How CD Burners Work

by Tom Harris

In 2000, one of the biggest news stories was the rise of Napster and similar file-sharing programs. With these programs, you could get an MP3 version of just about any song you want without shelling out a dime. The record companies were fairly upset over this turn of events, and understandably so: They weren't making any money off the distribution of their product to millions of people.

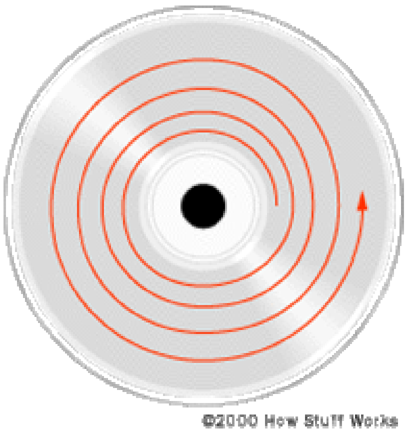
An external writable CD drive, also called a CD burner: With this type of drive, you can take music or data files from your computer and make your own CDs.

But there was money to be made on the "Napster revolution," as electronics manufacturers and retailers soon discovered. In 1999, 2000 and early 2001, sales of CD burners and blank CD-Recordable discs skyrocketed. Suddenly it was feasible for the average person to gather songs and make their own CDs, and music-mix makers everywhere wanted to get 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.

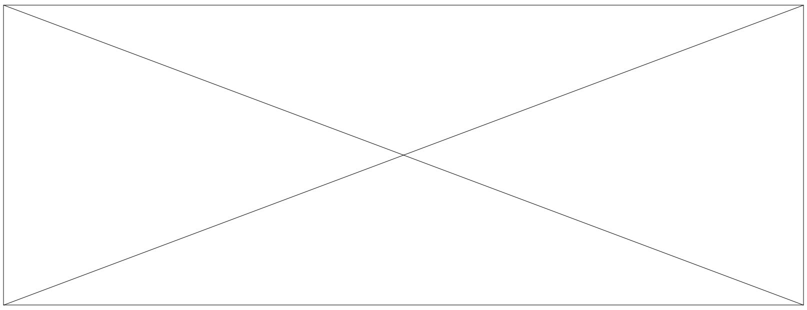
CD Basics

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.



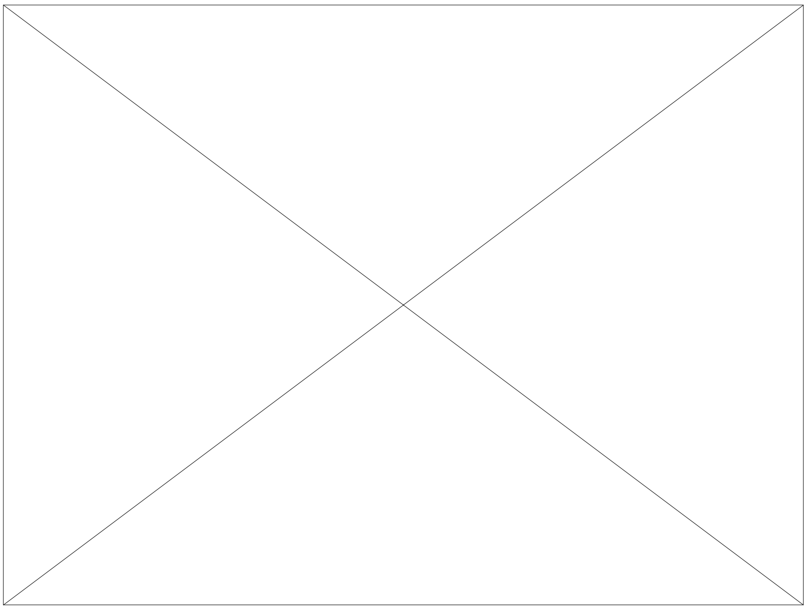
A CD has a long, spiraled data track. If you were to unwind this track, it would extend out 3.5 miles (5 km).

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 **0**.



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.

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.



The CD player spins the disc while moving the laser assembly outward from the middle. To

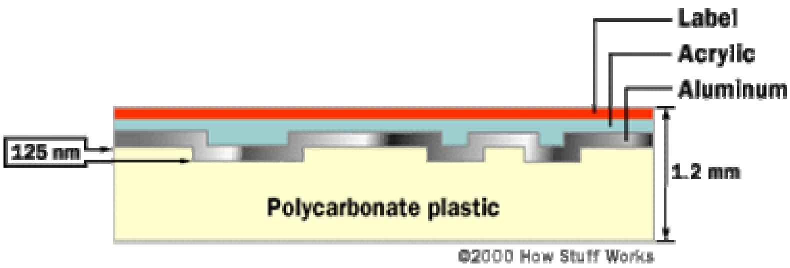
keep the laser scanning the data track at a constant speed, the player must slow the disc as the assembly moves outward.

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.

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

Reading & Writing CDs

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.



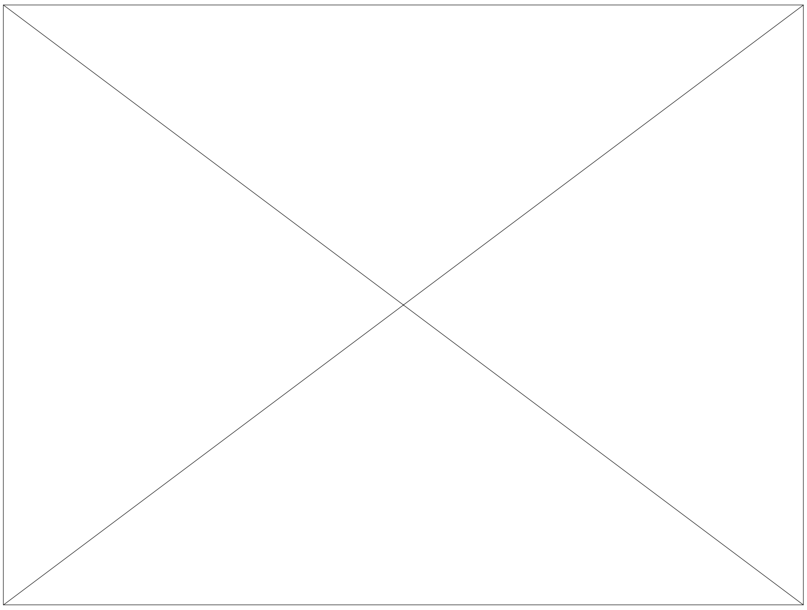
The different layers of a conventional CD

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.

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.

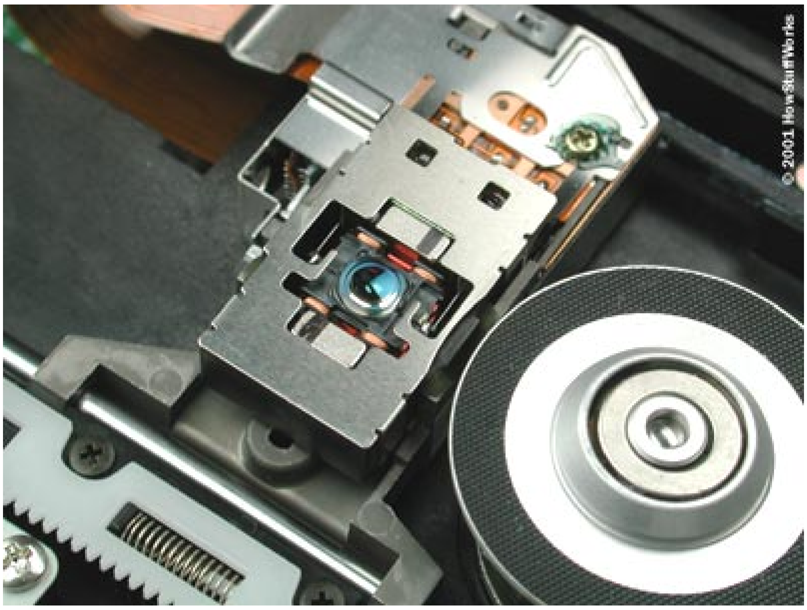
By selectively darkening particular points along the CD track, and leaving other areas of dye translucent, you can create a digital pattern that a standard CD player can read. The light from the player's laser beam will only bounce back to the sensor when the dye is left translucent, in the same way 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

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.



The laser assembly inside a CD burner

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**.

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.

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.

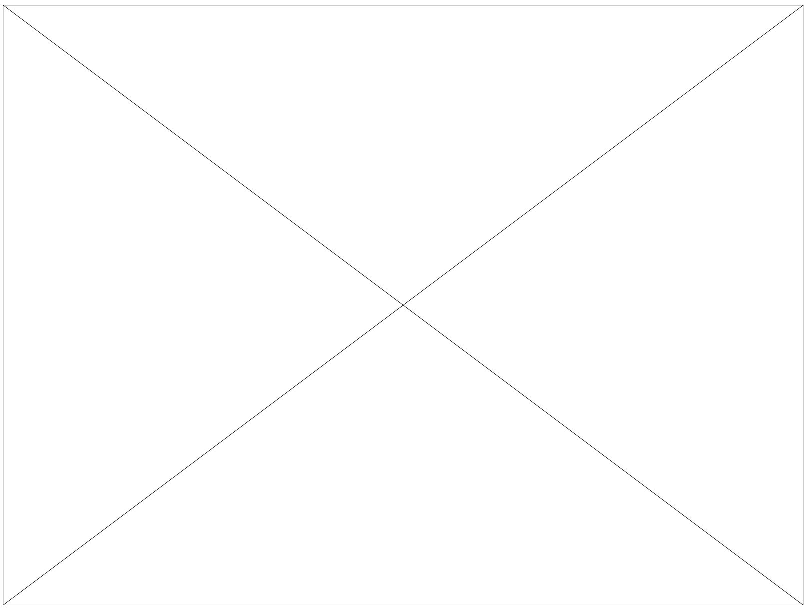
The main advantage of CD-R discs is that they work in almost all CD players and CD-ROMS, which are among the most prevalent media players today. In addition to this **wide compatibility**, CD-Rs are relatively **inexpensive**.

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.

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.

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

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**.

Photo courtesy Yamaha Electronics Corporation

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.

This is accomplished by carefully arranging the recorded data and mixing it with a lot of extra digital information. There are a number of important aspects involved in this system:

- 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.

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.

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.

Creating Your Own CDs

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).

Music Management Programs

MP3 Decoding

- Winamp
- Media Jukebox
- Easy CD Creator Deluxe
- MusicMatch Jukebox
- Real Jukebox
- CoolPlayer

Playlist Organization

- MusicMatch Jukebox
- Real Jukebox
- CoolPlayer
- PCDJ
- Collectorz.com MP3 Collector

CD Ripping

- Nero Burning ROM
- MusicMatch Jukebox
- Easy CD Creator Deluxe
- Audiograbber

CD Burning

- Nero Burning ROM
- Roxio Easy CD Creator 5 Platinum
- Toast 5 Titanium
- Gear Pro 5.02

Multi-Function Software

- MusicMatch Jukebox
- Winamp
- Real Jukebox

- Media Jukebox

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 sites like MP3.com or with file-sharing programs like Gnutella. 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.

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.

MP3 Sites

Legal Sites

- MP3.com
- RollingStone.com
- EMusic.com
- Amazon.com: Free Music Downloads

Quasi-Legal Sites
(legality yet to be determined)

- KazaA
- Audio Galaxy
- Vitaminic
- Morpheus
- WinMX
- XoloX

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.

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!