LASER

SUPERTOOL OF THE 1980s

JEFF HECHT AND DICK TERESI

TICKNOR & FIELDS
NEW YORK

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To Lois, Leah, and Jolyn, who put up with everything—J.H.

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PREFACE TO THE NEW EDITION

The laser world has been a busy place since the first edition of this book was published. President Reagan put lasers into the headlines when he suggested using them to defend against a nuclear attack. Laser communications systems that transmit signals through optical fibers have spread across the country, and in just a half-dozen years have reached what some call a third generation of technology. The latest expensive toy for affluent audiophiles — the digital Compact Disc player — uses a laser to play back music with superb fidelity. Growth has occurred throughout the laser industry, and laser stocks have become hot items on Wall Street. There is even a mutual fund that invests about half its assets in laser stocks.

There have been enough changes that, if we were starting this book anew, some details would differ. Yet in looking back, we find that we anticipated most of the important developments. Some of the high-capacity laser communications systems we mentioned in chapter 6 are here already; others are still to come. President Reagan's March 1983 "Star Wars" speech would not have surprised you if you had read chapter 7 a year earlier. And the coming of the Compact Disc was foretold at the end of chapter 13, long before it was on the market. Nonetheless, we do need to touch on the high points of the last couple of years.

The biggest advances in lasers have come at the highest and lowest powers. More free-electron lasers have been demonstrated, and the prospects for taming those strange beasts to produce high-power beams look better than ever. There are unofficial reports of progress in the government's super-secret effort to build high-powered X-ray lasers, although controlling such lasers won't be easy — their energy source is a nuclear explosion. Great strides have been made in improving low-power semiconductor lasers, which are finding many new uses in communications, measurement, and in the reading and writing of information.

The epic battle over credit for inventing the laser continues, starring Gordon Gould's laser patents (see chapter 4) and a cast of a thousand lawyers. Passage of a law allowing patents to be re-examined after they are issued has added still another twist to the convoluted tale. The legal wheels continue to grind slowly, and we've lost count of the number of court cases and appeals in the works. Meanwhile, on the other side of the globe, another laser pioneer is having a different interaction with the laws of his country. Nobel laureate Nikolai G. Basov was elected to the Presidium of the Supreme Soviet in late 1982, at the same time as Soviet leader Yuri Andropov.

Laser medicine continues its steady advance, although there have been no dramatic laser "miracle cures." Much exciting work has involved the use of low-power lasers to help heal wounds, to alleviate pain, or for "biostimulation." Los Angeles physician Judith Walker has found that a low-power laser beam can cause a nerve to fire — the first evidence of real physiological effects. However, another low-power laser treatment, which purports to use laser beams to smooth out wrinkles, has generated a storm of controversy. The American Society of Plastic and Reconstructive Surgeons says that laser "facelifts" are worthless, but the unorthodox physicians who use the technique claim the real problem is misleading advertising by a few medical hucksters.

Advances in laser communications have even surprised some of the professional wild-eyed optimists who try to predict the sales of new products. Companies in the United States and abroad are spending hundreds of millions of dollars on new "third generation" systems in which a single fiber can carry thousands of telephone conversations between telephone-company switching centers. In the United States and Great Britain, some of these communication links will run alongside railroad tracks. An even stranger blend of old and new technology has been suggested in Britain — running fiber-optic cables through sewers to deliver television programs to homes. (We wonder if the people planning X-rated cable television have heard of the idea.) Fiber-optic links to homes have been tested in Japan, Canada, and Europe, but only France has shown any interest in "fibering up" many homes in this decade. The Japanese have become the leaders in installing fiber-optic links in cars partly because American automakers blew their early advantage.

It is far from clear who holds the technological lead in laser weaponry — the United States or the Soviet Union. Gloom-and-doom prophecies of a fleet of orbiting Soviet battle stations remain unfulfilled, and some analysts think the United States is ahead. The possibility of antisatellite lasers is being taken very seriously — the Air Force is considering adding them to its shopping list of new weapons — although Pentagon analysts are now doubtful that the Soviets tested such a laser against an American satellite in the mid-1970s, as originally reported. Laser weapons have yet to make a big hit on the battlefield; it took the Air Force's Airborne Laser Laboratory nearly two years, from the time it started airborne tests, to bag its first air-to-air missile. The biggest controversy now surrounds antimissile laser weapons. It's easy to poke fun at the idea by pointing out that its main advocates are conservative politicians with names like "ray gun" and "wallop," but the issue is a deadly serious one (see chapter 7 for details on Senator Malcolm Wallop's laser battle station plan). Advances in X-ray and free-electron lasers have not overcome the real limitations on laser-weapon concepts, but neither have harsh words from skeptics succeeded in consigning laser weapons to the Pentagon's boondoggle archives.

Energy may have dropped from the headlines for a while, but laser energy research continues, though with little spectacular to report. The big fusion lasers at the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory have been replaced by somewhat bigger ones, and physicists think that they've learned more about fusion, but each year the fusion labs have to fight for their share of the budget. The Department of Energy did pick a laser process for enriching uranium isotopes — the atomic-vapor uranium process developed at Livermore — and that program is continuing. However, some people have begun to wonder who needs all that much enriched uranium, in light of the slow growth of nuclear power.

The spread of machining and measurement lasers in industry slowed as the recession hurt sales of all sorts of machine tools, but that trend turned around with the economy. Meanwhile, laser-automated check-out counters became commonplace at supermarkets. My six-year-old daughter now takes them for granted; while playing store one day she rang up purchases by passing items over a counter and saying "beep." Of course, the laser that reads the striped codes on food packages is rarely mentioned — it wouldn't do to let the customers confuse President Reagan's missile-zapping lasers with the innocuous ones under the check-out counter. Mercifully, talking check-out counters have yet to appear in many neighborhoods. The company that makes them claims that customers like the robot voices, but we've heard that supermarket customers in Lexington, Massachusetts, told them to shut up — appropriately enough for the place where the first shots in the American Revolution were fired two centuries ago.

The laser videodisk hasn't become a big hit on the consumer market, but the technology that makes it possible has found other uses. Audiodisk players containing tiny semiconductor lasers are reading digital recordings to reproduce ultrapure music. Modified laser videodisk players are generating the pictures and action for some video games. And a refined version of the technology can be used to store billions of bits of digital data on a reflective disk the size of a phonograph record.

Progress in some laser fields has been limited by technical, commercial, or other factors. Much of the novelty of laser displays has worn off; the laserium shows continue, but some laser artists have grown frustrated with the limitations of the medium. The hand-held game that was to use a holographic display never made it to the market; Atari, the manufacturer, became preoccupied with home computers and other products. Holography makes quiet inroads in industry, but in many ways the promise of holography is as hard to grasp as the holographic image itself.

All in all, laser technology is growing ever more important. *Lasers & Applications* magazine estimates that nearly $350 million worth of lasers was sold in 1982 and that those lasers were incorporated into systems selling for a total of $2.6 billion. The United States government is spending about three quarters of a billion dollars a year on laser research, mostly for weapons, fusion, and isotope enrichment. These figures show the extent to which the device that two decades ago was a laboratory curiosity has become a widely used tool.

What of the future? Look closely and you will see many futures, for the single label "laser" covers many diverse devices. The semiconductor lasers that promise to revolutionize telecommunications are worlds apart from the high-energy lasers that might someday revolutionize defense strategy. Lasers are already a vital part of the "information era," and their importance in the reading, writing, storage, and processing of information will grow. The laser will find a home in chemistry as it has in medicine, doing small and specialized jobs far better than anything else can. The supertool will be with us far beyond the 1980s.

Jeff Hecht, September 1983

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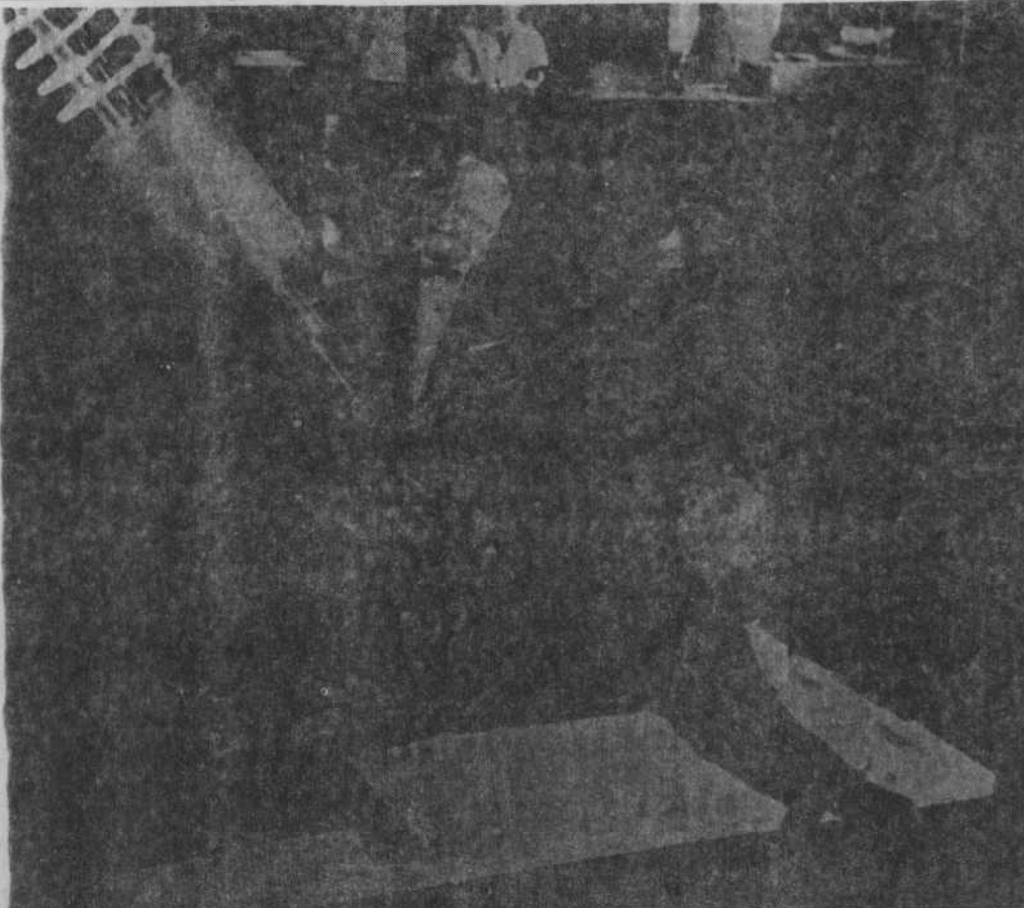
1 INTRODUCTION: SUPERTOOL

In H. G. Wells's *The War of the Worlds,* published in 1898, extraterrestrial aliens wreak destruction on our planet with their "heat ray," a beam of energy so hot, so powerful, that it destroys anything it touches. "Suddenly there was a flash of light," wrote Wells. "It was sweeping round swiftly and steadily, this flaming death, this invisible, inevitable sword of heat." Wells's heat ray, which inspired generations of science-fiction writers to imagine ray guns and death rays, was a chillingly accurate premonition of plans to use the high-energy infrared laser as a weapon.

When real lasers finally arrived—in 1960—writers and moviemakers immediately leaped upon their destructive power and substituted the word "laser" for ray gun. A laser was one of the leading pieces of machinery in the James Bond techno-spy thriller *Goldfinger* in the early 1960s. As you may recall, Bond (Sean Connery played the role at the time) was tied down to a metal table by the villain Goldfinger, his legs spread apart, while a laser made its way directly toward his genitals. The laser's bright, red, thick beam easily cut a swath through the table. It obviously had the power to tear him asunder, lengthwise.

This is, alas, the most popular image of the laser. A ray gun. A death ray. And indeed, some lasers *do* cut through metal and some *can* be used as weapons. But this image of the laser is a reflection more of the need for drama in works of fiction than of the laser's potential usefulness in our society. Most laser beams can't cut or burn and are at best faint pencil lines in the air, light scattered by dust. The nice sharp pictures of laser beams in this book are taken by projecting the beams through clouds of smoke, which scatter their light enough to allow them to be seen and photographed.



The laser, as portrayed in the movie *Goldfinger*, was simply an instrument of destruction. Courtesy Movie Star News

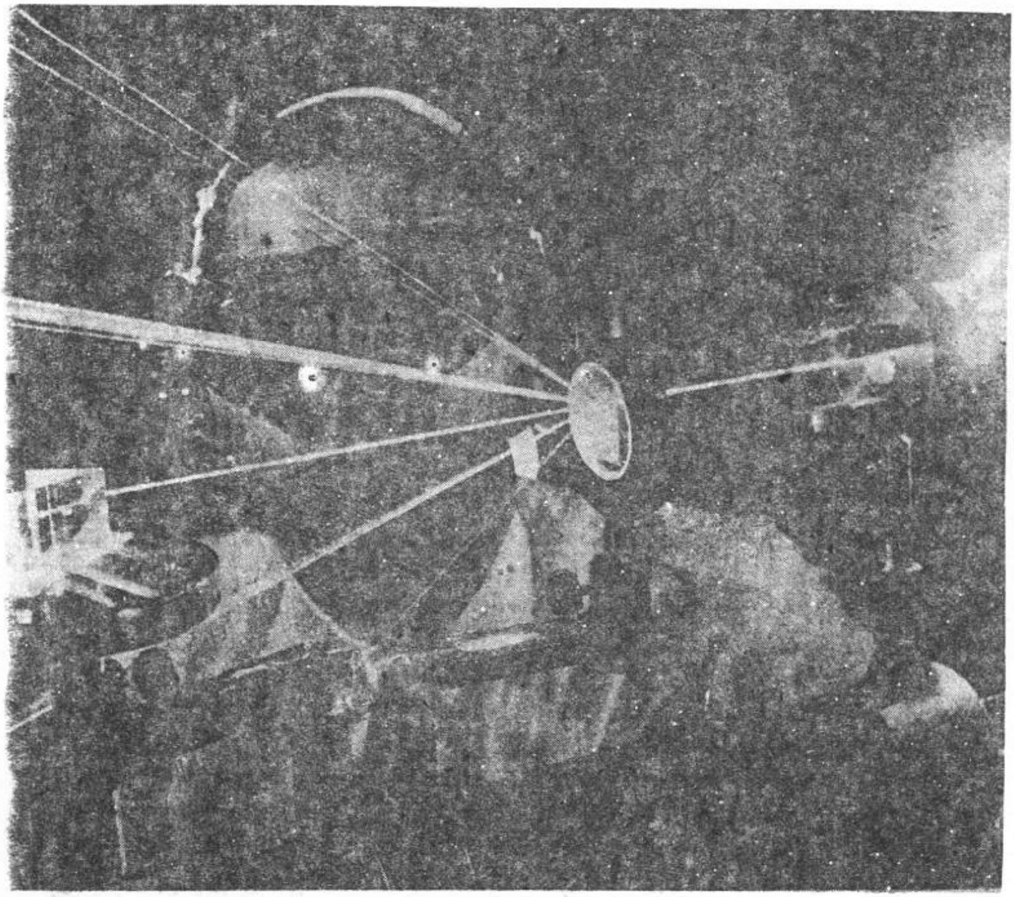
But many lasers are perfectly safe, such as this Associated Press Laserphoto device. The beam doesn't harm the man's hand, and in fact he can't even feel it. Encoded in the beam is information that Associated Press uses to reproduce photographs. Courtesy Wide World Photos

So how should you think of the laser? Think of it simply as a tool. One that uses light instead of mechanical energy. And a tool that allows its user to control the form and amount of energy directed at a particular place. The laser can cut through a two-inch-thick sheet of steel or detect a single atom. It can perform a task as dramatic as igniting a thermonuclear fusion reaction or as seemingly mundane as drilling a hole in a baby-bottle nipple.

WHAT IS A LASER?

A laser is a device that produces a very special kind of light. You can think of it as a super flashlight. But the beam that comes out of a laser differs from the light that comes out of a flashlight in four basic ways:

- Laser light is *intense.* Yet only a few lasers are *powerful.* That's not the contradiction you might think. Intensity is a measure of power per unit area, and even a laser that emits only a few milliwatts can produce a lot of intensity in a beam that's only a millimeter in diameter. In fact, it can produce an intensity equal to that of sunlight. An ordinary light bulb emits more light than a small laser like this, but that light spreads out all over the room. Some lasers can produce many thousands of watts continuously; others can produce trillions of watts in a pulse only a billionth of a second long.
- Laser beams are narrow and will not spread out like ordinary light beams. This quality is called *directionality.* You know that even the most powerful flashlight beam will not travel far. Aim one at the sky, and its beam seems to disappear quickly. The beam begins to spread out as soon as it leaves the flashlight, eventually dispersing so much as to be useless. On the other hand, beams from lasers with only a few watts of power were bounced off the moon, and the light was still bright enough to be seen back on the earth. One of the first laser beams shot at the moon—in 1962—spread out only two and a half miles on the lunar surface. Not bad when you consider that it had traveled a quarter of a million miles!
- Laser light is *coherent.* This means that all the light waves coming out of a laser are lined up with each other. An ordinary light source, such as a light bulb, generates light waves that start at different times and head in different directions. It's like throwing a handful of pebbles into a lake. You cause some tiny splashes and a few ripples, but that's about all. But if you take the same pebbles and throw them one by one,



Laser beams are extremely intense and directional; that is, they are like super searchlights, able to travel long distances without spreading out or breaking up. Because of this, mirrors, prisms, and special optical elements called *beam splitters* can be used to split a laser beam into many separate beams and to bounce them all over the place. Shown here is an argon ion laser, which can be used to measure distances, carry voice and television signals, expose printing plates, and make holograms. Courtesy Hughes Aircraft Company

at exactly the right rate, at the same spot, you can generate a more sizeable wave in the water. This is what a laser does, and this special property is useful in a variety of ways. Put another way, a light bulb or a flashlight is like a shotgun; a laser is like a machine gun.

• Lasers produce light of only one color. Or, to say it in a more technical way, the light is *monochromatic*. Ordinary light combines all the colors of visible light (i.e., the *spectrum*). Mixed together, they come out white. Laser beams have been produced in every color of the rainbow (red is the most common laser color), as well as in many kinds of invisible light, but each laser can emit one color and one color only. There are such things as tunable lasers, which can be adjusted to produce several different colors, but even they can emit only one color at a time. A few lasers can emit several monochromatic wavelengths at once—but not a *continuous* spectrum containing all the colors of visible light as a light bulb does. And then there are many lasers that project invisible light, such as infrared and ultraviolet light.

We'll discuss these laser qualities—intensity, directionality, coherence, and monochromaticity—at greater length in the following chapter.

WHAT ARE LASERS GOOD FOR?

The range of uses for the laser is striking, going far beyond the original ideas of the scientists who developed the first models (though they don't like to admit this), as well as vastly beyond the visions of the early science-fiction writers, who more often than not were simply looking for a futuristic weapon (though they too are not about to admit their lack of vision).

The wide variety of lasers is also striking. At one end of the scale, there are lasers made from tiny semiconductor chips similar to those used in electronic circuits, no larger than grains of salt (a kind of laser that Gordon Gould, one of the pioneers of the field, says surprised him when it was introduced). At the other end, there are the building-size laser weapons that the military is testing, quite different from the hand-held ray guns of science-fiction writers.

Our purpose in this book is not only to explain lasers but to tell you about all the ways in which they're now used—and will be used in the near future—and about how lasers will therefore affect our lives. The tasks that lasers perform range from the mundane to the esoteric, but they usually have a common element: they are difficult or impossible with any other tool. Lasers are relatively expensive tools and are usually brought in to do a job only because they can deliver the required type and amount of energy to the desired spot. Charles H. Townes, one of the inventors of the laser and a Nobel prize-winner, told us recently that he believes the laser "is going to touch on a very great number of areas. The laser will do almost anything. But it costs. That is the only limitation."

THE $50,000 SCALPEL AND TELEVISION FIBERS

A typical surgical laser, for example, costs from $30,000 to $50,000 and up, or about a thousand times more than a good conventional scalpel. And to be honest, for many operations a scalpel may be better than a laser. But if you have a detached retina, a condition that could lead to blindness, you may be happy that these expensive scalpels exist. A laser can do what a knife can't: weld the retina back to the eyeball. No incision is required for this delicate surgery, which can be performed right in the doctor's office. The laser beam shines through the lens of the patient's eye and is focused on the retina, producing a small lesion that helps hold it to the eyeball. Exotic as this sounds, a similar laser treatment has become a standard way of curing blindness caused by diabetes. (Charles Townes finds this application of the laser amazing. He admitted to us recently that the adaptation of the laser for medical uses took him by surprise, especially the detached retina procedure.)

Laser medicine probably hasn't touched you personally (you'd know if it had), but laser communication has undoubtedly served you already. If you watched the 1980 Winter Olympics from Lake Placid, New York, or any recent football game from Tampa Bay (Florida) Stadium on television, you saw signals that were transmitted part of the way to your home by lasers. Lasers carry telephone signals in dozens of places around the country. In both cases, light from the lasers is carried through hair-thin fibers of glass—fiber optics—a technology that could ultimately bring a multitude of new communication services into your home.

DEATH RAYS, DRILLS, NUCLEAR FUSION

Lasers are already commonplace items among our military, but probably not in the way you think. Their main function in the business of war is that of range finder and target designator, not ray gun. Lasers measure the distances to targets or pinpoint them with a "bull's-eye," helping either guns or missiles to home in on the enemy. And yes, in an offshoot of H. G. Wells's idea, the U.S. military is also spending about $300 million a year trying to build lasers able to destroy targets ranging from helicopters to ballistic missiles and satellites. The Soviet Union has a comparable program and is believed to have already used a laser to temporarily blind the sensitive electronic "eyes" of a U.S. spy satellite.

In factories around the world, lasers are now used routinely to drill holes in diamonds, label automotive parts, and weld battery cases for heart pacemakers. Laser quality-control "inspectors" sit ever-vigilant on assembly lines, making sure that the sizes of parts do not deviate from an acceptable range.

One of the hopes for ending our energy problems is *thermonuclear fusion,* the process by which our sun generates its energy. One way of creating fusion here on earth is to heat and compress pellets containing hydrogen to the temperatures and pressures needed to fuse the nuclei of the hydrogen atoms together, creating tiny hydrogen bombs and thus generating incredible power. What can compress these pellets? Lasers, of course.

THREE-DIMENSIONAL IMAGES AND SUPER READERS

Lasers are what make *holograms* possible—those three-dimensional images that seem to float before you, suspended in space. But holography has many seemingly mundane applications as well, from testing the quality of aircraft tires to measuring heat flow to aiding in the design of such things as hair dryers.

Lasers have made new art and new entertainment forms possible, even beyond holography. Laser light shows, the best known of which is *Laserium,* have been seen by millions of people around the world. A laser is also at the heart of one type of videodisk player, that new device that plays back movies and television programs prerecorded on phonographlike disks.

Lasers can read. Those cryptic bar codes on food packages in supermarkets are read by scanning them with a laser beam. The pattern of reflected light is decoded to tell a computer in the back of the store what the label says. This not only tabulates the price on the cash register but automatically registers in the computer's inventory memory. Lasers also read special typewriter faces, so that manuscripts can be typeset automatically, without human aid.

And lasers can write. It's simple for a computer to control a laser, making it write on film, special paper, or the drum of a copying machine, for later transfer to paper. Lasers expose printing plates for newspapers and print statements for insurance companies and mutual funds.

A BILLION DOLLARS A YEAR

Lasers also serve the interests of pure scientific research. They are used in experiments that would require a book as long as this just to explain. Lasers can cause and control chemical reactions and someday might even propel rockets and aircraft. We'll cover all these things in the following pages.

The laser's catalogue of wonders is growing larger each day, as is the thriving laser industry. The market for lasers and related equipment hit $1 billion for the first time in 1980. That figure, which doesn't include sizeable efforts in the Soviet Union and China, is nearly double the 1977 total sales figure.

But the laser has a long way to go. Its potential is only just beginning to be exploited. While that $1-billion figure may sound impressive, it is far less than the annual sales of many companies you've never heard of. To pick a familiar name, the RCA Corporation alone sold $7.5-billion worth of merchandise and services in 1979.

In the chapters that follow, we'll tell you about the laser and how it's used—its promises and the problems it has to overcome. Don't be misled by our emphasis on problems; we're realists, not pessimists. We'd be misleading you if we pretended that there weren't problems. That's why all these dramatic new uses of the laser haven't changed our lives more extensively already.

The obstacles to be overcome demand sophisticated and elaborate techniques—or the simple, brilliant insight that leads to breakthroughs. Similar obstacles have been faced and overcome before. That's how we got to where we are now.

What we're about to tell you is the story of the laser: where it came from, what it's doing for us, and where it might eventually take us.

Before we begin, we'd like first to explain the organization of this book. We've arranged it so that you don't have to read every chapter but can skip around, reading only those chapters about laser applications in which you have a special interest. However, we do encourage you to read chapter 2—Lasers: What They Are, How They Work—first, as knowing how the laser works will help you understand the rest of the book. Chapters 3 and 4, on the different types of lasers and the recent history of the laser's various inventors, respectively, are informative but can be skipped by those of you who wish to get into the various applications of lasers faster.

Here then is the story of the laser—past, present, and future.

2 LASERS: WHAT THEY ARE, HOW THEY WORK

In most of the rest of this book, we will be looking at the laser simply as a very special type of light bulb, which produces a very special type of light. In this chapter, however, we're going to look *inside* the laser, to get an idea of what it is and how it works.

The word *laser* stands for Light Amplification by Stimulated Emission of Radiation. In this chapter, we will explain all of these terms (though not necessarily in that order) and tell you how they come together to make a laser. In the process, we'll cover a few centuries of scientific achievement. For the laser is a synthesis of the work of many great scientists. Illuminated in its beam are the ideas of Newton, Maxwell, Einstein, and many other scientists you are about to meet.

Let us begin, then, at the beginning.

IT STARTS WITH LIGHT (THE L OF L.A.S.E.R.)

Back in the early 1700s, in his book *Optiks,* Isaac Newton explained to the world how light behaves. He explained, for example, why we see rainbows after rain. The water droplets act as prisms, taking white light and dividing it into the colors of the spectrum. A prism, or a raindrop, said Newton, slows down some colors more than others, so that each emerges at a slightly different angle. This discovery is still important today to anyone who makes lenses or mirrors—or lasers.

Newton also cleverly deduced that since light travels in straight lines, it must be composed of streams of tiny particles. Newton was applauded by other scientists of the time for having arrived at this definition of light, but it turns out that he was only partly correct.

By the early 1800s, it was clearly established that light, while trav-