

# APPENDIX J

## DISK STORAGE DEVICES

**William Stallings**

Copyright 2014

### J.1 MAGNETIC DISK

- Data Organization and Formatting
- Physical Characteristics

### J.2 OPTICAL MEMORY

- CD-ROM
- CD Recordable
- CD Rewritable
- Digital Versatile Disk
- High-Definition Optical Disks

Supplement to  
Operating Systems, Eighth Edition  
Pearson 2014  
<http://williamstallings.com/OperatingSystems/>

## J.1 MAGNETIC DISK

A disk is a circular platter constructed of metal or of plastic coated with a magnetizable material. Data are recorded on and later retrieved from the disk via a conducting coil named the **head**. During a read or write operation, the head is stationary while the platter rotates beneath it.

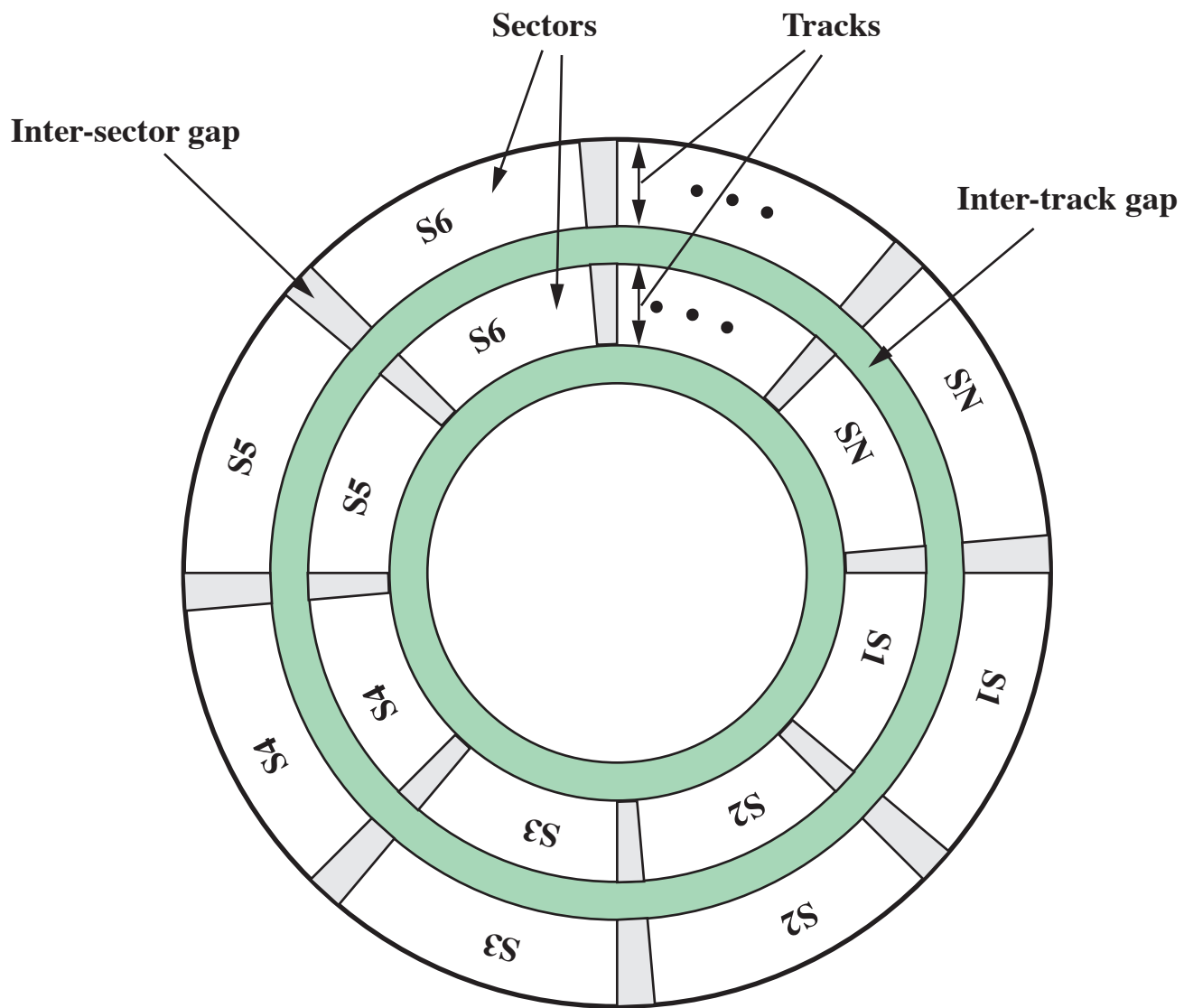
The write mechanism is based on the fact that electricity flowing through a coil produces a magnetic field. Electric pulses are sent to the head, and magnetic patterns are recorded on the surface below, with different patterns for positive and negative currents. The read mechanism is based on the fact that a magnetic field moving relative to a coil produces an electrical current in the coil. When the surface of the disk passes under the head, it generates a current of the same polarity as the one already recorded.

### Data Organization and Formatting

The head is a relatively small device capable of reading from or writing to a portion of the platter rotating beneath it. This gives rise to the organization of data on the platter in a concentric set of rings, called **tracks**. Each track is the same width as the head. There are thousands of tracks per surface.

Figure J.1 depicts this data layout. Adjacent tracks are separated by **gaps**. This prevents, or at least minimizes, errors due to misalignment of the head or simply interference of magnetic fields.

Data are transferred to and from the disk in **sectors** (Figure J.1). There are typically hundreds of sectors per track, and these may be of either fixed or variable length. In most contemporary systems, fixed-length sectors are used, with 512 bytes being the nearly universal sector size. To avoid

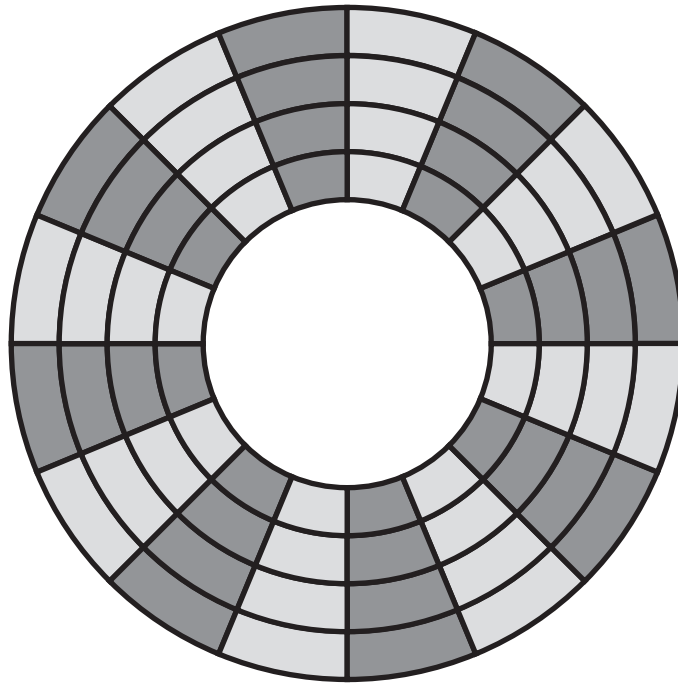


**Figure J.1 Disk Data Layout**

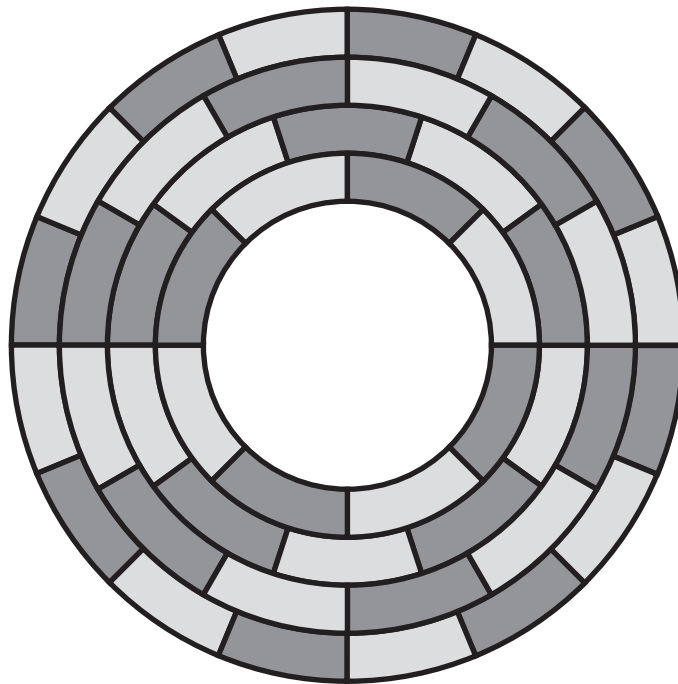
imposing unreasonable precision requirements on the system, adjacent sectors are separated by intratrack (intersector) gaps.

A bit near the center of a rotating disk travels past a fixed point (such as a read-write head) slower than a bit on the outside. Therefore, some way must be found to compensate for the variation in speed so that the head can read all the bits at the same rate. This can be done by increasing the spacing between bits of information recorded in segments of the disk. The information can then be scanned at the same rate by rotating the disk at a fixed speed, known as the **constant angular velocity (CAV)**. Figure J.2a shows the layout of a disk using CAV. The disk is divided into a number of pie-shaped sectors and into a series of concentric tracks. The advantage of using CAV is that individual blocks of data can be directly addressed by track and sector. To move the head from its current location to a specific address, it only takes a short movement of the head to a specific track and a short wait for the proper sector to spin under the head. The disadvantage of CAV is that the amount of data that can be stored on the long outer tracks is the same as what can be stored on the short inner tracks.

Because the **density**, in bits per linear inch, increases in moving from the outermost track to the innermost track, disk storage capacity in a straightforward CAV system is limited by the maximum recording density that can be achieved on the innermost track. To increase density, modern hard disk systems use a technique known as **multiple zone recording**, in which the surface is divided into a number of concentric zones (16 is typical). Within a zone, the number of bits per track is constant. Zones farther from the center contain more bits (more sectors) than zones closer to the center. This allows for greater overall storage capacity at the expense of somewhat more complex circuitry. As the disk head moves from one zone to another, the length (along the track) of individual bits changes, causing a change in the timing for reads and writes. Figure J.2b suggests the nature of



**(a) Constant angular velocity**



**(b) Multiple zoned recording**

**Figure J.2 Comparison of Disk Layout Methods**

multiple zone recording; in this illustration, each zone is only a single track wide.

Some means is needed to locate sector positions within a track. Clearly, there must be some starting point on the track and a way of identifying the start and end of each sector. These requirements are handled by means of control data recorded on the disk. Thus, the disk is formatted with some extra data used only by the disk drive and not accessible to the user.

## Physical Characteristics

Table J.1 lists the major characteristics that differentiate among the various types of magnetic disks. First, the head may either be fixed or movable with respect to the radial direction of the platter. In a **fixed-head disk**, there is one read/write head per track. All of the heads are mounted on a rigid arm that extends across all tracks; such systems are rare today. In a **movable-head disk**, there is only one read/write head. Again, the head is mounted on an arm. Because the head must be able to be positioned above any track, the arm can be extended or retracted for this purpose.

**Table J.1 Physical Characteristics of Disk Systems**

<b>Head Motion</b> Fixed head (one per track) Movable head (one per surface)	<b>Platters</b> Single platter Multiple platter
<b>Disk Portability</b> Nonremovable disk Removable disk	<b>Head Mechanism</b> Contact (floppy) Fixed gap Aerodynamic gap (Winchester)
<b>Sides</b> Single sided Double sided	

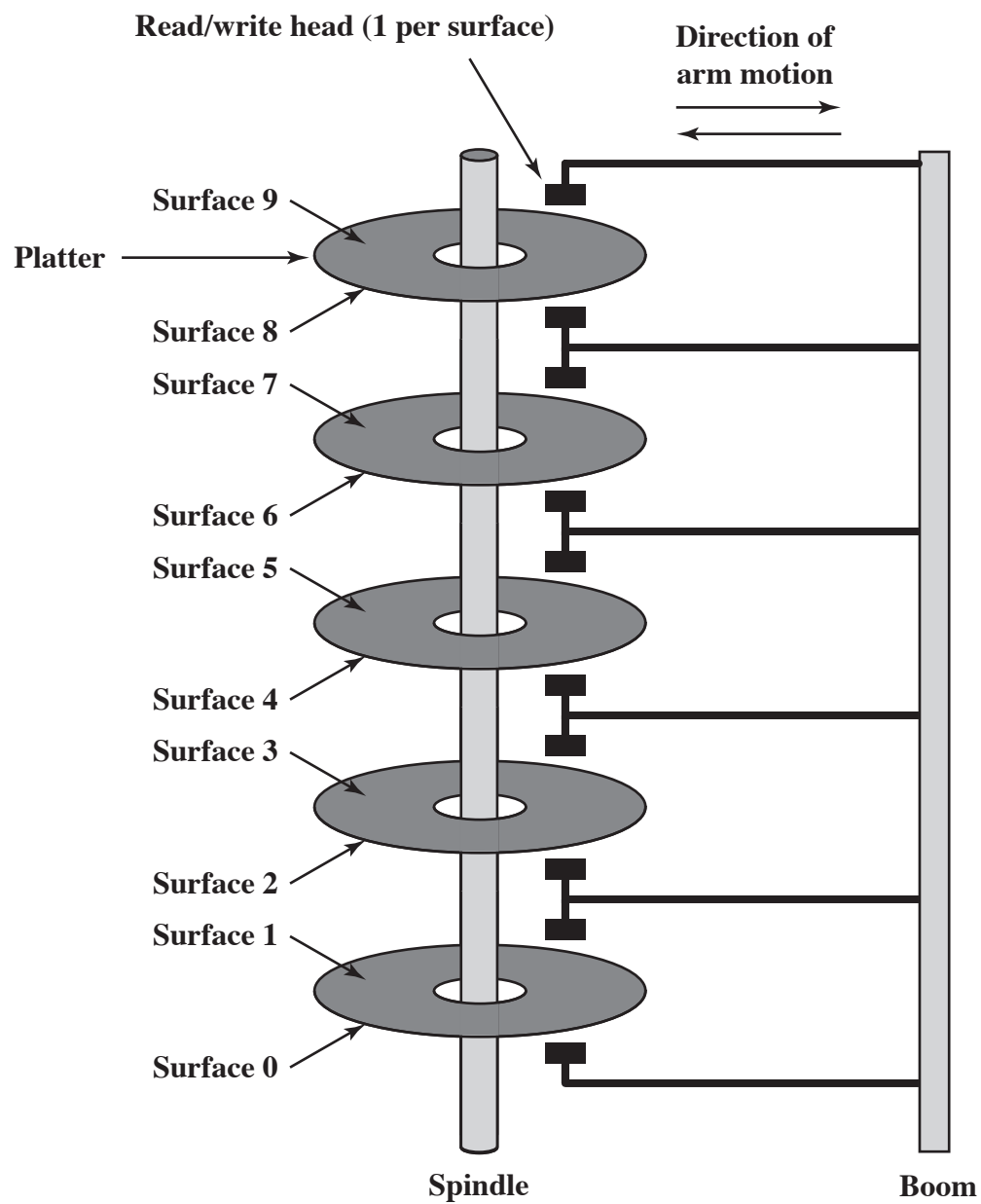
The disk itself is mounted in a disk drive, which consists of the arm, a spindle that rotates the disk, and the electronics needed for input and output of binary data. A **nonremovable disk** is permanently mounted in the disk drive; the hard disk in a personal computer is a nonremovable disk. A **removable disk** can be removed and replaced with another disk. The advantage of the latter type is that unlimited amounts of data are available with a limited number of disk systems. Furthermore, such a disk may be moved from one computer system to another. Floppy disks and ZIP cartridge disks are examples of removable disks.

For most disks, the magnetizable coating is applied to both sides of the platter, which is then referred to as **double sided**. Some less expensive disk systems use **single-sided** disks.

Some disk drives accommodate **multiple platters** stacked vertically a fraction of an inch apart. Multiple arms are provided (Figure J.3). Multiple-platter disks employ a movable head, with one read-write head per platter surface. All of the heads are mechanically fixed so that all are at the same distance from the center of the disk and move together. Thus, at any time, all of the heads are positioned over tracks that are of equal distance from the center of the disk. The set of all the tracks in the same relative position on the platter is referred to as a **cylinder**. For example, all of the shaded tracks in Figure J.4 are part of one cylinder.

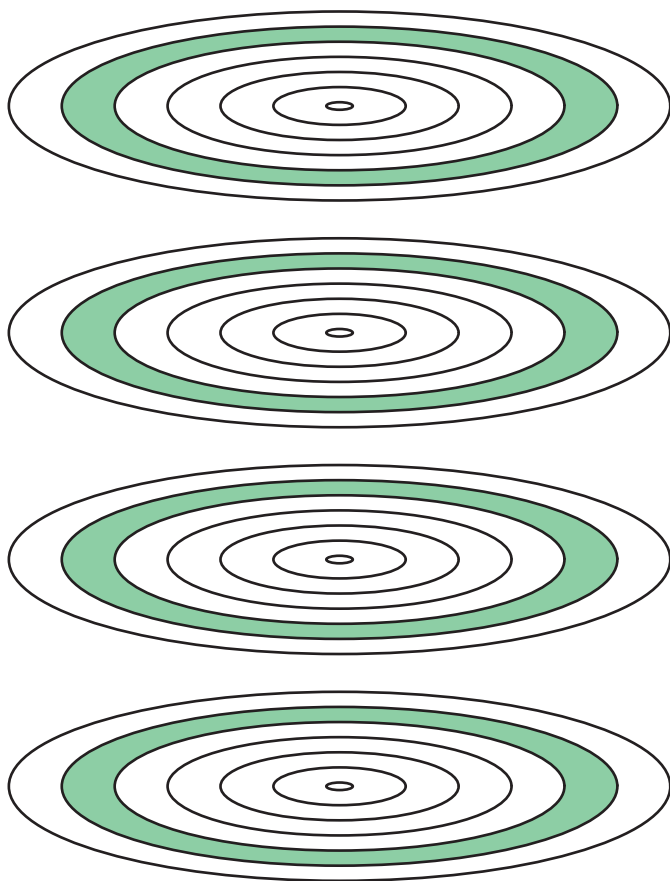
Finally, the head mechanism provides a classification of disks into three types. Traditionally, the read/write head has been positioned at a fixed distance above the platter, allowing an air gap. At the other extreme is a head mechanism that actually comes into physical contact with the medium during a read or write operation. This mechanism is used with the **floppy disk**, which is a small, flexible platter and the least expensive type of disk.

To understand the third type of disk, we need to comment on the relationship between data density and the size of the air gap. The head must



**Figure J.3 Components of a Disk Drive**





**Figure J.4 Tracks and Cylinders**

generate or sense an electromagnetic field of sufficient magnitude to write and read properly. The narrower the head is, the closer it must be to the platter surface to function. A narrower head means narrower tracks and therefore greater data density, which is desirable. However, the closer the head is to the disk, the greater the risk of error from impurities or imperfections. To push the technology further, the **Winchester disk** was developed. Winchester heads are used in sealed drive assemblies that are almost free of contaminants. They are designed to operate closer to the disk's surface than conventional rigid disk heads, thus allowing greater data density. The head is actually an aerodynamic foil that rests lightly on the platter's surface when the disk is motionless. The air pressure generated by a spinning disk is enough to make the foil rise above the surface. The resulting noncontact system can be engineered to use narrower heads that operate closer to the platter's surface than conventional rigid disk heads.

Table J.2 gives disk parameters for typical contemporary high-performance disks.

**Table J.2 Typical Hard Disk Drive Parameters**

<b>Characteristics</b>	<b>Seagate Barracuda ES.2</b>	<b>Seagate Barracuda 7200.10</b>	<b>Seagate Barracuda 7200.9</b>	<b>Seagate</b>	<b>Hitachi Microdrive</b>
Application	High-capacity server	High-performance desktop	Entry-level desktop	Laptop	Handheld devices
Capacity	1 TB	750 GB	160 GB	120 GB	8 GB
Minimum track-to-track seek time	0.8 ms	0.3 ms	1.0 ms	—	1.0 ms
Average seek time	8.5 ms	3.6 ms	9.5 ms	12.5 ms	12 ms
Spindle speed	7200 rpm	7200 rpm	7200	5400 rpm	3600 rpm
Average rotational delay	4.16 ms	4.16 ms	4.17 ms	5.6 ms	8.33 ms
Maximum transfer rate	3 GB/s	300 MB/s	300 MB/s	150 MB/s	10 MB/s
Bytes per sector	512	512	512	512	512
Tracks per cylinder (number of platter surfaces)	8	8	2	8	2

## **J.2 OPTICAL MEMORY**

In 1983, one of the most successful consumer products of all time was introduced: the compact disk (CD) digital audio system. The CD is a nonerasable disk that can store more than 60 minutes of audio information on one side. The huge commercial success of the CD enabled the development of low-cost optical-disk storage technology that has revolutionized computer data storage. A variety of optical-disk systems are in use (Table J.3). We briefly review each of these.

### **CD-ROM**

The audio CD and the CD-ROM (compact disk read-only memory) share a similar technology. The main difference is that CD-ROM players are more rugged and have error-correction devices to ensure that data are properly transferred from disk to computer. Both types of disk are made the same way. The disk is formed from a resin, such as polycarbonate. Digitally recorded information (either music or computer data) is imprinted as a series of microscopic pits on the surface of the polycarbonate. This is done, first of all, with a finely focused, high-intensity laser to create a master disk. The master is used, in turn, to make a die to stamp out copies onto polycarbonate. The pitted surface is then coated with a highly reflective surface, usually aluminum or gold. This shiny surface is protected against dust and scratches by a top coat of clear acrylic. Finally, a label can be silkscreened onto the acrylic.

**Table J.3 Optical Disk Products**

**CD**

Compact Disk. A nonerasable disk that stores digitized audio information. The standard system uses 12-cm disks and can record more than 60 minutes of uninterrupted playing time.

**CD-ROM**

Compact Disk Read-Only Memory. A nonerasable disk used for storing computer data. The standard system uses 12-cm disks and can hold more than 650 Mbytes.

**CD-R**

CD Recordable. Similar to a CD-ROM. The user can write to the disk only once.

**CD-RW**

CD Rewritable. Similar to a CD-ROM. The user can erase and rewrite to the disk multiple times.

**DVD**

Digital Versatile Disk. A technology for producing digitized, compressed representation of video information, as well as large volumes of other digital data. Both 8 and 12 cm diameters are used, with a double-sided capacity of up to 17 Gbytes. The basic DVD is read-only (DVD-ROM).

**DVD-R**

DVD Recordable. Similar to a DVD-ROM. The user can write to the disk only once. Only one-sided disks can be used.

**DVD-RW**

DVD Rewritable. Similar to a DVD-ROM. The user can erase and rewrite to the disk multiple times. Only one-sided disks can be used.

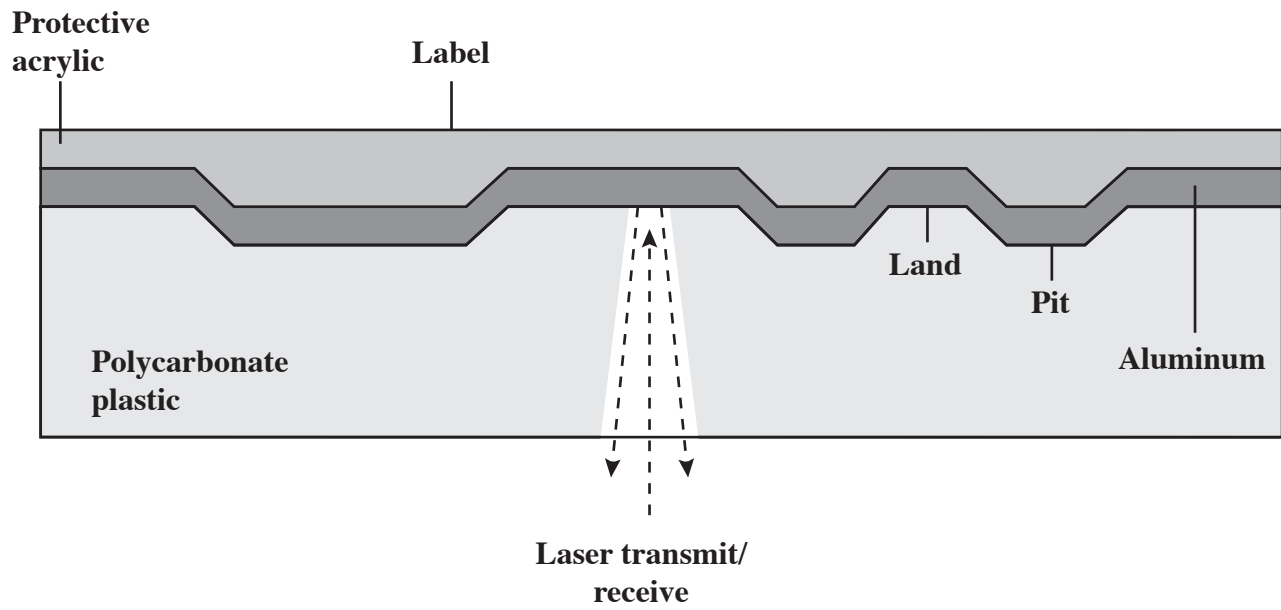
**Blu-Ray DVD**

High definition video disk. Provides considerably greater data storage density than DVD, using a 405-nm (blue-violet) laser. A single layer on a single side can store 25 Gbytes.

Information is retrieved from a CD or CD-ROM by a low-powered laser housed in an optical-disk player, or drive unit. The laser shines through the clear polycarbonate while a motor spins the disk past it (Figure J.5). The intensity of the reflected light of the laser changes as it encounters a pit. Specifically, if the laser beam falls on a pit, which has a somewhat rough surface, the light scatters and a low intensity is reflected back to the source. The areas between pits are called *lands*. A land is a smooth surface, which reflects back at higher intensity. The change between pits and lands is detected by a photosensor and converted into a digital signal. The sensor tests the surface at regular intervals. The beginning or end of a pit represents a 1; when no change in elevation occurs between intervals, a 0 is recorded.

Recall that on a magnetic disk, information is recorded in concentric tracks. With the simplest constant angular velocity (CAV) system, the number of bits per track is constant. An increase in density is achieved with multiple zoned recording, in which the surface is divided into a number of zones, with zones farther from the center containing more bits than zones closer to the center. Although this technique increases capacity, it is still not optimal.

To achieve greater capacity, CDs and CD-ROMs do not organize information on concentric tracks. Instead, the disk contains a single spiral track, beginning near the center and spiraling out to the outer edge of the disk. Sectors near the outside of the disk are the same length as those near the inside. Thus, information is packed evenly across the disk in segments of the same size and these are scanned at the same rate by rotating the disk at a variable speed. The pits are then read by the laser at a **constant linear velocity (CLV)**. The disk rotates more slowly for accesses near the outer edge than for those near the center. Thus, the capacity of a track and the



**Figure J.5 CD Operation**

rotational delay both increase for positions nearer the outer edge of the disk. The data capacity for a CD-ROM is about 680 MB.

CD-ROM is appropriate for the distribution of large amounts of data to a large number of users. Because of the expense of the initial writing process, it is not appropriate for individualized applications. Compared with traditional magnetic disks, the CD-ROM has three major advantages:

- The information-storage capacity is much greater on the optical disk.
- The optical disk together with the information stored on it can be mass replicated inexpensively—unlike a magnetic disk. The database on a magnetic disk has to be reproduced by copying one disk at a time using two disk drives.
- The optical disk is removable, allowing the disk itself to be used for archival storage. Most magnetic disks are nonremovable. The information on nonremovable magnetic disks must first be copied to some other storage device before the disk drive/disk can be used to store new information.

The disadvantages of CD-ROM are as follows:

- It is read-only and cannot be updated.
- It has an access time much longer than that of a magnetic disk drive, as much as half a second.

## **CD Recordable**



To accommodate applications in which only one or a small number of copies of a set of data is needed, the write-once read-many CD, known as the CD recordable (CD-R) has been developed. For CD-R, a disk is prepared in such a way that it can be subsequently written once with a laser beam of modest intensity. Thus, with a somewhat more expensive disk controller than for CD-ROM, the customer can write once as well as read the disk.

The CD-R medium is similar to but not identical to that of a CD or CD-ROM. For CDs and CD-ROMs, information is recorded by the pitting of the surface of the medium, which changes reflectivity. For a CD-R, the medium includes a dye layer. The dye is used to change reflectivity and is activated by a high-intensity laser. The resulting disk can be read on a CD-R drive or a CD-ROM drive.

The CD-R optical disk is attractive for archival storage of documents and files. It provides a permanent record of large volumes of user data.

## **CD Rewritable**

The CD-RW optical disk can be repeatedly written and overwritten, as with a magnetic disk. Although a number of approaches have been tried, the only pure optical approach that has proved attractive is called phase change. The phase change disk uses a material that has two significantly different reflectivities in two different phase states. There is an amorphous state, in which the molecules exhibit a random orientation that reflects light poorly; and a crystalline state, which has a smooth surface that reflects light well. A beam of laser light can change the material from one phase to the other. The primary disadvantage of phase change optical disks is that the material eventually and permanently loses its desirable properties. Current materials can be used for between 500,000 and 1,000,000 erase cycles.

The CD-RW has the obvious advantage over CD-ROM and CD-R that it can be rewritten and thus used as a true secondary storage. As such, it

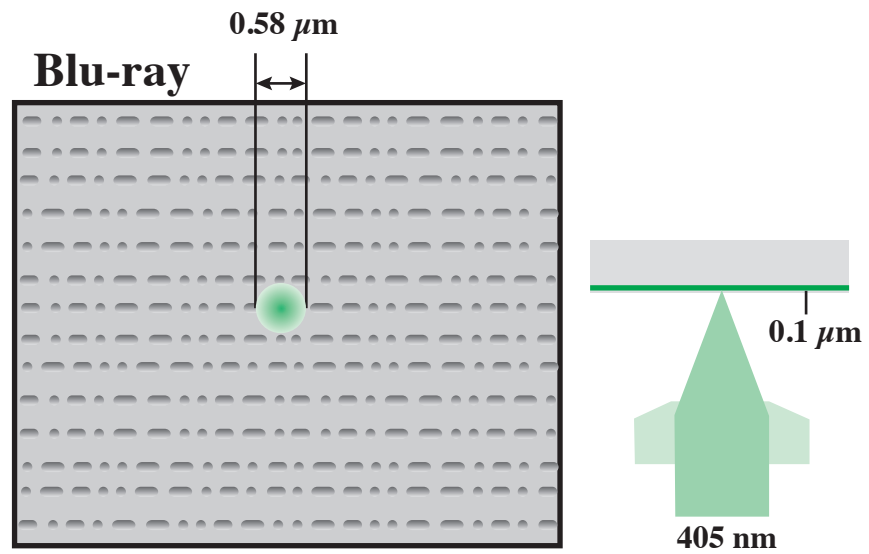
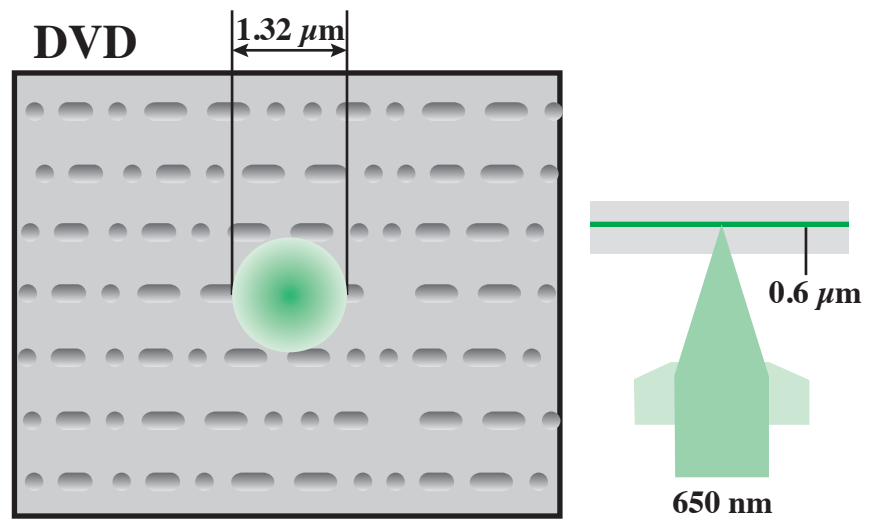
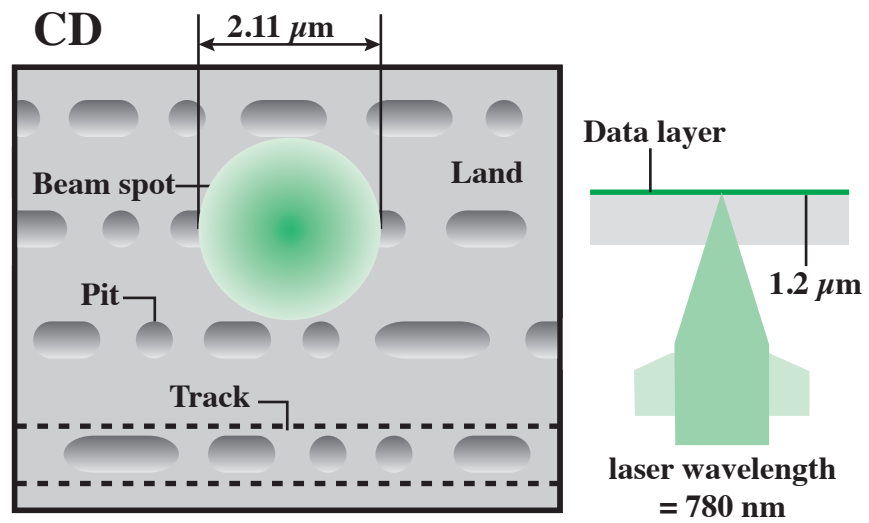
competes with magnetic disk. A key advantage of the optical disk is that the engineering tolerances for optical disks are much less severe than for high-capacity magnetic disks. Thus, they exhibit higher reliability and longer life.

## Digital Versatile Disk

With the capacious digital versatile disk (DVD), the electronics industry has at last found an acceptable replacement for the analog VHS video tape. The DVD will replace the video tape used in video cassette recorders (VCRs) and, more important for this discussion, replace the CD-ROM in personal computers and servers. The DVD takes video into the digital age. It delivers movies with impressive picture quality, and it can be randomly accessed like audio CDs, which DVD machines can also play. Vast volumes of data can be crammed onto the disk, currently seven times as much as a CD-ROM. With DVD's huge storage capacity and vivid quality, PC games will become more realistic and educational software will incorporate more video. Following in the wake of these developments will be a new crest of traffic over the Internet and corporate intranets, as this material is incorporated into Web sites.

The DVD's greater capacity is due to three differences from CDs (Figure 6.6):

1. Bits are packed more closely on a DVD. The spacing between loops of a spiral on a CD is  $1.6\text{ }\mu\text{m}$  and the minimum distance between pits along the spiral is  $0.834\text{ }\mu\text{m}$ . The DVD uses a laser with shorter wavelength and achieves a loop spacing of  $0.74\text{ }\mu\text{m}$  and a minimum distance between pits of  $0.4\text{ }\mu\text{m}$ . The result of these two improvements is about a sevenfold increase in capacity, to about 4.7 GB.



**Figure J.6 Optical Memory Characteristics**

2. The DVD employs a second layer of pits and lands on top of the first layer. A dual-layer DVD has a semireflective layer on top of the reflective layer, and by adjusting focus, the lasers in DVD drives can read each layer separately. This technique almost doubles the capacity of the disk, to about 8.5 GB. The lower reflectivity of the second layer limits its storage capacity so that a full doubling is not achieved.
3. The DVD-ROM can be two sided, whereas data are recorded on only one side of a CD. This brings total capacity up to 17 GB.

As with the CD, DVDs come in writeable as well as read-only versions (Table J.3).

## High-Definition Optical Disks

High-definition optical disks are designed to store high-definition videos and to provide significantly greater storage capacity compared to DVDs. The higher bit density is achieved by using a laser with a shorter wavelength, in the blue-violet range. The data pits, which constitute the digital 1s and 0s, are smaller on the high-definition optical disks compared to DVD because of the shorter laser wavelength.

Two competing disk formats and technologies initially competed for market acceptance: HD DVD and Blu-ray DVD. The Blu-ray scheme ultimately achieved market dominance. The HD DVD scheme can store 15 GB on a single layer on a single side. Blu-ray positions the data layer on the disk closer to the laser (shown on the right-hand side of each diagram in Figure J.6). This enables a tighter focus and less distortion and thus smaller pits and tracks. Blu-ray can store 25 GB on a single layer. Three versions are available: read only (BD-ROM), recordable once (BD-R), and rerecordable (BD-RE).