Chapter 1

Introducing Optics, the Science of Light

In This Chapter

- Uncovering the basic properties of light
- Getting a glimpse of optics applications

Light is probably one of those things that you take for granted, kind of like gravity. You don't know what it is or where it comes from, but it's always there when you need it. Your sight depends on light, and the information you get about your environment comes from information carried by the light that enters your eye.

Humans have spent centuries studying light, yet it remains something of a mystery. We do know many properties of light and how to use them to our benefit, but we don't yet know everything. Therefore, *optics* is the continuing study of light, from how you make it to what it is and what you can do with it. In fact, optics consists of three fields: geometrical optics, physical optics, and quantum optics. As we learn more about light, we find new ways to use it to improve our lives. This chapter shines a little, well, light on light.

Illuminating the Properties of Light

Because of an accidental mathematical discovery, light is called an *electromagnetic wave,* a distinction indicating that light waves are made up of electric and magnetic fields. You're probably used to thinking of light as the stuff your eyes can detect. For many people who work with light on a regular basis, however, the term *light* applies to all electromagnetic radiation, anything from ultra-low frequencies to radio frequencies to gamma rays.

Light has both wave and particle properties (as I discuss in the chapters in Part I), but you can't see both at the same time. Regardless of the properties, light is produced by atoms and accelerating charges. You can choose from many different arrangements to produce light with the desired wavelength or frequency (basically, the color that you want). Optics covers every light source from light bulbs to radio transmissions.

You have three ways to manipulate where light goes (that is, to make light do what you want): reflection, refraction, and diffraction, which I introduce in the following sections. You can use some basic equations to calculate the result of light undergoing all these processes. Optics then goes farther to investigate ways to find practical uses of these phenomena, including forming an image and sending digital data down a fiber.

Creating images with the particle property of light

You most commonly see the particle property of light when you're working with *geometrical optics,* or making images (see Part II). In this theory, the particles of light follow straight-line paths from the source to the next surface. This idea leads to the simplest type of imaging: shadows. Shadows don't give you a lot of information, but you can still tell the shape of the object as well as where the light source is.

Two important concepts in geometrical optics are reflection and refraction. *Reflection* describes light bouncing off a surface. *Refraction* deals with the bending of the path of the light as the light goes from one material to another. You can use these processes to create and modify images, and knowledge of these effects can also help you deal with factors called *aberrations,* which cause an image to be blurry. You can also use the lenses and mirrors that work with refraction and reflection to eliminate the washed-out effect you sometimes get when creating an image; if you have too much light, all the images created wash each other out, so all you see is light.

Harnessing interference and diffraction with the wave property of light

Physical optics, which I cover in Part III, looks at the wave properties of light. *Interference* (where two or more waves interact with each other) and *diffraction* (the unusual behavior of waves to bend around an obstacle to fill the space behind it) are unique to waves.

To explain *optical interference* (interference between light waves), you need to know about optical polarization. *Optical polarization* describes the orientation of the plane that the light wave's electric field oscillates in. In optics, only the electric field matters in almost all interactions with matter, because the electric field can do work on charged particles and the magnetic field can't. Several devices can change the polarization state so that light can be used for many different applications, including lasers and optical encoding.

The wave property allows you to use interference to help measure many things, such as the index of refraction and surface feature height or irregularities. Specifically, several optical setups called *interferometers* use interference for measurement.

Diffraction, the other unique wave phenomenon, determines resolution, which is how close two objects can be while still being distinguishable. Arrangements with many slits placed very close together create a *diffraction grating,* which you can use to help identify materials by separating the different colors of light the materials emit.

Using Optics to Your Advantage: Basic Applications

Understanding the basic properties of light is one thing, but being able to do something practical with them is another. (Head to the earlier section "Illuminating the Properties of Light" for more on these basic characteristics.) Putting the fundamental knowledge to good use means developing optical instruments for a wide variety of uses, as I discuss in Part IV. Here's just a taste of some of the practical applications of optical devices:

- **Manipulating images:** As I note earlier in the chapter, knowing how images are made and changed with different types of lenses or mirrors allows you to design simple optical devices to change what the images look like. Eyeglasses are designed and built to correct nearsightedness or farsightedness, and a simple magnifying glass creates an enlarged image of rather small objects.

  Physical characteristics limit how large an image a simple magnifier can make, so you can build a simple microscope with two lenses placed in the right positions to provide greater enlargement of even smaller objects. To see things far away, you can build a telescope and to project an image onto a large screen, you can build a projector.

- **Developing lighting:** You can use also use optics principles to design lighting sources for particular applications, such as specific task lighting, general area lighting, and decorative lighting. The development of incandescent light bulbs, compact fluorescent bulbs, and future devices such as light emitting diodes (LEDs) all start with knowledge of the optical properties of materials.
- **Seeing where the eye can't see:** Optics, and particularly fiber optics, can send light into areas that aren't directly in your line of sight, such as inside a collapsed building or a body. Fiber optics relies on knowledge of total internal reflection (see Chapter 4) to be able to trap light inside a small glass thread.

Expanding Your Understanding of Optics

The fundamental principles of optics can tell you what will happen with light in different situations, but making something useful with these principles isn't so easy. Applications of optics, including optical systems, combine two or more optical phenomena to create a desired output. Most applications of optics require knowledge about how optical principles work together in one system; making optical systems requires careful thought to make sure that the light behaves in the way you want it to when you look at the final result, whether that's light from a particular source (such as a light bulb or laser) or an image from a telescope or camera.

Why are such advanced applications important? Seeing how all the optics phenomena work together (often in subtle ways) is the point of optical engineering. Knowing how light interacts with different materials and being able to read this information has led to advances in important fields such as medical imaging and fiber-optic communication networks.

Considering complicated applications

Some optics applications, such as those in Part V, require combinations of many different optics principles to make useful devices. Cameras that record images require knowledge of image formation, focusing, and intensity control to make nice pictures. Holography and three-dimensional movies put depth perception and diffraction gratings to work. Many medical-imaging techniques exploit the effects of light and how light carries information.

Lasers are a special light source with many uses. Because lasers are light, you have to understand how light works so that you can use them effectively and safely. Lasers today are involved in medical applications, various fabrication tasks, numerous quality control arrangements, optical storage discs such as CDs and DVDs, and a variety of military and law enforcement applications (but no laser guns yet).

Complex imaging devices can also allow you to see in low- or no-light situations. Thermal cameras create images based on temperature differences rather than the amount of reflected light. The age-old arrangement of looking at the heavens requires modifications of the simple telescope to overcome some of the limitations of using refracting optics.

Adding advanced optics

Advanced optics (see Part VI) covers phenomena that aren't simply based on simple refraction. When the index of refraction — normally independent of the intensity of the light — changes with the intensity, weird things can happen, such as frequency conversion in crystals. The area of advanced optics that studies these effects is called *nonlinear optics,* and it has provided numerous new diagnostic capabilities and laser wavelengths.

Another area of advanced optics is single photon applications. Single photon applications show some rather bizarre behavior associated with the fact that light is in an indeterminate state unless you make a measurement. This subject (also presented in Part VI) is the basis for new applications in secure communications and super-fast computing.

Paving the Way: Contributions to Optics

The field of optics is full of contributions from students challenging the establishment and the established way of thinking. Part VII includes some experiments you can try to experience some of the optics principles presented in this book; building some simple optical devices lets you begin to discover the challenges of building optical systems. After all, experiments are the root of discovery, so Part VII also looks at some important optics breakthroughs and the people who performed them.

All this information allows you to see how knowledge of optics advanced with contributions from newcomers to the field as well as established optical scientists. Using the basic principles outlined in this book, you'll have enough knowledge to be able to delve deeper into any optics subject you encounter in school, work, or just your curiosity. As optics technology progresses, you'll have the basic background knowledge to tackle any of the technology paths that develop. After all, the field of optics benefited from contributions from many different levels; if that doesn't motivate you to make the next significant contribution to the science of light, I don't know what will.