# Chapter 1

# Understanding Your World: Physics II, the Sequel

## In This Chapter

- Looking at electricity and magnetism
- Studying sound and light waves
- Exploring relativity, radioactivity, and other modern physics

Physics is not really some esoteric study presided over by guardians who make you take exams for no apparent reason other than cruelty, although it may seem like it at times. Physics is the human study of *your* world. So don't think of physics as something just in books and the heads of professors, locking everybody else out.

Physics is just the result of a questioning mind facing nature. And that's something everyone can share. These questions — what is light? Why do magnets attract iron? Is the speed of light the fastest anything can go? — concern everybody equally. So don't let physics scare you. Step up and claim your ownership of the topic. If you don't understand something, demand that it be explained to you better — don't assume the fault is with you. This is the human study of the natural world, and you own a piece of that.

Physics II takes up where Physics I leaves off. This book is meant to cover — and unravel — the topics normally covered in a second-semester intro physics class. You get the goods on topics such as electricity and magnetism, light waves, relativity (the special kind), radioactivity, matter waves, and more. This chapter gives you a sneak preview.

# Getting Acquainted with Electricity and Magnetism

Electricity and magnetism are intertwined. Electric charges in motion (not static, nonmoving charges) give rise to magnetism. Even in bar magnets, the tiny charges inside the atoms of the metal cause the magnetism. That's why you always see these two topics connected in Physics II discussions. In this section, I introduce electricity, magnetism, and AC circuits.

## Looking at static charges and electric field

Electricity is a very big part of your world — and not just in lightning and light bulbs. The configuration of the electric charges in every atom is the foundation of chemistry. As I note in Chapter 14, the arrangement of electrons gives rise to the chemical properties of matter, giving you everything from metals that shine to plastics that bend. That electron setup even gives you the very color that materials reflect when you shine light on them.

Electricity studies usually start with electric charges, particularly the force between two charges. The fact that charges can attract or repel each other is central to the workings of electricity and to the structure of the atoms that make up the matter around you. In Chapter 3, you see how to predict the exact force involved and how that force varies with the distance separating the two charges.

Electric charges also fill the space around them with electric field — a fact familiar to you if you've ever felt the hairs on your arm stir when you've unloaded clothes from a dryer. Physicists measure electric field as the force per unit charge, and I show you how to calculate the electric field from arrangements of charges.

Next up is the idea of *electric potential,* which you know as *voltage.* Voltage is the work done per unit charge, taking that charge between two points. And yes, this is exactly the kind of voltage you see stamped on batteries.

With those three quantities — force, electric field, and voltage, you nail down static electric charges.

## Moving on to magnetism

What happens when electric charges start to move? You get magnetism, that's what. *Magnetism* is an effect of electric charge that's related to but distinct from the electric field; it exists only when charges are in motion. Give an electron a push, send it sailing, and presto! You've got magnetic field. The idea that moving electric charges cause magnetic field was big news in physics — that fact's not obvious when you simply work with magnets.

Electric charges in motion form a *current,* and various arrangements of electric current create different magnetic fields. That is, the magnetic field you see from a single current-bearing wire is different from what you see from a loop of current — let alone a whole bunch of loops of current, an arrangement known as a *solenoid.* I show you how to predict magnetic field in Chapter 4.

Not only do moving electric charges give rise to magnetic fields, but magnetic fields also affect moving electric charges. When an electric charge moves through a magnetic field, that charge feels a force on it at right angles to the magnetic field and the direction of motion. The upshot is that left to themselves, moving charges in uniform magnetic fields travel in circles (an idea chemists appreciate, because that's what allows a mass spectrometer to sort out the chemical makeup of a sample). How big is the circle? How does the radius of the circle correlate with the speed of the charge? Or with the magnitude of the charge? Or with the strength of the magnetic field? Stay tuned. The answers to all these questions are coming up in Chapter 4.

## AC circuits: Regenerating current with electric and magnetic fields

Students often meet electrical circuits in Physics I (you can read about simple direct current [DC] circuits in *Physics For Dummies*). In Chapter 5, you get the Physics II version: You take a look at what happens when the voltage and current in a circuit fluctuate in time in a periodic way, giving you *alternating voltage* and *currents*. You also encounter some new circuit elements, the inductor and capacitor, and see how they behave in AC circuits. Many of the electrical devices that people use every day depend on such elements in alternating currents.

In reading about the inductor, you also encounter one of the fundamental laws that relates electric and magnetic fields: Faraday's law, which explains how a changing magnetic field induces a voltage that generates its own magnetic field. This law doesn't just apply to inductors; it applies to all electric and magnetic fields, wherever they occur in the universe!

# Riding the Waves

Waves are a huge topic in Physics II. A *wave* is a traveling disturbance that carries energy. If the disturbance is *periodic,* the amount of disturbance repeats in space and time over a distance called the *wavelength* and a time called the *period*. Chapter 6 delves into the workings of waves so you can see the relationships among the wave's speed, wavelength, and *frequency* (the rate at which cycles pass a particular point). In the rest of the chapters in Part III of this book, you explore particular types of waves, including electromagnetic waves (such as light and radio waves) and sound.

## Getting along with sound waves

Sound is just a wave in air, and the various interactions of sound waves are just a result of the behaviors shared by all waves. For instance, sound waves can reflect off a surface — just let sound waves collide with walls and listen for the echo. Sound waves also interfere with other waves, and you can hear the effects — or silence, as the case may be. These two kinds of interaction form the basis for understanding the harmonic tones in music.

The qualities of a sound, such as pitch and loudness, depend on the properties of the wave. As you may have noticed by hearing the change of pitch of a siren on a police car as it passes by, pitch changes when the source or the listener moves. This is called the *Doppler effect*. You can take this to the extreme by examining the shock wave that happens when objects move very quickly through the air, breaking the sound barrier. This is the origin of the sonic boom. I cover all this and more in Chapter 7.

## Figuring out what light is

You focus on light a good deal in Physics II. How light works is now well-known, but that wasn't always the case. Imagine the excitement James Clerk Maxwell must've felt when the speed of light suddenly jumped out of his equations and he realized that by combining electricity and magnetism, he'd come up with light waves. Before that, light waves were a mystery — what made them up? How could they carry energy?

After Maxwell, all that changed, because physicists now knew that light was made up of electrical and magnetic oscillations. In Chapter 8, you follow in Maxwell's footsteps to come up with his amazing result. There, you see how to calculate the speed of light using two entirely different constants having to do with how well electric and magnetic fields can penetrate empty space.

As a wave, light carries energy as it travels, and physicists know how to calculate just how much energy it can carry. That amount of energy is tied to the magnitude of the wave's electric and magnetic components. You get a handle on how much power that light of a certain intensity can carry in Chapter 8.

Of course, light is only the visible portion of the *electromagnetic spectrum* — and it's a small part at that. All kinds of electromagnetic radiation exist, classified by the frequency of the waves: X-rays, infrared light, ultraviolet light, radio waves, microwaves, even ultra-powerful gamma waves.

## Reflection and refraction: Bouncing and bending light

Light's interaction with matter makes it interesting. For instance, when light interacts with materials, some light is absorbed and some reflected. This process gives rise to everything you see around you in the daily world.

Reflected light obeys certain rules. Primarily, the *angle of incidence* of a light ray — that is, the angle at which the light strikes the surface (measured from a line pointing straight out of that surface) — must equal the *angle of reflection* — the angle at which the light leaves the surface. Knowing how light is going to bounce off objects is essential to all kinds of devices, from the periscopes in submarines to telescopes, fiber optics, and even the reflectors that the Apollo astronauts placed on the moon. Chapter 10 covers the rules of reflection.

Light can also travel through materials, of course (or people wouldn't have windows, sunglasses, stained glass, and a lot more). When light enters one material from another, it bends, a process known as *refraction* — which is a big topic in Chapter 9. The amount the light bends depends on the materials involved, as measured by their *indexes of refraction*. That's useful to know in all kinds of situations. For example, when lens-makers understand how light bends when it enters and leaves a piece of glass, they can shape the glass to produce images. You take a look through lenses next.

## Searching for images: Lenses and mirrors

If you're eager to look at the practical applications of Physics II topics, you'll probably enjoy optics. Here, you work with lenses and mirrors, allowing you to explore the workings of telescopes, cameras, and more.

### Focusing on lenses

Lenses can focus light, or they can diverge it. In either case, you can get an image (sometimes upright, sometimes upside down, sometimes bigger than the object, sometimes smaller). The image is either virtual or real. In a *real image,* the light rays converge, so you can put a screen at the image location and see the image on the screen (like at the movies). A *virtual image* is an image from which the light appears to diverge, such as an image in a magnifying glass.

Armed with a little physics, you have the lens situation completely under control. If you're visually inclined, you can find info on the image using your drawing skills. I explain how to draw ray diagrams, which show how light passes through a lens, in Chapter 9.

You can also get numeric on light passing through lenses. The thin-lens equation gives you all you need to know here about the object and image, and you can even derive the magnification of lenses from that equation. So given a certain lens and an object a certain distance away, you can predict exactly where the image will appear and how big it will be (and whether it'll be upside down or not).

If one lens is good, why not try two? Or more? After all, that's the idea behind microscopes and telescopes. You get the goods on such optical instruments in Chapter 9, and if you want, you can be designing microscopes and telescopes in no time.

### All about mirrors/srorrim tuoba llA

You can get numeric on the way mirrors reflect light, whether a mirror is flat or curved. For instance, if you know just how much a mirror curves and where an object is with reference to the mirror, you can predict just where the image of the object will appear.

In fact, you can do more than that — you can calculate whether the image will be upright or upside down. You can calculate just how high it will be compared to the original object. You can even calculate whether the image will be real (in front of the mirror) or virtual (behind the mirror). I discuss mirrors in Chapter 10.

### Calling interference: When light collides with light

Not only can light rays interact with matter; they can also interact with other light rays. That shouldn't sound too wild — after all, light is made up of electric and magnetic components, and those components are what interact with the electric fields in matter. So why shouldn't those components also interact with similar electric and magnetic components from other light rays?

When the electric component of a light ray is at its maximum and it encounters a light ray with its electric component at a minimum, the two components cancel out. Conversely, if the two light rays happen to hit just where the electric components are at a maximum, they add together. The result is that when light collides with light, you can get *diffraction* patterns — arrangements of light and dark bands, depending on whether the net result is at a maximum or minimum. In Chapter 11, you see how to calculate what the diffraction patterns look like for an assortment of different light sources, all of which has been borne out by experiment.

## Branching Out with Modern Physics

The 20th century saw an explosion of physics topics, and collectively, those topics are called *modern physics.* Some revolutionary ideas — such as quantum mechanics and Einstein's theory of special relativity — changed the foundations of how physicists saw the universe; Isaac Newton's mechanics didn't always apply. As physicists delved deeper into the workings of the world, they found more and more powerful ideas, which allowed them to describe exponentially more about the world. This led to developments in technology, which meant that experiments could probe the universe ever more minutely (or expansively).

Most people have heard of relativity and radioactivity, but you may not be familiar with other topics, such as *matter waves* (the fact that when matter travels, it exhibits many wave-like properties, just like light) or *blackbody radiation* (the study of how warm objects emit light). I introduce you to some of these modern-physics ideas in this section.

### Shedding light on blackbodies: Warm bodies make their own light

If you've ever seen an incandescent light bulb at work (or you've glanced at the sun), you know that hot things emit light. In fact, any body with any warmth at all emits electromagnetic waves, such as light.

In particular, physicists can calculate the wavelength of the electromagnetic waves where the emitted spectrum peaks, given an object's temperature. This topic is intimately tied up with *photons* — that is, particles of light — and you can predict how much energy a photon carries, given its wavelength. Details are in Chapter 13.

## Speeding up with relativity: Yes, $E = mc^2$

Here it is at last: special relativity and Einstein. What, exactly, does $E = mc^2$ mean? It means that matter and energy can be considered interchangeable, and it gives the energy-equivalent of a mass $m$ at rest. That is, if you have a tomato that suddenly blows up, converting all its mass into energy (not a likely event), you can calculate how much energy would be released. (***Note:*** Converting 100 percent of a tomato's mass into pure energy would create a huge explosion; a nuclear explosion converts only a small percentage of the matter involved into energy.)

Besides $E = mc^2$, Einstein also predicted that at high speeds, time stretches and length contracts. That is, if a rocket ship passes you traveling at 99 percent of the speed of light, it'll appear contracted along the direction of travel. And time on the rocket ship passes more slowly than you'd expect, using a clock at rest with respect to you. So if you watch a rocket ship pass by at high speed, do clocks tick more slowly on the rocket ship than they do for you, or is that some kind of trick? No trick — in fact, the people on the rocket ship age more slowly than you do, too.

Airplanes travel at much slower speeds, but the same effect applies to them — and you can calculate just how much younger a jet passenger is than you (but here's a disappointing tip to people searching for the fountain of youth: It's an immeasurably small amount of time). You explore special relativity in Chapter 12.

## Assuming a dual identity: Matter travels in waves, too

Light travels in waves — that much doesn't take too many people by surprise. But the fact that matter travels in waves can be a shocker. For example, take your average electron, happily speeding on its way. In addition to exhibiting particle-like qualities, that electron also exhibits wave-like qualities — even so much so that it can interfere with other electrons in flight, just as two light rays can, and produce actual diffraction patterns.

And electrons aren't the only type of matter that has a wavelength. Everything does — pizza pies, baseballs, even tomatoes on the move. You wrap your mind around this when I discuss matter waves in Chapter 13.

## Meltdown! Knowing the αβγ's of radioactivity

Nuclear physics has to do with, not surprisingly, the nucleus at the center of atoms. And when you have nuclear physics, you have radioactivity.

In Chapter 15, you find out what makes up the nucleus of an atom. You see what happens when nuclei divide *(nuclear fission)* or combine *(nuclear fusion)* — and in particular, you see what happens when nuclei decay by themselves, a process known as *radioactivity.*

Not all radioactive materials are equally radioactive, of course, and *half-life* — the time it takes for half of a sample to decay — is one good measure of radioactivity. The shorter the half-life, the more intensely radioactive the sample is.

You encounter all the different types of radioactivity — alpha, beta, and gamma — in the tour of the subject in Chapter 15.