How CDs Work

By: Marshall Brain | Updated: May 12, 2021



Have you ever wonder how compact discs work? WILLIAM WHITEHURST / GETTY IMAGES

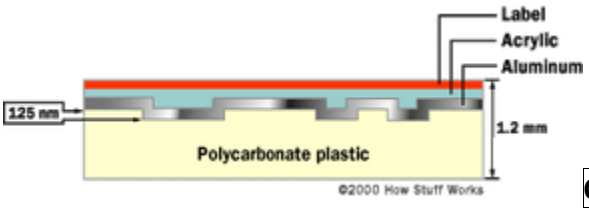
CDs and DVDs are everywhere these days. Whether they are used to hold music, data or computer software, they have become the standard medium for distributing large quantities of information in a reliable package. Compact discs are so easy and cheap to produce that America Online sends out millions of them every year to entice new users. And if you have a computer and CD-R drive, you can create your own CDs, including any information you want.

In this article, we will look at how CDs and CD drives work. We will also look at the different forms CDs take, as well as what the future holds for this technology.

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Understanding the CD: Material



Cross-section of a CD

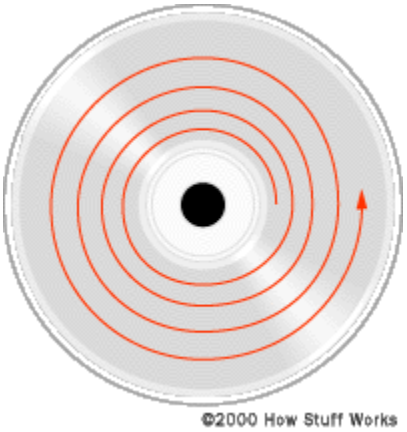
As discussed in How Analog and Digital Recording Works, a CD can store up to 74 minutes of music, so the total amount of digital data that must be stored on a CD is:

44,100 samples/channel/second x 2 bytes/sample x 2 channels x 74 minutes x 60 seconds/minute = 783,216,000 bytes

To fit more than 783 megabytes (MB) onto a disc only 4.8 inches (12 cm) in diameter requires that the individual bytes be very small. By examining the physical construction of a CD, you can begin to understand just how small these bytes are.

A CD is a fairly simple piece of plastic, about four one-hundredths (4/100) of an inch (1.2 mm) thick. Most of a CD consists of an **injection-molded piece of clear polycarbonate plastic**. During manufacturing, this plastic is impressed with microscopic bumps arranged as a single, continuous, extremely long spiral track of data. We'll return to the bumps in a moment. Once the clear piece of polycarbonate is formed, a thin, reflective aluminum layer is sputtered onto the disc, covering the bumps. Then a thin acrylic layer is sprayed over the aluminum to protect it. The label is then printed onto the acrylic. A cross section of a complete CD (not to scale) looks like this:

Understanding the CD: The Spiral



A CD has a single spiral track of data, circling from the inside of the disc to the outside. The fact that the spiral track starts at the center means that the CD can be smaller than 4.8 inches (12 cm) if desired, and in fact there are now plastic baseball cards and business cards that you can put in a CD player. CD business cards hold about 2 MB of data before the size and shape of the card cuts off the spiral.

What the picture on the right does not even begin to impress upon you is how incredibly small the data track is -- it is approximately 0.5 microns wide, with 1.6 microns separating one track from the next. (A micron is a millionth of a meter.) And the bumps are even more miniscule...

Understanding the CD: Bumps



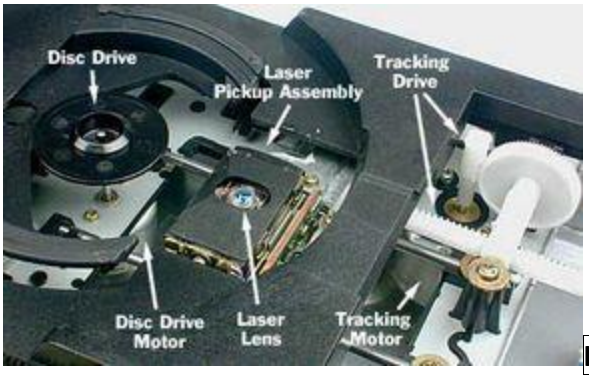
The elongated bumps that make up the track are each 0.5 microns wide, a minimum of 0.83 microns long and 125 nanometers high. (A nanometer is a billionth of a meter.) Looking through the polycarbonate layer at the bumps, they look something like this:

You will often read about "pits" on a CD instead of bumps. They appear as pits on the aluminum side, but on the side the laser reads from, they are bumps.

The incredibly small dimensions of the bumps make the spiral track on a CD extremely long. If you could lift the data track off a CD and stretch it out into a straight line, it would be 0.5 microns wide and almost 3.5 miles (5 km) long!

To read something this small you need an incredibly precise disc-reading mechanism. Let's take a look at that.

CD Player Components



Inside a CD player

The CD player has the job of finding and reading the data stored as bumps on the CD. Considering how small the bumps are, the CD player is an exceptionally precise piece of equipment. The drive consists of three fundamental components:

- A **drive motor** spins the disc. This drive motor is precisely controlled to rotate between 200 and 500 rpm depending on which track is being read.
- A **laser** and a **lens system** focus in on and read the bumps.
- A **tracking mechanism** moves the laser assembly so that the laser's beam can follow the spiral track. The tracking system has to be able to move the laser at micron resolutions.

What the CD Player Does: Laser Focus

Inside the CD player, there is a good bit of computer technology involved in forming the data into understandable data blocks and sending them either to the DAC (in the case of an audio CD) or to the computer (in the case of a CD-ROM drive).

The fundamental job of the CD player is to focus the laser on the track of bumps. The laser beam passes through the polycarbonate layer, reflects off the aluminum layer and hits an opto-electronic device that detects changes in light. The bumps reflect light differently than the "lands" (the rest of the aluminum layer), and the opto-electronic sensor detects that change in reflectivity. The electronics in the drive interpret the changes in reflectivity in order to read the bits that make up the bytes.

What the CD Player Does: Tracking

The hardest part is keeping the laser beam centered on the data track. This centering is the job of the **tracking system**. The tracking system, as it plays the CD, has to continually move the laser outward. As the laser moves outward from the center of the disc, the bumps move past the laser faster -- this happens because the linear, or tangential, speed of the bumps is equal to the radius times the speed at which the disc is revolving (rpm). Therefore, as the laser moves outward, the **spindle motor** must slow the speed of the CD. That way, the bumps travel past the laser at a constant speed, and the data comes off the disc at a constant rate.

CD Encoding Issues



Recordable CD

PHOTO COURTESY ERNEST VON ROSEN, AMGMEDIA

If you have a CD-R drive, and want to produce your own audio CDs or CD-ROMs, one of the great things you've got going in your favor is the fact that software can handle all the details for you. You can say to your software, "Please store these songs on this CD," or "Please store these data files on this CD-ROM," and the software will do the rest. Because of this, you don't need to know anything about CD data formatting to create your own CDs. However, CD data formatting is complex and interesting, so let's go into it anyway.

To understand how data are stored on a CD, you need to understand all of the different conditions the designers of the data encoding methodology were trying to handle. Here is a fairly complete list:

- Because the laser is tracking the spiral of data using the bumps, there cannot be extended gaps where there are no bumps in the data track. To solve this problem, data is encoded using EFM (eight-fourteen modulation). In EFM, 8-bit bytes are converted to 14 bits, and it is guaranteed by EFM that some of those bits will be 1s.
- Because the laser wants to be able to move between songs, data needs to be encoded into the music telling the drive "where it is" on the disc. This problem is solved using what is known as **subcode data**. Subcode data can encode the absolute and relative position of the laser in the track, and can also encode such things as song titles.
- Because the laser may misread a bump, there need to be **error-correcting codes** to handle single-bit errors. To solve this problem, extra data bits are added that allow the drive to detect single-bit errors and correct them.
- Because a scratch or a speck on the CD might cause a whole packet of bytes to be misread (known as a burst error), the drive needs to be able to recover from such an event. This problem is solved by actually **interleaving** the data on the disc, so that it is stored non-sequentially around one of the disc's circuits. The drive actually reads data one revolution at a time, and un-interleaves the data in order to play it.
- If a few bytes are misread in music, the worst thing that can happen is a little fuzz during playback. When data is stored on a CD, however, any data error is catastrophic. Therefore, additional error correction codes are used when storing data on a CD-ROM.

CD Data Formats

There are several different formats used to store data on a CD, some widely used and some long-forgotten. The two most common are **CD-DA** (audio) and **CD-ROM** (computer data).

Originally Published: Apr 1, 2000

How CD Burners Work

By: Tom Harris

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An external writable CD drive, also called a CD burner, lets you take music or data files from your computer and make your own CDs.

The advent of CD burners marked a huge cultural shift. The technology made it feasible for the average person to gather songs and make their own CDs. Suddenly, music-mix makers everywhere had their hands on the means of production.

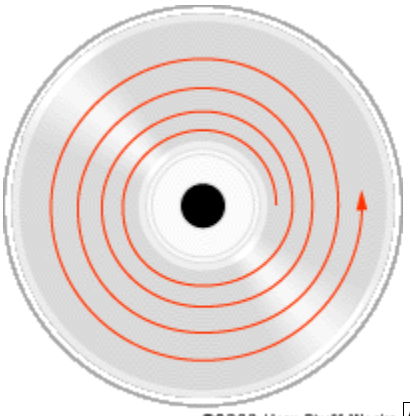
Today, writable CD drives (CD burners) are standard equipment in new PCs, and more and more audio enthusiasts are adding separate CD burners to their stereo systems. In less than five years, CDs have eclipsed cassette tapes as the mix medium of choice.

In this article, you'll find out how CD burners encode songs and other information onto blank discs. We'll also look at CD re-writable technology, see how the data files are put together and find out how you can make your own music mixes with a CD burner.

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CD Basics: The Bumps



A CD has a long, spiraled data track. If you were to unwind this track, it would extend out 3.5 miles (5 km).

If you've read How CDs Work, you understand the basic idea of CD technology. CDs store music and other files in **digital** form -- that is, the information on the disc is represented by a series of 1s and 0s (see How Analog and Digital Recording Works for more information). In conventional CDs, these 1s and 0s are represented by millions of tiny bumps and flat areas on the disc's reflective surface. The bumps and flats are arranged in a continuous track that measures about 0.5 microns (millionths of a meter) across and **3.5 miles** (5 km) long.

To read this information, the CD player passes a laser beam over the track. When the laser passes over a **flat** area in the track, the beam is reflected directly to an **optical sensor** on the laser assembly. The CD player interprets this as a **1**. When the beam passes over a **bump**, the light is bounced away from the optical sensor. The CD player recognizes this as a .

A CD player guides a small laser along the CD's data track.

In conventional CDs, the flat areas, or lands, reflect the light back to the laser assembly; the bumps deflect the light so it does not bounce back.

CD Basics: The Path

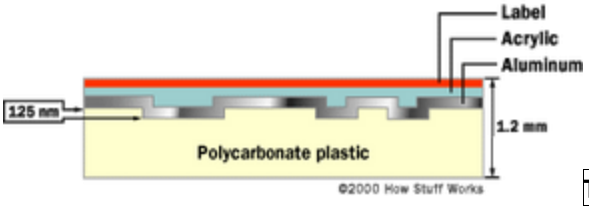
The bumps are arranged in a spiral path, starting at the center of the disc. The CD player spins the disc while the laser assembly moves **outward** from the center of the CD. At a steady speed, the bumps move past any point at the outer edge of the CD more rapidly than they move past any point nearer the CD's center. In order to keep the bumps moving past the laser at a **constant rate**, the player must slow the spinning speed of the disc as the laser assembly moves outward.

At its heart, this is all there is to a CD player. The execution of this idea is fairly complicated, because the pattern of the spiral must be encoded and read with incredible precision, but the basic process is pretty simple.

The CD player spins the disc while moving the laser assembly outward from the middle. To keep the laser scanning the data track at a constant speed, the player must slow the disc as the assembly moves outward.

In the next section, you'll find out how data is recorded on CDs, both by professional equipment and the home CD burner.

Reading CDs



The different layers of a conventional CD

In the last section, we saw that conventional CDs store digital data as a pattern of bumps and flat areas, arranged in a long spiral track. The CD fabrication machine uses a high-powered laser to etch the bump pattern into **photoresist** material coated onto a glass plate. Through an elaborate imprinting process, this pattern is pressed onto acrylic discs. The discs are then coated with **aluminum** (or another metal) to create the **readable** reflective surface. Finally, the disc is coated with a transparent **plastic layer** that **protects** the reflective metal from nicks, scratches and debris.

As you can see, this is a fairly complex, delicate operation, involving many steps and several different materials. Like most complex manufacturing processes (from newspaper printing to television

assembly), conventional CD manufacturing isn't practical for home use. It's only feasible for manufacturers who produce hundreds, thousands or millions of CD copies.

Consequently, conventional CDs have remained a "**read only**" storage medium for the average consumer, like LPs or conventional DVDs. To audiophiles accustomed to recordable cassettes, as well as computer users who were fed up with the limited memory capacity of floppy disks, this limitation seemed like a major drawback of CD technology. In the early '90s, more and more consumers and professionals were looking for a way to make their own CD-quality digital recordings.

Writing CDs

In response to this demand, electronics manufacturers introduced an alternative sort of CD that could be encoded in a few easy steps. **CD-recordable discs**, or **CD-Rs**, don't have any bumps or flat areas at all. Instead, they have a **smooth** reflective metal layer, which rests on top of a layer of **photosensitive dye**.

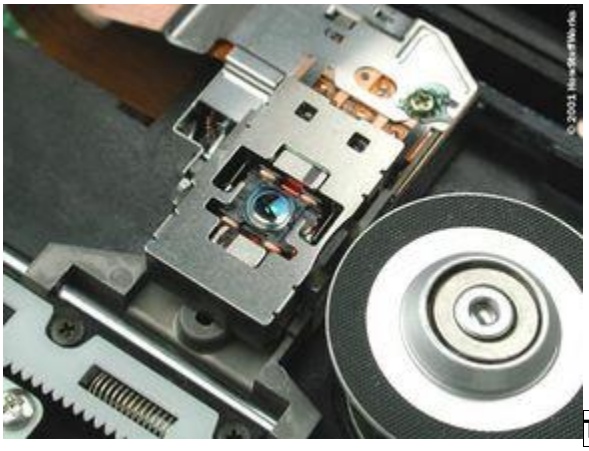
When the disc is blank, the dye is **translucent**: Light can shine through and reflect off the metal surface. But when you **heat** the dye layer with concentrated light of a particular frequency and intensity, the dye turns **opaque**: It darkens to the point that light can't pass through.

A CD-R doesn't have the same bumps and lands as a conventional CD. Instead, the disc has a dye layer underneath a smooth, reflective surface. On a blank CD-R disc, the dye layer is completely translucent, so all light reflects. The write laser darkens the spots where the bumps would be in a conventional CD, forming non-reflecting areas.

By selectively darkening particular points along the CD track, and leaving other areas of dye translucent, you can create a digital pattern that a standard CD player can read. The light from the player's laser beam will only bounce back to the sensor when the dye is left translucent, in the same way that it will only bounce back from the flat areas of a conventional CD. So, even though the CD-R disc doesn't have any bumps pressed into it at all, it behaves just like a standard disc.

A CD burner's job, of course, is to "burn" the digital pattern onto a blank CD. In the next section, we'll look inside a burner to see how it accomplishes this task.

Burning CDs: Laser Assembly



The laser assembly inside a CD burner

In the last section, we saw that CD burners darken microscopic areas of CD-R discs to record a digital pattern of reflective and non-reflective areas that can be read by a standard CD player. Since the data must be accurately encoded on such a small scale, the burning system must be extremely precise. Still, the basic process at work is quite simple.

The CD burner has a moving laser assembly, just like an ordinary CD player. But in addition to the standard "read laser," it has a "write laser." The **write laser** is more powerful than the read laser, so it interacts with the disc differently: It **alters the surface** instead of just bouncing light off it. Read lasers are not intense enough to darken the dye material, so simply playing a CD-R in a CD drive will not destroy any encoded information.

On the next page, you'll find out how this write laser operates.

Burning CDs: Write Laser



The machinery in a CD burner looks pretty much the same as the machinery in any CD player. There is a mechanism that spins the disc and another mechanism that slides the laser assembly.

The write laser moves in exactly the same way as the read laser: It moves outward while the disc spins. The bottom plastic layer has grooves pre-pressed into it, to guide the laser along the correct path. By

calibrating the rate of spin with the movement of the laser assembly, the burner keeps the laser running along the track at a constant rate of speed. To **record the data**, the burner simply turns the laser writer on and off in synch with the pattern of 1s and 0s. The laser **darkens the material to encode a 0** and leaves it **translucent to encode a 1**.

Most CD burners can create CDs at multiple speeds. At 1x speed, the CD spins at about the same rate as it does when the player is reading it. This means it would take you about 60 minutes to record 60 minutes of music. At 2x speed, it would take you about half an hour to record 60 minutes, and so on. For faster burning speeds, you need more advanced laser-control systems and a faster connection between the computer and the burner. You also need a blank disc that is designed to record information at this speed.

The main advantage of CD-R discs is that they work in almost all CD players and CD-ROMS, which are among the most prevalent media players today. In addition to this **wide compatibility**, CD-Rs are relatively **inexpensive**.

The main drawback of the format is that you can't reuse the discs. Once you've burned in the digital pattern, it can't be erased and re-written. In the mid '90s, electronics manufacturers introduced a new CD format that addressed this problem. In the next section, we'll look at these **CD-rewritable** discs, commonly called **CD-RWs**, to see how they differ from standard CD-R discs.

Erasing CDs

In the last section, we looked at the most prevalent writable CD technology, CD-R. CD-R discs hold a lot of data, work with most CD players and are fairly inexpensive. But unlike tapes, floppy disks and many other data-storage mediums, you cannot re-record on CD-R disc once you've filled it up.

CD-RW discs have taken the idea of writable CDs a step further, building in an **erase function** so you can record over old data you don't need anymore. These discs are based on **phase-change technology**. In CD-RW discs, the phase-change element is a chemical compound of silver, antimony, tellurium and indium. As with any physical material, you can change this compound's form by heating it to certain temperatures. When the compound is heated above its melting temperature (around 600 degrees Celsius), it becomes a liquid; at its **crystallization temperature** (around 200 degrees Celsius), it turns into a solid.

In a CD-RW disc, the reflecting lands and non-reflecting bumps of a conventional CD are represented by phase shifts in a special compound. When the compound is in a crystalline state, it is translucent, so light can shine through to the metal layer above and reflect back to the laser assembly. When the compound is melted into an amorphous state, it becomes opaque, making the area non-reflective.

Phase-change Compounds

In **phase-change compounds**, these shifts in form can be "locked into place": They persist even after the material cools down again. If you heat the compound in CD-RW discs to the melting temperature and let it cool rapidly, it will remain in a fluid, amorphous state, even though it is below the crystallization temperature. In order to crystallize the compound, you have to keep it at the crystallization temperature for a certain length of time so that it turns into a solid before it cools down again.

In the compound used in CD-RW discs, the crystalline form is translucent while the amorphous fluid form will absorb most light. On a new, blank CD, all of the material in the writable area is in the crystalline form, so light will shine through this layer to the reflective metal above and bounce back to the light sensor. To encode information on the disc, the CD burner uses its **write laser**, which is powerful enough to heat the compound to its melting temperature. These "melted" spots serve the same purpose as the bumps on a conventional CD and the opaque spots on a CD-R: They block the "read" laser so it won't reflect off the metal layer. Each **non-reflective area** indicates a 0 in the digital code. Every spot that remains crystalline is still **reflective**, indicating a 1.

The Erase Laser

As with CD-Rs, the **read laser** does not have enough power to change the state of the material in the recording layer -- it's a lot weaker than the write laser. The **erase laser** falls somewhere in between: While it isn't strong enough to melt the material, it does have the necessary intensity to heat the material to the crystallization point. By holding the material at this temperature, the erase laser restores the compound to its crystalline state, effectively erasing the encoded 0. This clears the disc so new data can be encoded.

CD-RW discs do not reflect as much light as older CD formats, so they cannot be read by most older CD players and CD-ROM drives. Some newer drives and players, including all CD-RW writers, can adjust the read laser to work with different CD formats. But since CD-RWs will not work on many CD players, these are not a good choice for music CDs. For the most part, they are used as **back-up storage devices** for computer files.

As we've seen, the reflective and non-reflective patterns on a CD are incredibly small, and they are burned and read very quickly with a speeding laser beam. In this system, the chances of a **data error** are fairly high. In the next section, we'll look at some of the ways that CD burners compensate for various encoding problems.

CD Formats



The Yamaha CDR-D651, a dual-tray stereo-component burner: With this burner, you take music tracks directly off of another CD, instead of from your hard drive. Burners like this are usually fast and accurate, but typically can only be used to create music CDs.

PHOTO COURTESY YAMAHA ELECTRONICS CORPORATION

In the previous sections, we looked at the basic idea of CD and CD-burner technology. Using precise lasers or metal molds, you can mark a pattern of more-reflective areas and less-reflective areas that represent a sequence of 1s and 0s. The system is so basic that you can encode just about any sort of digital information. There is no inherent limitation on what kind of mark pattern you put down on the disc.

But in order to make the information **accessible** to another CD drive (or player), it has to be encoded in an understandable form. The established form for music CDs, called **ISO 9660**, was the foundation for later CD formats. This format was specifically designed to **minimize the effect of data errors**.

This is accomplished by carefully arranging the recorded data and mixing it with a lot of extra digital information. On the next page, you'll learn about the extra information encoded on a burned CD.

Encoding Data

There are a number of important aspects involved in making a CD readable to a CD player:

- The CD track is marked with a sort of **timecode**, which tells the CD player what part of the disc it is reading at any particular time. Discs are also encoded with a **table of contents**, located at the beginning of the track (the center of the disc), which tells the player where particular songs (or files) are written onto the disc.
- The data track is broken up by extra **filler**, so there are no long strings of 1s or 0s. Without frequent shifts from 1 to 0, there would be large sections without a changing pattern of reflectivity. This could cause the read laser to "lose its place" on the disc. The filler data breaks up these large sections.
- Extra data bits are included to help the player recognize and fix a **mistake**. If the read laser misreads a single bit, the player is able to correct the problem using the additional encoded data.
- Recorded information is not encoded sequentially; it is **interlaced** in a set pattern. This reduces the risk of losing whole sections of data. If a scratch or piece of debris makes a part of the track unreadable, it will damage separate bits of data from different parts of the song or file, instead of eliminating an entire segment of information. Since only small pieces of each file segment are unreadable, it's easier for the CD player to correct the problem or recover from it.

The actual arrangement of information on music CDs is incredibly complex. And CD-ROMS -- compact discs that contain computer files rather than song tracks -- have even more extensive error-correction systems. This is because an error in a computer file could corrupt an entire program, while a small uncorrected error on a music CD only means a bit of fuzz or a skipping noise. If you are interested in the various ways that data is arranged on different types of CDs, check out Audio Compact Disc - Writing and Reading the Data.

With some writable CD formats, you have to **prepare** all of the information before you begin burning. This limitation is built into the original format of CDs as well as the physical design of the disc itself. After all, the long track forms one continuous, connected string of 1s and 0s, and it's difficult to break this up into separate sections. With newer disc formats, you can record files one "**packet**" at a time, adding the table of contents and other unifying structures once you've filled up the disc.

CD burners are an amazing piece of technology, and the inner workings are certainly fascinating. But to the typical computer user, the most compelling aspect of burners is what you can do with them. In the next section, we'll find out how you can put all of this technology to work and make your own music mix.

Trailer Track

CD-Rs and CD-RWs have a component that ordinary music CDs do not have -- an extra bit of track at the beginning of the CD, before **time zero** (00:00), which is the starting point recognized by CD players. This additional track space includes the **power memory area** (PMA) and the **power calibration area** (PCA). The PMA stores a temporary table of contents for the individual packets on a disc that has been only partially recorded. When you complete the disc, the burner uses this information to create the final table of contents.

The PCA is a sort of testing ground for the CD burner. In order to ensure that the write laser is set at the right level, the burner will make a series of **test marks** along the PCA section of track. The burner will then read over these marks, checking for the intensity of reflection in marked areas as compared to unmarked areas. Based on this information, the burner determines the optimum laser setting for writing onto the disc.

Read More

Creating Your Own CDs: Software

While CD-Rs can store all sorts of digital information, the most widespread application these days is making **music-mix CDs** with a computer. If you're new to the world of CD burners, this can seem like a daunting task. But it's actually very simple, once you have the right software and know the general procedure.

If you have already hooked up your CD burner, the first step in making a CD is loading the software you need. This music-management software serves several functions:

- It converts songs to the correct format for burning.
- It allows you to arrange the songs for your mix.
- It controls the encoding process for writing to the CD.

These days, most burners are packaged with one or more music programs, but you can also buy programs or download them over the Internet. You may need separate media applications to handle different elements in the process, but there are some good programs that handle everything (see below). Click here to do a search for software related to burning your own CDs.

Creating Your Own CDs: Music

When you have all of the software you need, it's time to gather some songs. You may want to take songs directly from your CD collection. To do this, you need to "**rip**" the songs -- copy them from your CD to your computer's hard drive. You'll need an extraction program to do this. To copy a particular track, insert the CD into your built-in CD-ROM drive (or the CD-burner itself) and select the song you want through the extraction program. Essentially, the program will play the song and **re-record** it into a usable data format. It's legal to make copies of songs you own, as long as the CD is only for your personal use.

You can also gather MP3s over the Internet. You can download MP3s from pay-for-music sites or with file-sharing programs. Some MP3s are free, and can be legally downloaded and copied onto a CD. Most are illegal copies, however, and it is a copyright violation to download them and burn them onto a CD. To search for MP3-related Web sites, click here.

MP3s are **compressed files**, and you must expand (**decode**) them in order to burn them onto a CD. Standard music-management programs can decode these files. If you don't have the right software, there are a number of decoding programs that you can download over the Internet.

Once you've gathered the songs, you can use your music manager to arrange them in the order you want. Keep in mind that you have a limited amount of disc space to work with. CD-Rs have varying **capacities**, measured in both megabytes and minutes. These days, most CD-Rs are either 74 minutes or 80 minutes long. Before you move on to burning your CD, you should make sure that your mix isn't too long for the blank disc.

Creating Your Own CDs: Burning

Once the mix is complete and you have saved it, all you need to do is insert a blank CD-R disc into the burner and choose the "burn" or "write" option in your music-management software. Be sure to select "**music CD**" rather than "data CD," or you won't be able to play the disc on ordinary CD players. You'll also need to choose the **speed** at which you want to burn the disc. Typically, a **slower** speed reduces the chance of a major error during the writing process.

A lot of things can go wrong when you're burning a CD, so don't be surprised if some of them don't come out right. Since CD-Rs can not be overwritten, any irreversible mistake means you'll have to junk the

whole disc. Among the CD-burning set, this is called "**making a coaster**," as that's pretty much all you can do with the damaged CD.

If you continually have problems burning CDs, your drive may be defective or your music-management program may be faulty. Before you return your burner, try out some other programs and see if they yield better results.

To make a **CD-ROM**, you'll go through a similar process -- but you'll code the disc as a **data CD**, not a music CD. Some newer CD players and DVD players can read untranslated MP3 data files, and you may be able to make CD-ROM music mixes this way. Since MP3s are compressed files, you can fit a lot more of them on a single disc, which means you can make a longer mix. The drawback, of course, is that your disc won't work in the vast majority of CD players.

CD burners have opened up a whole new world to the average computer user. You can record music that will run in most anybody's CD player, or you can put together CD-ROMs containing photos, Web pages or movies. With a piece of equipment about the size of a car stereo, and about the price of a cheap bicycle, you can set up your own multimedia production company!

For more information on CD burners and related topics, check out the links on the next page.

Frequently Answered Questions

What do you mean by CD burning?

CD burning is the process of copy music, pictures, and videos from your PC to a blank CD or DVD.

Is CD burning legal?

It is legal to burn CDs for personal use. However, it is illegal to copy and distribute copyrighted material without permission from the copyright holder.

Why do we burn CD?

CDs are burned in order to store data or music on them.

Lots More Information