Normal music CDs and CD-ROMs are made from pre-pressed discs and encased in plastic. The actual data is stored through pits, or tiny indentations, on the silver surface of the internal disc. To read the disc, the CD-ROM shines a laser onto the surface, and by interpreting the way in which the laser light is reflected from the disc it can tell whether the area under the laser is indented or not.

Thanks to sophisticated laser focusing and error detection routines, this process is pretty much ideal. However, thereís no way the laser can change the indentations of the silver disc, which in turn means thereís no way of writing new data to the disc once its been created. Thus, the technological developments to enable CD-ROMs to be written or rewritten to have necessitated changes to the disc media as well as to the read/write mechanisms in the associated CD-R and CD-RW drives.

At the start of 1997 it appeared likely that CD-R and CD-RW drives would be superseded by DVD technology almost before they had got off the ground. In the event, during that year DVD Forum members turned on each other triggering a DVD standards war and delaying product shipment. Consequently, the writable and rewritable CD formats were given a new lease of life.

For professional users, developers, small businesses, presenters, multimedia designers and home recording artists the recordable CD formats offer a range of powerful storage applications. Their big advantage over alternative removable storage technologies such as MO, LIMDOW and PD is that of CD media compatibility; CD-R and CD-RW drives can read nearly all the existing flavours of CD-ROMs and discs made by CD-R and CD-RW devices can be read on both (MultiRead-capable) CD-ROM drives and current and all future generations of DVD-ROM drive. A further advantage, itself a consequence of their wide compatibility, is the low cost of media; CD-RW media is cheap and CD-R media even cheaper. Their principal disadvantage is that there are limitations to their rewriteability; CD-R, of course, isn't rewritable at all and until recently CD-RW discs had to be reformatted to recover the space taken by 'deleted' files when a disc becomes full, unlike the competing technologies which all offer true drag-and-drop functionality with no such limitation. Even now, however, CD-RW rewriteability is less than perfect, resulting in a reduction of a CD-RW disc's storage capacity

Formats

ISO 9660 is a data format designed by the International Standards Organisation in 1984. It's the accepted cross-platform protocol for filenames and directory structures. Filenames are restricted to uppercase letters, the digits '0' to '9' and the underscore character, '_'. Nothing else is allowed. Directory names can be a maximum of only eight characters (with no extension) and can only be eight sub-directories deep. The standard can be ignored under Windows 95 - but older CD-ROM drives may not be able to handle the resulting 'non-standard' discs.

Every CD has a table of contents (TOC) which carries track information. Orange Book solves the problems of writing CDs, where subsequent recording sessions on the same disc require their own update TOC. Part of the appeal of Kodakís Photo-CD format is that its not necessary to fill the disc with images on the first go: more images can be added at later until the disc is full. The information on a Photo-CD is Yellow Book CD-ROM format and consequently readable on any ëmulti-session compatibleí drive.

However, the ISO 9660 file format used by CD and CD-R discs and the original disc or session-at-a-time standards didn't lend themselves to adding data in small increments. Writing multiple sessions to a disc results in about 13Mb of disc space being wasted for every session, and the original standard limits the number of tracks that can be put on a disc to 99. These limitations were subsequently addressed by the OSTAís (Optical Storage Technology Association) ISO 13346 Universal Disc Format (UDF) standard. This operating-system independent standard for storing data on optical media, including CD-R, CD-RW and DVD devices, uses a redesigned directory structure which allows a drive to be written to efficiently a file (or 'packet') at a time.

CDs measure 12cm in diameter with a 15mm diameter centre hole.

The audio or computer data is stored from radius 25mm (after the lead-in) to radius 58mm maximum where the lead-out starts. The Orange Book CD-R standard basically splits the CD into two areas: the System Use Area (SUA) and the Information Area. While the latter is a general storage space, the SUA acts much like the boot sector of a hard disk, taking up the first 4mm of the CD's surface. It tells the reader device what kind of information to expect and what format the data will be in, and is itself divided into two parts: the Power Calibration Area (PCA) and the Program Memory Area (PMA):

On every disc, the PCA acts as a testing ground for a CD-recorder's laser. Every time a disc is inserted into a CD-R drive, the laser is fired at the surface of the PCA to judge the optimum power setting for burning the CD. Various things can influence this optimum setting - the recording speed, humidity, ambient temperature and the type of disc being used. Every time a disc is calibrated, a bit is set to '1' in a counting area, and only a maximum of 99 calibrations are allowed per disc.

Meanwhile, in the PMA, data is stored to record up to 99 track numbers and their start and stop times (for music), or sector addresses for the start of data files on a data CD.

The Information Area, the area of the disc which contains data, is divided into three areas:

The Lead-in contains digital silence in the main channel plus the Table of Contents (TOC) in the subcode Q-channel. It allows the laser pickup head to follow the pits and synchronise to the audio or computer data before the start of the program area. The length of the lead-in is determined by the need to store the Table of Contents for up to 99 tracks

The Program Area contains up to about 76 minutes of data divided into 99 tracks maximum. The actual bits and bytes on a CD are not stored as might be expected. On traditional media, eight bits form a byte, which in turn forms the standard unit of data. On a CD, a mathematical process called Eight To Fourteen Modulation (EFM) encodes each 8-bit symbol as 14 bits plus 3 merging bits. The EFM data is then used to define the pits on the disc. The merging bits ensure that pit and land lengths are not less than 3 and no more than 11 channel bits, thereby reducing the effect of jitter and other distortions. This is just the first step in a complex procedure involving error correction, merge bits, frames, sectors and logical segments which converts the peaks and troughs on the CD into machine-readable data.

The Lead-out, containing digital silence or zero data. This defines the end of the CD program area.

In addition to the main data channel, a CD disc has 8 subcode channels, designated 'P' to' W', interleaved with the main channel and available for use by CD audio and CD-ROM players. When the CD was first developed, the subcode was included as a means of placing control data on the disc, with use of the main channel being restricted to audio or CD-ROM data; the P-channel indicates the start and end of each track, the Q-channel contains the timecodes (minutes, seconds and frames), the TOC (in the lead-in), track type and catalogue number; and channels R to W are generally used for CD graphics. As the technology has evolved, the main channel has in fact been used for a number of other data types and the new DVD specification omits the CD subcode channels entirely.

CD-R

Write Once/Read Many storage (WORM) has been around since the late 1980s, and is a type of optical drive that can be written to and read from. When data is written to a WORM drive, physical marks are made on the media surface by a low-powered laser and since these marks are permanent, they cannot be erased, hence write once.

The characteristics of a recordable CD were specifie in the Orange Book II standard in 1990 and Philips was first to market with a CD-R product in mid-1993. It uses the same technology as WORM, changing the reflectivity of the organic dye layer which replaces the sheet of reflective aluminium in a normal CD disc. In its early days, cyanine dye and its metal-stabilised derivatives were the de facto standard for CD-R media. Indeed, the Orange Book, Part II, referred to the recording characteristics of cyanine-based dyes in establishing CD-Recordable standards. Phthalocyanine dye is a newer dye that appears to be less sensitive to degradation from ordinary light such as ultraviolet (UV), fluorescence and sunshine. Azo dye has been used in other optical recording media and is now also being used in CD-R. These dyes are photosensitive organic compounds, similar to those used in making photographs. The media manufacturers use these different dyes in combination with dye thickness, reflectivity thickness and material and groove structure to fine tune their recording characteristics for a wide range of recording speeds, recording power and media longevity. To recreate some of the properties of the aluminium used in standard CDs and to protect the dye, a microscopic reflective layer - either a proprietary silvery alloy or 24-carat gold - is coated over the dye. The use of noble metal reflectors eliminates the risk of corrosion and oxidation. The CD-R media manufacturers have performed extensive media longevity studies using industry defined tests and mathematical modelling techniques, with results claiming longevity from 70 years to over 200 years. Typically, however, they will claim an estimated shelf life of between 5 and 10 years.

The colour of the CD-R disc is related to the colour of the specific dye that was used in the recording layer. This base dye colour is modified when the reflective coating (gold or silver) is added. Some of the dye-reflective coating combinations appear green, some appear blue and others appear yellow. For ,example, gold/green discs combine a gold reflective layer with a cyan-coloured dye, resulting in a gold appearance on the label side and a green appearance on the writing side. Taiyo Yuden produced the original cyanine dye-based gold/green CDs, which were used during the development of the Orange Book standard. Mitsui Toatsu Chemicals invented the process for gold/gold CDs. Silver/blue CD-Rs, mmanufactured with a process patented by Verbatim, first became widely available in 1996. Ricoh's silver/silver 'Platinum' discs, based on 'advanced phthalocyanine dye', appeared on the market in mmid-1998.

The disc has a spiral track which is preformed during manufacture, onto which data is written during the recording process. This ensures that the recorder follows the same spiral pattern as a conventional CD, and has the same width of 0.6mm and pitch of 1.6mm as a conventional disc. Discs are written from the inside of the disc outward. The spiral track makes 22,188 revolutions around the CD, with roughly 600 track revolutions per millimetre.

Instead of mechanically pressing a CD with indentations, a CD-R writes data to a disc by using it's laser to physically burn pits into the organic dye. When heated beyond a critical temperature, the area ëburnedí becomes opaque (or absorptive) through a chemical reaction to the heat and subsequently reflects less light than areas that have not been heated by the laser. This system is designed to mimic the way light reflects cleanly off a ëlandí on a normal CD, but is scattered by a ëpití, so a CD-R discís data is represented by burned and non-burned areas, in a similar manner to how data on a normal CD is represented by its pits and lands. Consequently, a CD-R disc can generally be used in a normal CD player as if it were a normal CD.

However, CD-R is not strictly WORM. Whilst, like WORM, it is not possible to erase data - once a location on the CD-R disc has been written to, the colour change is permanent - CD-R allows multiple write sessions to different areas of the disc. The only problem here is that only multi-session compatible CD-ROM drives can read subsequent sessions; anything recorded after the first session will be invisible to older drives.

CD-Recorders have seen a dramatic drop in price and rise in specification since the mid-1990s. By mid-1998 drives were capable of writing at quad-speed and reading at twelve-speed (denoted as ë4X/12Xí) and were bundled with much improved CD mastering software. By the end of 1999 CD-R drive performance had doubled to 8X/24X, by which time the trend was away from pure CD-R drives and towards their more versatile CD-RW counterparts. The faster the writing speed the more susceptible a CD-R writer is to buffer underruns - the most serious of all CD recording errors. To reduce the chances of underruns CD writers are generally fitted with caches which can range from between 256KB to 2MB in size. Faster devices also allow the write process to be slowed down to two-speed or even single speed. This is particularly useful in avoiding underruns when copying poor quality CD-ROMs.

With prices down to a similar level of that of a high-speed CD-ROM drive, CD-R had finally became viable as a storage or back-up device. Indeed, it offers a number of advantages over alternative technologies.

CD-Rs generally come in 63- or 74-minute formats holding up to 550MB or 650MB of data respectively and provide a cheap bulk storage medium, working out at about 1p per megabyte. Furthermore, the ubiquity of CD-ROM drives means that discs will be readable on many PCs, a fact that also makes CD-R an excellent medium for transferring large files. Unlike tape, CD-R is a random-access device, which makes it fast to get at archive material and discs are also more durable than tape cartridges and canít be wiped by coming into contact with, say a magnetic field. Finally, just about any form of data can be stored on a CD-ROM, it being possible to mix video, Photo-CD images, graphics, sound and conventional data on a single disc.

The CD-R format has not been free of compatibility issues however. Unlike ordinary CDs, the reflective surface of a CD-R (CD-Recordable) is made to exactly match the 780nm laser of an ordinary CD-ROM drive. Put a CD-R in a first generation DVD-ROM drive and it wonít reflect enough 650nm light for the drive to read the data. Subsequent, dual-wavelength head devices solved this problem. Also, some CD-ROM drives' lasers, especially older ones, may not be calibrated to read recordable CDs.

However, CD-R's real disadvantage is that the writing process is permanent. The media can't be erased and written to again. Only by leaving a session 'open' - that is, not recording on the entire CD and running the risk of it not playing on all players - can data be incrementally added to a disc. This, of course, is not the most ideal of backup solutions and wastes resources. Consequently, after months of research and development, Philips and Sony announced another standard of CD: the CD-Rewritable (CD-RW).