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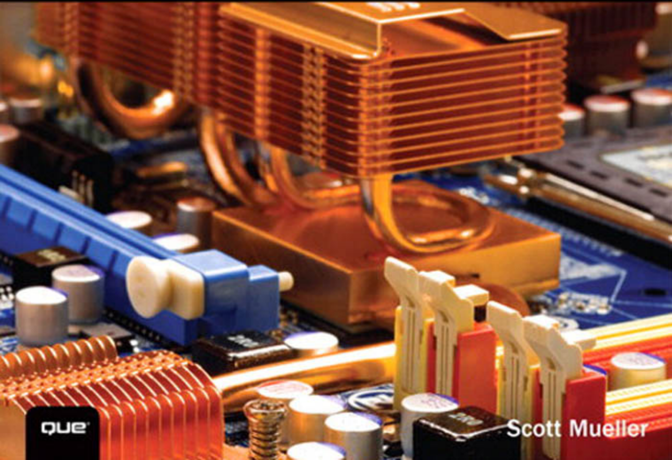
Scott Mueller's

UPGRADING AND REPAIRING PCs

20th EDITION



QUE

Scott Mueller

UPGRADING AND REPAIRING PCs,

20th Edition

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Indianapolis, Indiana 46240

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About the Author

Scott Mueller is the president of Mueller Technical Research (MTR), an international research and corporate training firm. Since 1982, MTR has produced the industry's most in-depth, accurate, and effective seminars, books, articles, videos, and FAQs covering PC hardware and data recovery. MTR maintains a client list that includes Fortune 500 companies, the U.S. and foreign governments, major software and hardware corporations, as well as PC enthusiasts and entrepreneurs. Scott's seminars have been presented to several thousands of PC support professionals throughout the world.

Scott personally teaches seminars nationwide covering all aspects of PC hardware (including troubleshooting, maintenance, repair, and upgrade), A+ Certification, and data recovery/forensics. He has a knack for making technical topics not only understandable, but entertaining; his classes are never boring! If you have 10 or more people to train, Scott can design and present a custom seminar for your organization.

Although he has taught classes virtually nonstop since 1982, Scott is best known as the author of the longest-running, most popular, and most comprehensive PC hardware book in the world, *Upgrading and Repairing PCs*, which has become the core of an entire series of books, including *Upgrading and Repairing PCs*, *Upgrading and Repairing Laptops*, and *Upgrading and Repairing Windows*.

Scott's premiere work, *Upgrading and Repairing PCs*, has sold well over two million copies, making it by far the most popular and longest-running PC hardware book on the market today. Scott has been featured in *Forbes* magazine and has written several articles for *PC World* magazine, *Maximum PC* magazine, the Scott Mueller Forum, various computer and automotive newsletters, and the *Upgrading and Repairing PCs* website.

Contact MTR directly if you have a unique book, article, or video project in mind or if you want Scott to conduct a custom PC troubleshooting, repair, maintenance, upgrade, or data-recovery seminar tailored for your organization:

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Dedication

To Emerson, congratulations on your graduation.

Acknowledgments

I must give a *very* special thanks to Rick Kughen at Que. Through the years Rick is the number-one person responsible for championing this book and the *Upgrading and Repairing* series. I cannot say enough about Rick and what he means to all the *Upgrading and Repairing* books. With all that he's been through working on this book, I have a feeling I might be responsible for a few gray hairs. (Sorry!)

I'd also like to thank Todd Brakke for doing the development editing for this edition, which was fairly substantial considering all the rewrites and new material. His excellent tips and suggestions really help to keep the material concise and up-to-date.

Special thanks also go to Karen Gill who helped tremendously with the editing and to Jovana San Nicolas-Shirley for shepherding the manuscripts through a tight publishing schedule. I'd also like to thank the proofreader, illustrator, designer, and indexer who work so hard to complete the finished product and get this book out the door! They are a wonderful team that produces clearly the best computer books on the market. I am happy and proud to be closely associated with all the people at Que.

I would also like to say thanks to my publisher Greg Wiegand, who has stood behind all the *Upgrading and Repairing* book and video projects. Greg is a fellow motorcycle enthusiast—someday, hopefully, we can go riding together.

All the people at Que make me feel as if we are on the same team, and they are just as dedicated as I am to producing the best books possible.

I would also like to say thanks to Mark Reddin, who has become the primary technical editor for this book since the 13th edition. Not only is he extremely diligent in verifying details, but he makes numerous suggestions about additional coverage. His input has been extremely important in helping me to ensure the highest level of technical accuracy and depth of coverage.

Many readers write me with suggestions and even corrections for the book, for which I am especially grateful. I welcome any and all of your comments and even your criticisms. I take them seriously and apply them to the continuous improvement of this book. Interaction with my readers is the primary force that helps maintain this book as the most up-to-date and relevant work available *anywhere* on the subject of PC hardware.

Finally, I would like to thank the thousands of people who have attended my seminars; you have no idea how much I learn from each of you and all your questions!

We Want to Hear from You!

As the reader of this book, *you* are our most important critic and commentator. We value your opinion and want to know what we're doing right, what we could do better, what areas you'd like to see us publish in, and any other words of wisdom you're willing to pass our way.

As an associate publisher for Que Publishing, I welcome your comments. You can email or write me directly to let me know what you did or didn't like about this book—as well as what we can do to make our books better.

Please note that I cannot help you with technical problems related to the topic of this book. We do have a User Services group, however, where I will forward specific technical questions related to the book.

When you write, please be sure to include this book's title and author as well as your name, email address, and phone number. I will carefully review your comments and share them with the author and editors who worked on the book.

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Visit our website and register this book at quepublishing.com/register for convenient access to any updates, downloads, or errata that might be available for this book.

Installing the DVD

The DVD accompanying this book is playable on both a standalone DVD player (DVD player attached to your television/home theater system) and a DVD drive installed in or connected to your PC.

Standalone DVD Video Players

To play the videos on this DVD, insert the DVD into your standalone DVD video player and navigate the menus using your DVD player's remote, just as you would do with any DVD.

Note

The DVD is coded to play in all regions. Technical Reference files and Windows Media Player–formatted videos are also available on Scott's website at `quepublishing.com/upgrading.`

PC-Based DVD Drives

To play the DVD video content, do the following:

1. Insert the DVD into your PC's DVD capable optical drive.
2. Run your previously installed DVD player application and select Play.
3. Navigate the DVD menus as you would any standard DVD video.

Most DVD drives include a DVD player/decoder application. If you do not currently have a DVD player/decoder installed on your system, you can do one of the following:

- Play the disc in a standard set-top DVD player.
- Use Windows Media Player 9 or later along with an existing DVD decoder plug-in (`http://windows.microsoft.com/en-US/windows/products/windows-media`).
- Purchase a DVD decoder plug-in to use with Windows Media Player (`http://windows.microsoft.com/en-US/windows/downloads/windows-media-player/plug-ins`).
- Download and install a free media player/decoder combination, such as Media Player Classic Home Cinema (`http://mpc-hc.sourceforge.net`) or the VLC media player (`www.videolan.org`).
- Purchase and install a commercial DVD player/decoder combination, such as PowerDVD by CyberLink (`www.cyberlink.com`) or WinDVD by Corel (`www.corel.com`).

Here's how to access the Technical Reference files, glossary, previous edition of the book, and any other files on the DVD-ROM:

1. Insert the DVD into your PC's DVD capable drive.
2. Open Windows Explorer (explorer.exe).
3. Right-click the icon for the DVD drive containing the disc.
4. Select Open or Explore.
5. Navigate through the folders and files just as if you were viewing files stored on your computer's hard drive, look for the DVD-ROM Content folder to find the extra files.

Note

The documents included in the DVD-ROM Content section of the DVD are in PDF format, which require Adobe Reader to view. The Adobe Reader is freely available at `www.adobe.com`.

System Requirements for DVD-ROM Video

The minimum system configuration is as follows:

- Windows 98 SE, Me, 2000, XP, Vista, 7 or newer
- DVD capable optical drive
- DVD player and decoder software installed

Note

Your system must also meet the minimum requirements for the specific DVD player/decoder software you are using. Check with the player/decoder software manufacturer for more information.

Access to DVD Content Without a DVD Player or DVD Drive

If you do not have a set-top DVD player or DVD drive, you can still access all the files included on the DVD-ROM by visiting `quepublishing.com/upgrading`. To access these materials on the Web, follow these steps:

1. Remove the DVD from the package insert and write down the password on the DVD label.
2. Visit `quepublishing.com/upgrading` and follow the DVD Vault link from the home page.
3. You will see videos available for many editions of the book. Select the 20th Edition and follow the on-screen directions. You will need to enter the password found on the DVD's label.
4. You can then download any of the files provided there, including Windows Media Player versions of the videos, Technical Reference files, glossary, previous edition of the book, and any other files on the DVD-ROM.

Introduction

Welcome to *Upgrading and Repairing PCs, 20th edition*. Since debuting as the first book of its kind on the market in 1988, no other book on PC hardware has matched the depth and quality of the information found in this tome. This edition continues *Upgrading and Repairing PCs*' role as not only the best-selling book of its type, but also the most comprehensive and complete PC hardware reference available. This book examines PCs in depth, outlines the differences among them, and presents options for configuring each system.

The 20th edition of *Upgrading and Repairing PCs* provides you with the in-depth knowledge you need to work with the most recent systems and components as well as providing you with an unexcelled resource for understanding older systems. We have worked to make this book keep pace with the rapid changes in the PC industry so that it continues to be the most accurate, complete, and in-depth book of its kind on the market today.

I wrote this book for all PC enthusiasts who want to know everything about their PCs: how they originated; how they've evolved; how to upgrade, troubleshoot, and repair them; and everything in between. This book covers the full gamut of PC-compatible systems, from the oldest 8-bit machines to the latest high-end 64-bit multicore processors and systems. If you need to know everything about PC hardware from the original to the latest technology on the market today, this book and the accompanying information-packed disc is definitely for you.

Upgrading and Repairing PCs also doesn't ignore the less glamorous PC components. Every part of your PC plays a critical role in its stability and performance. Over the course of this book, you'll find out exactly why your motherboard's chipset might just be the most important part of your PC and what can go wrong when you settle for a run-of-the-mill power supply that can't get enough juice to that monster graphics card you just bought. You'll also find in-depth coverage of technologies such as new six-core processors from Intel and AMD, processors with onboard graphics, graphics cards for the fastest 3D gaming, the latest audio cards for sound producers and audiophiles, SATA 6Gbps and USB 3.0 in the latest motherboards, advances in Blu-ray and solid state drives, and more—it's all in here, right down to the guts-level analysis of your mouse and keyboard.

Book Objectives

Upgrading and Repairing PCs focuses on several objectives. The primary objective is to help you learn how to maintain, upgrade, and troubleshoot your PC system. To that end, *Upgrading and Repairing PCs* helps you fully understand the family of computers that has grown from the original IBM PC, including all PC-compatible systems. This book discusses all areas of system improvement, such as motherboards, processors, memory, and even case and power-supply improvements. It covers proper system and component care, specifies the most failure-prone items in various PC systems, and tells you how to locate and identify a failing component. You'll learn about powerful diagnostics hardware and software that enable a system to help you determine the cause of a problem and how to repair it.

As always, PCs are moving forward rapidly in power and capabilities. Processor performance increases with every new chip design. *Upgrading and Repairing PCs* helps you gain an understanding of all the processors used in PC-compatible computer systems.

This book covers the important differences between major system architectures, from the original Industry Standard Architecture (ISA) to the latest PCI Express interface standards. *Upgrading and Repairing PCs* covers each of these system architectures and their adapter boards to help you make decisions about which type of system you want to buy in the future and to help you upgrade and troubleshoot such systems.

The amount of storage space available to modern PCs is increasing geometrically. *Upgrading and Repairing PCs* covers storage options ranging from larger, faster hard drives to state-of-the-art storage devices.

When you finish reading this book, you should have the knowledge to upgrade, troubleshoot, and repair almost any system and component.

The 20th Edition DVD-ROM

The 20th edition of *Upgrading and Repairing PCs* includes a DVD containing valuable content that greatly enhances this book!

First, there's the all-new DVD video with new segments covering hard disk construction, options for external storage, the inner workings of PC power supplies and the critical role of capacitors in motherboard operation and how the so-called "capacitor plague" has been a nightmare for system builders.

The DVD-ROM content includes my venerable Technical Reference material, a repository of reference information that has appeared in previous editions of *Upgrading and Repairing PCs* but has been moved to the disc to make room for coverage of newer technologies. The DVD-ROM also includes the complete 19th edition of this book, a comprehensive PC glossary, a detailed list of acronyms, and much more available in printable PDF format. There's more PC hardware content and knowledge here than you're likely to find from any other single source.

My Website: informit.com/upgrading

Don't forget about the InformIT Upgrading website! Here, you'll find a cache of helpful material to go along with the book you're holding. I've loaded this site with tons of material—mine as well as from other authors—ranging from video clips to book content and technology updates.

If you discover that the video on this book's disc isn't enough, you'll find even more of my previously recorded videos on the website. Not to mention that it is the best place to look for information on all of Que's *Upgrading and Repairing* titles.

I also have a private forum (www.forum.scottmueller.com) designed exclusively to support those who have purchased my recent books and DVDs. I use the forum to answer questions and otherwise help my loyal readers. If you own one of my current books or DVDs, feel free to join in and post questions. I endeavor to answer each question personally, but I also encourage knowledgeable members to respond. Anybody can view the forum without registering, but to post a question of your own you need to join. Even if you don't join in, the forum is a tremendous resource because you can still benefit from all the reader questions I have answered over the years.

Be sure to check the informit.com/upgrading website for more information on all my latest books, videos, articles, FAQs, and more!

A Personal Note

When asked which was his favorite Corvette, Dave McLellan, former manager of the Corvette platform at General Motors, always said, "Next year's model." Now with the new 20th edition, next year's model has just become this year's model, until *next* year that is…

I believe this book is absolutely the best book of its kind on the market, and that is due in large part to the extensive feedback I have received from both my seminar attendees and book readers. I am so grateful to everyone who has helped me with this book through each edition, as well as all the loyal readers who have been using this book, many of you since the first edition was published. I have had personal contact with many thousands of you in the seminars I have been teaching since 1982, and I enjoy your comments and even your criticisms tremendously. Using this book in a teaching environment has been a major factor in its development. Some of you might be interested to know that I originally began writing this book in early 1985; back then it was self-published and used exclusively in my PC hardware seminars before being professionally published by Que in 1988.

In one way or another, I have been writing and rewriting this book for more than 25 years! In that time, *Upgrading and Repairing PCs* has proven to be not only the first but also the most comprehensive and yet approachable and easy-to-understand book of its kind. With this new edition, it is even better than ever. Your comments, suggestions, and support have helped this book to become the best PC hardware book on the market. I look forward to hearing your comments after you see this exciting new edition.

Scott

Chapter

11

Optical Storage

Optical Technology

There are basically two types of disk storage for computers: magnetic and optical. In *magnetic* storage, data is recorded magnetically on rotating disks. *Optical* disc storage is similar to magnetic disk storage in basic operation, but it reads and writes using light (optically) instead of magnetism. Although most magnetic disk storage is fully read and write capable many times over, many optical storage media are either read-only or write-once. Note the convention in which we refer to magnetic as *disk* and optical as *disc*. This is not a law or rule but is followed by most in the industry.

At one time, it was thought that optical storage would replace magnetic as the primary online storage medium. However, optical storage has proven to be much slower and far less dense than magnetic storage and is much more adaptable to removable-media designs. As such, optical storage is more often used for backup or archival storage purposes and as a mechanism by which programs or data can be loaded onto magnetic drives. Magnetic storage, being significantly faster and capable of holding much more information than optical media in the same amount of space, is more suited for direct online storage and most likely won't be replaced in that role by optical storage anytime soon.

Optical technology standards for computers can be divided into three major types:

- CD (compact disc)
- DVD (digital versatile disc)
- BD (Blu-ray disc)

All of these are descended from popular music and video entertainment standards; CD-based devices can also play music CDs, and DVD and BD-based devices can play the same video discs you can purchase or rent. However, computer drives that can use these types of media also offer many additional features.

In the following sections, you will learn how optical drives and media are similar, how they differ from each other, and how they can be used to enhance your storage and playback options.

CD-Based Optical Technology

The first type of optical storage that became a widespread computing standard is the CD-ROM. CD-ROM, or *compact disc read-only memory*, is an optical read-only storage medium based on the original CD-DA (digital audio) format first developed for audio CDs. Other formats, such as CD-R (CD-recordable) and CD-RW (CD-rewritable), expanded the compact disc's capabilities by making it writable.

Older CD-ROM discs held 74 minutes of high-fidelity audio in CD audio format or 650MiB (682MB) of data. However, the current CD-ROM standard is an 80-minute disc with a data capacity of 700MiB (737MB). When MP3, WMA, or similar compressed audio files are stored on CD, several hours of audio can be stored on a single disc (depending on the compression format and bit rate used). Music only, data only, or a combination of music and data (Enhanced CD) can be stored on one side (only the bottom is used) of a 120mm (4.72-inch) diameter, 1.2mm (0.047-inch) thick plastic disc.

CD-ROM has the same form factor (physical shape and layout) of the familiar CD-DA audio compact disc and can, in fact, be inserted into a normal audio player. Sometimes it isn't playable, though, because the player reads the subcode information for the track, which indicates that it is data and not audio. If it could be played, the result would be noise—unless audio tracks precede the data on the CD-ROM. (See the section "Blue Book—CD EXTRA," later in this chapter.)

Accessing data from a CD using a computer is much faster than from a floppy disk but slower than a modern hard drive.

CDs: A Brief History

In 1979, the Philips and Sony corporations joined forces to coproduce the CD-DA (Compact Disc-Digital Audio) standard. Philips had already developed commercial laserdisc players, and Sony had a decade of digital recording research under its belt. The two companies were poised for a battle—the introduction of potentially incompatible audio laser disc formats—when instead they came to terms on an agreement to formulate a single industry-standard digital audio technology.

Philips contributed most of the physical design, which was similar to the laserdisc format it had previously created with regards to using pits and lands on the disk that are read by a laser. Sony contributed the digital-to-analog circuitry, and especially the digital encoding and error-correction code designs.

In 1980, the companies announced the CD-DA standard, which has since been referred to as the *Red Book format* (so named because the cover of the published document was red). The Red Book included the specifications for recording, sampling, and—above all—the 120mm (4.72-inch) diameter physical format you live with today. This size was chosen, legend has it, because it could contain all of Beethoven's approximately 70-minute *Ninth Symphony* without interruption, compared to 23 minutes per side of the then-mainstream 33-rpm LP record.

After the specification was set, both manufacturers were in a race to introduce the first commercially available CD audio drive. Because of its greater experience with digital electronics, Sony won that race and beat Philips to market by one month, when on October 1, 1982 Sony introduced the CDP-101 player and the world's first commercial CD recording—Billy Joel's *52nd Street* album. The player was introduced in Japan and then Europe; it wasn't available in the United States until early 1983. In 1984, Sony also introduced the first automobile and portable CD players.

Sony and Philips continued to collaborate on CD standards throughout the decade, and in 1983 they jointly released the Yellow Book CD-ROM standard. It turned the CD from a digital audio storage medium to one that could now store read-only data for use with a computer. The Yellow Book used the same physical format as audio CDs but modified the decoding electronics to allow data to be stored reliably. In fact, all subsequent CD standards (usually referred to by their colored book binders) have referred to the original Red Book standard for the physical parameters of the disc. With the advent of the Yellow Book standard (CD-ROM), what originally was designed to hold a symphony could now be used to hold practically any type of information or software.

For more information on the other CD book formats, see the section "CD Formats," later in this chapter.

CD Construction and Technology

A CD is made of a polycarbonate wafer, 120mm in diameter and 1.2mm thick, with a 15mm hole in the center. This wafer base is stamped or molded with a single physical track in a spiral configuration starting from the inside of the disc and spiraling outward. The track has a pitch, or spiral separation, of 1.6 microns (millionths of a meter, or thousandths of a millimeter). By comparison, an LP record has a physical track pitch of about 125 microns. When viewed from the reading side (the bottom), the disc rotates counterclockwise. If you examined the spiral track under a microscope, you would see that along the track are raised bumps, called *pits*, and flat areas between the pits, called *lands*. It seems strange to call a raised bump a *pit*, but that is because when the discs are pressed, the stamper works from the top side. So, from that perspective, the pits are actually depressions made in the plastic.

The laser used to read the disc would pass right through the clear plastic, so the stamped surface is coated with a reflective layer of metal (usually aluminum) to make it reflective. Then the aluminum is coated with a thin protective layer of acrylic lacquer, and finally a label or printing is added.

Caution

You should handle optical media with the same care as a photographic negative. The disc is an optical device and degrades as its optical surface becomes dirty or scratched. Also, it is important to note that, although discs are read from the bottom, the layer containing the track is actually much closer to the top of the disc because the protective lacquer overcoat is only 6–7 microns thick. Writing on the top surface of a disc with a ballpoint pen, for example, easily damages the recording underneath. You need to be careful even when using a marker to write on the disc. The inks and solvents used in some markers can damage the print and lacquer overcoat on the top of the disc, and subsequently the information layer right below. Use only markers designed for or tested as being compatible with optical media. The important thing is to treat both sides of the disc carefully, especially the top (label) side.

Mass-Producing CDs

Commercial mass-produced optical discs are stamped or pressed and not burned by a laser as many people believe (see Figure 11.1). Although a laser is used to etch data onto a glass master disc that has been coated with a photosensitive material, using a laser to directly burn discs would be impractical for the reproduction of hundreds or thousands of copies.

The steps in manufacturing CDs are as follows. (Use Figure 11.1 as a visual.)

1. **Photoresist coating**—A circular 240mm diameter piece of polished glass 6mm thick is spin-coated with a photoresist layer about 150 microns thick and then hardened by baking at 80°C (176°F) for 30 minutes.
2. **Laser recording**—A Laser Beam Recorder (LBR) fires pulses of blue/violet laser light to expose and soften portions of the photoresist layer on the glass master.
3. **Master development**—A sodium hydroxide solution is spun over the exposed glass master, which then dissolves the areas exposed to the laser, thus etching pits in the photoresist.
4. **Electroforming**—The developed master is then coated with a layer of nickel alloy through a process called *electroforming*. This creates a metal master called a *father*.

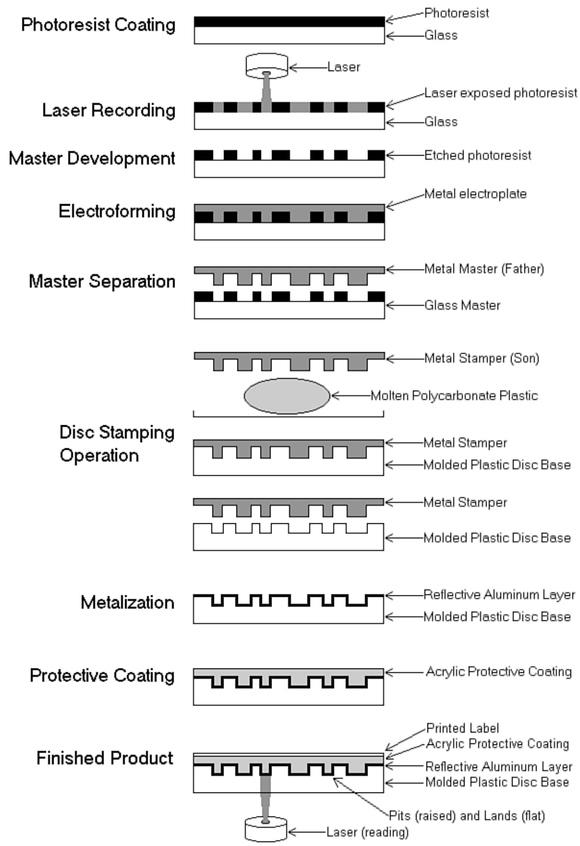

Figure 11.1 CD manufacturing process.

5. **Master separation**—The metal master father is then separated from the glass master. The father is a metal master that can be used to stamp discs, and for short runs, it may in fact be used that way. However, because the glass master is damaged when the father is separated, and because a stamper can produce only a limited number of discs before it wears out, the father often is electroformed to create several reverse image mothers. These mothers are then subsequently electroformed to create the actual stampers. This enables many more discs to be stamped without ever having to go through the glass mastering process again.
6. **Disc-stamping operation**—A metal stamper is used in an injection molding machine to press the data image (pits and lands) into approximately 18 grams of molten (350°C or 662°F) polycarbonate plastic with a force of about 20,000psi. Normally, one disc can be pressed every 2–3 seconds in a modern stamping machine.
7. **Metalization**—The clear stamped disc base is then sputter-coated with a thin (0.05–0.1 micron) layer of aluminum to make the surface reflective.
8. **Protective coating**—The metalized disc is then spin-coated with a thin (6–7 micron) layer of acrylic lacquer, which is then cured with UV (ultraviolet) light. This protects the aluminum from oxidation.
9. **Finished product**—Finally, a label is affixed or printing is screen-printed on the disc and cured with UV light.

Although the manufacturing process shown here was for CDs, the process is almost identical for other types of optical media.

Pits and Lands

Reading the information back from a disc is a matter of bouncing a low-powered laser beam off the reflective layer in the disc. The laser shines a focused beam on the underside of the disc, and a photosensitive receptor detects when the light is reflected back. When the light hits a land (flat spot) on the track, the light is reflected back; however, when the light hits a pit (raised bump), no light is reflected back.

As the disc rotates over the laser and receptor, the laser shines continuously while the receptor sees what is essentially a pattern of flashing light as the laser passes over pits and lands. Each time the laser passes over the edge of a pit, the light seen by the receptor changes in state from being reflected to not reflected, or vice versa. Each change in state of reflection caused by crossing the edge of a pit is translated into a 1 bit digitally. Microprocessors in the drive translate the light/dark and dark/light (pit edge) transitions into 1 bits, translate areas with no transitions into 0 bits, and then translate the bit patterns into actual data or sound.

The individual pits on a CD are 0.125 microns deep and 0.6 microns wide. Both the pits and lands vary in length from about 0.9 microns at their shortest to about 3.3 microns at their longest. The track is a spiral with 1.6 microns between adjacent turns (see Figure 11.2).

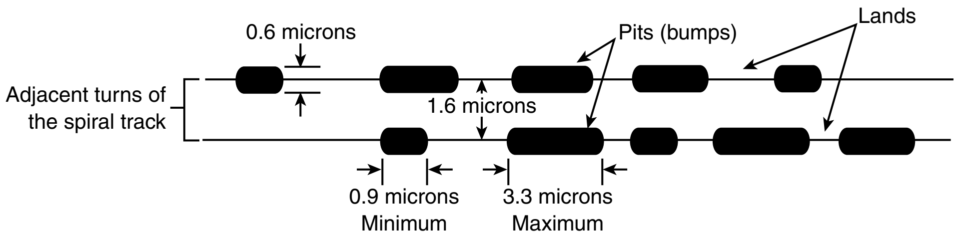

Figure 11.2 Pit, land, and track geometry on a CD.

The height of the pits above the land is especially critical because it relates to the wavelength of the laser light used when reading the disc. The pit (bump) height is exactly 1/4 of the wavelength of the laser light used to read the disc. Therefore, the light striking a land travels 1/2 of a wavelength of light farther than light striking the top of a pit (1/4 + 1/4 = 1/2). This means the light reflected from a pit is 1/2 wavelength out of phase with the rest of the light being reflected from the disc. The out-of-phase waves cancel each other out, dramatically reducing the light that is reflected back and making the pit appear dark even though it is coated with the same reflective aluminum as the lands.

The read laser in a CD drive is a 780nm (nanometer) wavelength laser of about 1 milliwatt in power. The polycarbonate plastic used in the disc has a refractive index of 1.55, so light travels through the plastic 1.55 times more slowly than through the air around it. Because the frequency of the light passing through the plastic remains the same, this has the effect of shortening the wavelength inside the plastic by the same factor. Therefore, the 780nm light waves are now compressed to 500nm (780/1.55). One quarter of 500nm is 125nm, which is 0.125 microns—the specified height of the pit.

Note

DVD drives use two different lasers: a 780nm laser for CD media and a 650nm laser for DVD media. Consequently, a DVD drive could suffer a failure of one laser, causing it to no longer read (or write) one type of media while continuing to read (or write) the other type of media.

Drive Mechanical Operation

An optical drive operates by using a laser to reflect light off the bottom of the disc. A photo detector then reads the reflected light. The overall operation of an optical drive is as follows (see Figure 11.3):

1. The laser diode emits a low-energy infrared beam toward a reflecting mirror.
2. The servo motor, on command from the microprocessor, positions the beam onto the correct track on the disc by moving the reflecting mirror.
3. When the beam hits the disc, its refracted light is gathered and focused through the first lens beneath the platter, bounced off the mirror, and sent toward the beam splitter.
4. The beam splitter directs the returning laser light toward another focusing lens.
5. The last lens directs the light beam to a photo detector that converts the light into electric impulses.
6. These incoming impulses are decoded by the microprocessor and sent along to the host computer as data.

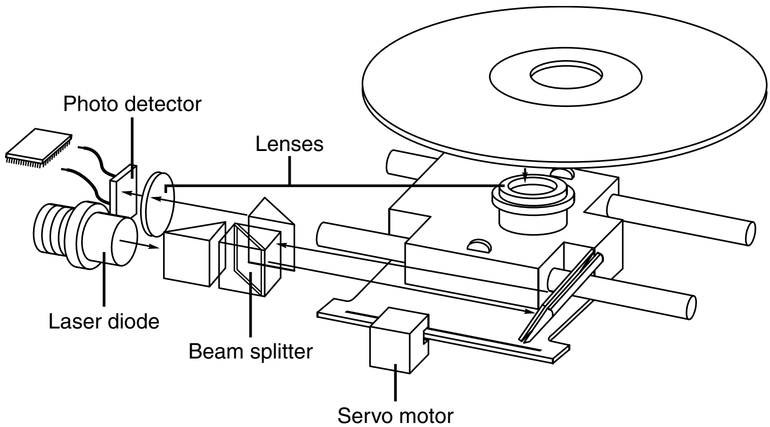

Figure 11.3 Typical components inside an optical drive.

When introduced, CD-ROM drives were too expensive for widespread adoption. After the production costs of both drives and discs began to drop, however, CDs were rapidly assimilated into the PC world. This was particularly due to the ever-expanding size of PC applications. Virtually all software is now supplied on optical media, even if the disc doesn't contain data representing a tenth of its potential capacity.

Tracks and Sectors

On the traditional 74-minute CD, the pits are stamped into a single spiral track with a spacing of 1.6 microns between turns, corresponding to a track density of 625 turns per millimeter, or 15,875 turns per inch. This equates to a total of 22,188 turns for a typical 74-minute (650MiB) disc. Current 80-minute CDs gain their extra capacity by decreasing the spacing between turns. See Table 11.1 for more information about the differences between 74-minute and 80-minute CDs.

The disc is divided into six main areas (discussed here and shown in Figure 11.4):

- **Hub clamping area**—The hub clamp area is just that: a part of the disc where the hub mechanism in the drive can grip the disc. No data or information is stored in that area.
- **Power calibration area (PCA)**—This is found only on writable discs and is used only by recordable drives to determine the laser power necessary to perform an optimum burn. A single CD-R or CD-RW disc can be tested this way up to 99 times.
- **Program memory area (PMA)**—This is found only on writable discs and is the area where the TOC (table of contents) is temporarily written until a recording session is closed. After the session is closed, the TOC information is written to the lead-in area.
- **Lead-in**—The lead-in area contains the disc (or session) TOC in the Q subcode channel. The TOC contains the start addresses and lengths of all tracks (songs or data), the total length of the program (data) area, and information about the individual recorded sessions. A single lead-in area exists on a disc recorded all at once (Disc At Once or DAO mode), or a lead-in area starts each session on a multisession disc. The lead-in takes up 4,500 sectors on the disc (1 minute if measured in time, or about 9.2MB worth of data). The lead-in also indicates whether the disc is multisession and what the next writable address on the disc is (if the disc isn't closed).
- **Program (data) area**—This area of the disc starts at a radius of 25mm from the center.
- **Lead-out**—The lead-out marks the end of the program (data) area or the end of the recording session on a multisession disc. No actual data is written in the lead-out; it is simply a marker. The first lead-out on a disc (or the only one if it is a single session or Disk At Once recording) is 6,750 sectors long (1.5 minutes if measured in time, or about 13.8MB worth of data). If the disc is a multisession disc, any subsequent lead-outs are 2,250 sectors long (0.5 minutes in time, or about 4.6MB worth of data).

The hub clamp, lead-in, program, and lead-out areas are found on all CDs, whereas only recordable CDs (such as CD-Rs and CD-RWs) have the additional power calibration area and program memory area at the start of the disc.

Figure 11.4 shows these areas in actual relative scale as they appear on a disc.

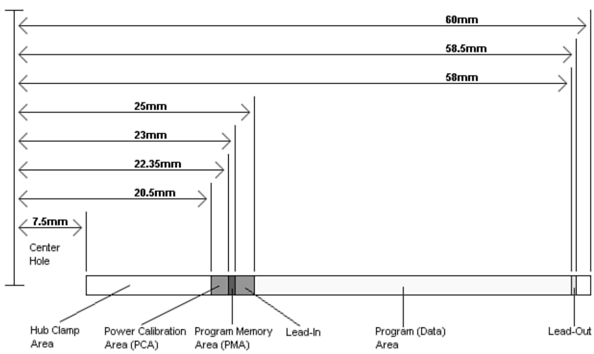

Figure 11.4 Areas on a CD (side view).

Officially, the spiral track of a standard CD starts with the lead-in area and ends at the finish of the lead-out area, which is 58.5mm from the center of the disc, or 1.5mm from the outer edge. This single spiral track is about 5.77 kilometers, or 3.59 miles, long. An interesting fact is that in a 56x CAV (constant angular velocity) drive, when the outer part of the track is being read, the data moves at an actual speed of 162.8 miles per hour (262km/h) past the laser. What is more amazing is that even when the data is traveling at that speed, the laser pickup can accurately read bits (pit/land transitions) spaced as little as only 0.9 microns (or 35.4 millionths of an inch) apart!

Table 11.1 shows some of the basic information about the two main CD capacities, which are 74 and 80 minutes. The CD standard originally was created around the 74-minute disc; the 80-minute versions were added later and basically stretch the standard by tightening the track spacing within the limitations of the original specification. A poorly performing or worn-out drive can have trouble reading the 80-minute discs.

Table 11.1 CD Technical Parameters

Advertised CD capacity (MiB)	650	700
1x read speed (m/sec)	1.3	1.3
Laser wavelength (nm)	780	780
Numerical aperture (lens)	0.45	0.45
Media refractive index	1.55	1.55
Track (turn) spacing (um)	1.6	1.48
Turns per mm	625	676
Turns per inch	15,875	17,162
Total track length (m)	5,772	6,240
Total track length (feet)	18,937	20,472
Total track length (miles)	3.59	3.88
Pit width (um)	0.6	0.6
Pit depth (um)	0.125	0.125
Min. nominal pit length (um)	0.90	0.90
Max. nominal pit length (um)	3.31	3.31
Lead-in inner radius (mm)	23	23
Data zone inner radius (mm)	25	25
Data zone outer radius (mm)	58	58
Lead-out outer radius (mm)	58.5	58.5
Data zone width (mm)	33	33
Total track area width (mm)	35.5	35.5
Max. rotating speed 1x CLV (rpm)	540	540
Min. rotating speed 1x CLV (rpm)	212	212
Track revolutions (data zone)	20,625	22,297
Track revolutions (total)	22,188	23,986

B = Byte (8 bits)
KB = Kilobyte (1,000 bytes)
KiB = Kibibyte (1,024 bytes)
MB = Megabyte (1,000,000 bytes)
MiB = Mebibyte (1,048,576 bytes)
m = Meters
mm = Millimeters (thousandths of a meter)
um = Micrometers = Microns (millionths of a meter)
CLV = Constant linear velocity
rpm = Revolutions per minute

The spiral track is divided into sectors that are stored at the rate of 75 sectors per second. On a disc that can hold a total of 74 minutes of information, that results in a maximum of 333,000 sectors. Each sector is then divided into 98 individual frames of information. Each frame contains 33 bytes: 24 bytes are audio data, 1 byte contains subcode information, and 8 bytes are used for parity/ECC (error correction code) information. Table 11.2 shows the sector, frame, and audio data calculations.

Table 11.2 CD Sector, Frame, and Audio Data Information

Advertised CD length (minutes)	74	80
Sectors/second	75	75
Frames/sector	98	98
Number of sectors	333,000	360,000
Sector length (mm)	17.33	17.33
Byte length (um)	5.36	5.36
Bit length (um)	0.67	0.67
Each Frame:		
Subcode bytes	1	1
Data bytes	24	24
Q+P parity bytes	8	8
Total bytes/frame	33	33
Audio Data:		
Audio sampling rate (Hz)	44,100	44,100
Samples per Hz (stereo)	2	2
Sample size (bytes)	2	2
Audio bytes per second	176,400	176,400
Sectors per second	75	75
Audio bytes per sector	2,352	2,352
Each Audio Sector (98 Frames):		
Q+P parity bytes	784	784
Subcode bytes	98	98
Audio data bytes	2,352	2,352
Bytes/sector RAW (unencoded)	3,234	3,234

Hz = Hertz (cycles per second)

mm = Millimeters (thousandths of a meter)

um = Micrometers = Microns (millionths of a meter)

Sampling

When music is recorded on a CD, it is sampled at a rate of 44,100 times per second (Hz). Each music sample has a separate left and right channel (stereo) component, and each channel component is digitally converted into a 16-bit number. This allows for a resolution of 65,536 possible values, which represents the amplitude of the sound wave for that channel at that moment.

The sampling rate determines the range of audio frequencies that can be represented in the digital recording. The more samples of a wave that are taken per second, the closer the sampled result will be to the original. The Nyquist theorem (originally published by American physicist Harry Nyquist in 1928) states that the sampling rate must be at least twice the highest frequency present in the sample to reconstruct the original signal accurately. That explains why Philips and Sony intentionally chose the 44,100Hz sampling rate when developing the CD—that rate could be used to accurately reproduce sounds of up to 20,000Hz, which is the upper limit of human hearing.

Subcodes

Subcode bytes enable the drive to find songs (which are confusingly also called *tracks*) along the spiral track and contain or convey additional information about the disc in general. The subcode bytes are stored as 1 byte per frame, which results in 98 subcode bytes for each sector. Two of these bytes are used as start block and end block markers, leaving 96 bytes of subcode information. These are then divided into eight 12-byte subcode blocks, each of which is assigned a letter designation P-W. Each subcode channel can hold about 31.97MB of data across the disc, which is about 4% of the capacity of an audio disc. The interesting thing about the subcodes is that the data is woven continuously throughout the disc; in other words, subcode data is contained piecemeal in every sector on the disc.

The P and Q subcode blocks are used on all discs, and the R-W subcodes are used only on CD+G (graphics) or CD TEXT-type discs.

The P subcode identifies the start of the tracks on the CD. The Q subcode contains a multitude of information, including the following:

- Whether the sector data is audio or data. This prevents most players from trying to "play" CD data discs, which might damage speakers due to the resulting noise that would occur.
- Whether the audio data is two or four channel. Four channel is rarely if ever used.
- Whether digital copying is permitted. PC-based CD-R and RW drives ignore this; it was instituted to prevent copying to DAT (digital audio tape) or home audio optical drives.
- Whether the music is recorded with pre-emphasis. This is a hiss or noise reduction technique.
- The track (song) layout on the disc.
- The track (song) number.
- The minutes, seconds, and frame number from the start of the track (song).
- A countdown during an intertrack (intersong) pause.
- The minutes, seconds, and frames from the start of the first track (song).
- The barcode of the CD.
- The ISRC (International Standard Recording Code). This is unique to each track (song) on the disc.

The R-W subcodes are used on CD+G (graphics) discs to contain graphics and text. This enables a limited amount of graphics and text to be displayed while the music is being played. The most common use for CD+G media is karaoke "sing-along" media. These same subcodes are used on CD TEXT discs to store disc- and track-related information that is added to standard audio CDs for playback on compatible CD audio players. The CD TEXT information is stored as ASCII characters in the R-W channels in the lead-in and program areas of a CD. On a CD TEXT disc, the lead-in area subcodes contain text information about the entire disc, such as the album, track (song) titles, and artist names. The program area subcodes, on the other hand, contain text information for the current track (song), including track title, composer, performers, and so on. The CD TEXT data is repeated throughout each track to reduce the delay in retrieving the data.

CD TEXT–compatible players typically have a text display to show this information, ranging from a simple one- or two-line, 20-character display, such as on many newer RBDS (radio broadcast data system) automobile radio/CD players, to up to 21 lines of 40-color, alphanumeric or graphics characters on home- or computer-based players. The specification also allows for future additional data, such as Joint Photographic Experts Group (JPEG) images. Interactive menus also can be used for the selection of text for display.

Note

Current versions of Windows Media Player (WMP) do not natively support CD TEXT for playback or during the creation of music CDs. However, a free plug-in called WMPCDText is available to add CD TEXT support to WMP. Other media players such as Winamp (www.winamp.com) support CD TEXT natively. Popular CD-burning programs with support for CD TEXT include Nero (www.nero.com), Roxio Creator (www.roxio.com), and the free ImgBurn program (www.imgburn.com).

Handling Read Errors

Handling errors when reading a disc was a big part of the original Red Book CD standard. CDs use parity and interleaving techniques called *cross-interleave Reed-Solomon code* (CIRC) to minimize the effects of errors on the disk. This works at the frame level. When being stored, the 24 data bytes in each frame are first run through a Reed-Solomon encoder to produce a 4-byte parity code called "Q" parity, which then is added to the 24 data bytes. The resulting 28 bytes are then run though another encoder that uses a different scheme to produce an additional 4-byte parity value called "P" parity. These are added to the 28 bytes from the previous encoding, resulting in 32 bytes (24 of the original data plus the Q and P parity bytes). An additional byte of subcode (tracking) information is then added, resulting in 33 bytes total for each frame. Note that the P and Q parity bytes are not related to the P and Q subcodes mentioned earlier.

◀◀ To learn more about the concepts behind parity and error correction, which were originally used to guard against errors in memory and modem communications, **see** Chapter 6, "Memory," **p. 345**, and Chapter 16, "Internet Connectivity," **p. 780**.

To minimize the effects of a scratch or physical defect that would damage adjacent frames, several interleaves are added before the frames are actually written. Parts of 109 frames are cross-interleaved (stored in different frames and sectors) using delay lines. This scrambling decreases the likelihood of a scratch or defect affecting adjacent data because the data is actually written out of sequence.

With CDs, the CIRC scheme can correct errors up to 3,874 bits long (which would be 2.6mm in track length). In addition, for audio CDs, only the CIRC can also conceal (through interpolation) errors up to 13,282 bits long (8.9mm in track length). *Interpolation* is the process in which the data is estimated or averaged to restore what is missing. That would, of course, be unacceptable on a data CD, so this applies only to audio discs. The Red Book CD standard defines the *block error rate* (BLER) as the number of frames (98 per sector) per second that have any bad bits (averaged over 10 seconds) and requires that this be less than 220. This allows a maximum of up to about 3% of the frames to have errors, and yet the disc will still be functional.

An additional layer of error-detection and -correction circuitry is the key difference between audio CD players and data CD drives. Audio CDs convert the digital information stored on the disc into analog signals for a stereo amplifier to process. In this scheme, some imprecision is acceptable because it would be virtually impossible to hear in the music. Data CDs, however, can't tolerate imprecision. Each bit of data must be read accurately. For this reason, data CDs have a great deal of additional ECC information written to the disc along with the actual stored information. The ECC can detect and correct most minor errors, improving the reliability and precision to levels that are acceptable for data storage.

In the case of an audio CD, missing data can be interpolated—that is, the information follows a predictable pattern that enables the drive to guess the missing values. For example, if three values are stored on an audio disc (say, 10, 13, and 20 appearing in a series), and the middle value is missing—because of damage or dirt on the CD's surface—you could interpolate a middle value of 15, which is midway between 10 and 20. Although this might not be exactly correct, in the case of audio recording, it probably won't be noticeable to the listener. If those same three values appear on a data CD in an executable program, there is no way to guess at the correct value for the middle sample. Interpolation can't work because executable program instructions or data must be exact; otherwise, the program will crash or improperly read data needed for a calculation. Using the previous example with a data CD running an executable program, guessing 15 is not merely slightly off—it is completely wrong.

In a CD on which data is stored instead of audio information, additional information is added to each sector to detect and correct errors as well as to identify the location of data sectors more accurately. To accomplish this, 304 bytes are taken from the 2,352 that originally were used for audio data and are instead used for sync (synchronizing bits), ID (identification bits), ECC, and EDC information. This leaves 2,048 bytes for actual user data in each sector. Just as when reading an audio CD, on a 1x (standard speed) CD, sectors are read at a constant speed of 75 per second. This results in a standard CD transfer rate of 153,600 bytes per second (2,048×75), which is expressed as either 153.6KBps or 150KiBps.

Note

Some of the copy-protection schemes used on audio CDs intentionally interfere with the audio data and CIRC information in such a way as to make the disc appear to play correctly, but copies of the audio files or of the entire disc will be filled with noise. Copy protection for both audio and data CDs is discussed in more detail later in this chapter.

CD Capacity

Each second of a CD contains 75 blocks of data containing 2,048 bytes per block. From this information, you can calculate the absolute maximum storage capacity of an 80-minute or 74-minute CD, as shown in Table 11.3. The table also shows the structure and layout of each sector on a CD on which data is stored.

Table 11.3 CD Sector Information and Capacity

Each Data Sector (Mode 1):	74-Minute	80-Minute
Each Data Sector (Mode 1):	74-Minute	80-Minute
Q+P parity bytes	784	784
Subcode bytes	98	98
Sync bytes	12	12
Header bytes	8	8
ECC/EDC bytes	284	284
Data bytes	2,048	2,048
Bytes/sector RAW (unencoded)	3,234	3,234

Table 11.3 Continued

Actual CD Data Capacity:		
B	681,984,000	737,280,000
KiB	666,000	720,000
KB	681,984	737,280
MiB	650.39	703.13
MB	681.98	737.28

B = Byte (8 bits)
KB = Kilobyte (1,000 bytes)
KiB = Kibibyte (1,024 bytes)
MB = Megabyte (1,000,000 bytes)
MiB = Mebibyte (1,048,576 bytes)
ECC = Error correction code
EDC = Error detection code

This information assumes the data is stored in Mode 1 format, which is used on virtually all data discs. You can learn more about the Mode 1/Mode 2 formats in the section on the Yellow Book and XA standards later in this chapter.

With data sectors, you can see that out of 3,234 actual bytes per sector, only 2,048 are user data. Most of the other 1,186 bytes are used for the intensive error-detection and -correction schemes to ensure error-free performance.

Data Encoding on the Disc

The final part of how data is actually written to the CD is very interesting. After all 98 frames are composed for a sector (whether audio or data), the information is then run through a final encoding process called *eight to fourteen modulation* (EFM). This scheme takes each byte (8 bits) and converts it into a 14-bit value for storage. The 14-bit conversion codes are designed so that there are never fewer than two or more than ten adjacent 0 bits. This is a form of Run Length Limited (RLL) encoding called RLL 2,10 (RLL x,y, where x equals the minimum and y equals the maximum run of 0s). This is designed to prevent long strings of 0s, which could more easily be misread, as well as to limit the minimum and maximum frequency of transitions actually placed on the recording media. With as few as two or as many as ten 0 bits separating 1 bits in the recording, the minimum distance between 1s is 3 bit time intervals (usually referred to as 3T), and the maximum spacing between 1s is 11 time intervals (11T).

Because some of the EFM codes start and end with a 1 or more than five 0s, three additional bits called *merge bits* are added between each 14-bit EFM value written to the disc. The merge bits usually are 0s but might contain a 1 if necessary to break a long string of adjacent 0s formed by the adjacent 14-bit EFM values. In addition to the now 17 bits created for each byte (EFM plus merge bits), a 24-bit sync word (plus three more merge bits) is added to the beginning of each frame. This results in a total of 588 bits (73.5 bytes) actually being stored on the disc for each frame. Multiply this for 98 frames per sector and you have 7,203 bytes actually being stored on the disc to represent each sector. An 80-minute disc, therefore, really has something like 2.6GB of actual data being written, which, after being fully decoded and stripped of error-correcting codes and other information, results in about 737MB (703MiB) of actual user data.

The calculations for EFM-encoded frames and sectors are shown in Table 11.4.

Table 11.4 EFM-Encoded Data Calculations

EFM-Encoded Frames:	74-Minute	80-Minute
Sync word bits	24	24
Subcode bits	14	14
Data bits	336	336
Q+P parity bits	112	112
Merge bits	102	102
EFM bits per frame	588	588
EFM-Encoded Sectors:		
EFM bits per sector	57,624	57,624
EFM bytes per sector	7,203	7,203
Total EFM data on disc (MB)	2,399	2,593

B = Byte (8 bits)
KB = Kilobyte (1,000 bytes)
KiB = Kibibyte (1,024 bytes)
MB = Megabyte (1,000,000 bytes)
MiB = Mebibyte (1,048,576 bytes)
EFM = Eight to fourteen modulation

To put this into perspective, see Table 11.5 for an example of how familiar data would actually be encoded when written to a CD. As an example, I'll use the letters *N* and *O* as they would be written on the disc.

Table 11.5 EFM Data Encoding on a CD

Character	N	O
ASCII decimal code	78	79
ASCII hexadecimal code	4E	4F
ASCII binary code	01001110	01001111
EFM code	00010001000100	00100001000100

ASCII = American Standard Code for Information Interchange
EFM = Eight to fourteen modulation

Figure 11.5 shows how the encoded data would actually appear as pits and lands stamped into a CD.

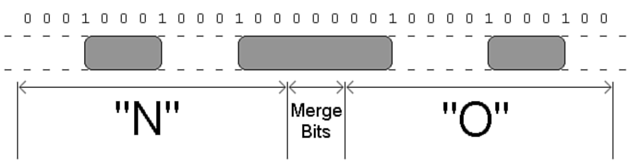

Figure 11.5 EFM data physically represented as pits and lands on a CD.

The edges of the pits are translated into the binary 1 bits. As you can see, each 14-bit grouping represents a byte of actual EFM-encoded data on the disc, and each 14-bit EFM code is separated by three merge bits (all 0s in this example). The three pits produced by this example are 4T (4 transitions), 8T, and 4T long. The string of 1s and 0s on the top of the figure represents how the actual data would be read; note that a 1 is read wherever a pit-to-land transition occurs. It is interesting to note that this drawing is actually to scale, meaning the pits (raised bumps) would be about that long and wide relative to each other. If you could use a microscope to view the disc, this is what the word "NO" would look like as actually recorded.

Writable CDs

Optical disc recording has come a long way since 1988, when the first CD-R recording system was introduced at the cost of $50,000 (back then, they used a $35,000 Yamaha audio recording drive along with thousands of dollars of additional error correction and other circuitry for CD-ROM use), operated at 1x speed only, and was part of a subsystem that was the size of a washing machine! The blank discs also cost about $100 each—compared to less than 5 cents each in bulk cakebox form. (You provide your own jewel or slimline cases.) Originally, the main purpose for CD recording was to produce prototype CDs that could then be replicated via the standard stamping process.

In 1991, Philips introduced the first 2x recorder (the CDD 521), which was about the size of a stereo receiver and cost about $12,000. Sony in 1992 and then JVC in 1993 followed with their 2x recorders, and the JVC was the first drive that had the half-height 5 1/4-inch form factor that most desktop system drives still use today. In 1995, Yamaha released the first 4x recorder (the CDR100), which sold for $5,000. A breakthrough in pricing came in late 1995 when Hewlett-Packard released a 2x recorder (the 4020i, which was actually made for them by Philips) for less than $1,000. This proved to be exactly what the market was waiting for. With a surge in popularity after that, prices rapidly fell to below $500, and then down to $200 or less. In 1996, Ricoh introduced the first CD-RW drive.

Two main types of recordable CD discs are available, called CD-R (recordable) and CD-RW (rewritable). However, because the CD-RW discs are more expensive than CD-R discs, only half as fast (or less) as CD-R discs, and won't work in all CD audio or CD-ROM drives, people usually use CD-R media instead of CD-RW.

Note

Because of differences in reflectivity of the media, some older optical drives can't read CD-RW media. Most newer drives conform to the MultiRead specification and as such can read CD-RWs. However, due to differences in the Universal Disk Format (UDF) standards used by CD-RW, a CD-RW disc created on one computer might not be readable on another computer. Therefore, if you are recording something that many people or systems will need to read, CD-R is your best choice for overall compatibility.

CD-R media is a WORM (write once, read many) media, meaning that after you fill a CD-R with data, it is permanently stored and can't be erased. The write-once limitation makes this type of disc less than ideal for system backups or other purposes in which it would be preferable to reuse the same media over and over. However, because of the low cost of CD-R media, you might find that making permanent backups to essentially disposable CD-R discs is as economically feasible as tape or other media.

CD-RW discs can be reused up to 1,000 times, making them suitable for almost any type of data storage task. The following sections examine these two standards and how you can use them for your own data storage needs.

CD-R

Once recorded, CD-R discs can be played back or read in any standard CD drive. CD-R discs are useful for archival storage and creating master CDs, which can be duplicated for distribution within a company.

CD-Rs function using the same principle as standard CD-ROMs.The main difference is that instead of being stamped or embossed into plastic as on regular CDs, CD-Rs have images of pits burned onto a raised groove instead. Therefore, the pits are not really raised bumps like on a standard CD, but instead are rendered as dark (burned) areas on the groove that reflect less light. Because the overall reflectivity of pit and land areas remains the same as on a stamped disc, normal CD drives can read CD-Rs exactly as if they were stamped discs.

Part of the recording process with CD-Rs starts before you even insert the disc into the drive. CD-R media is manufactured much like a standard CD—a stamper is used to mold a base of polycarbonate plastic. However, instead of stamping pits and lands, the stamper imprints a spiral groove (called a *pre-groove*) into the disc. From the perspective of the reading (and writing) laser underneath the disc, this groove is seen as a raised spiral ridge and not a depression.

The pre-groove (or ridge) is not perfectly straight; instead it has a slight wobble. The amplitude of the wobble is generally very small compared to the track pitch (spacing). The groove separation is 1.6 microns, but it wobbles only 0.030 microns from side to side. The wobble of a CD-R groove is modulated to carry supplemental information read by the drive. The signal contained in the wobble is called *absolute time in pre-groove* (ATIP) because it is modulated with time code and other data. The time code is the same minutes:seconds:frame format that will eventually be found in the Q-subcode of the frames after they are written to the disc. The ATIP enables the drive to locate positions on the disc before the frames are actually written. Technically, the wobble signal is frequency shift-keyed with a carrier frequency of 22.05KHz and a deviation of 1KHz. The wobble uses changes in frequency to carry information.

To complete the CD-R disc, an organic dye is evenly applied across the disc by a spin-coating process. Next, a gold or silver reflective layer is applied (some early low-cost media used aluminum), followed by a protective coat of UV-cured lacquer to protect the reflective and dye layers. Gold or silver is used in recent and current CD-R discs to get the reflectivity as high as possible (gold is used in archival CD-Rs designed for very long-term storage), and it was found that the organic dye tends to oxidize aluminum. Then, silk-screen printing is applied on top of the lacquer for identification and further protection. When seen from the underside, the laser used to read (or write) the disc first passes through the clear polycarbonate and the dye layer, hits the gold layer where it is reflected back through the dye layer and the plastic, and finally is picked up by the optical pickup sensor in the drive.

The dye and reflective layer together have the same reflective properties as a *virgin* CD. In other words, a CD reader would read the groove of an unrecorded CD-R disc as one long land. To record on a CD-R disc, a laser beam of the same wavelength (780nm) as is normally used to read the disc, but with 10 times the power, is used to heat up the dye. The laser is fired in a pulsed fashion at the top of the ridge (groove), heating the layer of organic dye to between 482°F and 572°F (250°–300°C). This temperature literally burns the organic dye, causing it to become opaque. When read, this prevents the light from passing through the dye layer to the gold and reflecting back, having the same effect of canceling the laser reflection that an actual raised pit would on a normal stamped CD.

Figure 11.6 shows the CD-R media layers, along with the pre-groove (raised ridge from the laser perspective) with burned pits.

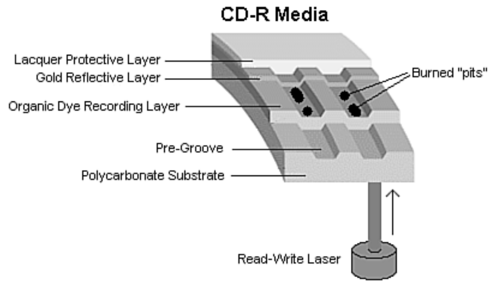

Figure 11.6 CD-R media layers.

The drive reading the disc is fooled into thinking a pit exists, but no actual pit exists—there's simply a spot of less-reflective material on the ridge. This use of heat to create the pits in the disc is why the recording process is often referred to as *burning* a CD. When burned, portions of the track change from a reflective to a nonreflective state. This change of state is permanent and can't be undone, which is why CD-R is considered a write-once medium.

CD-R Capacity

All CD-R drives can work with the original 650MiB (682MB) CD-R media (equal to 74 minutes of recorded music), as well as the now-standard higher-capacity 700MiB (737MB) CD-R blanks (equal to 80 minutes of recorded music).

Some drives and burning software are capable of overburning, whereby they write data partially into the lead-out area and essentially extend the data track. This is definitely risky as far as compatibility is concerned. Many drives, especially older ones, fail when reading near the end of an overburned disc. It's best to consider this form of overclocking CDs somewhat experimental. It might be useful for your own purposes if it works with your drives and software, but interchangeability will be problematic.

Some vendors sell 90-minute (790MiB) and 99-minute (870MiB) media to make overburning easier. Most standard CD-RW drives can reliably burn up to 89:59 of music onto the 90-minute media, and the resulting CD-R can be played on a variety of late-model auto and home electronics players.

CD-R Media Color

There has been some controversy over the years about which colors of CD-R media provide the best performance. Table 11.6 shows the most common color combinations, along with which brands use them and some technical information.

Some brands are listed with more than one color combination, due to production changes or different product lines. You should check color combinations whenever you purchase a new batch of CD-R media if you've found that particular color combinations work better for you in your applications.

Table 11.6 CD-R Media Color and Its Effect on Recording

Media Color (First Color Is Reflective Layer; Second Is Dye Layer)	Brands	Technical Notes
Gold-gold	Mitsui, Kodak, Maxell, Ricoh	Phthalocyanine dye. Less tolerance for power variations. Has a rate life span of up to 100 years. Might be less likely to work in a variety of drives. Invented by Mitsui Toatsu Chemicals. Works best in drives that use a Long Write Strategy (longer laser pulse) to mark media.
Gold-green	Imation (nee 3M), Memorex, Kodak, BASF, TDK, Verbatim	Cyanine dye. More forgiving of disc-write and disc-read variations. Has a rated lifespan of 10 years (older media). Recent media has a rated lifespan of 20–50 years (silver/green). Color combination developed by Taiyo Yuden. Used in the development of the original CD-R standards. De facto standard for CD-R industry and was the original color-combination used during the development of CD-R technology. Works best in drives that use a Short Write Strategy (shorter laser pulse) to mark media.
Silver-blue	Verbatim, DataLifePlus, HiVal, Maxell, TDK	Process developed by Verbatim. Azo dye. Similar performance to green media, plus rated to last up to 100 years. A good choice for long-term archiving.

Note

Original PlayStation games came on discs that were tinted black for appearance. Soon blank CD-R recordable discs were also available with this same black tint in the polycarbonate. The black tint is purely cosmetic—it is invisible to the infrared laser that reads/writes the disc. In other words, "black" CD-R discs are functionally identical to clear discs and can be made using any of the industry-standard dyes in the recording layer. The black tint hides the recording layer visually, so although the laser passes right through it, the black tint prevents you from directly observing the color of the dye in the recording layer.

Ultimately, although the various color combinations have their advantages, the best way to choose a media type is to try a major brand of media in your drive with both full-disc and small-disc recording jobs and then try the completed disc in as wide a range of drive brands and speeds as you can.

Note

If you are planning to record music mixes for use in automobile based or portable CD players, be sure to test compatibility in these devices as well.

The perfect media for you will be the ones that offer you the following:

- High reliability in writing (check your drive model's list of recommended media)
- No dye or reflective surface dropouts (areas where the media won't record properly)
- Durability through normal handling (scratch-resistant coating on media surface)
- Compatibility across the widest range of CD drives
- Lowest unit cost

If you have problems recording reliably with certain types of media, or if you find that some brands with the same speed rating record much more slowly than others, contact your drive vendor for a firmware upgrade. Firmware upgrades can also help your drive recognize new types of faster media from different vendors.

CD-R Media Recording Speed Ratings

With CD-R mastering speeds ranging from 1x (now-discontinued first-generation units) up through the current 48x–52x rates, it's important to check the speed rating (x-rating) of your CD-R media.

Most branded media on the market today is rated to work successfully at up to 52x recording speeds (some are limited to 48x). Some brands indicate this specifically on their packaging, whereas you must check the websites for others to get this information. If necessary, install the latest firmware updates to reach maximum recording speed.

▶▶ **See** "Updating the Firmware in an Optical Drive," **p. 599** (this chapter).

Note

The 52x CD-R recording speed is the fastest speed available, but higher spin rates can result in excessive vibration and even disc failure.

If speed ratings are unavailable for your media, you might want to restrict your burning to 32x or lower for data. If you are burning audio CDs, you might find that some devices work better with media burned at 8x or lower speeds than with media burned at higher speeds.

Tip

Most drives and mastering software support a setting that automatically determines the best speed to use for burning a CD-R. Software that supports this type of feature analyzes the media and adjusts writing methods and write speed during the write process to ensure the best results. Using this feature with media with an unknown speed rating helps you get a reliable burn no matter what the speed rating of the media is.

CD-RW

Beginning in early 1996, an industry consortium that included Ricoh, Philips, Sony, Yamaha, Hewlett-Packard, and Mitsubishi Chemical Corporation announced the CD-RW format. The design was largely led by Ricoh, and it was the first manufacturer to introduce a CD-RW drive (in May 1996). This drive was the MP6200S, which was a 2/2/6 (2x record, 2x rewrite, 6x read) rated unit. At the same time, the Orange Book Part III was published, which officially defined the CD-RW standard.

CD-RW drives rapidly replaced CD-R-only drives, and although rewritable DVD drives have largely replaced CD-RW drives, any rewritable DVD drive can function as a CD-R/CD-RW drive. Some low-cost systems include DVD combo drives, which combine DVD-ROM and CD-R/CD-RW capabilities.

You can burn and write to CD-RW discs just like CD-Rs; the main difference is that you can erase and reburn CD-RWs again and again. They are very useful for prototyping a disc that will then be duplicated in less expensive CD-R or even stamped CDs for distribution. They can be rewritten at least 1,000 times or more. Additionally, with packet-writing software (software that supports the Universal Disk Format standard), CD-RWs can even be treated like giant floppy disks, where you can simply drag and drop or copy and delete files at will. Although CD-RW discs are about 1.5–2 times more expensive than CD-R media, CD-RWs are still far cheaper than optical cartridges and other removable formats. This makes CD-RW a viable technology for small-scale system backups, file archiving, and virtually any other data storage task where rewritable DVD is not suitable.

Note

The CD-RW format originally was referred to as CD-Erasable, or CD-E.

Four main differences exist between CD-RW and CD-R media. In a nutshell, CD-RW discs are

- Rewritable
- More expensive
- Slower when writing
- Less reflective

Besides the CD-RW media being rewritable and costing a bit more, it is writable at about half (or less) the speed of CD-R discs. This is because the laser needs more time to operate on a particular spot on the disk when writing. This media also has a lower reflectivity, which limits readability in older drives. Many older standard CD-ROM and CD-R drives can't read CD-RWs. However, MultiRead capability is now found in virtually all CD drives, enabling them to read CD-RWs without problems. In general, CD-DA drives—especially the car audio players—seem to have the most difficulty reading CD-RWs. So, for music recording or compatibility with older drives, you should probably stick to CD-R media. Check the drive or device specifications to determine compatibility with CD-RW media.

CD-RW drives and media use a phase-change process to create the illusion of pits on the disc. As with CD-R media, the disc starts out with the same polycarbonate base with a wobbled pre-groove molded in, which contains ATIP information. Then, on top of the base a special dielectric (insulating) layer is spin-coated, followed by the phase-change recording layer, another dielectric layer, an aluminum reflective layer, and finally a UV-cured lacquer protective layer (and optional screen printing). The dielectric layers above and below the recording layer are designed to insulate the polycarbonate and reflective layers from the intense heat used during the phase-change process.

Figure 11.7 shows the CD-RW media layers, along with the pre-groove (raised ridge from the laser perspective) with burned pits in the phase change layer.

Instead of burning an organic dye as with CD-R, the recording layer in a CD-RW disc is made up of a phase-change alloy consisting of silver, indium, antimony, and tellurium (Ag-In-Sb-Te). The reflective part of the recording layer is an aluminum alloy, the same as used in normal stamped discs. As a result, the recording side of CD-RW media looks like a mirror with a slight blue tint. The read/write laser works from the underside of the disk, where the groove again appears like a ridge, and the recording is made in the phase-change layer on top of this ridge. The recording layer of Ag-In-Sb-Te alloy normally has a polycrystalline structure that is about 20% reflective. When data is written to a CD-RW disc, the laser in the drive alternates between two power settings, called P-write and P-erase. The higher power setting (P-write) is used to heat the material in the recording layer to a temperature between 500°C and 700°C (932°–1,292°F), causing it to melt. In a liquid state the molecules of the material flow freely, losing their polycrystalline structure and taking what is called an *amorphous* (random) state. When the material then solidifies in this amorphous state, it is only about 5% reflective. When being read, these areas lower in reflectivity simulate the pits on a stamped CD-ROM disc.

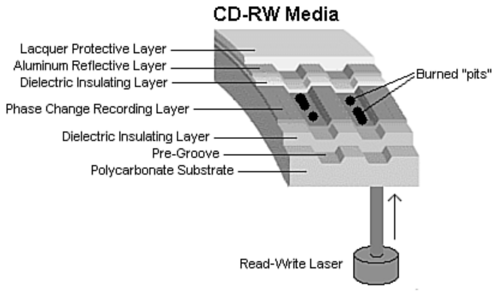

Figure 11.7 CD-RW media layers.

To return the material back to a polycrystalline state, the laser is set to the lower-power P-erase mode. This heats the active material to approximately 200°C (392°F), which is well below the liquid melting point but high enough to soften the material. When the material is softened and allowed to cool more slowly, the molecules realign from a 5% reflective amorphous state back to a 20% reflective polycrystalline state. These higher reflective areas simulate the lands on a stamped CD-ROM disc.

Note that despite the name of the P-erase laser power setting, the disc is not ever explicitly "erased." Instead, CD-RW uses a recording technique called *direct overwrite*, in which a spot doesn't have to be erased to be rewritten; it is simply rewritten. In other words, when data is recorded, the laser remains on and pulses between the P-write and P-erase power levels to create amorphous and polycrystalline areas of low and high reflectivity, regardless of which state the areas were in prior. It is similar in many ways to writing data on a magnetic disk that also uses direct overwrite. Every sector already has data patterns, so when you write data, all you are really doing is writing new patterns. Sectors are never really erased; they are merely overwritten. The media in CD-RW discs is designed to be written and rewritten up to 1,000 times.

The original Orange Book Part III Volume 1 (CD-RW specification) allowed for CD-RW writing at up to 4x speeds. New developments in the media and drives were required to support speeds higher than that. So in May 2000, Part III Volume 2 was published, defining CD-RW recording at speeds from 4x to 10x. This revision of the CD-RW standard is called *High-Speed Rewritable*, and both the discs and drives capable of CD-RW speeds higher than 4x will indicate this via the logos printed on them. Part III Volume 3 was published in September 2002 and defines Ultra-Speed drives, which are CD-RW drives capable of recording speeds 8x–24x.

Because of the differences in High-Speed and Ultra-Speed media, High-Speed media can be used only in High-Speed and Ultra-Speed drives; Ultra-Speed Media can be used only in Ultra-Speed drives. Both High-Speed and Ultra-Speed drives can use standard 2x–4x media, enabling them to interchange data with computers that have standard-speed CD-RW drives. Thus, choosing the wrong media to interchange with another system can prevent the other system from reading the media. If you don't know which speed of CD-RW media the target computer supports, I recommend you either use standard 2x–4x media or create a CD-R.

Because of differences in the UDF standards used by the packet-writing software that drags and drops files to CD-RW drives, the need to install a UDF reader on systems with CD-ROM drives, and the incapability of older CD-ROM and first-generation DVD-ROM drives to read CD-RW media, I recommend using CD-RW media for personal backups and data transfer between your own computers. However, when you send CD data to another user, CD-R is universally readable, making it a better choice.

MultiRead Specifications

The original Red and Yellow Book CD standards specified that, on a CD, the lands should have a minimum reflectance value of about 70%, and the pits should have a maximum reflectance of about 28%. Therefore, the area of a disc that represents a land should reflect back no less than 70% of the laser light directed at it, whereas the pits should reflect no more than 28%. In the early 1980s when these standards were developed, the photodetector diodes used in the drives were relatively insensitive, and these minimum and maximum reflectance requirements were deliberately designed to create enough brightness and contrast between pits and lands to accommodate them.

On a CD-RW disc, the reflectance of a land is approximately 20% (plus or minus 5%) and the reflectivity of a pit is only 5%—obviously well below the original requirements. Fortunately, it was found that by the addition of a relatively simple AGC circuit, the ratio of amplification in the detector circuitry can be changed dynamically to allow for reading the lower-reflective CD-RW discs. Therefore, although CD-ROM drives were not initially capable of reading CD-RW discs, modifying the existing designs to enable them to do so wasn't difficult. Where you might encounter problems reading CD-RW discs is with CD audio drives, especially older ones. Because CD-RW first came out in 1996 (and took a year or more to become popular), most CD-ROM drives manufactured in 1997 or earlier have problems reading CD-RW discs.

DVDs also have some compatibility problems. With DVD, the problem isn't just simple reflectivity as it is an inherent incompatibility with the laser wavelength used for DVD versus CD. The problem in this case stems from the dyes used in the recording layer of CD-R and RW discs, which are very sensitive to the wavelength of light used to read them. At the proper CD laser wavelength of 780nm, they are very reflective, but at other wavelengths, the reflectivity falls off markedly. Normally, CD drives use a 780nm (infrared) laser to read the data, whereas DVD drives use a shorter wavelength 650nm (red) laser. Although the shorter wavelength laser works well for reading commercial CD-ROM discs because the aluminum reflective layer they use is equally reflective at the shorter DVD laser wavelength, it doesn't work well at all for reading CD-R or RW discs.

Fortunately, a solution was introduced by Sony and then similarly by all the other DVD drive manufacturers. This solution consists of a dual-laser pickup that incorporates both a 650nm (DVD) and 780nm (CD) laser. Some of these used two discrete pickup units with separate optics mounted to the same assembly, but they eventually changed to dual-laser units that use the same optics for both, making the pickup smaller and less expensive. Because most manufacturers wanted to make a variety of drives—including cheaper ones without the dual-laser pickup—a standard needed to be created so that someone purchasing a drive would know the drive's capabilities.

So how can you tell whether your CD or DVD drive is compatible with CD-R and RW discs? In the late 1990s, the OSTA created the MultiRead specifications to guarantee specific levels of compatibility:

- **MultiRead**—For CD drives
- **MultiRead2**—For DVD drives

In addition, a similar MultiPlay standard exists for consumer DVD-Video and CD-DA devices.

Table 11.7 shows the two levels of MultiRead capability that you can assign to drives and the types of media guaranteed to be readable in such drives.

Table 11.7 MultiRead and MultiRead2 Compatibility Standards for CD/DVD Drives

Media	MultiRead	MultiRead2	Media	MultiRead	MultiRead2
CD-DA	X	X	DVD-ROM	—	X
CD-ROM	X	X	DVD-Video	—	X
CD-R	X	X	DVD-Audio	—	X
CD-RW	X	X	DVD-RAM	—	X

X = Compatible; drive will read this media.

— = Incompatible; drive won't read.

Note that MultiRead also indicates that the drive is capable of reading discs written in Packet Writing mode because this mode is now being used more commonly with both CD-R and DVD rewritable media.

If you use only rewritable CD or DVD drives, you don't need to worry about compatibility. However, if you still use nonrewritable drives, you should check compatibility with other types of media. Although the MultiRead and MultiRead2 logos shown in Figure 11.8 are not widely used today, you can determine a particular drive's compatibility with a given media type by viewing its specification sheet.

Figure 11.8 MultiRead and MultiRead2 logos. These logos can be found on some older drives meeting these specifications.

You can obtain the MultiRead specification (revision 1.11, October 23, 1997) and MultiRead 2 specification (revision 1.0, December 6, 1999) from the OSTA website.

DVD

DVD in simplest terms is a high-capacity CD. In fact, every DVD-ROM drive *is* a CD-ROM drive; that is, it can read CDs as well as DVDs. (Some older standalone DVD players can't read CD-R or CD-RW discs, however.) DVD uses the same optical technology as CD, with the main difference being higher density. The DVD standard dramatically increases the storage capacity of, and therefore the useful applications for, CD-sized discs. A CD can hold a maximum of about 737MB (80-minute disc) of data, which might sound like a lot but is simply not enough for many applications, especially where the use of video is concerned. DVDs, on the other hand, can hold up to 4.7GB (single layer) or 8.5GB (dual layer) on a single side of the disc, which is more than 11 1/2 times greater than a CD. Double-sided DVDs can hold up to twice that amount, although you currently must manually flip the disc over to read the other side.

Up to two layers of information can be recorded to DVDs, with an initial storage capacity of 4.7GB of digital information on a single-sided, single-layer disc—a disc that is the same overall diameter and thickness of a current CD. With Moving Picture Experts Group standard 2 (MPEG-2) compression, that's enough to contain approximately 133 minutes of video, which is enough for a full-length, full-screen, full-motion feature film—including three channels of CD-quality audio and four channels of subtitles. Using both layers, a single-sided disc could easily hold 240 minutes of video or more. This initial capacity is no coincidence; the creation of DVD was driven by the film industry, which has long sought a storage medium cheaper and more durable than videotape.

Note

It is important to know the difference between the DVD-Video and DVD-ROM standards. DVD-Video discs contain only video programs and are intended to be played in a DVD player connected to a television and possibly an audio system. DVD-ROM is a data-storage medium intended for use by PCs and other types of computers. The distinction is similar to that between an audio CD and a CD-ROM. Computers might be capable of playing audio CDs as well as CD-ROMs, but dedicated audio CD players can't use a CD-ROM's data tracks. Likewise, computer DVD drives can play DVD-Video discs (with MPEG-2 decoding in either hardware or software), but DVD-Video players can't access data on a DVD-ROM. This is the reason you must select the type of DVD you are trying to create when you make a writable or rewritable DVD.

The initial application for DVDs was as an upgrade for CDs as well as a replacement for prerecorded videotapes. As with CDs, which initially were designed only for music, DVDs have since developed into a wider range of uses, including video rental, computer data storage, and high-quality audio.

DVD History

DVD had a somewhat rocky start. During 1995, two competing standards for high-capacity CD drives were being developed to compete with each other for future market share. One standard, called Multimedia CD, was introduced and backed by Philips and Sony, whereas a competing standard, called the Super Density (SD) disc, was introduced and backed by Toshiba, Time Warner, and several other companies. If both standards had hit the market as is, consumers as well as entertainment and software producers would have been in a quandary over which one to choose.

Fearing a repeat of the Beta/VHS situation that occurred in the videotape market, several organizations, including the Hollywood Video Disc Advisory Group and the Computer Industry Technical Working Group, banded together to form a consortium to develop and control the DVD standard. The consortium insisted on a single format for the industry and refused to endorse either competing proposal. With this incentive, both groups worked out an agreement on a single, new, high-capacity CD-type disc in September 1995. The new standard combined elements of both previously proposed standards and was called DVD, which originally stood for *digital video disc* but has since been changed to *digital versatile disc*. The single DVD standard has avoided a confusing replay of the VHS-versus-Beta-tape fiasco for movie fans and has given the software, hardware, and movie industries a single, unified standard to support.

After copy protection and other items were agreed on, the DVD-ROM and DVD-Video standards were officially announced in late 1996. Players, drives, and discs were announced in January 1997 at the Consumer Electronics Show (CES) in Las Vegas, and the players and discs became available in March 1997. The initial players were about $1,000 each. Only 36 movies were released in the first wave, and they were available only in seven cities nationwide (Chicago, Dallas, Los Angeles, New York, San Francisco, Seattle, and Washington, DC) until August 1997 when the full release began. After a somewhat rocky start (much had to do with agreements on copy protection to get the movie companies to go along, and there was a lack of titles available in the beginning), DVD has become an incredible success. The organization that controls the DVD video standard is called the DVD Forum and was founded by 10 companies, including Hitachi, Matsushita, Mitsubishi, Victor, Pioneer, Sony, Toshiba, Philips, Thomson, and Time Warner. Since its founding in April 1997, more than 230 companies have joined the forum. Because it is a public forum, anybody can join and attend the meetings; the site for the DVD Forum is www.dvdforum.org. Because the DVD Forum was unable to agree on a universal recordable format, its members who are primarily responsible for CD and DVD technology (Philips, Sony, and others) split off to form the DVD+RW Alliance in June 2000; their site is www.dvdservices.org. They have since introduced the DVD+RW format, which is the fastest, most flexible and backward-compatible recordable DVD format. DVD-R/RW and DVD+R/RW are not just for computer uses either: You can purchase DVD set-top recorders from many vendors (some of which also contain VCRs to enable you to dub non-copy-protected VCR tapes to DVD).

DVD Construction and Technology

DVD technology is similar to CD technology. Both use the same size discs (120mm diameter, 1.2mm thick, with a 15mm hole in the center) with pits and lands stamped in a polycarbonate base. Unlike a CD, though, DVDs can have two layers of recordings on a side and be double-sided. Each layer is separately stamped, and the layers are bonded together to make the final 1.2mm-thick disc. The manufacturing process is largely the same, with the exception that each layer on each side is stamped from a separate piece of polycarbonate plastic. These are then bonded together to form the completed disc. The main difference between CD and DVD is that DVD is a higher-density recording read by a laser with a shorter wavelength, focused more closely to the disc, which enables more information to be stored. Also, whereas CDs are single-sided and have only one layer of stamped pits and lands, DVDs can have up to two layers per side and can have information on both sides.

As with CDs, each layer is stamped or molded with a single physical track in a spiral configuration starting from the inside of the disc and spiraling outward. The disc rotates counterclockwise (as viewed from the bottom), and each spiral track contains pits (bumps) and lands (flat portions), just as on a CD. Each recorded layer is coated with a thin film of metal to reflect the laser light. The outer layer has a thinner coating to allow the light to pass through to read the inner layer. If the disc is single-sided, a label can be placed on top; if it's double-sided, only a small ring near the center provides room for labeling.

Just as with a CD, reading the information back on a DVD is a matter of bouncing a low-powered laser beam off one of the reflective layers in the disc. The laser shines a focused beam on the underside of the disc, and a photosensitive receptor detects when the light is reflected back. When the light hits a land (flat spot) on the track, the light is reflected back; when the light hits a pit (raised bump), the phase differential between the projected and reflected light causes the waves to cancel and no light is reflected back.

The individual pits on a DVD are 0.105 microns deep and 0.4 microns wide. The pits and lands vary in length from about 0.4 microns at their shortest to about 1.9 microns at their longest (on single-layer discs).

Refer to the section "CD Construction and Technology," earlier in this chapter, for more information on how the pits and lands are read and converted into actual data, as well as how the drives physically and mechanically work.

DVD uses the same optical laser read pit and land storage that CDs do. The greater capacity is made possible by several factors, including the following:

- A 2.25 times smaller pit length (0.9–0.4 microns)
- A 2.16 times reduced track pitch (1.6–0.74 microns)
- A slightly larger data area on the disc (8,605–8,759 square millimeters)
- About 1.06 times more efficient channel bit modulation
- About 1.32 times more efficient error-correction code
- About 1.06 times less sector overhead (2,048/2,352–2,048/2,064 bytes)

The DVD disc's pits and lands are much smaller and closer together than those on a CD, allowing the same physical-sized platter to hold much more information. Figure 11.9 shows how the grooved tracks with pits and lands are just over four times as dense on a DVD as compared to a CD.

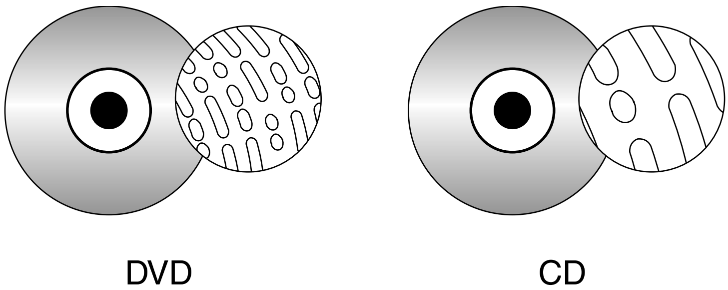

Figure 11.9 DVD data markings (pits and lands) versus those of a standard CD.

DVD drives use a shorter wavelength laser (650nm) to read these smaller pits and lands. A DVD can have nearly double the initial capacity by using two separate layers on one side of a disc and double it again by using both sides of the disc. The second data layer is written to a separate substrate below the first layer, which is then made semi-reflective to enable the laser to penetrate to the substrate beneath it. By focusing the laser on one of the two layers, the drive can read roughly twice the amount of data from the same surface area.

DVD Tracks and Sectors

The pits are stamped into a single spiral track (per layer) with a spacing of 0.74 microns between turns, corresponding to a track density of 1,351 turns per millimeter or 34,324 turns per inch. This equates to a total of 49,324 turns and a total track length of 11.8km or 7.35 miles in length. The track is composed of sectors, with each sector containing 2,048 bytes of data. The disc is divided into four main areas:

- **Hub clamping area**—The hub clamp area is just that: a part of the disc where the hub mechanism in the drive can grip the disc. No data or information is stored in that area.
- **Lead-in zone**—The lead-in zone contains buffer zones, reference code, and mainly a control data zone with information about the disc. The control data zone consists of 16 sectors of information repeated 192 times, for a total of 3,072 sectors. Contained in the 16 (repeated) sectors is information about the disc, including disc category and version number, disc size and maximum transfer rate, disc structure, recording density, and data zone allocation. The entire lead-in zone takes up to 196,607 (2FFFFh) sectors on the disc. Unlike CDs, the basic structure of all sectors on a DVD is the same. The buffer zone sectors in the lead-in zone have all 00h (zero hex) recorded for data.
- **Data zone**—The data zone contains the video, audio, or other data on the disc and starts at sector number 196,608 (30000h). The total number of sectors in the data zone can be up to 2,292,897 per layer for single-layer discs.
- **Lead-out (or middle) zone**—The lead-out zone marks the end of the data zone. All the sectors in the lead-out zone contain zero (00h) for data. This is called the middle zone if the disc is dual-layer and is recorded in opposite track path (OPT) mode, in which the second layer starts from the outside of the disc and is read in the opposite direction from the first layer.

The center hole in a DVD is 15mm in diameter, so it has a radius of 7.5mm from the center of the disc. From the edge of the center hole to a point at a radius of 16.5mm is the hub clamp area. The lead-in zone starts at a radius of 22mm from the center of the disc. The data zone starts at a radius of 24mm from the center and is followed by the lead-out (or middle) zone at 58mm. The disc track officially ends at 58.5mm, which is followed by a 1.5mm blank area to the edge of the disc. Figure 11.10 shows these zones in actual relative scale as they appear on a DVD.

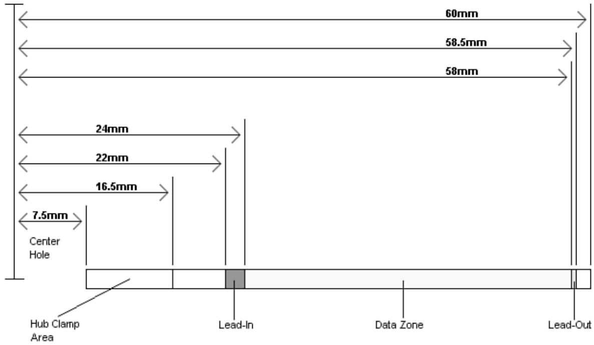

Figure 11.10 Areas on a DVD (side view).

Officially, the spiral track of a standard DVD starts with the lead-in zone and ends at the finish of the lead-out zone. This single spiral track is about 11.84 kilometers or 7.35 miles long. An interesting fact is that in a 20x CAV drive, when the outer part of the track is being read, the data moves at an actual speed of 156 miles per hour (251km/h) past the laser. What is more amazing is that even when the data is traveling at that speed, the laser pickup can accurately read bits (pit/land transitions) spaced as little as only 0.4 microns or 15.75 millionths of an inch apart!

DVDs come in both single- and dual-layer as well as single- and double-sided versions. The double-sided discs are essentially the same as two single-sided discs glued together back to back, but subtle differences do exist between the single- and dual-layer discs. Table 11.8 shows some of the basic information about DVD technology, including single- and dual-layer DVDs. The dual-layer versions are recorded with slightly longer pits, resulting in slightly less information being stored in each layer.

Table 11.8 DVD Technical Parameters

DVD Type:	Single-Layer	Dual-Layer
1x read speed (m/sec)	3.49	3.84
Laser wavelength (nm)	650	650
Numerical aperture (lens)	0.60	0.60
Media refractive index	1.55	1.55
Track (turn) spacing (um)	0.74	0.74
Turns per mm	1,351	1,351
Turns per inch	34,324	34,324
Total track length (m)	11,836	11,836
Total track length (feet)	38,832	38,832
Total track length (miles)	7.35	7.35

Table 11.8 Continued

Media bit cell length (nm)	133.3	146.7
Media byte length (um)	1.07	1.17
Media sector length (mm)	5.16	5.68
Pit width (um)	0.40	0.40
Pit depth (um)	0.105	0.105
Min. nominal pit length (um)	0.40	0.44
Max. nominal pit length (um)	1.87	2.05
Lead-in inner radius (mm)	22	22
Data zone inner radius (mm)	24	24
Data zone outer radius (mm)	58	58
Lead-out outer radius (mm)	58.5	58.5
Data zone width (mm)	34	34
Data zone area (mm2)	8,759	8,759
Total track area width (mm)	36.5	36.5
Max. rotating speed 1x CLV (rpm)	1,515	1,667
Min. rotating speed 1x CLV (rpm)	570	627
Track revolutions (data zone)	45,946	45,946
Track revolutions (total)	49,324	49,324
Data zone sectors per layer per side	2,292,897	2,083,909
Sectors per second	676	676
Media data rate (Mbps)	26.15625	26.15625
Media bits per sector	38,688	38,688
Media bytes per sector	4,836	4,836
Interface data rate (Mbps)	11.08	11.08
Interface data bits per sector	16,384	16,384
Interface data bytes per sector	2,048	2,048
DVD Type:	Single-Layer	Dual-Layer
Track time per layer (minutes)	56.52	51.37
Track time per side (minutes)	56.52	102.74
MPEG-2 video per layer (minutes)	133	121
MPEG-2 video per side (minutes)	133	242

B = Byte (8 bits)
KB = Kilobyte (1,000 bytes)
KiB = Kibibyte (1,024 bytes)
MB = Megabyte (1,000,000 bytes)
MiB = Mebibyte (1,048,576 bytes)
GB = Gigabyte (1,000,000,000 bytes)
GiB = Gibibyte (1,073,741,824 bytes)
Mbps = Megabits per second
m = Meters
mm = Millimeters (thousandths of a meter)
mm2 = Square millimeters
um = Micrometers = Microns (millionths of a meter)
nm = Nanometers (billionths of a meter)
rpm = Revolutions per minute
CLV = Constant linear velocity

As you can see from the information in Table 11.8, the spiral track is divided into sectors that are stored at the rate of 676 sectors per second. Each sector contains 2,048 bytes of data.

When being written, the sectors are first formatted into data frames of 2,064 bytes: 2,048 are data, 4 bytes contain ID information, 2 bytes contain ID error-detection (IED) codes, 6 bytes contain copyright information, and 4 bytes contain EDC for the frame.

The data frames then have ECC information added to convert them into ECC frames. Each ECC frame contains the 2,064-byte data frame plus 182 parity outer (PO) bytes and 120 parity inner (PI) bytes, for a total of 2,366 bytes for each ECC frame.

Finally, the ECC frames are converted into physical sectors on the disc. This is done by taking 91 bytes at a time from the ECC frame and converting them into recorded bits via 8-to-16 modulation. This is where each byte (8 bits) is converted into a special 16-bit value, which is selected from a table. These values are designed using an RLL 2,10 scheme, which is designed so that the encoded information never has a run of fewer than two or more than ten 0 bits in a row. After each group of 91 bytes is converted via the 8-to-16 modulation, 32 bits (4 bytes) of synchronization information are added. After the entire ECC frame is converted into a physical sector, 4,836 total bytes are stored.

Table 11.9 shows the sector, frame, and audio data calculations.

Table 11.9 DVD Data Frame, ECC Frame, and Physical Sector Layout and Information

DVD Data Frame:	
ID bytes	4
IED bytes	2
CI	6
Data bytes	2,048
Error detection code (EDC)	4
Data frame total bytes	2,064
DVD ECC Frame:	
Data frame total bytes	2,064
PO bytes	182
Parity inner (PI) bytes	120
ECC frame total bytes	2,366
DVD Media Physical Sectors:	
ECC frame bytes	2,366
8-to-16 modulation bits	37,856
Synchronization bits	832
Total encoded media bits/sector	38,688
Total encoded media bytes/sector	4,836
Original data bits/sector	16,384
Original data bytes/sector	2,048
Ratio of original to media data	2.36

ID = Identification Data
IED = ID Error Detection code
CI = Copyright Info
EDC = Error Detection Code
PO = Parity Outer
GB = Gigabyte (1,000,000,000 bytes)
GiB = Gibibyte (1,073,741,824 bytes)
Mbps = Megabits per second
m = Meters
mm = Millimeters (thousandths of a meter)
mm2 = Square millimeters
um = Micrometers = Microns (millionths of a meter)
nm = Nanometers (billionths of a meter)
rpm = Revolutions per minute
CLV = Constant linear velocity

Unlike CDs, DVDs do not use subcodes. Instead, they use the ID bytes in each data frame to store the sector number and information about the sectors.

Handling DVD Errors

DVDs use more powerful error-correcting codes than were first devised for CDs. Unlike CDs, which have different levels of error correction depending on whether audio/video or data is being stored, DVDs treat all information equally and apply the full error correction to all sectors.

The main error correcting in DVDs takes place in the ECC frame. Parity Outer (column) and Parity Inner (row) bits are added to detect and correct errors. The scheme is simple yet effective. The information from the data frames is first broken up into 192 rows of 172 bytes each. Then a polynomial equation is used to calculate and add 10 PI bytes to each row, making the rows 182 bytes each. Finally, another polynomial equation is used to calculate 16 PO (Parity Outer) bytes for each column, resulting in 16 bytes (rows) being added to each column. What started out as 192 rows of 172 bytes becomes 208 rows of 182 bytes with the PI and PO information added.

The function of the PI and PO bytes can be explained with a simple example using simple parity. In this example, 2 bytes are stored (01001110 = N, 01001111 = O). To add the error-correcting information, they are organized in rows, as shown here:

```
              Data bits
              1 2 3 4 5 6 7 8
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _.
Byte 1        0 1 0 0 1 1 1 0
Byte 2        0 1 0 0 1 1 1 1
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _.
```

Then one PI bit is added for each row, using odd parity. This means you count up the 1 bits: In the first row there are four, so the parity bit is created as a 1, making the sum an odd number. In the second row, the parity bit is a 0 because the sum of the 1s was already an odd number. The result is as follows:

```
             Data bits           ¦
             1 2 3 4 5 6 7 8     ¦  PI
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _. ¦_ _ _ _.
Byte 1       0 1 0 0 1 1 1 0     ¦  1
Byte 2       0 1 0 0 1 1 1 1     ¦  0
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _. ¦_ _ _ _.
```

Next, the parity bits for each column are added and calculated the same as before. In other words, the parity bit will be such that the sum of the 1s in each column is an odd number. The result is as follows:

```
             Data bits         ¦
             1 2 3 4 5 6 7 8   ¦  PI
—————————————————————————————- ¦—————-
Byte 1       0 1 0 0 1 1 1 0   ¦  1
Byte 2       0 1 0 0 1 1 1 1   ¦  0
—————————————————————————————- ¦—————-
     PO      1 1 1 1 1 1 1 0   ¦  1
```

Now the code is complete, and the extra bits are stored along with the data. So, instead of just the 2 bytes being stored, 11 additional bits are stored for error correction. When the data is read back, the error-correction-bit calculations are repeated and they're checked to see whether they are the same as before. To see how this works, let's change one of the data bits (due to a read error) and recalculate the error-correcting bits as follows:

```
             Data bits         ¦
             1 2 3 4 5 6 7 8   ¦  PI
—————————————————————————————- ¦—————-
Byte 1       0 1 0 0 1 1 1 0   ¦  1
Byte 2       0 1 0 0 1 1 1 1   ¦  0
—————————————————————————————- ¦—————-
     PO      1 1 1 1 1 0 1 0   ¦  1
```

Now, when you compare the PI and PO bits you calculated after reading the data to what was originally stored, you see a change in the PI bit for byte (row) 1 and in the PO bit for bit (column) 6. This identifies the precise row and column where the error was, which is at byte 1 (row 1), bit 6 (column 6). That bit was read as a 0, and you now know it is wrong, so it must have been a 1. The error-correction circuitry then simply changes it back to a 1 before passing it back to the system. As you can see, with some extra information added to each row and column, error-correction codes can indeed detect and correct errors on the fly.

Besides the ECC frames, DVDs also scramble the data in the frames using a bit-shift technique and also interleave parts of the ECC frames when they are actually recorded on the disc. These schemes serve to store the data somewhat out of sequence, preventing a scratch from corrupting consecutive pieces of data.

DVD Capacity (Sides and Layers)

Four main types of DVDs are available, categorized by whether they are single- or double-sided, and single- or dual-layered. They are designated as follows:

- **DVD-5 (4.7GB single-side, single-layer)**—A DVD-5 is constructed from two substrates bonded with adhesive. One is stamped with a recorded layer (called Layer 0), and the other is blank. An aluminum coating typically is applied to the single recorded layer.
- **DVD-9 (8.5GB single-side, dual-layer)**—A DVD-9 is constructed of two stamped substrates bonded together to form two recorded layers for one side of the disc, along with a blank substrate for the other side. The outer stamped layer (0) is coated with a semitransparent gold coating to both reflect light if the laser is focused on it and pass light if the laser is focused on the layer below. A single laser is used to read both layers; only the focus of the laser is changed.
- **DVD-10 (9.4GB double-side, single-layer)**—A DVD-10 is constructed of two stamped substrates bonded together back to back. The recorded layer (Layer 0 on each side) usually is coated with aluminum. Note that these discs are double-sided; however, drives have a read laser only on the bottom, which means the disc must be removed and flipped to read the other side.
- **DVD-18 (17.1GB double-side, dual-layer)**—A DVD-18 combines both double layers and double sides. Two stamped layers form each side, and the substrate pairs are bonded back to

back. The outer layers (Layer 0 on each side) are coated with semitransparent gold, whereas the inner layers (Layer 1 on each side) are coated with aluminum. The reflectivity of a single-layer disc is 45%–85%, and for a dual-layer disc the reflectivity is 18%–30%. The automatic gain control (AGC) circuitry in the drive compensates for the different reflective properties.

Figure 11.11 shows the construction of each of the DVD disc types.

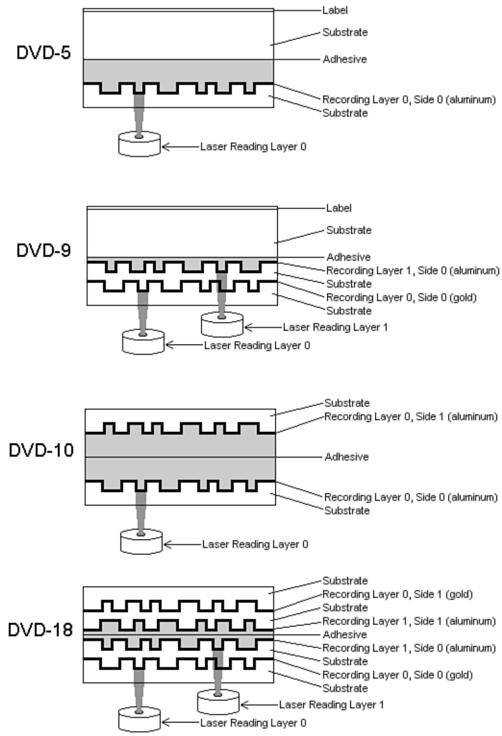

Figure 11.11 DVD disk types and construction.

Note that although Figure 11.11 shows two lasers reading the bottom of the dual-layer discs, in actual practice only one laser is used. Only the focus is changed to read the different layers.

Dual-layer discs can have the layers recorded in two ways: either opposite track path (OTP) or parallel track path (PTP). OTP minimizes the time needed to switch from one layer to the other when reading the disc. When reaching the inside of the disc (end of Layer 0), the laser pickup remains in the same location—it merely moves toward the disc slightly to focus on Layer 1. When written in OTP mode, the lead-out zone toward the outer part of the disc is called a middle zone. Discs written in PTP have both spiral layers written (and read) from the inside out. When changing from Layer 0 to Layer 1, PTP discs require the laser pickup to move from the outside (end of the first layer) back to the inside (start of the second layer), as well as for the focus of the laser to change. Virtually all discs are written in OTP mode to make the layer change quicker. OTP recording is also used by dual-layer (DL) DVD rewritable drives.

To allow the layers to be read more easily even though they are on top of one another, discs written in PTP mode have the spiral direction changed from one layer to the other. Layer 0 has a spiral winding clockwise (which is read counterclockwise), whereas Layer 1 has a spiral winding counterclockwise. This typically requires that the drive spin the disc in the opposite direction to read that layer, but with OTP the spiral is read from the outside in on the second layer. So Layer 0 spirals from the inside out, and Layer 1 spirals from the outside in.

Figure 11.12 shows the differences between PTP and OTP on a DVD.

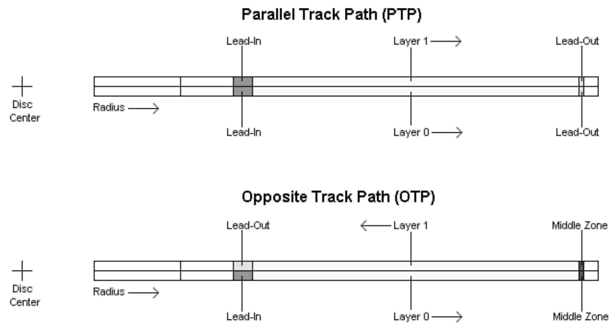

Figure 11.12 PTP versus OTP.

DVDs store up to 17.1GB, depending on the type. Table 11.10 shows the precise capacities of the various types of DVDs.

Table 11.10 DVD Capacity

	Single-Layer	Dual-Layer
DVD Designation	DVD-5	DVD-9
B	4,695,853,056	8,535,691,264
KiB	4,585,794	8,335,636
KB	4,695,853	8,535,691
MiB	4,478	8,140
MB	4,696	8,536
GiB	4.4	7.9
	Single-Layer	Dual-Layer
DVD Designation	DVD-5	DVD-9
GB	4.7	8.5
MPEG-2 video (approx. minutes)	133	242
MPEG-2 video (hours:minutes)	2:13	4:02
	Single-Layer Double-Sided	Dual-Layer Double-Sided
DVD Designation	DVD-10	DVD-18
B	9,391,706,112	17,071,382,528
KiB	9,171,588	16,671,272
KB	9,391,706	17,071,383

Table 11.10 Continued

MiB	8,957	16,281
MB	9,392	17,071
GiB	8.7	15.9
GB	9.4	17.1
MPEG-2 video (approx. minutes)	266	484
MPEG-2 video (hours:minutes)	4:26	8:04

B = Byte (8 bits)
KB = Kilobyte (1,000 bytes)
KiB = Kibibyte (1,024 bytes)
MB = Megabyte (1,000,000 bytes)
MiB = Mebibyte (1,048,576 bytes)
GB = Gigabyte (1,000,000,000 bytes)
GiB = Gibibyte (1,073,741,824 bytes)

As you might notice, the capacity of dual-layer discs is slightly less than twice of single-layer discs, even though the layers take up the same space on the discs. (The spiral tracks are the same length.) This was done intentionally to improve the readability of both layers in a dual-layer configuration. To accomplish this, the bit cell spacing was slightly increased, which increases the length of each pit and land. When reading a dual-layer disc, the drive spins slightly faster to compensate, resulting in the same data rate. However, because the distance on the track is covered more quickly, less overall data can be stored.

Besides the standard four capacities listed here, a double-sided disc with one layer on one side and two layers on the other can be produced. This would be called a DVD-14 and have a capacity of 13.2GB, or about 6 hours and 15 minutes of MPEG-2 video. Additionally, 80mm discs, which store less data in each configuration than the standard 120mm discs, can be produced.

Because of the manufacturing difficulties and the extra expense of double-sided discs—and the fact that they must be ejected and flipped to play both sides—most DVDs are configured as either a DVD-5 (single-sided, single-layer) or a DVD-9 (single-sided, dual-layer), which allows up to 8.5GB of data or 242 minutes of uninterrupted MPEG-2 video to be played. The 133-minute capacity of DVD-5 video discs accommodates 95% or more of the movies ever made.

Note

When you view a dual-layer DVD movie, you will see a momentary pause onscreen when the player starts to play the second layer. This is normal, and it takes so little time that if you blink, you might miss it.

Data Encoding on the DVD Disc

As with CDs, the pits and lands themselves do not determine the bits; instead, the transitions (changes in reflectivity) from pit to land and land to pit determine the actual bits on the disc. The disc track is divided into bit cells or time intervals (T), and a pit or land used to represent data is required to be a minimum of 3T or a maximum of 11T intervals (cells) long. A 3T long pit or land represents a 1001, and a 11T long pit or land represents a 100000000001.

Data is stored using eight to sixteen modulation, which is a modified version of the eight to fourteen modulation (EFM) used on CDs. Because of this, eight to sixteen modulation is sometimes called EFM+. This modulation takes each byte (8 bits) and converts it into a 16-bit value for storage. The 16-bit conversion codes are designed so that there are never fewer than two or more than ten adjacent 0 bits (resulting in no fewer than three or no more than eleven time intervals between 1s). EFM+ is a form of RLL encoding called RLL 2,10 (RLL x,y, where x equals the minimum and y equals the maximum run of 0s). This is designed to prevent long strings of 0s, which could more easily be misread due to clocks becoming out of sync, as well as to limit the minimum and maximum frequency of transitions actually placed on the recording media. Unlike CDs, no merge bits exist between codes. The 16-bit modulation codes are designed so that they will not violate the RLL 2,10 form without needing merge bits. Because the EFM used on CDs really requires more than 17 bits for each byte (due to the added merge and sync bits), EFM+ is slightly more efficient because only slightly more than 16 bits are generated for each byte encoded.

Note that although no more than ten 0s are allowed in the modulation generated by EFM+, the sync bits added when physical sectors are written can have up to thirteen 0s, meaning a time period of up to 14T between 1s written on the disc and pits or lands up to 14T intervals or bit cells in length.

Recordable DVD Standards

The history of recordable DVD drives has been a troubled one. It dates back to April 1997, when the DVD Forum announced specifications for rewritable and recordable DVD: DVD-RAM, and DVD-R. Later, it added DVD-RW to the mix. Dissatisfied with these standards, the industry leaders in optical recording and drives formed their own group called the DVD+RW Alliance and created another standard—DVD+R and DVD+RW. For several years, drives based on one family of standards could not freely interchange media with drives using the other family of standards.

Fortunately, all recent drives support both DVD-R/RW and DVD+R/RW media, including dual-layer (DL) DVD+R media, and most also support DVD-RAM. Thus, by using a modern drive that supports all of these types of media, you can choose the right media for a particular task. For example, use DVD-RAM for easy drag-and-drop file backups and DVD-R for creating video DVDs compatible with older DVD set-top boxes.

Table 11.11 compares the competing recordable DVD standards, and Table 11.12 breaks down the compatibilities between the drives and media.

Table 11.11 Recordable DVD Standards

Format	Introduced	Capacity	Compatibility
DVD-RAM	July 1997	Up to 4.7GB per side	Compatible with SuperMulti and Super AllWrite drives. Incompatible with older DVD drives that do not support the MultiRead2 standard.
DVD-R/RW	July 1997; Nov. 1999	4.7GB per side	Compatible with DVD-R/RW, SuperMulti and Super AllWrite DVD recorders/drives. Compatible with most DVD set-top boxes.
DVD+R/RW	Mar. 2001; May 2001	4.7GB per side	Compatible with DVD+R/RW, SuperMulti and Super AllWrite DVD recorders/drives. Compatible with most recent DVD set-top boxes.
DVD+R DL	Oct. 2003	8.5GB	Older DVD drives may require firmware updates to read DL media. Some older SuperMulti and Super AllWrite drives do not support DL media.
DVD-R DL	Feb. 2005	8.5GB	For compatibility with older DVD drives, use the Layer Jump Recording method. Older DVD drives may also require firmware updates to read DL media. Some older SuperMulti and Super AllWrite drives do not support DL media.

Table 11.12 DVD Drive and Media Compatibility

	Media (Discs)								
Drives	**CD-ROM**	**CD-R**	**CD-RW**	**DVD Drive**	**DVD-ROM**	**DVD-R**	**DVD-RAM**	**DVD-RW**	**DVD+RW**	**DVD+R**
DVD-Video Player	R	?	?	R	—	R	?	R	R	R
DVD-ROM Drive	R	R	R	R	R	R	?	R	R[1]	R
DVD-R Drive	R	R/W	R/W	R	R	R/W	—	R	R	R
DVD-RAM Drive	R	R	R	R	R	R[6]	R/W	R	R[1]	R
DVD-RW Drive	R	R/W	R/W	R	R	R/W	—	R/W	R	R
DVD+R/RW Drive	R	R/W	R/W	R	R	R	R[3]	R	R/W	R/W[2]
DVD-Multi Drive[4]	R	R/W	R/W	R	R	R	R/W	R/W	R[1]	R
DVD±R/RW Drive	R	R/W	R/W	R	R	R/W	R[5]	R/W	R/W	R/W
DVD Super Multi Drive[7]	R	R/W	R/W	R	R	R/W[8]	R/W	R/W	R/W	R/W[9]

R = Read.

W = Write.

— = Will not read or write.

? = MultiRead/MultiPlay drives will read.

1 = Might require media's compatibility bit be changed to alternate (Type 2).

2 = Some first-generation DVD+RW drives will not write DVD+R discs; see your drive manufacturer for an update or trade-in.

3 = Read compatibility with DVD-RAM varies by drive; check documentation for details.

4 = DVD Forum specification for drives that are compatible with all DVD Forum standards. (DVD+R/RW is not a DVD Forum standard.)

5 = Some of these drives can also write to DVD-RAM media.

6 = Some of these drives can also write to DVD-R media.

7 = Identifies drives that work with DVD+R/RW, DVD-R/RW, DVD+R DL, and DVD-RAM media.

8 = Some of these drives also work with dual-layer (DL) media.

9 = Also supports dual-layer (DL) media.

DVD+R/RW offers low drive and media prices, provides the highest compatibility with existing formats, and has features that make it the most ideal for both video recording and data storage in PCs. However, with most recent drives, you can now select the best media for the job.

DVD-RAM

DVD-RAM is the rewritable DVD standard endorsed by Panasonic, Hitachi, and Toshiba; it is part of the DVD Forum's list of supported standards. DVD-RAM uses a phase-change technology similar to that of CD-RW. Unfortunately, DVD-RAM discs can't be read by most standard DVD-ROM drives because of differences in both reflectivity of the media and the data format. (DVD-R, by comparison, is backward-compatible with DVD-ROM.)

DVD-ROM drives that can read DVD-RAM discs began to come on the market in early 1999 and follow the MultiRead2 specification. DVD-ROM drives and DVD-Video players labeled as "MultiRead2 compliant" are capable of reading DVD-RAM discs. See the section "MultiRead Specifications," earlier in this chapter, for more information. Although the MultiRead2 logo is not used on current products, some recent and current DVD-ROM drives can read DVD-RAM media; check the specification sheet for a particular drive to verify compatibility.

The first DVD-RAM drives were introduced in spring 1998 and had a capacity of 2.6GB (single-sided) or 5.2GB (double-sided). DVD-RAM Version 2 discs with 4.7GB arrived in late 1999, and double-sided 9.4GB discs arrived in 2000. DVD-RAM drives typically read DVD-Video, DVD-ROM, and CD media. Although DVD-ROM drives, older DVD+R/RW and DVD-R/RW drives, and DVD-Video players can't read DVD-RAM media, DVD Multi and DVD Super Multi drives can read/write DVD-RAM.

DVD-RAM uses what is called the *wobbled land and groove recording* method, which records signals on both the lands (the areas between grooves) and inside the grooves that are preformed on the disc. The tracks wobble, which provides clock data for the drive. Special sector header pits are prepressed into the disc during the manufacturing process as well. See Figure 11.13, which shows the wobbled tracks (lands and grooves) with data recorded both on the lands and in the grooves. This is unlike CD-R or CD-RW, in which data is recorded on the groove only.

The disc is recorded using *phase-change recording*, in which data is written by selectively heating spots in the grooves or on the lands with a high-powered laser. The DVD-RAM drive write laser transforms the film from a crystalline to an amorphous state by heating a spot, which is then rendered less reflective than the remaining crystalline portions. The signal is read as the difference of the laser reflection rate between the crystalline and amorphous states. The modulation and error-correction codes are the same as for DVD-Video and DVD-ROM, ensuring compatibility with other DVD formats. For rewriting, a lower-powered laser reheats the spot to a lower temperature, where it recrystallizes.

Disc cartridges or caddies originally were required for both single- and double-sided discs but have now been made optional for single-sided discs and are seldom used today. Double-sided discs must remain inside the caddy at all times for protection; however, single-sided discs can be taken out of the cartridge if necessary.

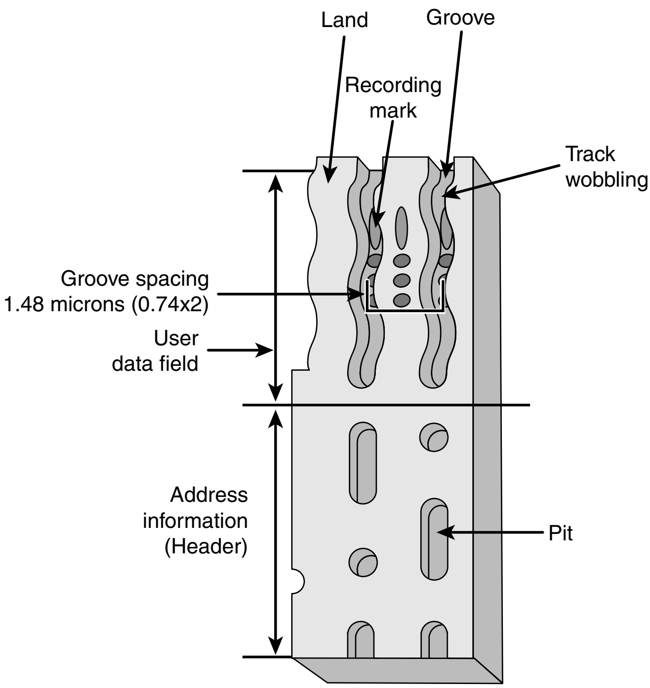

Figure 11.13 DVD-RAM wobbled land and groove recording.

DVD-RAM specifications are shown in Table 11.13.

Table 11.13 DVD-RAM Specifications

Storage capacity	2.6GB single-sided; 5.2GB double-sided
Disc diameter	80mm–120mm
Disc thickness	1.2mm (0.6mm×2: bonded structure)
Recording method	Phase change
Laser wavelength	650nm
Data bit length	0.41–0.43 microns
Recording track pitch	0.74 microns
Track format	Wobbled land and groove

In the past, I have been opposed to DVD-RAM because of a lack of compatibility with other drive types. However, if you use drives supporting the DVD Super Multi standard, you can read and write DVD-RAM as well as other rewritable DVD formats. With the ability to read, write, and erase data without the need to use UDF packet-writing software, DVD-RAM can be a useful alternative to other types of rewritable DVD—assuming all your drives can use it.

DVD-R

DVD-R is a write-once medium similar to CD-R, which was originally created by Pioneer and released by the DVD Forum in July 1997. You can play DVD-R discs on standard DVD-ROM drives. Some DVD-RAM drives can also write to DVD-R media.

DVD-R has a single-sided storage capacity of 4.7GB—about seven times that of a CD-R-and double that for a double-sided disc. These discs use an organic dye recording layer that allows for a low material cost, similar to CD-R.

To enable positioning accuracy, DVD-R uses a wobbled groove recording, in which special grooved tracks are preengraved on the disc during the manufacturing process. Data is recorded within the grooves only. The grooved tracks wobble slightly right and left, and the frequency of the wobble contains clock data for the drive to read, as well as clock data for the drive. The grooves are spaced more closely together than with DVD-RAM, but data is recorded only in the grooves and not on the lands (see Figure 11.14).

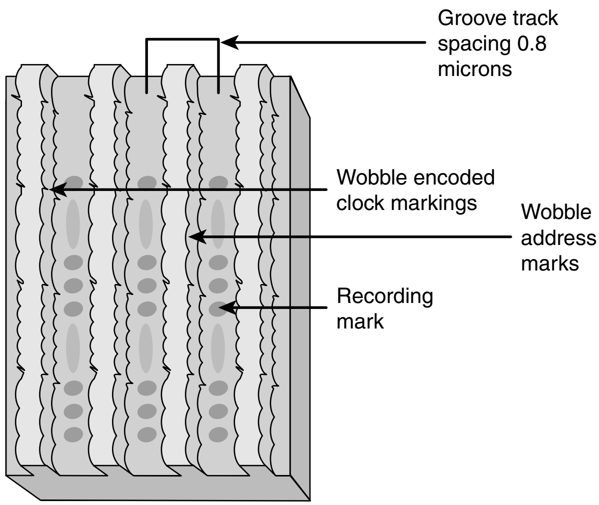

Figure 11.14 DVD-R wobbled groove recording.

Table 11.14 has the basic specifications for DVD-R drives.

Table 11.14 DVD-R Specifications

Storage capacity	4.7GB single-sided; 9.4GB double-sided
Disc diameter	80mm–120mm
Disc thickness	1.2mm (0.6mm×2: bonded structure)
Recording method	Organic dye layer recording method
Laser wavelength	635nm (recording); 635nm/650nm (playback)
Data bit length	0.293 microns
Recording track pitch	0.80 microns
Track format	Wobbled groove

DVD-R media is currently available in speeds up to 16x, although some drives feature faster burn speeds. Some vendors are now producing double-sided single-layer DVD-R media with capacities of 9.4GB. This media is designed primarily for DVD jukeboxes, although it can be used by standard DVD rewritable drives.

DVD-R DL

DVD-R DL was introduced in February 2005 and is sometimes known as DVD-R for Dual Layer or DVD-R9. DVD-R DL is essentially a dual-layer version of the DVD-R disc, using the same recording method, laser wavelength, and other specifications. However, DVD-R DL discs have two recording layers, with the reflective surface of the top layer being semi-transparent to permit recording on the second layer. Because of the lower reflectivity of the top layer, some DVD-ROM drives cannot read DVD-R DL media.

Note

If you are unable to read DVD-R DL media with a DVD drive, try using the Layer Jump Recording (LJR) recording method in your DVD mastering software if your drive and software support it. LJR alternates between recording layers during the writing process, rather than filling one layer before writing to the other layer. This permits a disc to support multisession recording and is intended to make it easier for DVD drives to read dual-layer media.

DVD-R DL media is currently available in 4x speed from a relatively small number of suppliers, although some rewritable DVD drives support faster write speeds.

DVD-RW

The DVD Forum introduced DVD-RW in November 1999. Created and endorsed originally by Pioneer, DVD-RW is basically an extension to DVD-R, just as CD-RW is an extension to CD-R. DVD-RW uses a phase-change technology and is somewhat more compatible with standard DVD drives than DVD-RAM. Drives based on this technology began shipping in late 1999, but early models achieved only moderate popularity because Pioneer was the only source for the drives and because of limitations in their performance.

The most common types of DVD-RW media support 2x speeds, although 4x and 6x media is also available. Drives supporting 2x/4x and faster media have several advantages over original 1x/2x DVD-RW drives, including these:

- **Quick formatting**—1x/2x drives require that the entire DVD-RW disc be formatted before the media can be used, a process that can take about an hour. 2x/4x and faster drives can use DVD-RW media in a few seconds after insertion, formatting the media in the background as necessary. This is similar to the way in which DVD+RW drives work.
- **Quick finalizing**—2x/4x DVD-RW drives close media containing small amounts of data (under 1GB) more quickly than 1x/2x drives.
- **Quick grow**—Instead of erasing the media to add files, as with 1x/2x DVD-RW drives, 2x/4x and faster DVD-RW drives can unfinalize the media and add more files without deleting existing files.

However, most DVD-RW drives still don't support lossless linking, Mount Rainier, or selective deletion of files—all of which are major features of DVD+RW.

Note

Plextor's Zero Link technology does support selective file erasure on DVD-RW media. Essentially, Zero Link provides an equivalent to DVD+RW's lossless link feature, enabling DVD-Video players that support DVD-RW media to play edited disks.

DVD+RW and DVD+R

DVD+RW, also called DVD Phase Change Rewritable, has been the premier DVD recordable standard because it is the least expensive, easiest to use, fastest, and most compatible with existing formats. It was developed and is supported by Philips, Sony, Hewlett-Packard, Mitsubishi Chemical (MCC/Verbatim), Ricoh, Yamaha, and Thomson, who are all part of an industry standard group called the DVD+RW Alliance (www.dvdservices.org). Microsoft joined the alliance in February 2003. DVD+RW is also supported by major DVD/CD-creation software vendors and many drive vendors, including HP, Philips, Ricoh, and many remarketers of OEM drive mechanisms. Although DVD-RW has increased in popularity with the advent of faster burning times and easier operation, DVD+RW is the most popular rewritable DVD format.

Table 11.15 lists the basic specifications for DVD+RW drives.

Table 11.15 DVD+RW Specifications

Storage capacity	4.7GB single-sided; 9.4GB double-sided
Disc diameter	120mm
Disc thickness	1.2mm (0.6mm×2: bonded structure)
Recording method	Phase change
Laser wavelength	650nm (recording/playback)
Data bit length	0.4 microns
Recording track pitch	0.74 microns
Track format	Wobbled groove

Note that DVD+R, the recordable version of DVD+RW, was actually introduced *after* DVD+RW. This is the opposite of DVD-RW, which grew out of DVD-R. One of the major reasons for the development of DVD+R was to provide a lower-cost method for permanent data archiving with DVD+RW drives, and another was because of compatibility issues with DVD-ROM and DVD video players being incapable of reading media created with DVD+RW drives. However, most standard DVD-ROM drives or DVD players can read both DVD+R and DVD+RW media without problems.

The basic structure of a DVD+RW or DVD+R disc resembles that of a DVD-R disc with data written in the grooves only (refer to Figure 11.14), but the groove is wobbled at a frequency different from that used by DVD-R/RW or DVD-RAM. The DVD+R/RW groove also contains positioning information. These differences mean that DVD+R/RW media offers more accurate positioning for lossless linking, but drives made only for DVD+R/RW media can't write to other types of DVD rewritable or recordable media.

Although some first-generation DVD+RW drives worked only with rewritable media, all current and future DVD+RW drives are designed to work with both DVD+R (writable) and DVD+RW (rewritable) media. The +R discs can be written only once and are less expensive than the +RW discs.

Some of the features of DVD+RW include the following:

- Single-sided discs (4.7GB).
- Double-sided discs (9.4GB).
- Up to 4 hours video recording (single-sided discs).
- Up to 8 hours video recording (double-sided discs).
- Bare discs—no caddy required.
- 650nm laser (same as DVD-Video).
- Constant linear data density.
- CLV and CAV recording.
- Write speeds 1x–4x and higher (depending on the drive).
- DVD-Video data rates.
- UDF (Universal Disc Format) file system.
- Defect management integral to the drive.
- Quick formatting.
- Uses same 8-to-16 modulation and error-correcting codes as DVD-ROM.
- Sequential and random recording.
- Lossless linking. (Multiple recording sessions don't waste space.)
- Spiral groove with radial wobble.
- After recording, all physical parameters comply with the DVD-ROM specification.

DVD+RW technology is similar to CD-RW, and DVD+RW drives can read DVD-ROMs and all CD formats, including CD-R and CD-RW.

With DVD+RW, the writing process can be suspended and continued without a loss of space linking the recording sessions together. This increases efficiency in random writing and video applications. This "lossless linking" also enables the selective replacement of any individual 32KB block of data (the minimum recording unit) with a new block, accurately positioning with a space of 1 micron. To enable this high accuracy for placement of data on the track, the pre-groove is wobbled at a higher frequency. The timing and addressing information read from the groove is very accurate.

The quick formatting feature means you can pop a DVD+R or DVD+RW blank into the drive and almost instantly begin writing to it. The actual formatting is carried out in the background ahead of where any writing will occur.

DVD+R/RW is the format I prefer and recommend, and it has been the format most users prefer for data recording. However, today's multiformat drives support both DVD+R/RW and DVD-R/RW (and Super Multi Drives support DVD-RAM), so you can choose the right media for a particular task.

When DVD+RW drives were introduced in 2001, some users of DVD-ROM and standalone DVD players were unable to read DVD+RW media, even though others were able to do so. The first drives to support DVD+R (writable) media (which works with a wider range of older drives) was not introduced until mid-2002, so this was a significant problem.

The most common reason for this problem turned out to be the contents of the Book Type Field located in the lead-in section of every DVD disc. Some drives require that this field indicate that the media is a DVD-ROM before they can read it. However, by default, DVD+RW drives write DVD+RW as the type into this field when DVD+RW media is used.

The following are three possible solutions:

- Upgrade the firmware in the DVD+RW recorder so it writes compatible information into the Book Type Field automatically.
- Change the Book Type Field during the creation of a disc with a DVD mastering program.
- Use a compatibility utility to change the contents of the Book Type Field for a particular DVD+RW disc as necessary. These utilities may be provided by the drive manufacturer (sometimes a firmware upgrade is also necessary) or by a third-party utility.

Changing the Book Type Field is known as *bitsetting*.

▶▶ **See** "Updating the Firmware in an Optical Drive," **p. 599** (this chapter).

DVD+R DL

DVD+R DL, also known as DVD-R9, is a dual-layer version of the DVD+R standard that was introduced in October 2003. DVD+R DL is essentially a dual-layer version of the DVD+R disc, using the same recording method, laser wavelength, and other specifications. However, DVD+R DL discs have two recording layers, with the reflective surface of the top layer being semi-transparent to permit recording on the second layer. Because of the lower reflectivity of the top layer, some DVD-ROM drives cannot read DVD+R DL media. DVD+RW DL media is typically rated at 8x recording speeds.

Multiformat Rewritable DVD Drives

The DVD Multi specification from the DVD Forum was developed for drives and players that are compatible with all DVD Forum standards, including DVD-R/RW, DVD-RAM, DVD-ROM, DVD-Video, and eventually DVD Audio (DVD+R/RW are not DVD Forum specifications and are not supported). The original version of DVD Multi was published in February 2001; the current version, version 1.01, was approved by the DVD Forum and published in December 2001. The first DVD Multi products for computers reached the market in early 2003.

To provide support for different types of DVD media in a single drive, all rewritable DVD drive vendors now sell drives compatible with both DVD+R/RW and DVD-R/RW discs. These drives are commonly known as DVD'R/RW. LG's Super Multi Drive series was the first to also add compatibility with DVD-RAM, and most current DVD'R/RW drives from other makers are also compatible with DVD-RAM. Many (but not all) current drives also support DVD-R DL, so you can now buy a single drive that supports all common formats supported by both the DVD Forum and the DVD+RW Alliance. Lite-On uses the term Super AllWrite to refer to drives that support all these media types.

BD

In February 2002, the leading optical storage companies formed the Blu-ray Disc Founders (BDF) and announced the initial specifications for BD, a high-capacity optical disc format. By May 2002, BD specification 1.0 was released, and in April 2003, Sony released the BDZ-S77 for the Japanese market, the first commercially available BD recorder. In January 2006, the Blu-ray Disc Association also released a 2.0 specification for BD-RE discs. Blu-ray is a fully rewritable format that enables recording up to 25GB of data or up to 11.5 hours of standard-definition video on a single-sided, single-layer 12cm diameter disc (which is the same as existing CDs and DVDs) using a 405nm blue-violet laser. Dual-layer BD-R DL recorders are also available and can record up to 50GB or 23 hours of standard-definition video. The latest BD specifications, BDXL (recordable) and BD-RE XL (rewritable), can store up to 100GB or 128GB at 2x or 4x speeds.

Although backward compatibility with DVD and CD is not a requirement of the Blu-ray specification, it is a feature drive manufacturers have included. One of the main applications for higher-capacity optical storage is recording high-definition TV, which takes an incredible amount of storage. Current DVD recorders can't store enough data to handle high-definition video. Blu-ray, on the other hand, is designed to store up to 4.5 hours of high-definition video (or more than 13 hours of standard broadcast-quality TV) on a single-layer disc, and 9 hours on dual-layer versions. As with DVD, Blu-ray uses the industry-standard MPEG-2 compression technology.

Figure 11.15 compares the track size and laser types used for CD, DVD, and standard BD media.

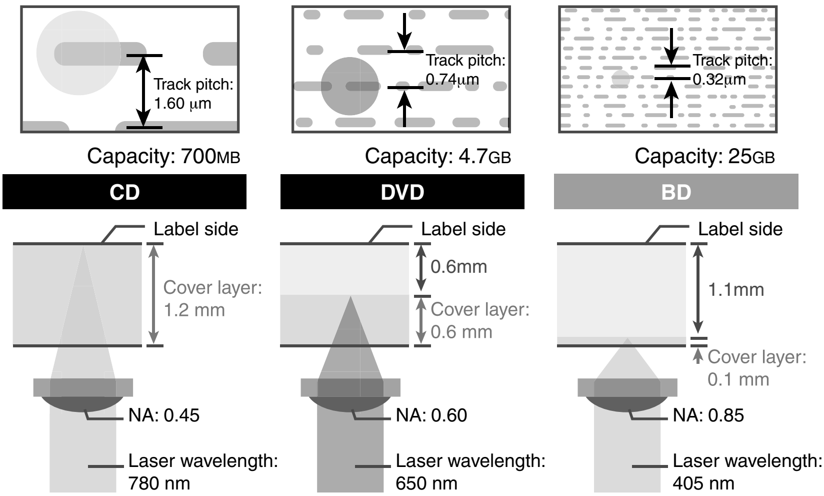

Figure 11.15 CD, DVD, and BD media and laser comparison.

Note

When a mixture of HD video and standard video is stored on a BD, you can store up to 2.25 hours of HD video and 2 hours of standard video (used for bonus features) on a single-layer disc. A dual-layer BD can store up to 3 hours of HD video and 9 hours of standard video. Capacities can also vary with bit rates used for movie storage because Blu-ray can support a range of bit rates.

The BD specification includes the following formats:

- **BD-ROM**—Read-only for prerecorded content
- **BD-R**—Recordable
- **BD-RE**—Rewritable
- **BD-RE XL**—Rewritable

The data transfer speed of a BD depends on the speed rating of the drive and media. The practical maximum rotational speed of an optical disc is 10,000 rpm, which limits the maximum speed of BD drives to 12x, which equates to a 54MBps transfer rate. The time to read or write an entire single- or dual-layer disc at various BD drive/media speeds is shown in Table 11.16.

Table 11.16 BD Drive/Media Speeds and Disc Read/Write Times

Drive Speed	Data Rate	Single-Layer Disc Read/Write Time	Dual- Layer Disc Read/Write Time
1×	4.5 MBps	90 minutes	180 minutes
2×	9 MBps	45 minutes	90 minutes
4×	18 MBps	23 minutes	45 minutes
6×	27 MBps	15 minutes	30 minutes
8×	36 MBps	12 minutes	23 minutes
12×	54 MBps	8 minutes	15 minutes

Standard CDs use a 780nm (infrared) laser combined with a 0.45 numerical aperture lens, whereas DVDs use a 650nm (red) laser combined with a 0.60 numerical aperture lens. Blu-ray uses a much shorter 405nm (blue-violet) laser with a 0.85 numerical aperture lens. *Numerical aperture* is a measurement of the light-gathering capability of a lens, as well as the focal length and relative magnification. The numerical aperture of a lens is derived by taking the sine of the maximum angle of light entering the lens. For example, the lens in a CD drive gathers light at up to a 26.7° angle, which results in a numerical aperture of SIN(26.7) = 0.45. By comparison, the lens in a DVD drive gathers light at up to a 36.9° angle, resulting in a numerical aperture of SIN(36.9) = 0.60. Blu-ray drives gather light at up to a 58.2° angle, resulting in a numerical aperture of SIN(58.2) = 0.85. Higher numerical apertures allow increasingly oblique (angled) rays of light to enter the lens and therefore produce a more highly resolved image.

The higher the aperture, the shorter the focal length and the greater the magnification. The lens in a CD drive magnifies roughly 20 times, whereas the lens in a DVD drive magnifies about 40 times. The Blu-ray lens magnifies about 60 times. This greater magnification is necessary because the distance between tracks on a BD is reduced to 0.32um, which is almost half that of a regular DVD. A comparison of BD and standard DVD is shown in Table 11.17.

Table 11.17 Comparison of BD and DVD Specifications

Disc Type	BD	DVD
Laser	405nm	650nm
Numerical aperture	0.85	0.60
Storage capacity (single layer)	25GB	4.7GB
Storage capacity (dual layer)	50GB	8.5GB
SD Video (single layer)	11.5 hours	2 hours
SD Video (dual layer)	23 hours	4 hours
HD Video (single layer)	4.5 hours	—
HD Video (dual layer)	9 hours	—
Video codecs	MPEG-4 AVC (H.264),VC-1, MPEG-2	MPEG-2
Lossless audio codecs	Linear PCM	—
Optional: MLP(TrueHD) [2-ch, 8-ch]*	Linear PCM[2-ch]	—
Lossy audio codecs	Dolby Digital Plus/DTS/ Dolby Digital/ MPEG Audio	Dolby Digital/MPEG Audio
Max. transfer rate	54.0Mbps	11.08Mbps
Content protection	AACS 128-bit	CSS 40-bit
Max. video resolution	1920×1080p (HDTV)	720×480p (SDTV)

**Requires HDMI 1.1 or greater for 8-channel support; most home theater systems downmix to 2-channel or use a lossy codec for 5.1 or 7.1 surround audio.*

Note

For more information about BD, see www.blu-raydisc.com.

HD-DVD

HD-DVD, also known as *Advanced Optical Disc* (AOD), is a defunct optical disc format originally developed by Toshiba and NEC. HD-DVD was similar to Blu-ray (but not compatible) and used blue-laser technology to achieve a higher storage capacity.

The introduction of both HD-DVD and BD in 2006 started a format war similar to the Betamax/VHS war in the 1970s. Both were incompatible, and both had supporters and detractors. Blu-ray was arguably superior from a technological standpoint, but that means little because in these situations external influences such as politics, marketing, and overall industry support decides what will become the de facto standard. By 2008, it had become clear that BD was winning in overall market share, and this prompted several HD-DVD supporters to switch to the Blu-ray camp, thus ending the war. The decline of HD-DVD started near the end of 2007 when the largest U.S. video rental company (Blockbuster) declared it would only rent BDs. Then a major blow came in January 2008, when Warner Brothers announced it would not release new movies in HD-DVD, which started an industry-wide chain reaction with several other studios following suit. The final blow came in February 2008, when Toshiba announced it would cease production of HD-DVD players, effectively ending the war once and for all.

Although a few combo Blu-Ray writable/HD-DVD readable drives (which also feature backward-compatibility with standard DVD and CD media) were introduced (the first combo drives feature LG's Super Multi Blue drive technology), HD-DVD players and discs quickly disappeared from the market after 2008.

Optical Disc Formats

Optical drives can use many types of disc formats and standards. This section discusses the formats and file systems used by optical drives, so you can make sure you can use media recorded in a particular format with your drive.

CD Formats

After Philips and Sony created the Red Book CD-DA format discussed earlier in the chapter, they began work on other format standards that would allow CDs to store computer files, data, and even video and photos. These standards control how the data is formatted so that the drive can read it, and additional file format standards can then control how the software and drivers on your PC can be designed to understand and interpret the data properly. Note that the physical format and storage of data on the disc as defined in the Red Book was adopted by all subsequent CD standards. This refers to the encoding and basic levels of error correction provided by CD-DA discs. The other "books" specify primarily how the 2,352 bytes in each sector are to be handled, what type of data can be stored, how it should be formatted, and more.

All the official CD standard books and related documents can be purchased from Philips for $100—$150 each. See the Philips licensing site at www.ip.philips.com for more information.

Table 11.18 describes the various standard CD formats, which are discussed in more detail in the following sections.

Table 11.18 Compact Disc Formats

Format	Name	Introduced	Notes
Red Book	CD-DA (compact disc digital audio)	1980—by Philips and Sony	• The original CD audio standard on which all subsequent CD standards are based.
Yellow Book	CD-ROM (compact disc read-only memory)	1983—by Philips and Sony	• Specifies additional ECC and EDC for data in several sector formats, including Mode 1 and Mode 2.
Green Book	CD-i (compact disc-interactive)	1986—by Philips and Sony	• Specifies an interactive audio/video standard for non-PC-dedicated player. hardware (now mostly obsolete) and discs used for interactive presentations. • Defines Mode 2, Form 1 and Mode 2, Form 2 sector formats along with interleaved MPEG-1 video and ADPCM audio.
CD-ROM XA	CD-ROM XA (extended architecture)	1989—by Philips, Sony, and Microsoft	• Combines Yellow Book and CD-i to bring CD-i audio and video capabilities to PCs.
Orange Book	CD-R (recordable) and CD-RW (rewritable)	1989—by Philips and Sony (Part I/II) 1996—by Philips and Sony (Part III)	• Defines single-session, multisession, and packet writing on recordable discs. • Part I—CD-MO (magneto-optical, with drawn).

Table 11.18 Continued

Format	Name	Introduced	Notes
			• Part II—CD-R (recordable). • Part III—CD-RW (rewritable).
Photo-CD	CD-P	1990—by Philips and Kodak	• Combines CD-ROM XA with CD-R multi-session capability in a standard for photo storage on CD-R discs.
White Book	VCD	1993—by Philips, JVC, Matsushita, and Sony	• Based on CD-i and CD-ROM XA. Stores up to 74 minutes of MPEG-1 video and ADPCM digital audio data.
Blue Book	CD EXTRA (formerly CD-Plus or enhanced music)	1999—by Philips and Sony	• Multisession format for stamped discs; used by musical artists to incorporate videos, liner notes, and other information on audio CDs.
Purple Book	CD Double-Density	2000—by Philips and Sony	• Double-density (1.3GB) versions of CD-ROM, CD-R, and CD-RW (DD-ROM, DD-R, DD-RW).
Scarlet Book	Super Audio CD	1999—by Philips and Sony	• High-capacity (4.7GiB) music disc; hybrid SA-CD discs also feature a CD-DA layer or compatibility with standard players.
DualDisc	DualDisc	2004—by Sony BMG, EMI, Universal Music Group, and Warner Music Group	• Double-sided disc; modified CD-DA format for music on one side; flip side is DVD-Video for videos and other content. Slightly thicker than normal CD or DVD media.

Red Book—CD-DA

The Red Book introduced by Philips and Sony in 1980 is the father of all compact-disc specifications because all other "books" or formats are based on the original CD-DA Red Book format. The Red Book specification includes the main parameters, audio specification, disc specification, optical stylus, modulation system, error correction system, and control and display system. The latest revision of the Red Book is dated May 1999.

For more information on the original Red Book format, see the section "CDs: A Brief History," earlier in this chapter.

Yellow Book—CD-ROM

The Yellow Book was published by Philips, Sony, and Microsoft in 1983 and has been revised and amended several times since. The Yellow Book standard took the physical format of the original CD-DA (or Red Book) standard and added another layer of error detection and correction to enable data to be stored reliably. It also provided additional synchronization and header information to enable sectors to be more accurately located. The Yellow Book specifies two types of sectoring—called Mode 1 (with error correction) and Mode 2—which offer different levels of error-detection and -correction schemes. Some data (computer files, for example) can't tolerate errors. However, other data, such as a video image or sound, can tolerate minor errors. By using a mode with less error-correction information, more data can be stored, but with the possibility of uncorrected errors.

In 1989, the Yellow Book was issued as an international standard by the ISO as "ISO/IEC 10149, Data Interchange on Read-Only 120mm Optical Discs (CD-ROM)." The latest version of the Yellow Book is dated May 1999.

Sector Modes and Forms

Mode 1 is the standard Yellow Book CD sector format with ECC and EDC to enable error-free operation. Each Mode 1 sector is broken down as shown in Table 11.19.

Table 11.19 Yellow Book Mode 1 Sector Format Breakdown

Yellow Book (CD-ROM) Sectors (Mode 1):	
Q+P parity bytes	784
Subcode bytes	98
Sync bytes	12
Header bytes	4
Data bytes	2,048
EDC bytes	4
Blank (0) bytes	8
ECC bytes	276
Bytes/sector RAW (unencoded)	3,234

Orange Book

The Orange Book defines the standards for recordable CDs and was announced in 1989 by Philips and Sony. The Orange Book comes in three parts. Part I describes a format called CD-MO (magneto-optical), which was to be a rewritable format but was withdrawn before any products really came to market. Part II (1989) describes CD-R, and Part III (1996) describes CD-RW. Note that originally CD-R was referred to as CD-WO (write-once), and CD-RW originally was called CD-E (erasable).

The Orange Book Part II CD-R design is known as a WORM format. After a portion of a CD-R disc is recorded, it can't be overwritten or reused. Recorded CD-R discs are Red Book and Yellow Book compatible, which means they are readable on conventional CD-DA or CD-ROM drives. The CD-R definition in the Orange Book Part II is divided into two volumes. Volume 1 defines recording speeds of 1x, 2x, and 4x the standard CD speed; the last revision, dated December 1998, is 3.1. Volume 2 defines recording speeds up to 48x the standard CD speed. The latest version released, 1.2, is dated April 2002.

Orange Book Part III describes CD-RW. As the name implies, CD-RW enables you to erase and overwrite information in addition to reading and writing. The Orange Book Part III CD-RW definition is broken into three volumes. Volume 1 defines recording speeds of 1x, 2x, and 4x the standard CD speed; the latest version, 2.0, is dated August 1998. Volume 2 (high-speed) defines recording speeds from 4x to 10x the standard CD speed; the latest version, 1.1, is dated June 2001. Volume 3 (ultra-speed) defines recording speeds from 8x to 32x; the latest version, 1.0, is dated September 2002.

Besides the capability to record on CDs, the most important feature instituted in the Orange Book specification is the capability to perform multisession recording.

Multisession Recording Overview

Before the Orange Book specification, CDs had to be written as a single session. A *session* is defined as a lead-in, followed by one or more tracks of data (or audio), followed by a lead-out. The lead-in takes up 4,500 sectors on the disc (1 minute if measured in time or about 9.2MB worth of data). The lead-in also indicates whether the disc is multisession and what the next writable address on the disc is (if the disc isn't closed). The first lead-out on a disc (or the only one if it is a single session or Disk At Once recording) is 6,750 sectors long (1.5 minutes if measured in time or about 13.8MB worth of data). If the disc is a multisession disc, any subsequent lead-outs are 2,250 sectors long (0.5 minutes in time or about 4.6MB worth of data).

A multisession CD has multiple sessions, with each individual session complete from lead-in to lead-out. The mandatory lead-in and lead-out for each session do waste space on the disc. In fact, 48 sessions would literally use up all of a 74-minute disc even with no data recorded in each session! Therefore, the practical limit for the number of sessions you can record on a disc would be much less than that.

CD-DA and older CD-ROM drives couldn't read more than one session on a disc, so that is the way most pressed CDs are recorded. The Orange Book allows multiple sessions on a single disc. To allow this, the Orange Book defines three main methods or modes of recording:

- Disk At Once (DAO)
- Track At Once (TAO)
- Packet Writing

DAO

DAO is a single-session method of writing CDs in which the lead-in, data tracks, and lead-out are written in a single operation without the writing laser ever turning off; then the disc is closed. A disc is considered closed when the last (or only) lead-in is fully written and the next usable address on the disc is not recorded in that lead-in. In that case, the CD recorder is incapable of writing any further data on the disc. Note that it is not necessary to close a disc to read it in a normal CD-ROM drive, although if you were submitting a disc to a CD-duplicating company for replication, most require that it be closed.

TAO

Multisession discs can be recorded in either TAO or Packet Writing mode. In TAO recording, each track can be individually written (laser turned on and off) within a session, until the session is closed. Closing a session is the act of writing the lead-out for that session, which means no more tracks can be added to that session. If the disc is closed at the same time, no further sessions can be added either.

The tracks recorded in TAO mode are typically divided by gaps of 2 seconds. Each track written has 150 sectors of overhead for run-in, run-out, pre-gap, and linking. A rewritable drive can read the tracks even if the session is not closed, but to read them in a non-rewritable CD-DA or CD-ROM drive, the session must be closed. If you intend to write more sessions to the disc, you can close the session and not close the disc. At that point, you could start another session of recording to add more tracks to the disc. The main thing to remember is that each session must be closed (lead-out written) before another session can be written or before a normal CD-DA or CD-ROM drive can read the tracks in the session.

Packet Writing

Packet writing is a method whereby multiple writes are allowed within a track, thus reducing the overhead and wasted space on a disc. Each packet uses four sectors for run-in, two for run-out, and one for linking. Packets can be of fixed or variable length, but most drives and packet-writing software use a fixed length because dealing with file systems that way is much easier and more efficient.

With packet writing, you use the UDF version 1.5 or later file system, which enables the CD to be treated essentially like a big floppy drive. That is, you can literally drag and drop files to it, use the `copy` command to copy files onto the disc, and so on. The packet-writing software and UDF file system manage everything. If the disc you are using for packet writing is a CD-R, every time a file is overwritten or deleted, the file seems to disappear, but you don't get the space back on the disc. Instead, the file system simply forgets about the file. If the disc is a CD-RW, the space is indeed reclaimed and the disc won't be full until you literally have more than the limit of active files stored there.

Unfortunately, Windows versions up through Windows XP don't support packet writing or the UDF file system directly, so drivers must be loaded to read packet-written discs, and a packet-writing application must be used to write them. Fortunately, though, these typically are included with CD-RW and DVD rewritable drives The ISOBuster data recovery program reads the contents of damaged CD, DVD, and BD discs and can also be used as a UDF reader.

Windows 7 and Vista support UDF much more thoroughly than previous Windows versions. They are able to format optical media using the Live File System (LFS—Microsoft's term for UDF 2.01), older UDF versions (1.02, 1.5), and the new UDF version 2.5, as well as Mastered. UDF 2.01 discs can be read by Windows XP or later, and they support drag-and-drop file copying on Windows 7 or Vista. UDF version 1.02 is designed for use with DVD-RAM media and is supported by Windows 98 and many Apple computers. UDF version 1.5 works with Windows 2000/XP and Windows Server 2003 as well as Linux systems using kernel version 2.6 or greater. UDF version 2.5 is supported by Windows 7 and Vista. For Linux kernel 2.6.20 and later support of UDF version 2.5, install the UDF-2.50 patch available from http://sourceforge.net.

Note

By default, Windows 7 and Vista use the LFS (UDF 2.01) to format optical discs. To choose between LFS and Mastered (copies all files at once; does not support drag-and-drop file copying), select Show Formatting Options in the Burn a Disc dialog box. To choose a different UDF version, select Show Formatting Options and then Change Version in the Burn a Disc dialog box.

Note

Windows XP also has limited CD-RW support in the form of something called IMAPI (image mastering application program interface), which enables data to be temporarily stored on the hard drive (staged) before being written to the CD in one session. Additional sessions can be written to the same disc, but a 50MB overhead exists for each session. This gives some of the appearance of packet writing, but it is not really the same thing. To read packet-written discs in the UDF 1.5 or later format, you must install a UDF reader just as with previous versions of Windows. Instead of using IMAPI, I recommend installing a third-party CD-mastering program that also includes packet-writing UDF support, such as Roxio Creator 2011 or Nero.

When you remove a packet-written disc from the drive, the packet-writing software first asks whether you want the files to be visible in all drives. If you do, you must close the session. Even if the session is closed, you can still write more to the disc later, but there is an overhead of wasted space every time you close a session. If you are going to read the disc in a rewritable drive, you don't have to close the session because it will be capable of reading the files even if the session isn't closed.

Caution

If you are not sure what type of drive will be used to read the media, I recommend closing the media. This enables users of various types of drives to read the media, although a compatible UDF reader program must be installed in some cases.

A newer standard called Mount Rainier (Mt. Rainier) adds even more capability to packet writing. With Mount Rainier, packet writing can become an official part of the operating system (OS) and the drives can support the defect management necessary to make them usable as removable storage in the real world. For more information, see the section "Mount Rainier" later in this chapter.

Note

As part of Service Pack 1, Microsoft released updates for Windows XP that add native support for the Mount Rainier standard, which supports full drag-and-drop packet writing through CD-MRW drives as well as DVD+MRW drives. Microsoft Windows 7 and Vista include native support of Mount Rainier.

Photo CD

First announced back in 1990 but not available until 1992, Photo CD was a standard that used CD-R discs and drives to store photos. Although Kodak originally sold Photo CD "players" that were connected to TVs, most Photo CD users used computer-based optical drives along with software to decode and display the photos.

Perhaps the main benefit Photo CD brought to the table is that it was the first CD format to use the Orange Book Part II (CD-R) specification with multisession recordings. Additionally, the data is recorded in CD-ROM XA Mode 2, Form 2 sectors; therefore, more photo information could be stored on the disc.

Kodak's own PhotoYCC encoding format was used to store up to six resolutions for each image, as shown in Table 11.20. The x64 resolution was supported only by the Pro Photo CD master version of the service.

Table 11.20 Photo CD Resolutions

Base	Resolution (Pixels)	Description
/16	128×192	Thumbnail
/4	256×384	Thumbnail
x1	512×768	TV resolution
x4	1,024×1,536	HDTV resolution
x16	2,048×3,072	Print size
x64	4,096×6,144	Pro Photo CD master only

At a time when photo-editing software was in its infancy, the ability to select different sizes optimized for different purposes was quite useful. However, with the rise of high-speed PCs running Adobe Photoshop, Adobe Photoshop Elements, and other photo-editing programs, along with high-speed, low-cost recordable and rewritable optical drives, the Photo CD format became obsolete. Kodak discontinued development in the early twenty-first century, and third-party labs that offered the service discontinued it in 2004. Kodak still offers drivers, software, and firmware for Pro Photo CD at www.kodak.com/global/en/service/professional/products/ekn017045.jhtml.

Picture CD

As a replacement for Photo CD, Kodak now offers the simpler Picture CD service. Unlike Photo CD, Picture CD uses the industry-standard JPEG file format. It uses a CD-R, with up to 40 images stored at a single medium-resolution scan of 1,024×1,536 pixels. This resolution is adequate for 4-inch×6-inch and 5-inch×7-inch prints. The images can also be made available via Kodak Gallery, where the same images are posted online and can be downloaded.

The software provided with Picture CD enables the user to manipulate images with various automatic or semiautomatic operations, but unlike Photo CD, the standard JPEG (JPG) file format used for storage enables any popular image-editing program to work with the images without conversion. Services similar to Picture CD are also offered by Fujifilm and Agfa, and some stores allow you to order Kodak Picture CD with your choice of store-brand or Kodak film processing. You can also create a Picture CD at kiosks that include a Rapid Print Scanner.

Note

By scanning your own 35mm negatives with a high-performance flatbed or dedicated film scanner, you can achieve much higher resolutions (up to 4,800 dpi optical) that support larger images sizes than what Picture CD offers. For example, a 3,200 dpi scan of a full-frame 35mm film negative has a resolution of about 2,570×4,450 pixels. By scanning negatives yourself, you can also select the quality of JPEG images and save images in other formats, such as TIFF. Some photo labs offer high-resolution film developing and scanning services if you prefer not to scan your own film.

White Book—Video CD

The White Book standard was introduced in 1993 by Philips, JVC, Matsushita, and Sony. It is based on the Green Book (CD-i) and CD-ROM XA standards and allows for storing up to 74 minutes of MPEG-1 video and ADPCM digital audio data on a single disc. The latest version (2.0) was released in April 1995. Video CD (VCD) 2.0 supports MPEG-1 compression with a 1.15Mbps bit rate. The screen resolution is 352×240 for NTSC format and 352×288 for European PAL format. In addition, it supports Dolby Pro Logic–compatible stereo sound.

You can think of VCDs as a sort of poor man's DVD format, although the picture and sound quality can actually be quite good—certainly better than VHS or most other videotape formats. You can play VCDs on virtually any PC with an optical drive using the free WMP. (Other media player applications can be used as well.) You can also play VCDs on most DVD players. Although you can create VCDs with popular DVD production programs such as Roxio Creation 2011 or Adobe Premiere Elements, prerecorded VCD media is difficult to find today, thanks to the popularity of the higher-quality (and easier to copy-protect) DVD and Blu-ray formats.

Super Video CD

The Super Video CD specification 1.0, published in May 1999, is an enhanced version of the White Book VCD specification. It uses MPEG-2 compression, an NTSC screen resolution of 480×480, and a PAL screen resolution of 480×576; it also supports MPEG-2 5.1 surround sound and multiple languages.

Most home DVD-creation programs can create VCDs or Super VCDs.

Blue Book—CD EXTRA

Manufacturers of CD-DA media were looking for a standard method to combine both music and data on a single CD. The intention was for a user to be able to play only the audio tracks in a standard audio CD player while remaining unaware of the data track. However, a user with a PC or dedicated combination audio/data player could access both the audio and data tracks on the same disc.

The fundamental problem with nonstandard mixed-mode CDs is that if or when an audio player tries to play the data track, the result is static that could conceivably damage speakers and possibly hearing if the volume level has been turned up. Various manufacturers originally addressed this problem in different ways, resulting in a number of confusing methods for creating these types of discs, some of which still allowed the data tracks to be accidentally "played" on an audio player. In 1995, Philips and Sony developed the CD EXTRA specification, as defined in the Blue Book standard. CDs conforming to this specification usually are referred to as CD EXTRA (formerly called CD Plus or CD Enhanced Music) discs and use the multisession technology defined in the CD-ROM XA standard to separate the audio and data tracks. These are a form of stamped multisession disc. The audio portion of the disc can consist of up to 98 standard Red Book audio tracks, whereas the data track typically is composed of XA Mode 2 sectors and can contain video, song lyrics, still images, or other multimedia content. Such discs can be identified by the CD EXTRA logo, which is the standard CD-DA logo with a plus sign to the right. Often the logo or markings on the disc package are overlooked or somewhat obscure, and you might not know that an audio CD contains this extra data until you play it in a computer-based optical drive.

A CD EXTRA disc normally contains two sessions. Because audio CD players are only single-session capable, they play only the audio session and ignore the additional session containing the data. An optical drive in a PC, however, can see both sessions on the disc and access both the audio and data tracks.

Scarlet Book (SA-CD)

The Scarlet Book defines the official standard for Super Audio CD (SA-CD, also referred to as SACD) media and drives. It was codeveloped by Philips Electronics and Sony in 1999. Unlike the original Red Book CD-Audio standard, which samples music at 44.1KHz, Scarlet Book uses Direct Stream Digital encoding with a sampling rate of 2.822MHz—64 times the sampling frequency of Red Book.

Because of the higher sampling rate and the larger disc capacity necessary to store the audio (as well as SA-CD's support for video and text content), you cannot play standard or dual-layer SA-CD media in a standard CD player or computer's CD or DVD drive. Although standard SA-CD media has a capacity of 4.7GiB (the same as that of single-layer DVD), the formats are not interchangeable. SA-CD contents are copy-protected by a physical watermark known as Pit Signal Processing, which cannot be detected by standard computer DVD drives, although some high-end BD and DVD set-top boxes can also play SA-CD media.

Almost all SA-CD albums use a hybrid dual-layer design, in which the top layer stores standard CD audio playable on standard CD players and drives, and the lower layer contains the higher-density SA-CD content. Essentially, a hybrid SA-CD disc is like a CD-audio disc and a standard SA-CD disc in a single-sided disc (see Figure 11.16).

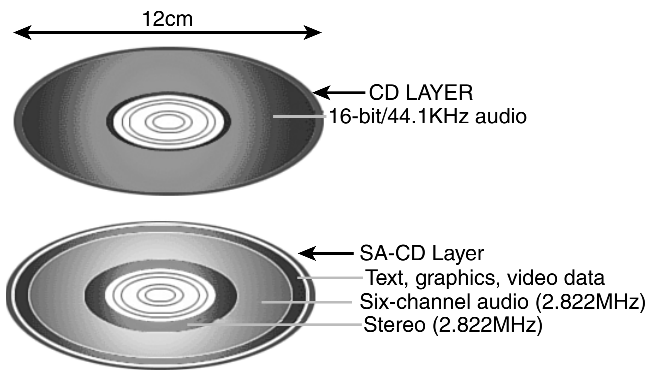

Figure 11.16 The structure of a hybrid SA-CD disc.

Note

Although you can play hybrid SA-CD media in standard players or computer-based drives, these devices are only playing the CD layer. To enjoy the enhanced audio of SA-CD, you must use a standalone SA-CD player.

An SA-CD disc (or the SA-CD layer of a hybrid disc) includes the stereo version of the album in its inner portion, a six-channel surround audio mix in the middle portion, and extra data such as lyrics, graphics, and video in the outer portion.

For listings of SA-CD albums and players and additional SA-CD information, see www.sa-cd.net.

DualDisc

DualDisc, introduced by a consortium of major record labels in the summer of 2004 is a combination of two different formats—music CD and DVD—on a single two-sided disc. DualDisc (sometimes referred to as Dual Disc), as the name suggests, is two discs in one: One side is a music CD, typically featuring support for surround audio or other advanced audio formats, and the other side is a DVD (using the single-layer DVD-5 format) that can include music videos, concert footage, web links, and other features.

Although DualDisc is designed to work in standard CD drives and players, it is not completely compatible with Red Book standards because the CD layer is only 0.9mm, compared to the Red Book standard of 1.1mm. To compensate for spherical aberration caused by a thinner CD layer, one method used is to increase the size of the pits on the CD side of a DualDisc, reducing playing time to 60 minutes. (Some later DualDisc media uses different methods to increase playtime.)

The total thickness of a DualDisc is 1.5mm, compared to 1.2mm for standard CD or DVD media, causing DualDiscs to be incompatible with slot-loading drives in car stereos, PCs, and mega-disc changers. Because DualDisc media is thicker than normal CD media and because the internal structure of the CD side is not compatible with Red Book standards, Philips and Sony (the co-creators of the CD format) do not use the CD logo on DualDisc media, and most DualDisc albums include warning labels that the disc will not work in slot-loaded drives and mega-disc changers and might not play in other types of players. DualDisc albums are typically packaged in CD-style jewel cases.

Caution

Some music vendors use the term *DualDisc* to refer to SA-CD as well as actual DualDisc albums. Be sure to check details of the media carefully to ensure that you can play the disc in your equipment.

Although DualDisc media, unlike SA-CD media, supports two standard formats, it is not nearly as popular as SA-CD media. Thousands of albums are available in SA-CD format, but only a few hundred are available in DualDisc format (virtually none after 2006). SA-CD provides far better audio quality than DualDisc (which provides only CD quality music), making it a better format for the serious audiophile.

DVD Formats and Standards

As with the CD standards, the DVD standards are published in reference books produced mainly by the DVD Forum, but also by other companies, such as the DVD+RW Alliance. The DVD Forum's DVD-Video and DVD-ROM standards are well established and are supported by virtually every DVD drive, regardless of age. However, rival recordable and rewritable DVD standards have been developed by both organizations. The DVD Forum developed the following standards:

- DVD-RAM (drag-and-drop file storage and erasure without any add-on software required)

- DVD-R (recordable DVD)
- DVD-RW (rewritable DVD)

After the development of DVD-RAM and DVD-R, the rival DVD+RW Alliance developed these standards:

- DVD+RW (rewritable DVD with support for lossless linking to prevent buffer underrun)
- DVD+R (recordable DVD)

Early rewritable DVD drives supported either DVD-RW or DVD+RW, but recent DVD rewritable drives support DVD+/-R/RW media, and so-called "Super Multi" drives using an LG-designed drive mechanism add support for DVD-RAM media as well. As a result, you can now choose the best DVD media for the task.

DVD rewritable drives support all of these media types.

The current standard and high-capacity DVD formats are shown in Table 11.21.

Table 11.21 Standard and High-Capacity DVD Formats and Capacities

Format	Data Size	Sides	Layers	Data Capacity	MPEG-2 Video Capacity
DVD-ROM Formats and Capacities					
DVD-5	120mm	Single	Single	4.7GB	2.2 hours
DVD-9	120mm	Single	Double	8.5GB	4.0 hours
DVD-10	120mm	Double	Single	9.4GB	4.4 hours
DVD-14	120mm	Double	Both	13.2GB	6.3 hours
DVD-18	120mm	Double	Double	17.1GB	8.1 hours
DVD-1	80mm	Single	Single	1.5GB	0.7 hours
DVD-2	80mm	Single	Double	2.7GB	1.3 hours
DVD-3	80mm	Double	Single	2.9GB	1.4 hours
DVD-4	80mm	Double	Double	5.3GB	2.5 hours
Recordable DVD Formats and Capacities					
DVD-R 1.0	120mm	Single	Single	3.95GB	1.9 hours
DVD-R 2.0	120mm	Single	Single	4.7GB	2.2 hours
DVD-R DL	120mm	Single	Double	8.5GB	4.0 hours
DVD-RAM 1.0	120mm	Single	Single	2.58GB	N/A
DVD-RAM 1.0	120mm	Double	Single	5.16GB	N/A
DVD-RAM 2.0	120mm	Single	Single	4.7GB	N/A
DVD-RAM 2.0	120mm	Double	Single	9.4GB	N/A
DVD-RAM 2.0	80mm	Single	Single	1.46GB	N/A
DVD-RAM 2.0	80mm	Double	Single	2.65GB	N/A
DVD-RW 2.0	120mm	Single	Single	4.7GB	N/A
DVD+RW 2.0	120mm	Single	Single	4.7GB	2.2hours
DVD+RW 2.0	120mm	Double	Single	9.4GB	4.4 hours
DVD+R 1.0	120mm	Single	Single	4.7GB	2.2 hours
DVD+R DL	120mm	Single	Double	8.5GB	4.0 hours

Table 11.21 Continued

Format	Data Size	Sides	Layers	Data Capacity	MPEG-2 Video Capacity
			High-Capacity Optical Formats and Capacities		
HD DVD-ROM*	120mm	Single	Single	15GB	4.0 hours HD
HD DVD-ROM*	120mm	Single	Double	30GB	8.0 hours HD
HD DVD-R*	120mm	Single	Single	15GB	4.0 hours HD
HD DVD-RW*	120mm	Single	Single	20GB, 32GB	5.5/8.4 hours HD
BD	120mm	Single	Single	25GB	4.5 hours HD
BD	120mm	Single	Double	50GB	9 hours HD
BD-XL	120mm	Single	Double	100/128GB	18/23 hours
			CD-ROM Formats and Capacities (for Comparison)		
CD-ROM/R/RW	120mm	Single	Single	0.737GB	N/A
CD-ROM/R/RW	80mm	Single	Single	0.194GB	N/A

HD – HDTV (720p, 1080i, or 1080p resolutions)

**Obsolete format, replaced by BD*

DVD drives are fully backward-compatible and as such are capable of reading CDs. When reading or playing existing CDs, the performance of most DVD drives is equivalent to a 40x or faster CD drive. DVD-rewritable drives, which also fully support CD formats, have replaced CD-RW drives at virtually every price point in both new systems and as upgrades at retail. The main reason to use CD media instead of DVD media at this point is for near-universal compatibility (especially when CD-R discs are used) with both older and recent systems.

With the development of BD, rewritable Blu-ray drives that are backward-compatible with DVD and CD media are now available. These drives are much more expensive than rewritable DVD drives; however, the cost of BD drives and media is falling rapidly.

DIVX (Discontinued Standard)

DIVX (Digital Video Express) was a short-lived proprietary DVD format developed by Digital Video Express (a Hollywood law firm) and Circuit City. It was discontinued on June 16, 1999, less than a year after it was released.

The name now lives on as an open encoding standard for DVD video. However, this encoding standard actually has no relation to the original DIVX format other than the name.

DVD Drive Compatibility

When DVD drives appeared on the market, they were touted to be fully backward-compatible with CD drives. Although that might be the case when reading commercially pressed CD-ROM discs, that was not necessarily true when reading CD-R or CD-RW media. Fortunately, the industry has responded with standards that let you know in advance how compatible your DVD drive will be. These standards are called *MultiRead* for computer-based drives and *MultiPlay* for consumer standalone devices, such as DVD-Video and CD-DA players. See the section "MultiRead Specifications," earlier in this chapter.

DVD Movie Playback on a PC

DVD video discs (like those included with most of my books) are designed to be played on standard "set-top" DVD players connected to a television. You can also play them on PCs, as long as the proper hardware (for example, a DVD or BD drive) and software are installed. Unfortunately, many people are unaware that the software required to play DVDs is not included by default with most versions of Windows. This means that to play DVDs under Windows, additional software must be installed.

The first versions of Windows to have any sort of built-in DVD-playing capability were Windows 98, 98SE (98 Second Edition), and Me (Millennium edition), all of which included a funky command-line utility called DVDPLAY.EXE. The version of DVDPLAY.EXE included with Windows 98 could only play DVDs if one of two supported hardware DVD decoders were installed, which were physically in the form of a PCI card. The DVDPLAY.EXE application included with Windows Me was the first to support a software decoder (that is, no special card required), as long as the PC had a 333MHz or faster processor. But few people used the DVDPLAY program because most retail PCs and DVD drives sold at the time included commercial DVD-playing software such as WinDVD (Intervideo/Corel) or PowerDVD (Cyberlink). The first version of WMP capable of playing DVDs was WMP 8, which was included with the original release of Windows XP in 2001.

Whereas WMP 8 was included with Windows XP, later WMP versions have been available as free downloads. For example, Windows 98SE, Me, and 2000 support up to WMP 9. (Note that the original Windows 98 release only supports up to WMP 7.1, which is not capable of playing DVDs.) Windows XP and Vista support up to WMP 11, whereas WMP 12 is included with Windows 7.

But just having WMP 8 or later isn't enough. To play DVDs, you must also have a WMP-compatible MPEG-2 decoder installed. An MPEG-2 decoder is included with Windows Vista Ultimate and Home Premium editions, but not with Vista Home Basic and Business editions. Windows 7 Home Premium, Professional, and Ultimate include a decoder, whereas Windows 7 Starter edition does not. No MPEG-2 decoder was included with Windows XP (not even Media Center Edition) or any earlier versions of Windows.

If an MPEG-2 decoder is the missing piece of software needed to play DVDs, where do you get one? Normally you get an MPEG-2 decoder bundled with standalone commercial DVD player programs such as WinDVD and PowerDVD; however, you can also purchase a decoder separately, or even download one for free. To see if you have a DVD decoder currently installed, you can use the Windows XP Video Decoder Checkup Utility (http://tinyurl.com/6xog7).

You can purchase standalone MPEG-2 codecs (coder/decoders) that are compatible with WMP for about $15. Microsoft has a page listing plug-ins for WMP at www.microsoft.com/windows/windowsmedia/player/plugins.aspx.

You can also get MPEG-2 codecs as part of several free "codec packs." My favorite codec packs are the K-Lite Codec Pack (I recommend the Standard or Full versions; http://codecguide.com) and the Vista/Win7 Codec Packages (http://shark007.net).

If you have the proper hardware plus a compatible MPEG-2 decoder installed, you can play DVDs using WMP 8 or later.

Optical Disc File Systems

Manufacturers of early data CDs required their own custom software to read the discs. This is because the Yellow Book specification for CD-ROM detailed only how data sectors—rather than audio sectors—could be stored on a disc and did not cover the file systems or deal with how data should be stored in files and how these should be formatted for use by PCs with different OSs. Obviously, noninterchangeable file formats presented an obstacle to industrywide compatibility for optical disc–based applications.

In 1985–1986, several companies got together and published the High Sierra file format specification, which was the first industry-standard CD-ROM file system that made CD-ROMs universally usable in PCs. Today several file systems are used on optical discs, including the following:

- High Sierra
- ISO 9660 (based on High Sierra)
- Joliet
- UDF (Universal Disk Format)
- Mac HFS (Hierarchical File Format)
- Rock Ridge
- Mount Rainier (also known as Mt. Rainier)

Not all optical disc file system formats can be read by all OSs. Table 11.22 shows the primary file systems used and which OSs support them.

Table 11.22 Optical Disc File System Formats

CD File System	DOS/Win 3.x	Win 9x and Later	Mac OS
High Sierra	Yes	Yes	Yes
ISO 9660	Yes	Yes	Yes
Joliet	Yes[1]	Yes	Yes[1]
UDF	No	Yes[2]	Yes[2]
Mac HFS	No	No	Yes
Rock Ridge (RockRidge)	Yes[1]	Yes[1]	Yes[1]
Mount Rainier	No	Yes[3]	Yes[3]

1. *A short name, such as (SHORTN~1.TXT), will be shown in place of long filenames.*
2. *Win 9x through XP—only if a third-party UDF reader is installed.*
3. *Requires Mount Rainier (also called EasyWrite) hardware and driver software (Win 9x/NT/2000); XP requires SP1 or later.*

Note

The Mac HFS and UNIX Rock Ridge file systems are not supported by PC OSs such as DOS and Windows and therefore are not covered in depth here.

High Sierra

To make optical discs readable on all systems without having to develop custom file systems and drivers, it was in the best interests of all PC hardware and software manufacturers to resolve the optical file format standardization issue. In 1985, representatives from TMS, DEC, Microsoft, Hitachi, LaserData, Sony, Apple, Philips, 3M, Video Tools, Reference Technology, and Xebec met at what was then called the High Sierra Hotel and Casino in Lake Tahoe, Nevada, to create a common logical format and file structure for CD-ROMs. In 1986, they jointly published this standard as the "Working Paper for Information Processing: Volume and File Structure of CD-ROM Optical Discs for Information Exchange (1986)." This standard was subsequently referred to as the High Sierra format.

This agreement enabled all drives using the appropriate driver (such as MSCDEX.EXE supplied by Microsoft with DOS) to read all High Sierra format discs, opening the way for the mass production and acceptance of CD-ROM software publishing. Adoption of this standard also enabled disc publishers to provide cross-platform support for their software and easily manufacture discs for DOS, UNIX, and other OS formats. Without this agreement, the maturation of the optical marketplace would have taken years longer and the production of optical-based information would have been stifled.

The High Sierra format was submitted to the International Organization for Standardization (ISO). Two years later (in 1988), with several enhancements and changes, it was republished as the ISO 9660 standard. ISO 9660 was not exactly the same as High Sierra, but all drivers that would read High Sierra–formatted discs were quickly updated to handle both ISO 9660 and the original High Sierra format on which it was based.

For example, Microsoft wrote the MSCDEX.EXE (Microsoft CD-ROM extensions) driver in 1988 and licensed it to optical hardware and software vendors to include with their products. It wasn't until 1993 when MS-DOS 6.0 was released that MSCDEX was included with DOS as a standard feature. MSCDEX enables DOS to read ISO 9660–formatted (and High Sierra–formatted) discs. This driver works with the AT Attachment Packet Interface (ATAPI) or Advanced SCSI Programming Interface (ASPI) hardware-level device driver that comes with the drive. Microsoft built ISO 9660 and Joliet file system support directly into Windows 95 and later, with no additional drivers necessary.

ISO 9660

The ISO 9660 standard enabled full cross-compatibility among different computer and operating systems. ISO 9660 was released in 1988 and was based on the work done by the High Sierra group. Although based on High Sierra, ISO 9660 does have some differences and refinements. It has three levels of interchange that dictate the features that can be used to ensure compatibility with different systems.

ISO 9660 Level 1 is the lowest common denominator of all CD file systems and is capable of being read by almost every computer platform, including UNIX and Macintosh. The downside of this file system is that it is very limited with respect to filenames and directories. Level 1 interchange restrictions include the following:

- Only uppercase characters A–Z, numbers 0–9, and the underscore (_) are allowed in filenames.
- Only 8.3 characters maximum for the name.extension (based on DOS limits).
- Directory names are eight characters maximum (no extension allowed).
- Directories are limited to eight levels deep.
- Files must be contiguous.

Level 2 interchange rules have the same limitations as Level 1, except that the filename and extension can be up to 30 characters long (both added together, not including the . separator). Finally, Level 3 interchange rules are the same as Level 2 except that files don't have to be contiguous.

Note that Windows 95 and later versions enable you to use file and folder names up to 255 characters long, which can include spaces as well as lowercase and many other characters not allowed in ISO 9660. To maintain backward compatibility with DOS, Windows 95 and later associate a short 8.3 format filename as an alias for each file that has a longer name. These alias short names are created automatically by Windows and can be viewed in the Properties for each file or by using the `DIR` command at a command prompt. To create these alias names, Windows truncates the name to six (or fewer) characters followed by a tilde (~) and a number starting with 1 and truncates the extension to three characters. Other numbers are used in the first part if other files that would have the same alias when truncated already exist. For example, the filename `This is a.test` gets `THISIS~1.TES` as an alias.

This filename alias creation is independent of your CD drive, but it is important to know that if you create or write to a CD using the ISO 9660 format using Level 1 restrictions, the alias short names are used when files are recorded to the disc, meaning any long filenames will be lost in the process. In fact, even the alias short name will be modified because ISO 9660 Level 1 restrictions don't allow a tilde—that character is converted to an underscore in the names written to the CD.

The ISO 9660 data starts at 2 seconds and 16 sectors into the disc, which is also known as *logical sector 16 of track one*. For a multisession disc, the ISO 9660 data is present in the first data track of each session. This data identifies the location of the volume area—where the actual data is stored. The system area also lists the directories in this volume as the volume table of contents (VTOC), with pointers or addresses to various named areas, as illustrated in Figure 11.17. A significant difference between the CD directory structure and that of a normal hard disk is that the CD's system area also contains direct addresses of the files within the subdirectories, allowing the CD to seek specific sector locations on the spiral data track. Because the CD data is all on one long spiral track, when speaking of tracks in the context of a CD, we're actually talking about sectors or segments of data along that spiral.

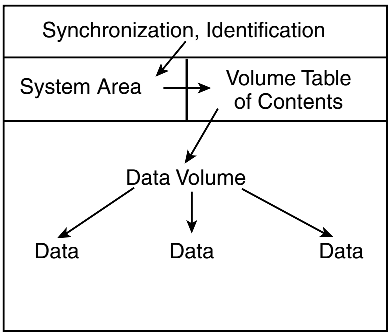

Figure 11.17 A diagram of basic ISO 9660 file organizational format.

To put the ISO 9660 format in perspective, the disc layout is roughly analogous to that of a floppy disk. A floppy disk has a system track that not only identifies itself as a floppy disk and reveals its density and OS, but tells the computer how it's organized (into directories, which are made up of files).

Joliet

Joliet is an extension of the ISO 9660 standard that Microsoft developed for use with Windows 95 and later. Joliet enables CDs to be recorded using filenames up to 64 characters long, including spaces and other characters from the Unicode international character set. Joliet also preserves an 8.3 alias for those programs that can't use the longer filenames.

In general, Joliet features the following specifications:

- File or directory names can be up to 64 Unicode characters (128 bytes) in length.
- Directory names can have extensions.
- Directories can be deeper than eight levels.
- Multisession recording is inherently supported.

Tip

Because Joliet supports a shorter path than Windows 9x and newer versions, you might have difficulties mastering a Joliet-format CD that contains extremely long pathnames. I recommend you shorten folder names in the file structure you create with the CD mastering software to avoid problems. Unfortunately, some CD mastering programs don't warn you about a pathname that is too long until after the burning process starts. If your CD mastering program offers an option to validate your disc structure, use this option to determine whether you need to shorten folder names. Some CD mastering programs will provide a suggested short name and shorten too-long folder names for you.

Due to backward-compatibility provisions, systems that don't support the Joliet extensions (such as older DOS systems) should still be capable of reading the disc. However, it will be interpreted as an ISO 9660 format using the short names instead.

Note

A bit of trivia: "Chicago" was the code name used by Microsoft for Windows 95. Joliet is the town outside of Chicago where Jake was locked up in the movie *The Blues Brothers*.

Universal Disk Format

UDF is a file system created by the Optical Storage Technology Association (OSTA) as an industry-standard format for use on optical media, but it can also be used by other types of removable-media drives, such as the Iomega REV drives. UDF has several advantages over the older ISO 9660 file system but is most noted because it is designed to work with packet writing, a technique for writing small amounts of data to an optical disc, treating it much like a standard magnetic drive. The UDF file system allows long filenames up to 255 characters per name. There have been several versions of UDF, with most packet-writing software using UDF 1.5 or later. Packet-writing software such as Roxio's DirectCD and Drag-to-Disc, Ahead Software's InCD, and Veritas and Sonic Solutions' DLA use the UDF file system. However, standard optical drives, drivers, and OSs such as DOS can't read UDF-formatted discs. Recordable drives can read them, but regular optical drives must conform to the MultiRead specification (see the section "MultiRead Specifications," earlier in this chapter) to be capable of reading UDF discs.

After you are sure that your drive can read UDF, you must check the OS. Most OSs can't read UDF natively—the support has to be added via a driver. DOS can't read UDF at all; however, with Windows 95 and later, UDF-formatted discs can be read by installing a UDF driver. Typically, such a driver is included with the software that comes with most CD-RW and rewritable DVD drives.

If you don't have a UDF reader, you can download one from the following websites:

- Get UDF Reader 2.5 for Windows XP from http://www.videohelp.com/tools/UDF_Reader
- Get UDF Volume Reader 7.1.0.95 for Windows 9x through XP from http://www.roxio.com/enu/support/udf/software_updates.html
- Get Nero AG Software's InCD Reader from the support section of www.nero.com.

After the UDF driver is installed, you do not need to take any special steps to read a UDF-formatted disc. The driver will be in the background waiting for you to insert a UDF-formatted disc.

If you are unable to read a disc written with UDF on another system, return it to the original system and close the media. This option is usually displayed as part of the Eject Settings dialog box. Closing the disc converts the filenames to Joliet format and causes them to be truncated to 64 characters.

You can download the latest (revision 2.60) version of the Universal Disk Format specification from the OSTA website at www.osta.org/specs/index.htm.

Tip

UDF discs can become unreadable for a variety of reasons, including incompatible UDF reader installed, disc not closed before removal of drive, table of contents not written due to system lockup, and so on. To recover data from UDF discs, try CD Roller (available from www.cdroller.com). It supports the most commonly used UDF versions (v1.02 through 2.01, and UDF Bridge) and also works with optical discs created by digital cameras, DVD recorders, and DVD-based camcorders. Another optical disc recovery program to consider is IsoBuster (www.isobuster.com). IsoBuster also works with BD formats.

Macintosh HFS

HFS is the file system used by the Macintosh OS. HFS can also be used on optical discs; however, if that is done, they will not be readable on a PC. A hybrid disc can be produced with both Joliet and HFS or ISO 9660 and HFS file systems, and the disc would then be readable on both PCs and Macs. In that case, the system will see only the disc that is compatible, which is ISO 9660 or Joliet in the case of PCs.

Rock Ridge

The Rock Ridge Interchange Protocol (RRIP) was developed by an industry consortium called the Rock Ridge Group. It was officially released in 1994 by the IEEE CD-ROM File System Format Working Group and specifies an extension to the ISO 9660 standard for CD-ROM that enables the recording of additional information to support UNIX/POSIX file system features. Neither DOS nor Windows includes support for the Rock Ridge extensions. However, because it is based on ISO 9660, the files are still readable on a PC and the RRIP extensions are simply ignored.

Note

An interesting bit of trivia is that the Rock Ridge name was taken from the fictional Western town in the movie Blazing Saddles.

Mount Rainier

Mount Rainier is a rewritable optical standard developed by Philips, Sony, Microsoft, and HP (Compaq). Also called EasyWrite (see Figure 11.18), Mount Rainier was designed to enable native OS support for data storage on rewritable optical discs.

Figure 11.18 The EasyWrite logo is used on some CD-RW and DVD+R/RW drives manufactured in 2003 and beyond that support the Mount Rainier standard.

Mount Rainier's main features include these:

- **Integral defect management**—Standard drives rely on driver software to manage defects.
- **Direct addressing at the 2KB sector level to minimize wasted space**—Standard CD-RW media uses a block size of 64KB.
- **Background formatting so that new media can be used in seconds after first insertion**—Standard CD-RW formatting can take up to 45 minutes depending on drive speed.
- **Standardized command set**—Standard software cannot work with new drives until revised command files are available.
- **Standardized physical layout**—Differences in standard UDF software can make reading media written by another program difficult.

Mount Rainier compatibility is also known as CD-MRW or DVD+MRW compatibility. Drives with the Mount Rainier or EasyWrite logo have this compatibility built in, but some existing CD-RW drives can be updated to MRW status by reflashing the firmware in the drive.

You must also have OS or application support to use Mount Rainier. Windows Vista and later have Mount Rainier support built in; Linux kernel version 2.6.2 and above also include Mount Rainier support. For Windows XP or older editions, you must use recent versions of Nero AG Software's InCD or Roxio's DirectCD or Drag-to-Disc or other Mount Rainier–compatible programs to support Mount Rainier.

Ripping/Copying Discs

All optical drives can *play* Red Book–formatted CD-DA discs, but not all optical drives can *read* CD-DA discs. The difference sounds subtle, but it is actually quite dramatic. If you enjoy music and want to use your PC to manage your music collection, the ability to read the audio data digitally is an important function for your CD (and DVD) drives because it enables you to much more easily and accurately store, manipulate, and eventually write back out audio tracks.

To record a song from CD to your hard disk, it was once necessary to play the disc at normal speed and capture the audio output as analog, hence the need for the four-wire analog audio cable connection from the rear of optical drives to your sound card. Fortunately, for several years drives have supported *digital audio extraction* (DAE). In this process, they read the digital audio sectors directly and, rather than decode them into analog signals, pass each 2,352-byte sector of raw (error-corrected) digital audio data directly to the PC's processor via the drive interface cable (ATA, SATA, SCSI, USB, or FireWire). Therefore, no digital-to-analog conversion (and back) occurs, and you essentially get the audio data exactly as it was originally recorded on the CD (within the limits of the CD-DA error-correction standards). You would have essentially extracted the exact digital audio data from the disc onto your PC.

Another term for digital audio extraction is *ripping*, so named because you can "rip" the raw audio data from the drive at full drive read speed, rather than the normal 1x speed at which you listen to audio discs. Actually, most drives can't perform DAE at their full rated speeds. Although some are faster (or slower) than others, most perform DAE at speeds from about one-half to two-thirds of their rated CD read speed. So, you might be able to extract audio data at speeds only up to 28x on a 40x rated drive. However, that is still quite a bit better than at 1x as it would be on drives that can't do DAE (not to mention skipping the conversion to analog and back to digital with the resultant loss of information).

Virtually all newer optical drives can perform digital audio extraction on music discs. How fast or accurately they do this varies from model to model. You might think any extraction (digital copy) of a given track (song) should be the same because it is a digital copy of the original; however, that is not always the case. The CD-DA format was designed to play music, not to transfer data with 100% accuracy. Errors beyond the capability of the CIRC in the CD-DA format cause the firmware in the drive to interpolate or approximate the data. In addition, time-based problems due to clock inaccuracies can occur in the drive, causing it to get slightly out of step when reading the frames in the sector (this is referred to as *jitter*). Differences in the internal software (firmware) in the drive and differences in the drivers used are other problems that can occur.

Note

When extracting (ripping) music from CDs, the default format is uncompressed WAV; however, other compressed formats such as MP3 can be used as well. Because WAV files match the high 44.1KHz sampling rate used on the CD, you have 176,400 bytes per second of sound information, which means 1 minute of music consumes nearly 10.6MB worth of space on your hard drive. MP3 compression can reduce that by a factor of 6 or more, with little to no perceptible loss in quality.

"For Music Use Only" CD-R/RW Discs

According to the Audio Home Recording Act of 1992, consumer CD recordable drives and media sold specifically for recording music are required to have specific safeguards against copying discs, mainly SCMS. That means these recorders can make digital copies only from original prerecorded discs. You can copy a copy, but in that case, the data being recorded goes from digital to analog and back to digital on the second copy, resulting in a generational loss of quality.

The media for these recorders must be special as well. They work only with special discs labeled "For Music Use," "For Audio," or "For Consumer." These carry the standard Compact Disk Digital Audio Recordable logo that most are familiar with, but below that, as part of the logo, is an added line that says "For Consumer." These discs feature a special track prerecorded onto the disc, which the consumer music recorders look for. Built into the price of the AHRA-compliant media is a royalty for the music industry that this track protects. The media costs about 20%–30% more than what regular CD-R/RW media costs. If you try to use standard non-AHRA-compliant CD-R/RW discs in these drives, the drive refuses to recognize the disc. These music devices also refuse to copy data discs.

Note that this does not apply to the optical drive you have installed or attached to your PC. It does not have to be AHRA compliant, nor does it need to use AHRA-compliant "For Music Use" media, even if you are copying or recording music discs. Additionally, you can make digital copies of copies—the SCMS does not apply, either. The bottom line is that you do not have to purchase AHRA-compliant discs for the optical drives in your PC. If you do purchase such discs, despite the "For Music Use Only" designation, AHRA-compliant discs can be used in your optical drives just as regular CD-R/RW discs can be used for storing data. The extra information indicating AHRA compliance is simply ignored.

CD Copy Protection

Worries about the public copying of software and music CDs has prompted the development of copy protection techniques that attempt to make these discs uncopyable. There are different methods of protecting software CDs versus music CDs, but the end result is the same: You are prevented from making normal copies, or the copies don't work properly. In the case of music CDs, the copy protection can be quite obtrusive, adding noise to the recording, and in extreme cases preventing the disc from even playing in a PC drive.

Several copy protection schemes are available for CD-DA (digital audio) discs, ranging from the simple to sophisticated. The most popular protection scheme for digital audio discs is called SafeAudio by Macrovision. Macrovision won't explain exactly how SafeAudio works, but it purchased the technology from a company called TTR Technologies and patents filed by TTR describe the scheme in detail. According to the patents, the disc is deliberately recorded with grossly erroneous values (bursts of noise) in both the audio data and the codes, which would typically be used to correct these errors. When the disc is read, the normal error-correction scheme fails, leaving small gaps in the music. When this happens on a standard audio CD player, the gaps are automatically bridged by circuitry or code in the player, which looks at the audio data on either side of the gap and interpolates (guesses) the missing values. The CD drive in a PC can do the same thing, so the interpolation occurs only when playing CDs in an audio player mode. However, the drive in a PC does not perform this same interpolation when "ripping" the data—that is, copying it directly to a hard drive, another CD, or some other medium. In that case, the unbridged gaps are heard as extremely loud clicks, pops, and noise. Both TTR and Macrovision claim that the interpolation that occurs when playing a SafeAudio disc is not discernable to the human ear, but many audio experts disagree. To an audiophile, the addition of any distortion or noise to the audio signal is unconscionable, plus you can't make legal backups of your music—something that is allowed by law. Because of these problems, I recommend avoiding the purchase of audio CDs containing SafeAudio or any other form of copy protection.

CD Digital Rights Management

Digital rights management (DRM) goes a step beyond standard copy protection by specifying what you can and cannot do with a recorded CD or other type of commercial media. When applied to downloaded music, for example, DRM features in audio tracks can prevent you from burning a song to CD an unlimited amount of times, playing a song past a particular date, or limit the number of times you can copy a song from one PC to another.

Although the use of DRM on CD media (as opposed to downloadable audio tracks) has been rare, the Sony rootkit scandal of 2005 is a useful case to keep in mind.

Sony BMG, one of the biggest music CD distributors, introduced a controversial method of copy protection and DRM in the fall of 2005 by adding copy protection and DRM to some of its music CDs. Affected CDs used either XCP (Extended Copy Protection, developed by First 4 Internet, now known as Fortium Technologies, Inc.) or MediaMax CD-3 (developed by SunnComm).

These programs limited the user's ability to work freely with the songs (as can be done with normal music CDs), and, worse yet, were installed on PCs without the user being notified. The type of installer Sony used is called a *rootkit*, which is a program that hides its presence from the OS and makes it easier for worms and other malware to attack the system.

After security and privacy advocates attacked Sony's use of DRM and rootkits without adequate notice to music purchasers, Sony introduced a rootkit removal tool and eventually recalled all albums in 2006, settling a lawsuit with the Federal Trade Commission. Although Sony's attempt to use DRM was botched by its failure to inform customers that CDs contained DRM software and the software did not provide a way for users to block installation, it's possible that DRM features that avoid Sony's mistakes may be used on CD and other types of media in the future.

DVD Copy Protection

DVD-Video discs employ several levels of protection that are mainly controlled by the DVD Copy Control Association (DVD CCA) and a third-party company called Macrovision (they developed SafeDisk).

This protection typically applies only to DVD-Video discs, not DVD-ROM software. So, for example, copy protection might affect your ability to make backup copies of *The Matrix*, but it won't affect a DVD encyclopedia or other software application distributed on DVD-ROM discs.

Note that every one of these protection systems has been broken, so with a little extra expense or the correct software, you can defeat the protection and make copies of your DVDs either to other digital media (hard drive, optical drive, flash drive, and so on) or to analog media (such as a VHS or other tape format).

A lot of time and money are wasted on these protection schemes, which can't really foil the professional bootleggers willing to spend the time and money to work around them. But they can make it difficult for the average person to legitimately back up his expensive media.

The four main protection systems used with DVD-Video discs are as follows:

- Regional Playback Control (RPC)
- Content Scrambling System (CSS)
- Analog Protection System (APS)
- ProtectDisc

Caution

The Digital Millennium Copyright Act (DMCA) signed into law in 1998 prohibits the breaking of copy-protection schemes or the distribution of information (such as tools, website links, and so forth) on how to break these schemes.

RPC

Regional playback was designed to allow discs sold in specific geographical regions of the world to play only on players sold in those same regions. The idea was to allow a movie to be released at different times in different parts of the world and to prevent people from ordering discs from regions in which the movie had not been released yet.

Eight regions are defined in the RPC standard. Discs (and players) usually are identified by a small logo or label showing the region number superimposed on a world globe. Multiregion discs are possible, as are discs that are not region locked. If a disc plays in more than one region, it has more than one number on the globe. The regions are as follows:

- **Region Code 1**—United States, Canada, U.S. Territories, Bermuda.
- **Region Code 2**—Japan, Western Europe, South Africa, and the Middle East.
- **Region Code 3**—Southeast Asia and East Asia.
- **Region Code 4**—Australia, New Zealand, Pacific Islands, Central America, Mexico, South America, and the Caribbean.
- **Region Code 5**—Eastern Europe (east of Poland and the Balkans), Indian subcontinent, Africa, North Korea, and Mongolia.
- **Region Code 6**—China and Tibet.
- **Region Code 7**—Reserved for future use.
- **Region Code 8**—International venues including aircraft and cruise ships.
- **Region Code All**—Has all flags set, allowing the disc to be played in any region or player. Sometimes called Region Code 0.

The region code is embedded in the hardware of DVD video players. Most players are preset for a specific region and can't be changed. Some companies who sell the players modify them to play discs from all regions; these are called *region-free* or *code-free* players. Some newer discs have an added region code enhancement (RCE) function that checks to see whether the player is configured for multiple or all regions and then, if it is, refuses to play. Most newer region-free modified players know how to query the disc first to circumvent this check as well.

DVD-ROM drives used in PCs originally did not have RPC in the hardware, placing that responsibility instead on the software used to play DVD video discs on the PC. The player software would usually lock the region code to the first disc that was played and then from that point on, play only discs from that region. Reinstalling the software enabled the region code to be reset, and numerous patches were posted on websites to enable resetting the region code even without reinstalling the software. Because of the relative ease of defeating the region-coding restrictions with DVD-ROM drives, starting on January 1, 2000, all DVD-ROM and rewritable DVD drives were required to have RPC-II, which embeds the region coding directly into the drive.

RPC-II (or RPC-2) places the region lock in the drive, and not in the playing or MPEG-2 decoding software. You can set the region code in RPC-II drives up to five times total, which basically means you can change it up to four times after the initial setting. Usually, the change can be made via the player software you are using, or you can download region-change software from the drive manufacturer. Upon making the fourth change (which is the fifth setting), the drive is locked on the last region set.

Region Codes Used by BD

A different region code scheme that divides the world into three regions is used by BD:

- Region A includes North America, Central America, South America, Korea, Japan, and South East Asia.
- Region B includes Europe, the Middle East, Africa, Australia, and New Zealand.
- Region C includes Russia, India, China, and the rest of the world.

A BD without a region code can be played by players with any region code.

CSS

The CSS provides the main protection for DVD-Video discs. It wasn't until this protection was implemented that the Motion Picture Association of America (MPAA) agreed to release movies in the DVD format, which is the main reason the rollout of DVD had been significantly delayed.

CSS originally was developed by Matsushita (Panasonic) and is used to digitally scramble and encrypt the audio and video data on a DVD-Video disc. Descrambling requires a pair of 40-bit (5-byte) keys (numeric codes). One of the keys is unique to the disc, whereas the other is unique to the video title set (VTS file) being descrambled. The disc and title keys are stored in the lead-in area of the disc in an encrypted form. The CSS scrambling and key writing are carried out during the glass mastering procedure, which is part of the disc manufacturing process.

You can see this encryption in action if you put a DVD disc into a DVD-ROM drive on a PC, copy the files to your hard drive, and then try to view the files. The files are usually called `VTS_xx_yy.VOB` (video object), where `xx` represents the title number and `yy` represents the section number. Typically, all the files for a given movie have the same title number and the movie is spread out among several 1GB or smaller files with different section numbers. These VOB files contain both the encrypted video and audio streams for the movie interleaved together. Other files with an IFO extension contain information used by the DVD player to decode the video and audio streams in the VOB files. If you copy the VOB and IFO files onto your hard drive and try to click or play the VOB files directly, you either see and hear scrambled video and audio or receive an error message about playing copy-protected files.

This encryption is not a problem if you use a CSS-licensed player (either hardware or software) and play the files directly from the DVD disc. All DVD players, whether they are consumer standalone units or software players on your PC, have their own unique CSS unlock key assigned to them. Every DVD video disc has 400 of these 5-byte keys stamped onto the disc in the lead-in area (which is not usually accessible by programs) on the DVD in encrypted form. The decryption routine in the player uses its unique code to retrieve and unencrypt the disc key, which is then used to retrieve and unencrypt the title keys. CSS is essentially a three-level encryption that originally was thought to be very secure but has proven otherwise.

In October 1999, a 16-year-old Norwegian programmer was able to extract the first key from one of the commercial PC-based players, which allowed him to very easily decrypt disc and title keys. A now famous program called DeCSS was then written that can break the CSS protection on any DVD video title and save unencrypted VOB files to a hard disk that can be played by any MPEG-2 decoder program. Needless to say, this utility (and others based on it) has been the cause of much concern in the movie industry and has caused many legal battles over the distribution and even links to this code on the Web. Do a search on DeCSS for some interesting legal reading.

As if that weren't enough, in March 2001, two MIT students published an incredibly short (only seven lines long!) and simple program that can unscramble CSS so quickly that a movie can essentially be unscrambled in real time while it is playing. They wrote and demonstrated the code as part of a two-day seminar they conducted on the controversial Digital Millennium Copyright Act, illustrating how trivial the CSS protection really is.

ProtectDisc

The newest DVD copy protection system is called ProtectDisc. Its DVD-Video version changes the standard structure of the disc to prevent copying. Unfortunately, a DVD movie created using ProtectDisc cannot be viewed with PC-based player programs such as WMP or WinDVD.

Cinavia

Ciniavia (http://www.cinavia.com/languages/english/index.html) is the company responsible for copy-protection for BD movies. If you attempt to create a copy of a BD disc, Cinavia displays messages such as "Copying Stopped. The content being copied is protected by Cinavia and is not authorized for copying from this device." Similar messages are displayed when attempting to play back an unauthorized copy. Cinavia can also mute audio from unauthorized copies.

Is Copy Protection "Unbreakable?"

Despite the claims of "unbreakable" copy protection, ProtectDisc's method, like the others discussed here, was quickly overcome. Similarly, enterprising users have figured out how to bypass Cinavia's copy protection methods (which apply only to BD set-top boxes, not to BD drives in PCs). As with other copy-protection schemes, legitimate users who don't try to "beat the system" often wind up being victimized—in the case of ProtectDisk, by being unable to use a PC to watch the movie.

Optical Drive Performance Specifications

Many factors in a drive can affect performance, and several specifications are involved. Typical performance figures published by manufacturers are the data transfer rate, the access time, the internal cache or buffers (if any), and the interface the drive uses. This section examines these specifications.

CD Data Transfer Rate

The data transfer rate for a CD drive tells you how quickly the drive can read from the disc and transfer to the host computer. Normally, transfer rates indicate the drive's capability for reading large, sequential streams of data.

Transfer speed is measured two ways. The one most commonly quoted with optical drives is the "x" speed, which is defined as a multiple of the particular standard base rate. For example, CD drives transfer at 153.6KBps according to the original standard. Drives that transfer twice that are 2x, 40 times that are 40x, and so on. DVD drives transfer at 1,385KBps at the base rate, whereas drives that are 20 times faster than that are listed as 20x. Note that because almost all faster drives feature CAV, the "x" speed usually indicated is a maximum that is seen only when reading data near the outside (end) of a disc. The speed near the beginning of the disc might be as little as half that, and of course average speeds are somewhere in the middle.

With today's optical drives supporting multiple disc formats, multiple read and write specifications are given for each form of media a drive supports.

CD Drive Speed

Because CDs originally were designed to record audio, the speed at which the drive reads the data had to be constant. To maintain this constant flow, CD data is recorded using a technique called *constant linear velocity* (CLV).

In the quest for greater performance, drive manufacturers began increasing the speeds of their drives by making them spin more quickly. A drive that spins twice as fast was called a 2x drive, one that spins four times faster was called 4x, and so on. This was fine until about the 12x point, where drives were spinning discs at rates from 2,568 rpm to 5,959 rpm to maintain a constant data rate. At higher speeds than this, it became difficult to build motors that could change speeds (spin up or down) as quickly as necessary when data was read from different parts of the disc. Because of this, most drives rated faster than 12x spin the disc at a fixed rotational, rather than linear speed. This is termed CAV because the angular velocity (or rotational speed) remains a constant.

CAV drives are also generally quieter than CLV drives because the motors don't have to try to accelerate or decelerate as quickly. A drive (such as most rewritables) that combines CLV and CAV technologies is referred to as *Partial-CAV* or *P-CAV*. Most writable drives, for example, function in CLV mode when burning the disc and in CAV mode when reading. Table 11.23 compares CLV and CAV.

Table 11.23 CLV Versus CAV Technology Quick Reference

	CLV (Constant Linear Velocity)	CAV (Constant Angular Velocity)
Speed of CD rotation	Varies with data position on disc. Faster on inner tracks than on outer tracks.	Constant.
Data transfer rate	Constant.	Varies with data position on disc. Faster on outer tracks than on inner tracks.
Average noise level	Higher.	Lower.

CD-ROM drives have been available in speeds from 1x up to 52x. Most nonrewritable drives up to 12x were CLV; most drives from 16x and up are CAV. With CAV drives, the disc spins at a constant speed, so track data moves past the read laser at various speeds, depending on where the data is physically located on the CD (near the inner or outer part of the track). This also means that CAV drives read the data at the outer edge (end) of the disk more quickly than data near the center (beginning). This allows for some misleading advertising. For example, a 12x CLV drive reads data at 1.84MBps no matter where that data is on the disc. On the other hand, a 16x CAV drive reads data at speeds up to 16x (2.46MBps) on the outer part of the disc, but it also reads at a much lower speed of only 6.9x (1.06MBps) when reading the inner part of the disc (that is the part they don't tell you). On average, this would be only 11.5x, or about 1.76MBps. In fact, the average is actually overly optimistic because discs are read from the inside (slower part) out, and an average would relate only to reading completely full discs. The real-world average could be much less than that.

Table 11.24 contains data showing CD drive speeds along with transfer rates and other interesting data. This information also applies to DVD or BD drives when CDs are used.

Table 11.24 CD-ROM Drive Speeds and Transfer Rates

Advertised CD-ROM Speed (Max. if CAV)	Time to Read 74-Minute CD if CLV	Time to Read 80-Minute CD if CLV	Transfer Rate (Bps) (Max. if CAV)	Actual CD-ROM Speed Minimum in CAV	Minimum Transfer Rate if CAV (Bps)
1x	74.0	80.0	153,600	0.4x	61,440
2x	37.0	40.0	307,200	0.9x	138,240
4x	18.5	20.0	614,400	1.7x	261,120
6x	12.3	13.3	921,600	2.6x	399,360
8x	9.3	10.0	1,228,800	3.4x	522,240
10x	7.4	8.0	1,536,000	4.3x	660,480
12x	6.2	6.7	1,843,200	5.2x	798,720
16x	4.6	5.0	2,457,600	6.9x	1,059,840
20x	3.7	4.0	3,072,000	8.6x	1,320,960
24x	3.1	3.3	3,686,400	10.3x	1,582,080
32x	2.3	2.5	4,915,200	13.8x	2,119,680
40x	1.9	2.0	6,144,000	17.2x	2,641,920
48x	1.5	1.7	7,372,800	20.7x	3,179,520
50x	1.5	1.6	7,680,000	21.6x	3,317,760
52x	1.4	1.5	7,987,200	22.4x	3,440,640
56x	1.3	1.4	8,601,600	24.1x	3,701,760

Each of the columns in Table 11.24 is explained here. Column 1 indicates the advertised drive speed. This is a constant speed if the drive is CLV (most 12x and lower) or a maximum speed only if CAV.

Columns 2 and 3 indicate how long it would take to read a full disc if the drive was CLV. For CAV drives, those figures would be longer because the average read speed is less than the advertised speed. The fourth column indicates the data transfer rate, which for CAV drives would be a maximum figure only when reading the end of a disc.

Columns 3–6 indicate the actual minimum "x" speed for CAV drives, along with the minimum transfer speed (when reading the start of any disc) and an optimistic average speed (true only when reading a full disc; otherwise, it would be even lower) in both "x" and byte-per-second formats.

Vibration problems can cause high-speed drives to drop to lower speeds to enable reliable reading. Your disc can become unbalanced, for example, if you apply a small paper label to its surface to identify the disc. For this reason, many of the faster optical drives come with autobalancing or vibration-control mechanisms to overcome these problems. The only drawback is that if they detect a vibration, they slow down the disc, thereby reducing the transfer rate performance.

Most recent optical drives use Z-CLV (zoned CLV) or P-CAV (partial CAV) designs, which help increase average performance while keeping rotational speeds under control.

Average CD-ROM Speed if CAV	**Average Transfer Rate if CAV (Bps)**	**Maximum Linear Speed (mps)**	**Maximum Linear Speed (mph)**	**Rotational Speed Min. if CLV Max. if CAV (rpm)**	**Rotational Speed Max. if CLV (rpm)**
0.7x	107,520	1.3	2.9	214	497
1.5x	222,720	2.6	5.8	428	993
2.9x	437,760	5.2	11.6	856	1,986
4.3x	660,480	7.8	17.4	1,284	2,979
5.7x	875,520	10.4	23.3	1,712	3,973
7.2x	1,098,240	13.0	29.1	2,140	4,966
8.6x	1,320,960	15.6	34.9	2,568	5,959
11.5x	1,758,720	20.8	46.5	3,425	7,945
14.3x	2,196,480	26.0	58.2	4,281	9,931
17.2x	2,634,240	31.2	69.8	5,137	11,918
22.9x	3,517,440	41.6	93.1	6,849	15,890
28.6x	4,392,960	52.0	116.3	8,561	19,863
34.4x	5,276,160	62.4	139.6	10,274	23,835
35.8x	5,498,880	65.0	145.4	10,702	24,828
37.2x	5,713,920	67.6	151.2	11,130	25,821
40.1x	6,151,680	72.8	162.8	11,986	27,808

Columns 7–8 indicate the maximum linear speeds the drive will attain, in both meters per second and miles per hour. CLV drives maintain those speeds everywhere on the disc, whereas CAV drives reach those speeds only on the outer part of a disc.

Columns 9–12 indicate the rotational speeds of a drive. The first of these shows how fast the disc spins when being reading from the start; this applies to either CAV or CLV drives. For CAV drives, the figure is constant no matter what part of the disc is being read. The last column shows the maximum rotational speed if the drive were a CLV type. Because most drives over 12x are CAV, these figures are mostly theoretical for the 16x and faster drives.

DVD Drive Speed

As with CDs, DVDs rotate counterclockwise (as viewed from the reading laser) and typically are recorded at a constant data rate called CLV. Therefore, the track (and thus the data) is always moving past the read laser at the same speed, which originally was defined as 3.49 meters per second (or 3.84 mps on dual-layer discs). Because the track is a spiral that is wound more tightly near the center of the disc, the disc must spin at varying rates to maintain the same track linear speed. In other words, to maintain a CLV, the disk must spin more quickly when the inner track area is being read and more slowly when the outer track area is being read. The speed of rotation in a 1x drive (3.49 meters per second is considered 1x speed) varies from 1,515 rpm when reading the start (inner part) of the track down to 570 rpm when reading the end (outer part) of the track.

Single-speed (1x) DVD drives provide a data transfer rate of 1.385MBps, which means the data transfer rate from a DVD at 1x speed is roughly equivalent to a 9x CD (1x CD data transfer rate is 153.6KBps, or 0.1536MBps). This does not mean, however, that a 1x DVD drive can read CDs at 9x rates: DVD drives actually spin at a rate that is just under three times faster than a CD drive of the same speed. So, a 1x DVD drive spins at about the same rotational speed as a 2.7x CD drive. Many

Table 11.25 DVD Speeds and Transfer Rates

Advertised DVD-ROM Speed (Max. if CAV)	Time to Read Single-Layer DVD if CLV	Time to Read Dual Layer DVD if CLV	Transfer Rate (Bytes/sec) (Max. if CAV)	Actual DVD Speed Minimum in CAV	Minimum Transfer Rate if CAV (Bytes/sec)
1x	56.5	51.4	1,384,615	0.4x	553,846
2x	28.3	25.7	2,769,231	0.8x	1,107,692
4x	14.1	12.8	5,538,462	1.7x	2,353,846
6x	9.4	8.6	8,307,692	2.5x	3,461,538
8x	7.1	6.4	11,076,923	3.3x	4,569,231
10x	5.7	5.1	13,846,154	4.1x	5,676,923
12x	4.7	4.3	16,615,385	5.0x	6,923,077
16x	3.5	3.2	22,153,846	6.6x	9,138,462
20x	2.8	2.6	27,692,308	8.3x	11,492,308
24x	2.4	2.1	33,230,769	9.9x	13,707,692
32x	1.8	1.6	44,307,692	13.2x	18,276,923
40x	1.4	1.3	55,384,615	16.6x	22,984,615
48x	1.2	1.1	66,461,538	19.9x	27,553,846
50x	1.1	1.0	69,230,769	20.7x	28,661,538

Each of the columns in Table 11.25 is explained here

Column 1 indicates the advertised drive speed. This is a constant speed if the drive is CLV or a maximum speed only if CAV (most DVD drives are CAV).

Columns 2 and 3 indicate how long it would take to read a full disc (single- or dual-layer) if the drive were CLV. For CAV drives, those figures are longer because the average read speed is less than the advertised speed. The fourth column indicates the data transfer rate, which for CAV drives is a maximum figure seen only when reading the end of a disc.

Columns 4–8 indicate the actual minimum "x" speed for CAV drives, along with the minimum transfer speed (when reading the start of any disc) and an optimistic average speed (true only when reading a full disc; otherwise, it's even lower) in both "x" and byte-per-second formats.

DVD drives list two speeds, for example, a DVD drive listed as a 16x/40x would indicate the performance when reading DVDs/CDs, respectively.

As with CD drives, DVD drive manufacturers began increasing the speeds of their drives by making them spin more quickly. A drive that spins twice as fast was called a 2x drive, a drive that spins four times as fast was 4x, and so on. At higher speeds, it became difficult to build motors that could change speeds (spin up or down) as quickly as needed when data was read from different parts of the disc. Because of this, faster DVD drives spin the disc at a fixed rotational speed rather than linear speed. This is termed CAV because the angular velocity (or rotational speed) remains a constant.

The faster drives are useful primarily for data, not video. Having a faster drive can reduce or eliminate the pause during layer changes when playing a DVD video disc, but having a faster drive has no effect on video quality.

DVD drives are available in speeds up to 20x or more, but because virtually all are CAV, they actually achieve the rated transfer speed only when reading the outer part of a disc. Table 11.25 shows the data rates for DVD drives reading DVDs and how that rate compares to a CD drive.

Average DVD Speed if CAV	Average Transfer Rate if CAV (Bytes/sec)	Maximum Linear Speed (m/sec)	Maximum Linear Speed (rpm)	Single-Layer Rot. Speed Min. if CLV Max. if CAV (rpm)	Single Layer Rot. Speed Max. if CLV (rpm)	Usual Transfer Rate When Reading CD-ROMs
0.7x	969,231	3.5	7.8	570	1,515	2.7x
1.4x	1,938,462	7.0	15.6	1,139	3,030	5.4x
2.9x	3,946,154	14.0	31.2	2,279	6,059	11x
4.3x	5,884,615	20.9	46.8	3,418	9,089	16x
5.7x	7,823,077	27.9	62.5	4,558	12,119	21x
7.1x	9,761,538	34.9	78.1	5,697	15,149	27x
8.5x	11,769,231	41.9	93.7	6,836	18,178	32x
11.3	15,646,154	55.8	124.9	9,115	24,238	43x
14.2	19,592,308	69.8	156.1	11,394	30,297	54x
17.0	23,469,231	83.8	187.4	13,673	36,357	64x
22.6	31,292,308	111.7	249.8	18,230	48,476	86x
28.3	39,184,615	139.6	312.3	22,788	60,595	107x
34.0	47,007,692	167.5	374.7	27,345	72,714	129x
35.4	48,946,154	174.5	390.3	28,485	75,743	134

Columns 9 and 10 indicate the maximum linear speeds the drive attains, in both meters per second and miles per hour. CLV drives maintain those speeds everywhere on the disc, whereas CAV drives reach those speeds only on the outer part of a disc.

Columns 11 and 12 indicate the rotational speeds of a drive. The first of these shows how quickly the disc spins when being read from the start. This applies to either CAV or CLV drives. For CAV drives, the figure is constant no matter what part of the disc is being read. The second of these two columns shows the maximum rotational speed if the drive were a CLV type. Because most faster drives are CAV, these figures are mostly theoretical for the faster drives.

Column 13 shows the speed the drive would be rated if it were a CD drive. This is based on the rotational speed, not the transfer rate. In other words, a 12x DVD drive would perform as a 32x CD drive when reading CDs. Most DVD drives list their speeds when reading CDs in the specifications. Due to the use of PCAV (Partial CAV) designs, some might have higher CD performances than the table indicates.

Access Time

The access time for an optical drive is measured the same way as for PC hard disk drives. In other words, the access time is the delay between the drive receiving the command to read and its actual first reading of a bit of data. Access rates quoted by many manufacturers are an average taken by calculating a series of random reads from a disc.

Buffer/Cache

Most optical drives include internal buffers or caches of memory installed onboard. These buffers are actual memory chips installed on the drive's circuit board that enable it to stage or store data in larger segments before sending it to the PC. A typical buffer can range from 2MB up to 8MB or more (depending on the drive). Generally, faster rewritable drives come with more buffer memory to handle the higher transfer rates.

Direct Memory Access and Ultra-DMA

Busmastering PATA controllers use Direct Memory Access (DMA) or Ultra-DMA transfers to improve performance and reduce CPU utilization. Virtually all modern PATA drives support Ultra-DMA utilization.

To determine whether your system has this feature enabled, open the Device Manager and check the properties sheet for the controller to view its capabilities.

To enable DMA transfers if your motherboard and drives support it, open the Device Manager and then open the properties sheet for the controller or drive. Click the Settings or Advanced Settings tab, and make sure DMA is enabled if available. Depending on which version of Windows you are using, some have the DMA setting in the controller properties and others have it with the individual drives.

Repeat the same steps to enable DMA transfers for any additional hard drives and ATAPI CD-ROM drives in your computer. Restart your computer after making these changes.

Note

If your system hangs after you enable this feature, you must restart the system in Safe mode and uncheck the DMA box.

If your drive is a parallel ATA model that supports any of the Ultra-DMA (also called Ultra-ATA) modes, you need to use an 80-conductor cable. Most motherboards refuse to enable Ultra-DMA modes faster than 33MBps if an 80-conductor cable is not detected. Note that these cabling issues affect only parallel ATA drives. If your drives are Serial ATA (SATA) models, these cabling issues do not apply.

Depending on your Windows version and when your motherboard chipset was made, you must install chipset drivers to enable Windows to properly recognize the chipset and enable DMA modes. Virtually all motherboard chipsets produced since 1995 provide busmaster ATA support. Most of those produced since 1997 also provide UltraDMA support for up to 33MHz (Ultra-ATA/33) or 66MHz (Ultra-ATA/66) speed operation. Still, you should make sure that DMA is enabled to ensure you are benefiting from the performance it offers. Enabling DMA can dramatically improve DVD performance, for example.

Interface

The drive's interface is the physical connection of the drive to the PC's expansion bus. The interface is the data pipeline from the drive to the computer, and you shouldn't minimize its importance. Four types of interfaces are normally used for attaching an optical drive to your system:

- **SATA (Serial ATA)**—The SATA interface is the same interface used by most recent computers for connecting their hard disk drives. With many recent systems featuring support for as little as one PATA (Parallel ATA) drive, but support for eight or more SATA drives, most optical drive vendors are now producing SATA versions of their drives.

  Compared to similar PATA optical drives, SATA drives feature equal performance, but are easier to install because it is not necessary to jumper the drive for master/slave or cable select.
- **PATA (Parallel AT Attachment)**—The PATA interface is the same interface most older computers use to connect to their hard disk drives. PATA is sometimes also referred to as ATA (AT Attachment) or IDE (Integrated Drive Electronics).
- **USB port**—Universal serial bus (USB) is normally used for external drives, and provides benefits such as hot-swappability, which is the capability to be plugged in or unplugged without removing the power or rebooting the system. USB 2.0 is the most common, but USB 3.0 drives might be available in the future.
- **FireWire (IEEE 1394)**— A few external optical drives are available with a FireWire (also called IEEE 1394 or i.LINK) interface instead of, or in addition to USB 2.0.

▶▶ **See** "Universal Serial Bus (USB)," **p. 692** and "IEEE 1394 (FireWire or i.LINK)," **p. 707** (Chapter 14, "External I/O Interfaces").

Some older drives were available in external versions using SCSI/ASPI (Small Computer System Interface/ Advanced SCSI Programming Interface) or parallel printer port interfaces, but these are obsolete.

Loading Mechanism

Three distinctly different mechanisms exist for loading a disc into an optical drive: the tray, caddy, and slot.

Most current drives use a tray-loading mechanism. This is similar to the mechanism used with a stereo system. Because you don't need to put each disc into a separate caddy, this mechanism is much less expensive overall. However, it also means that you must handle each disc every time you insert or remove it.

Some tray drives can't operate in a vertical (sideways) position because gravity prevents proper loading and operation. Check to see whether the drive tray has retaining clips that grab the hub of the disc or tabs that fold in or flip over from the outside of the tray to retain the disc. If so, you can run the drive in either a horizontal or vertical position.

The main advantage of the tray mechanism over the others is cost, and that is a big factor. Most drives today use the tray mechanism for handling discs.

Caddy systems have been used on several types of optical drives. The caddy system requires that you place the disc into a special caddy, which is a sealed container with a metal shutter. The caddy has a hinged lid you open to insert the disc, but after that the lid remains shut. When you insert the caddy containing the disc into the drive, the drive opens a metal shutter on the bottom of the caddy, allowing access to the disc by the laser.

The drawbacks to the caddy system include the expense and the inconvenience of having to put the discs into the caddies. Caddy-loaded drives were popular in early CD drives, but few were made or sold after 1994.

Some drives use a slot-loading mechanism, identical to that used in most automotive players. This is convenient because you just slip the disc into the slot, where the mechanism grabs it and draws it inside. Some drives can load several discs at a time this way, holding them internally inside the drive and switching discs as access is required.

The primary drawback to this type of mechanism is that if a jam occurs, it can be much more difficult to repair because you might have to remove the drive to free the disc. Another drawback is that slot-loading drives usually can't handle the smaller 80mm discs, card-shaped discs, or other modified disc physical formats or shapes, such as DualDisc.

Other Drive Features

Although drive specifications are of the utmost importance, you should consider other factors and features when evaluating optical drives. Besides quality of construction, the presence of drive sealing or self-cleaning lenses bears scrutiny when you are making a purchasing decision.

Dirt is your drive's biggest enemy. Dust or dirt, when it collects on the lens portion of the mechanism, can cause read errors or severe performance loss. Many manufacturers seal off the lens and internal components from the drive bay in airtight enclosures. Other drives, although not sealed, have double dust doors—one external and one internal—to keep dust from the inside of the drive. All these features help prolong the life of your drive.

Some drives are sealed, which means no air flows through the chamber in which the laser and lens reside. Always look for sealed drives in harsh industrial or commercial environments. In a standard office or home environment, it is probably not worth the extra expense.

To determine whether a particular drive is sealed, you may need to view FAQ or support questions considering drive cleaning; this information may not always be listed on the drives' spec sheet.

If the laser lens gets dirty, so does your data. The drive will spend a great deal of time seeking and reseeking or will finally give up. Lens-cleaning discs are available, but built-in cleaning mechanisms are now included on virtually all good-quality drives. This might be a feature you'll want to consider, particularly if you work in a less-than-pristine work environment or have trouble keeping your desk clean, let alone your drive laser lens. You can clean the lens manually, but it is generally a delicate operation requiring that you partially disassemble the drive. Also, damaging the lens mechanism by using too much force is pretty easy to do. Because of the risks involved, in most cases I do not recommend the average person disassemble and try to manually clean the laser lens.

Note

Before using a cleaning disc, check the drive vendor's recommendations to determine whether this method of maintenance is recommended. Some vendors do not recommend the use of cleaning discs because the felt pads or brushes used can scratch the laser lens.

How to Reliably Record Optical Discs

Six major factors influence your ability to create a working disc: interface type, drive buffer size, the location and condition of the data you want to record, the recording speed, whether the computer is performing other tasks while trying to create the disc, and the features available in your recording software. If you are having problems, there are some things you can check. The simplest thing you can do to ensure trouble-free recording is to make sure the drive has some form of buffer underrun protection. The data buffer in the drive holds information read from the original data source, so that if a pause in data reading occurs, there's less of a possibility of a buffer underrun until the on-drive buffer runs empty. Current drives with buffer underrun protection virtually eliminate this problem, no matter what size buffer is in the drive. Some mastering programs might offer an option to disable buffer underrun protection. However, you should leave it enabled at all times unless you are using an old drive that does not support this feature.

Tip

If you have problems with reliable disc creation at the drive's maximum speed, try using a lower speed. Your mastering job will take twice as long, but it's better to create a working disc more slowly than ruin a blank more quickly.

Buffer Underruns and Buffer Underrun Protection

Whenever a drive writes data to a disc in either DAO or TAO mode, it writes to the spiral track on the disc, alternating on and off to etch the pattern into the raw media. Originally, it was not possible for a drive to realign where it starts and stops writing like a hard drive can; after it started writing, it was necessary to continue until finished with the track or disc. Otherwise, the recording (and disc if it is not rewritable) would be ruined, creating a useless disc often referred to as a "coaster." To avoid this problem, the recording software, in combination with your system hardware, must be capable of delivering a consistent stream of data to the drive while it's writing.

Sanyo was the first to develop a technology that eliminates buffer underruns once and for all. It calls the technology BURN-Proof (BURN stands for *buffer underrun*), which sounds a little confusing (some people thought it prevented any writing on discs), but in practice it has proven to be excellent. Other technologies were developed by various vendors, including Ricoh's JustLink, Waste-Proof and Safeburn from Yamaha, SMART-Burn from Lite-On, and Superlink from Mediatek, among others. For a number of years, all recordable/rewritable drives have included some type of buffer underrun protection. Buffer underrun protection technology involves having a special chipset in the drive that monitors the drive buffer. When it anticipates that a buffer underrun might occur (the buffer is running low on data), it temporarily suspends the recording until more data fills the buffer. When the buffer is sufficiently restocked, the drive then locates exactly where the recording left off earlier and restarts recording again immediately after that position.

According to the Orange Book specification, gaps between data in a recording must not be more than 100 milliseconds in length. The buffer underrun technology can restart the recording with a gap of 40–45 milliseconds or less from where it left off, which is well within the specification. These small gaps are easily compensated for by the error correction built into the recording, so no data is lost.

If both your drive and recording software supports buffer underrun protection, you can multitask—do other things while burning discs—without fear of producing a bad recording.

Booting from a Floppy Disk with Optical Drive Support

Although modern OSs are distributed on bootable discs, you might need to boot from a floppy to start a restore process from a disk imaging utility or to install an older OS, such as Windows 9x or Me. Even if you are installing Windows 9x or Me in a virtualized environment such as those created with Microsoft Virtual PC or VMware, you need to boot the virtual machine with a floppy disc containing optical disc support before you can install the OS into the VM.

For an optical drive to function in a floppy boot environment, several drivers might be necessary:

- **A host adapter driver**—A set of universal ATAPI and SCSI host adapter drivers are included on Windows 98/Me startup disks.
- **MSCDEX**—Microsoft CD Extensions, which is included with DOS 6.0 and later, including the Windows 98/Me startup disks.

If you need to start a PC from a bootable floppy, the floppy must contain not only a bootable OS, but also the previously mentioned drivers; otherwise, the CD-ROM will be inaccessible.

You can find universal ATAPI and SCSI drivers on the Windows 98 and newer startup disks. Rather than create custom CONFIG.SYS and AUTOEXEC.BAT files, the best advice I can give is to merely boot from a Windows 98 or Me startup floppy because each time you boot from it, the proper drivers load and autodetect the optical drives, after which the drives are accessible. You can generate a Windows 98/Me startup disk on any system running Windows 98 or Me. If you don't have access to a Windows 98 or Me system, you can download an equivalent bootable floppy from www.bootdisk.com.

After you boot from a Windows 98/Me floppy, you see a menu that asks whether you want to boot with or without CD-ROM (and DVD) support. If you select yes, after the floppy finishes loading, you should be able to read discs in the optical drive.

Using an optical drive that conforms to the ATAPI specification under Windows does not require you to do anything. All the driver support for these drives is built into Windows 9x and later versions.

Bootable Optical Discs—El Torito

If your system BIOS is a version dated from 1998 or later, most likely it has "El Torito" support, which means it supports booting from a bootable optical disc. The El Torito name comes from the Phoenix/IBM Bootable CD-ROM Format Specification, which was actually named after the El Torito restaurant located near the Phoenix Software offices where the two engineers who developed the standard ate lunch. What El Torito means for the PC is the capability to boot from optical discs, which opens several possibilities, including creating bootable rescue discs, booting from newer OS discs when installing to new systems, creating bootable diagnostics and test discs, and more.

To create a bootable optical disc, ideally you need a burning application that allows the creation of bootable discs. Additionally, in some cases you need a bootable floppy that contains the drivers to support your CD drive in DOS mode (sometimes called real-mode drivers). The best source for these drivers (if needed) is a Windows 98 or Me startup floppy, which can be generated by any Windows 98 or Me system. Windows 98/Me startup disks can be used because these have the DOS-level CD-ROM support already configured and installed. If you don't have access to such a system to generate the disk, you can download one from www.bootdisk.com.

To create a bootable disc, simply follow the directions included with your burning application. Programs such as Nero and Roxio Media Creator make the creation of bootable discs relatively easy.

LightScribe and LabelFlash

There are two popular direct disc labeling systems, called LightScribe and LabelFlash. Hewlett-Packard (HP) developed the LightScribe direct disc labeling system in 2005 as a method for labeling CD (and later, DVD) discs without the need to print labels or use an inkjet printer equipped to print on CD or DVD media.

The top surface of a LightScribe disc is coated with a reactive dye that changes color when exposed to laser light. LightScribe uses the recording laser to etch text and graphics on the top surface of special LightScribe media. After the user records the disc, the user flips the disc over and runs a LightScribe program to transfer the desired design to the top of the disc. To prevent fading and surface damage, LightScribe discs should be stored in cases away from light when not in use.

LabelFlash was announced in October 2005 by Yamaha and Fujifilm. LabelFlash is based on the DiscT@2 ("disk tattoo") technology originally developed by Yamaha for writing text and graphics into the unused portion of the data side of a CD-R disc. However, LabelFlash can also write to the top side of media when the user flips the disc, just as with LightScribe. The top side of LabelFash media is designed to be more resistant to damage and to produce better image quality than LightScribe because the LabelFlash dye is 0.6mm below the disc surface.

The main drawback of either system is that they take up to half an hour or more to fully label a single disc. Another drawback is that both LightScribe and LabelFlash require drives, media, and software that support the specific system. For an updated list of products supporting these systems, visit the LightScribe (www.lightscribe.com) or LabelFlash (http://labelflash.jp) website.

Troubleshooting Optical Drives

Failure Reading Any Disc

If your drive fails to read a disc, try the following solutions:

- Check for scratches on the disc data surface.
- Check the drive for dust and dirt; use a cleaning disc.
- Make sure the drive shows up as a working device in System Properties. Check the drive's power and data cables if the drive is not listed.
- Try a disc that you know works.
- Restart the computer (the magic cure-all).
- Remove the drive from Device Manager in Windows, and allow the system to redetect the drive.

Failure to Read CD-R/RW Discs in CD-ROM or DVD Drive

If your CD-ROM or DVD drive fails to read CD-R and CD-RW discs, keep the following in mind:

- Some old 1x CD-ROM drives can't read CD-R media. Replace the drive with a newer, faster, cheaper model.
- Many early-model DVD drives can't read CD-R, CD-RW media; check compatibility.
- The CD-ROM drive must be MultiRead compatible to read CD-RW because of the lower reflectivity of the media; replace the drive.
- If some CD-Rs but not others can be read, check the media color combination to see whether some color combinations work better than others; change the brand of media.
- Packet-written CD-Rs (from Adaptec DirectCD or Drag to Disc and backup programs) can't be read on MS-DOS/Windows 3.1 CD-ROM drives because of the limitations of the operating system.
- Sometimes older drives can't read the pits/lands created at faster speeds. Record the media at a slower speed.
- If you are trying to read a packet-written CD-R created with DirectCD or Drag to Disc on a CD-ROM drive, reinsert the media into the original drive, eject the media, and select the option Close to Read on Any Drive.
- Download and install a UDF reader compatible with the packet-writing software used to create the CD-RW on the target computer. If you are not sure how the media was created, Software Architects offers a universal UDF reader/media repair program called FixUDF! (also included as part of WriteCD-RW! Pro). WriteDVD! Pro includes the similar FixDVD! UDF reader/media repair program for DVD drives.

Failure to Read a Rewritable DVD in DVD-ROM Drive or Player

If your DVD-ROM or DVD player fails to read a rewritable DVD, try the following solutions:

- Reinsert DVD-RW media into the original drive and finalize the media. Make sure you don't need to add any more data to the media if you use a first-generation (DVD-R 2x/DVD-RW 1x) drive because you must erase the entire disc to do so. You can unfinalize media written by second-generation DVD-R 4x/DVD-RW 2x drives. See your DVD-RW disc-writing software instructions or help file for details.
- Reinsert DVD+RW media into the original drive and change the compatibility setting to emulate DVD-ROM. See the section "DVD+RW and DVD+R," earlier in this chapter, for details.
- Write a single-layer disc and retry if the media is dual-layer. Most DVD-ROM drives can't read DL media.
- Make sure the media contains more than 521MB of data. Some drives can't read media that contains a small amount of data.

Failure to Create a Writable DVD

If you can't create a writable DVD but the drive can be used with CD-R, CD-RW, or rewritable DVD media, try the following solutions:

- Make sure you are using the correct media. +R and -R media can't be interchanged unless the drive is a DVD R/RW dual-mode drive.
- Be sure you select the option to create a DVD project in your mastering software. Some disc-mastering software defaults to the CD-R setting.
- Select the correct drive as the target. If you have both rewritable DVD and rewritable CD drives on the same system, be sure to specify the rewritable DVD drive.
- Try a different disc.
- Contact the mastering software vendor for a software update.

Failure Writing to CD-RW or DVD-RW 1x Media

If you can't write to CD-RW or DVD-RW 1x media, try the following solutions:

- Make sure the media is formatted. Use the format tool provided with the UDF software to prepare the media for use.
- If the media was formatted, verify it was formatted with the same or compatible UDF program. Different packet-writing programs support different versions of the UDF standard. I recommend you use the same UDF packet-writing software on the computers you use or use drives that support the Mount Rainier standard.
- Make sure the system has identified the media as CD-RW or DVD-RW. Eject and reinsert the media to force the drive to redetect it.
- Contact the packet-writing software vendor for a software update.
- Know that the disc might have been formatted with Windows XP's own limited CD-writing software (which uses the CDFS instead of UDF) instead of a UDF packet-writing program. Erase the disc with Windows XP after transferring any needed files from the media; then format it with your preferred UDF program.
- Contact the drive vendor for a firmware update. See "Updating the Firmware in an Optical Drive," later in this chapter.

PATA Optical Drive Runs Slowly

If your PATA drive performs poorly, consider the following items:

- Check the cache size in the Performance tab of the System Properties control panel in Windows XP. Select the quad-speed setting (largest cache size).
- Check to see whether the drive is set as the slave to your hard disk; move the drive to the secondary controller if possible.
- Make sure your PIO (Programmed I/O) or UDMA mode is set correctly for your drive in the BIOS. Check the drive specs and use autodetect in BIOS for the best results. (Refer to Chapter 5, "BIOS.")
- Check that you are using busmastering drivers on compatible systems; install the appropriate drivers for the motherboard's chipset and the OS in use. See the section "Direct Memory Access and Ultra-DMA," earlier in this chapter.
- With Windows 9x, open the System Properties control panel and select the Performance tab to see whether the system is using MS-DOS Compatibility Mode for CD-ROM drive. If all ATA drives are running in this mode, see www.microsoft.com and query on "MS-DOS Compatibility Mode" for a troubleshooter. If only the CD-ROM drive is in this mode, see whether you're using CD-ROM drivers in CONFIG.SYS and AUTOEXEC.BAT. Remove the lines containing references to the CD-ROM drivers (don't actually delete the lines but instead REM them), reboot the system, and verify that your CD-ROM drive still works and that it's running in 32-bit mode. Some older drives require at least the CONFIG.SYS driver to operate.

Problems Burning Discs Using Windows Built-In Recording

Windows XP's built-in CD-writing feature works only on drives that are listed in the Windows Hardware Compatibility List of supported drives and devices (www.microsoft.com/whdc/hcl/default.mspx). To install the latest updates for Windows XP, including updates to the CD-writing feature, use Windows Update. Microsoft Knowledgebase article 320174 discusses an update to the CD-writing feature. Search the Microsoft website for other solutions.

If you are using third-party writing applications, you may prefer to disable Windows' built-in writing feature. This feature is enabled or disabled with Windows Explorer. Open the drive's properties sheet Recording tab and clear the Enable CD/DVD Recording check box to disable recording, or click the empty box to enable recording.

If you have problems writing media or using your CD or DVD drive in Windows, see Microsoft Knowledgebase article 314060 for solutions.

Tip

If you are unable to create discs with Windows Vista and you have a USB flash memory drive connected to your computer, eject the flash drive and try the burn again.

Trouble Reading CD-RW Discs on CD-ROM

If you can't read CD-RW discs in your CD-ROM, try the following solutions:

- Check the vendor specifications to see whether your drive is MultiRead compliant. Some are not.
- If your drive is MultiRead compliant, try the CD-RW disc on a known-compliant CD-ROM drive (a drive with the MultiRead feature).

- Insert CD-RW media back into the original drive and check it for problems with the packet-writing software program's utilities.
- Insert CD-RW media back into the original drive and eject the media. Use the right-click Eject command in My Computer or Windows Explorer to properly close the media.
- Create a writable CD or DVD to transfer data to a computer that continues to have problems reading rewritable media.

Trouble Reading CD-R Discs on DVD Drive

If your DVD drive can't read a CD-R disc, check to see that the drive is MultiRead2 compliant because noncompliant DVDs can't read CD-R media. All current DVD drives support reading CD-R media.

Trouble Making Bootable Discs

If you are having problems creating a bootable disc, try these possible solutions:

- Check the contents of the bootable floppy disk from which you copied the boot image. To access the entire contents of a disc, a bootable floppy must contain CD-ROM drivers, AUTOEXEC.BAT, and CONFIG.SYS.
- Use the ISO 9660 format. Don't use the Joliet format because it is for long-filename CDs and can't boot.
- Check your system's BIOS for boot compliance and boot order; the optical drive should be listed first.

Trouble Reading BD Media or Viewing BD Movies

If you are having problems reading BD media, check the following:

- You must have a codec for BD (Blu-ray) media installed. These codecs are not included in Windows, but might be provided by BD drive vendors or by BD movie playback and creation programs.
- Clean the data side of your BD disc. See the next section, "Caring for Optical Media," for details.

If you are able to read BD media, but can't play back BD movies, check the following:

- Replace drivers for your BD drive and video card. In most cases, newer drivers are better. Note that sometimes you might need to use older drivers than those installed for better results.
- Switch to a different BD media playback program. Use a trial version if available before purchasing a different program to assure compatibility.

Caring for Optical Media

Some people believe that optical discs and drives are indestructible compared to their magnetic counterparts. Although optical discs are more reliable than the now-obsolete floppy disks, modern optical discs are far less reliable than modern hard drives. Reliability is the bane of any removable media, and optical discs are no exceptions.

By far the most common causes of problems with optical discs and drives are scratches, dirt, and other contamination. Small scratches or fingerprints on the bottom of the disc should not affect performance because the laser focuses on a point inside the actual disc, but dirt or deep scratches can interfere with reading a disc.

To remedy this type of problem, you can clean the recording surface of the disc with a soft cloth, but be careful not to scratch the surface in the process. The best technique is to wipe the disc in a radial fashion, using strokes that start from the center of the disc and emanate toward the outer edge. This way, any scratches will be perpendicular to the tracks rather than parallel to them, minimizing the interference they might cause. You can use any type of solution on the cloth to clean the disc, so long as it will not damage plastic. Most window cleaners are excellent at removing fingerprints and other dirt from the disc and don't damage the plastic surface.

If your disc has deep scratches, you can often buff or polish them out. A commercial plastic cleaner such as that sold in auto parts stores for cleaning plastic instrument cluster and tail-lamp lenses is good for removing these types of scratches. This type of plastic polish or cleaner has a mild abrasive that polishes scratches out of a plastic surface. Products labeled as cleaners usually are designed for more serious scratches, whereas those labeled as polishes are usually milder and work well as a final buff after using the cleaner. Try using the polish alone if the surface is not scratched deeply. You can use the SkipDR device made by Digital Innovations to make the polishing job easier.

Most people are careful about the bottom of the disc because that is where the laser reads, but at least for CDs, the top is actually more fragile! This is because the lacquer coating on top of a CD is thin, normally only 6–7 microns (0.24–0.28 thousandths of an inch). If you write on a CD with a ball point pen, for example, you will press through the lacquer layer and damage the reflective layer underneath, ruining the disc. Also, certain types of markers have solvents that can eat through the lacquer and damage the disc. You should write on discs only with felt tip pens that have compatible inks, such as the Sharpie and Staedtler Lumocolor brands, or other markers specifically sold for writing on discs, such as Maxell's DiscWriter pens. In any case, remember that scratches or dents on the top of the disc are more fatal than those on the bottom. It's also important to keep in mind that many household chemicals (and even certain beverages), if spilled on an optical disc, can damage the coating and cause the material to crack or flake off. This, of course, renders the media useless.

Read errors can also occur when dust accumulates on the read lens of your drive. You can try to clean out the drive and lens with a blast of "canned air" or by using a drive cleaner (which you can purchase at most stores that sell audio CDs).

If you are having problems reading media with an older drive and firmware upgrades are not available or did not solve the problem, consider replacing the drive. With new high-speed drives with read/write support available for well under $50, it does not make sense to spend any time messing with an older drive that is having problems. In almost every case, it is more cost-effective to upgrade to a new drive (which won't have these problems and will likely be much faster) instead.

If you have problems reading a particular brand or type of disk in some drives but not others, you might have a poor drive/media match. Use the media types and brands recommended by the drive vendor.

If you are having problems with only one particular disc and not the drive in general, you might find that your difficulties are in fact caused by a defective disc. See whether you can exchange the disc for another to determine whether that is indeed the cause.

Updating the Firmware in an Optical Drive

Just as updating the motherboard BIOS can solve compatibility problems with CPU and memory, support, USB ports, and system stability, upgrading the firmware in an optical drive can also solve problems with media compatibility, writing speed, and digital audio extraction from scratched discs, and it can even prevent potentially fatal mismatches between media and drives.

Determining Whether You Might Need a Firmware Update

If you encounter any of the following issues, a firmware update might be necessary:

- Your drive can't use a particular type of media, or it performs much more slowly with one type of media than other types/brands of media.
- Your drive can't play some types of burned discs or movies.
- Your writing software doesn't recognize the drive as a rewritable drive.
- You want to use faster media than what the drive was originally designed to use.
- Your BD drive can't play back some BD movies.

Because any firmware update runs a risk of failure and a failed firmware update can render your drive useless (I've seen it happen), you shouldn't install firmware updates casually. However, as the preceding examples indicate, in many cases an upgrade is recommended.

Because many rewritable drives have special characteristics, disc-burning programs may require updates to work. Get the update from the software vendor, or use the software provided with the drive.

Determining Which Drive Model and Firmware Are Installed

Before you can determine whether you need a firmware update for your rewritable drive, you need to know your drive model and which firmware version it's using. This is especially important if you use a drive that is an OEM product produced by a vendor other than the one that packaged the drive for resale.

To determine the firmware revision using the Windows Device Manager, follow this procedure:

1. Right-click My Computer and select Properties.
2. Click the Device Manager tab.
3. Click the plus sign (+) next to DVD/CD-ROM in the list of device types.
4. Double-click the rewritable drive icon to display its properties sheet.
5. With older Windows versions, click the Settings tab; the firmware version and drive name will be displayed.
6. On Windows XP or later, click the Details tab and select Hardware Ids. The firmware revision is usually displayed with several underscores on either side of it as part of the hardware IDs listed. For example, my Lite-On SHW-160P6S DVD drive uses firmware version PS0C, displayed as _______________PS0C_______________.

After you have this information, you can go to your rewritable drive vendor's website and see whether a firmware update is available and what the benefits of installing the latest version would be.

Installing New Drive Firmware

Generally speaking, the firmware update procedure works like this. (Be sure to follow the particular instructions given for your drive.)

1. If the firmware update is stored as a Zip file, you need to use an unzipping program or the integrated unzipping utility found in some versions of Windows to uncompress the update to a folder. Some vendors ship firmware updates as RAR files (RAR is a Linux compressed archive; it can be opened by many uncompression utilities for Windows).

2. If the drive maker provides a readme file, be sure to read it for help and troubleshooting. If the update file is an EXE file, it might display a readme file as part of step 3.
3. Double-click the EXE file to start the update process. Be sure to leave the system powered on during the process, which can take 2–3 minutes.
4. Follow the vendor's instructions for restarting your system.
5. After you restart your system, the computer might redetect the drive and assign it the next available drive letter. If the drive letter has changed, you can use the Computer Management service in Windows 2000 or later to reassign the correct drive letter to the drive.

Troubleshooting Firmware Updates

If you have problems performing a rewritable drive firmware update, check the vendor's readme file or website for help. In addition, here's a tip I've found useful: If the firmware update fails to complete, there might be interference from programs that control the drive, such as packet-writing programs (InCD, DirectCD) or the built-in Windows disc-writing feature. To disable resident software, restart the computer in Safe Mode and retry the update. Restart the system normally after the update is complete.

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