion of springs and pendulums.

Measuring speed, direction, velocity, and acceleration

Speeds are big with physicists — how fast is an object going? Is 35 miles per hour not fast enough? How about 3,500? No problem when you're dealing with physics. Besides speed, the direction an object is going is important if you want to describe its motion. If the home team is carrying a football down the field, you want to make sure that they're going in the right direction.

When you put speed and direction together, you get a *vector* — the velocity vector. Vectors are a very useful kind of quantity. Anything that has both magnitude (an amount) and direction is best described with a vector. Vectors are often represented as arrows, where the length of the arrow tells you the magnitude (size), and the direction of the arrow tells you, well, the direction. For a velocity vector, the length corresponds to the speed of the object, and the arrow points in the direction the object is moving. (To find out how to use vectors, head to Chapter 4.)

TIP

Everything has a velocity, so velocity is great for describing the world around you. Even if an object is at rest with respect to the ground, it's still on the Earth, which itself has a velocity due to its orbit around the Sun. (And the Sun's in motion around the center of the galaxy — hope you aren't dizzy now!)

If you've ever ridden in a car, you know that velocity isn't the end of the story. Cars don't start off traveling at 60 miles per hour; stepping on the accelerator pedal kicks off a chain of events that leads to a car accelerating until it reaches the speed limit (and maybe beyond — but we won't tell!). Like velocity, acceleration has not only a magnitude but also a direction, so acceleration is a vector in physics as well. We cover speed, velocity, and acceleration in Chapter 4.

Round and round: Rotational motion

Plenty of things go round and round in the everyday world: Figure skaters, tires, pitchers' arms, clothes in a dryer, roller coasters doing the loop, or just little kids spinning from joy in their first snowstorm. That being the case, physicists want to get in on the action with measurements. Just as you can have a car moving and accelerating in a straight line, its tires can rotate and accelerate in a circle.

Fortunately, switching from the linear to the rotational world is eminently doable thanks to a handy physics *analog* (a fancy word for "equivalent") for everything linear in the rotational world. For example, distance traveled (linear) becomes angle turned (rotational). Speed in meters per second becomes angular speed in angle turned per second. Even linear acceleration becomes rotational acceleration.

Once you're familiar with linear motion, rotational motion will quickly become second nature. You use the same equations for both linear and angular motion — just different symbols with slightly different meanings (angle replaces distance, for example). You'll be looping the loop in no time. Chapter 7 has the details.

Springs and pendulums: Simple harmonic motion

Have you ever watched something bouncing up and down on a spring? That kind of motion puzzled physicists for a long time, until they did what they do best: Derive equations! They discovered that when you stretch a spring, the force isn't constant. The spring pulls back, and the more you pull the spring, the stronger it pulls back.

So how does the force compare to the distance you pull a spring? The force is directly proportional to the amount you stretch the spring. Double the amount you stretch the spring, and you double the amount of force with which the spring pulls back. (Just don't overstretch it; damaged springs may not work as expected.)

Physicists were overjoyed — this was the kind of math they understood. Force proportional to distance? Great — you can put that relationship into an equation, and you can use that equation to describe the motion of the object tied to the spring. Physicists got results that revealed just how objects tied to springs would move — another triumph of physics.

REMEMBER

This particular triumph of physics is called *simple harmonic motion*. It's *simple* because force is directly proportional to distance, so the result is simple. It's *harmonic* because it repeats over and over again as the object on the spring bounces up and down. Physicists were able to derive simple equations that could tell you exactly where the object would be at any given time.

But that's not all. Simple harmonic motion applies to many objects in the real world, not just things on springs. For example, pendulums also move in simple harmonic motion. Say you have a stone that's swinging back and forth on a string. As long as the arc it swings through isn't too high, the stone on a string is a pendulum; therefore, it follows simple harmonic motion. If you know how long the string is and how big of an angle the swing covers, you can predict where the stone will be at any time. We discuss simple harmonic motion in Chapter 13.

When Push Comes to Shove: Forces

Forces are a particular favorite in physics. You need forces to get motionless things moving — literally. Consider a stone on the ground. Many physicists (except, perhaps, geophysicists) would disregard it altogether. It's just sitting there. What fun is that? What can you measure about that? After physicists had measured its size and mass, they'd lose interest.

But kick the stone — that is, apply a force — and watch the physicists come running over. Now something is happening! The stone started at rest, but now it's moving. You can find all kinds of numbers associated with this motion. For instance, you can connect the force you apply to the stone to its mass and get its acceleration. And physicists love numbers because numbers help describe what's happening in the physical world.

Physicists are experts in applying forces to objects and predicting the results. Got a refrigerator to push up a ramp and want to know if it'll go? Ask a physicist. Have a rocket to launch? Same thing.

Absorbing the energy around you

You don't have to look far to find your next occurrence of physics. (But, then again, you never do.) As you exit your house in the morning, for example, you may hear a crash up the street. Two cars have collided at a high speed, and, while locked together, they're sliding your way. Thanks to the physics of energy and momentum (presented in Part 3 of this book), you can make the necessary measurements and predictions to know exactly how far you have to move to get out of the way.

Your newfound grasp of energy and momentum allows you to solve these problems (which, we hope, are entirely theoretical.) You use these ideas to describe the motion of objects with mass. The energy of motion is called *kinetic energy*, and when you accelerate a car from 0 to 60 miles per hour in 10 seconds, the car ends up with plenty of kinetic energy.

Where does the kinetic energy come from? It comes from *work*, the phenomenon of a force moving an object through a distance. The energy can also come from *potential energy*, the energy stored in the object. Potential energy comes from the work done by a particular kind of force, such as gravity or electrical forces. Using gasoline, for example, an engine does work on the car to get it up to speed.

However, that's not the end of the story. You need a force to accelerate something, and the way the engine does work on the car, surprisingly, is to use the force of friction with the road. Without friction, the wheels would simply spin, but because of a frictional force, the tires impart a force on the road.

TIP

For every force between two objects, there is a reactive force of equal size but in the opposite direction. In the preceding car example, just as the car exerts a force onto the road, the road exerts forces onto the car. In one direction, this force causes the car to accelerate, and in the other, it prevents the car from falling through the road!

Or say that you're moving a piano up the stairs of your new place. After you move it up the stairs, your piano has potential energy, simply because you put in a lot of work against gravity to get the piano up those six floors. Unfortunately, your roommate hates pianos and drops yours out the window. What happens next? The potential energy of the piano — due to its height in a gravitational field — is converted into kinetic energy, the energy of motion. You decide to calculate the final speed of the piano as it hits the street. (Next, you calculate the bill for the piano, hand it to your roommate, and go back downstairs to get your drum set.)

Getting weighed down with pressures in fluids

Did you ever notice that when you're 5,000 feet down in the ocean, the pressure is different from at the surface? You've never been 5,000 feet beneath the ocean waves? Then you may have noticed the difference in pressure when you dive into a swimming pool. The deeper you go, the higher the pressure is because of the weight of the water above you exerting a force downward. *Pressure* is defined as force per unit area.

If you have a swimming pool, any physicists worth their salt can tell you the approximate pressure at the bottom if you tell them how deep the pool is. When working with fluids, you have all kinds of other quantities to measure, such as the velocity of fluids through small holes, a fluid's density, and so on. Once again, physics responds with grace under pressure (so to speak). You can read about forces in fluids in Chapter 8.

Feeling the Heat with Thermodynamics

Heat and cold are parts of your everyday life. Did you ever take a look at the beads of condensation on a cold glass of water in a warm room? Water vapor in the air is being cooled when it touches the glass, and it condenses into liquid water in the form of condensation beads. The condensing water vapor passes thermal energy to the glass, which passes thermal energy to the cold drink, which ends up getting warmer as a result.

Thermodynamics can tell you how much heat you're radiating away on a cold day, how many bags of ice you need to cool a lava pit, and anything else that deals with heat energy. You can also take the study of thermodynamics beyond planet Earth. Why is the darkness of space cold? Here on Earth, air insulates you and the world stays warm even after the Sun sets. In space, there is no air, and temperatures can drop hundreds of degrees as you go from sunlight to shadow (although it takes time for spacecraft, moons, and people who forgot their space suits to cool off).

Radiating heat is just one of the three ways heat can be transferred. You can discover plenty more about heat, whether created by a heat source like the Sun or by friction, through the topics in Part 4.