



[Home](#) [All topics](#) [Memory and storage](#) [Secondary storage](#)

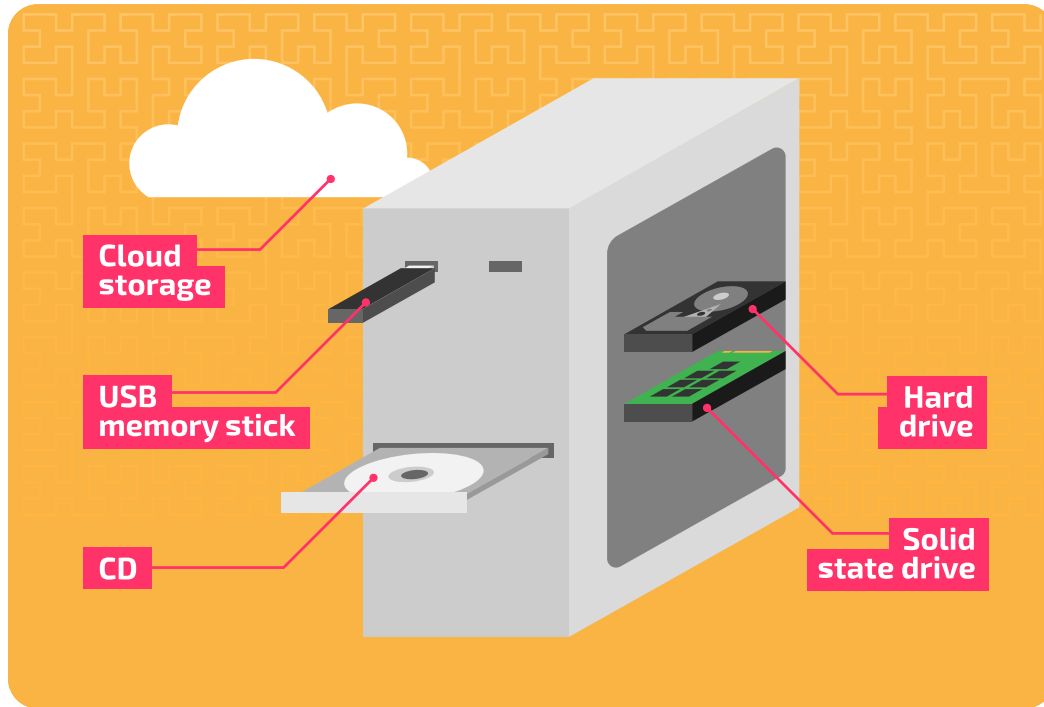
Secondary storage

Secondary storage is a term that applies to a wide range of devices that provide persistent (permanent) storage for data files and applications. Secondary storage is non-volatile, so does not require a power supply.

GCSE The need for secondary storage

You have already learnt that main memory is needed to store data and instructions during processing. Main memory is designed specifically for this purpose; it is high speed and can be accessed directly by location, however, it is expensive and volatile.

By contrast, secondary storage needs to be high capacity and low cost. It needs to be fast enough for loading and saving files, and it needs to provide reliable permanent storage so that files are not lost or easily corrupted. The type of secondary storage chosen will depend on budget and how it is intended to be used.



Secondary storage devices can be both internal and external

Secondary storage may be installed internally, i.e. inside the main system case. It can also be external, for example, a portable solid-state disk. External devices are often useful to transfer files from one computer to another, or where it is not possible to upgrade internal storage.

Most computers will have at least one type of secondary storage. Rapid developments in technology have seen solid-state devices and embedded MultiMediaCard (eMMC) become commonplace, replacing magnetic hard disks and optical discs.

There are three types of secondary storage that you need to be familiar with:

- Magnetic (hard) disk
- Solid-state disk
- Optical disc

GCSE Comparing and choosing secondary storage

When choosing a secondary storage device, you need to consider its purpose. These are some of the criteria that you will need to think about:

Capacity	How much storage does it provide? Some users, such as professional photographers, sound engineers, and videographers create a lot of very large files.
Speed	How quick is it to access files? Device manufacturers and reviewers will often publish performance data for read-write access. Sometimes, additional data will be provided for small and large files.
Cost	How much does it cost? Cost per Gb can be a useful measure.
Portability	Is it important that the disk can be transported? Does it need to be secured safely away from the computer, or transported between locations?
Compatibility	Compatibility is always an issue. If the device is designed to be installed inside a system case, it must be the right size for the slot(s) available and it must have the right kind of connector. External devices are usually connected by USB, but other connections are available.

A final consideration is that of **longevity and reliability**. Technology is changing at a rapid rate. Optical storage devices (CD/DVD) that were commonly found on computers ten years ago are rarely seen in new devices. If you store your photos on a CD (for example), will you have a means of accessing them in a few years time?

As far as reliability is concerned, any storage mechanism can fail, and data can be corrupted. Disk reliability is usually measured in terms of the mean time to failure (MTTF). However, the failures cannot be predicted and will be distributed over the entire time period; this means that theoretically, your hard disk could fail at any moment. Backing up important data is imperative, and cloud storage provides an easy, managed solution for most users.

GCSE Magnetic storage

Magnetic disk drives are often referred to as HDDs (**hard disk drives**) or just **hard drives**. Originally they were called 'hard' to differentiate them from floppy disks (also magnetic), which were commonly used in the 1980s.

Magnetic devices are the oldest form of digital storage and have been in use since the 1920s (before computers were even available).

Characteristics

The drives are mechanical devices with many moving parts. In theory, this means that it is more likely to fail. However, HDDs are sold as sealed units, so the disk medium and drive mechanism are well protected from contamination and wear and tear.

The disk unit usually comprises one or more metal **platters** with a magnetic coating, a **spindle** to hold/spin the platters, and a **read-write head** on an actuator arm.

Each platter is double-sided and the number of platters will determine the total storage capacity of the disk.

The read-write head is used to store and retrieve data on the platters.

How is data stored?

Data is represented on the surface of the metal platters with tiny magnetised dots. Binary data is represented through the two states of 'magnetised' and 'not-magnetised'.

Each platter is broken down into a set of concentric **tracks** that can hold the polarised dots that represent the binary data, as seen in **Figure 1**.

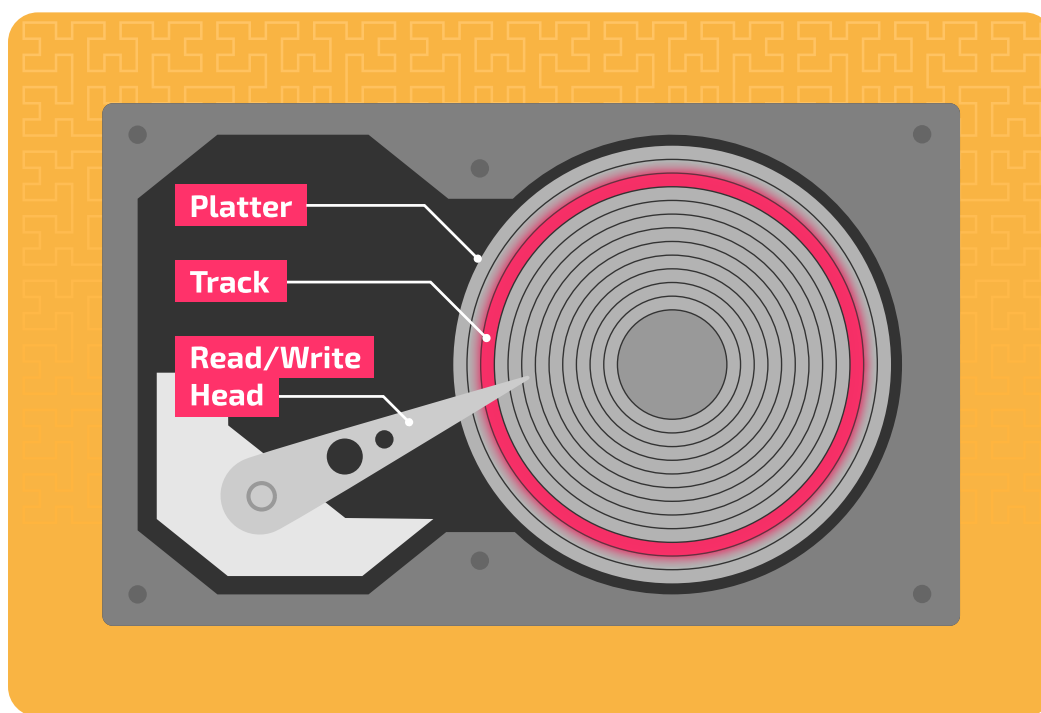


Figure 1: Hard-drive tracks form concentric circles on the platters

To read and write data, the device has two mechanical arms, one for each side of each platter. At the end of the arms are read-write heads with a tiny magnet.

The read-write process requires the disk to spin at a high speed. The speed of rotation is a crucial factor in measuring the rate of data access for a magnetic disk. Standard HDDs have read-write access speeds of between 80 and 200MB/s (megabytes per second).

Reading data

To read the data, the head sweeps across the tracks on the spinning platters. A small magnetometer (a sensor that reads magnetic

forces) reads the states of the magnetised dots underneath the read-write head. The magnetised states of the dots on the platters are then translated to 1s and 0s.

Writing data

In order to write data onto the platters, the magnet on the end of the read-write head is used to generate a small **magnetic field**. The field causes the dots to switch state, becoming either magnetised or not-magnetised. When the magnetic field is taken away the dots keep their new state, allowing data to be stored until another magnetic field is applied.

Advantages

The main advantages of a magnetic disk drive are its capacity and cost. This traditional format still offers greater capacity at a much lower unit cost than SSDs. However, the gap between the technologies is narrowing fast.

Magnetic disk drives are best suited to desktop and laptop devices where low purchase cost is the most important selection criterion. They are also well suited for the long term storage of huge sets of data, as they are quite reliable and do not degrade over time.

Disadvantages

Magnetic disk drives are not as portable as CDs, DVDs, or USB memory sticks. Typically they are built to live inside of a computer.

They can also be fragile. If a magnetic disk drive is bumped or dropped, it can damage the disk inside.

What characteristic of a magnetic disk drive makes it less durable than other forms of storage?

Click a button to show the answer

What is your level of confidence that your own answer is correct?

Low

Medium

High

GCSE **Optical discs**

Optical discs are a large family of different disc types, the most common of which are the CD (compact disc), DVD (digital versatile disc), and Blu-ray disc. When discussing optical storage, the word 'disc' is usually spelt like this ('disc'), in contrast to other types of disk storage.

Characteristics

An optical disc is made up of a set of layers. The base is usually polycarbonate, and provides the main structure of the disc. There is always a thin aluminium **reflective layer** on the disc's surface.

Each disc has a continuous track of data arranged in a spiral as shown in **Figure 2** (rather than a series of concentric tracks, like in a hard disk). Data is stored in the form of **pits (troughs)** and **lands (peaks)** in the structure of the disc.

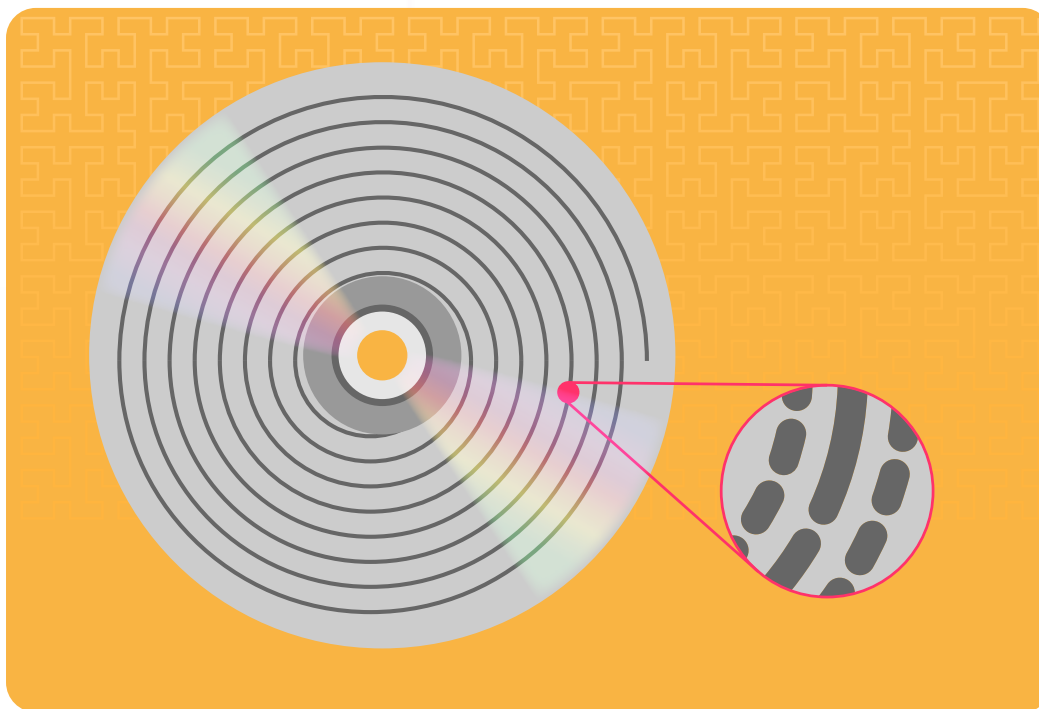


Figure 2: The tracks on an optical disc form a spiral

All formats of optical discs have three different types: ROM, R, and RW.

ROM

ROM discs are **read-only** versions and were primarily used to distribute data such as movies, music, and software. However, high speed internet connections have caused a steep decline in the use of discs for distribution.

R

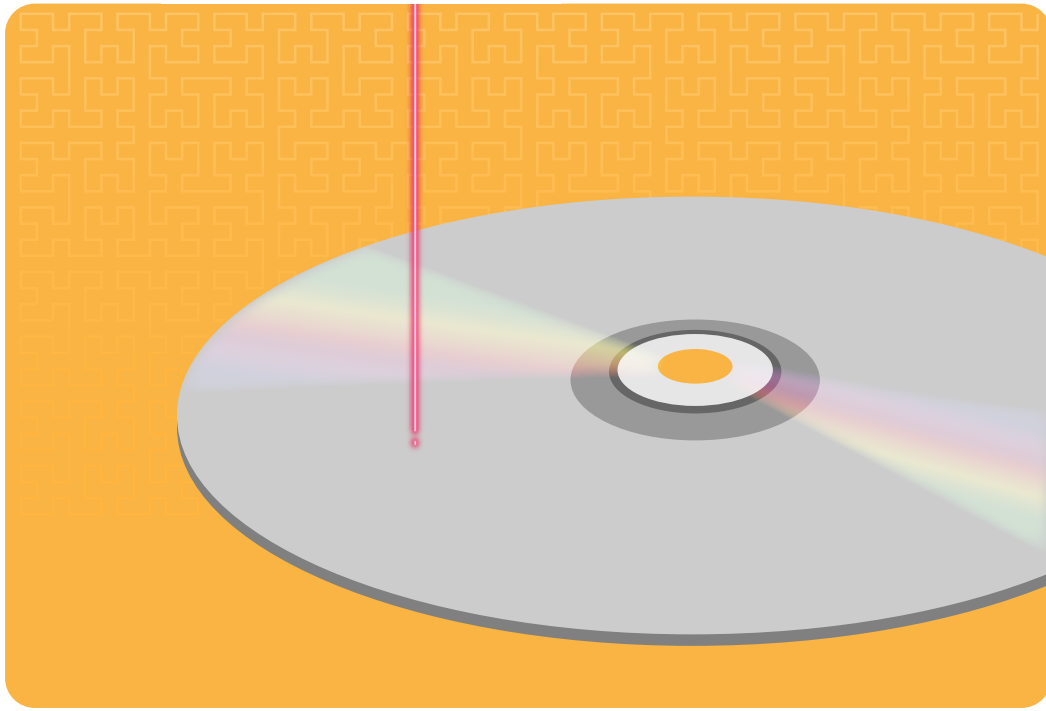
R stands for **recordable**. These discs can be written to once and then only read from that point on. They were typically used to archive data.

RW

RW means **rewritable**. These discs can be written and read many times. They are typically used to back up files for later retrieval or rewriting.

How is data stored?

Data is stored on the reflective surface of an optical disc. A laser is used to burn small marks into the surface and binary data is represented in the two states of pits/troughs (burns) and lands/peaks (no burn).



A laser is used to both read and write data to optical discs.

Reading data

To read the data, the laser is shone onto the surface of the disc. The pits and lands reflect different amounts of light. The electronics in the optical drive (installed in your computer) can interpret the changes in reflected light as 1s and 0s.

Writing data

To write to R or RW discs, the laser burns new troughs into the reflective surface of the disc. The laser is set to a higher intensity than it is while reading data.

RW discs use a chemical dye that allows the burning process to be reversed, allowing you to rewrite the data on a disc.

Advantages

Optical discs are extremely light and **portable**, which is why they are used for distribution.

They are also **relatively cheap**, but only for lower storage capacities.

Optical discs are also quite **reliable**. If you protect the reflective surface of the disc, they can last for a long time. If the surface of the disc is scratched, it can ruin the data stored on the disc.

Disadvantages

Optical discs have a much **lower capacity** than hard drives or SSDs.

They also have a **slow seek time**, which means that the disc must spin to the right location before the data can be accessed.

Some CDs, DVDs, and Blu-ray discs are **not rewritable**, so data can only be written to them once.

How would a scratch on the reflective surface affect the data stored on an optical disc?

Click a button to show the answer

What is your level of confidence that your own answer is correct?

Low

Medium

High

GCSE Solid-state storage

Often called **SSDs**, solid-state disks are a form of Flash memory used for the medium to long term storage of data. SSDs have **no moving parts** and can either be housed inside a computer or used as an external device.

You can also use smaller, portable solid-state devices, such as USB memory sticks and SD cards, for a more portable storage solution.

Characteristics

Solid-state devices can read and write data much **quicker** than both magnetic and optical storage devices.

SSDs are particularly suitable for storing files that are **read or changed frequently**. Having your operating system on an SSD is likely to dramatically improve the time that it takes for your system to go through its boot sequence. If there are applications and data that are accessed frequently, it may be beneficial to store these on SSDs too.

It is becoming increasingly common for computer systems to have both magnetic and solid-state disks. Having an SSD as an additional drive is a sensible upgrade for a computer system. A small SSD can be used to store the operating system and files (including applications) that are used frequently. Files (including applications) that are used less frequently can be stored on the larger magnetic disk.

How is data stored?

Inside of a solid-state storage device the binary data is stored in a similar way to RAM. The key difference is that solid-state disks are **non-volatile**, so the data remains when powered down.

Reading and writing data

Solid-state devices are **random access**, which means that the data can be accessed in any order and there is no seek time required (unlike magnetic hard drives or optical discs).

All solid-state devices have multiple memory modules. Each module is a collection of memory circuits wired together to form a grid, like the one seen below in **Figure 3**.

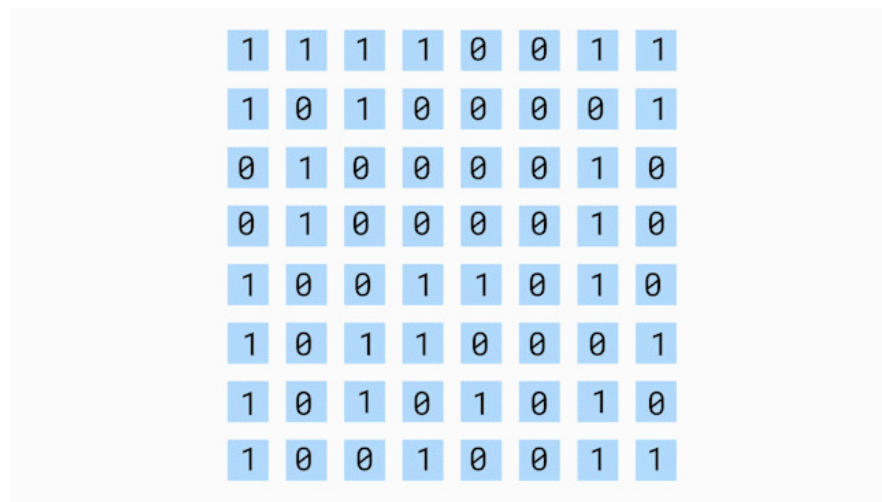


Figure 3: The binary data stored in an SSD is organised into a grid.

Why would storing your operating system on an SSD cause a computer to boot up quicker?

Click a button to show the answer

What is your level of confidence that your own answer is correct?

Low

Medium

High

Advantages

Compared to magnetic devices, solid-state storage offers many advantages. The main advantage is **speed of access** and portability.

The absence of moving parts means that mechanical failure is far less likely. The reduced likelihood of damage through day-to-day bumps and knocks makes a solid-state device a better choice of drive for portable devices. The lack of moving parts also reduces the amount of energy consumed, which, in turn, reduces the amount of heat generated in a computer system.

Disadvantages

While a solid-state device is robust, it does have a limited lifespan. The number of times that a solid-state device can be written to is **limited**. As a result, they are not suitable for the long term archiving of data.

GCSE

Cloud storage

Users often have access to storage that is not installed as part of their own computer system.

Cloud storage offers a way to store and access files through the internet. The data is stored on **servers with hard drives** that are owned and managed by commercial organisations. A popular business model, at the time of writing, is to provide a certain amount of cloud storage (typically 1GB) free of charge, and then to charge per GB for additional storage needs.

Cloud storage has had a huge impact on the way that we store files, and the way that we move data between devices. In particular, it has affected the market for portable storage devices such as optical discs and USB flash drives. Nowadays, it is quite rare to get an optical disc drive as standard when you buy a desktop or laptop computer.

Cloud storage can be configured so that it automatically synchronises with local drives. This means that there is always a local copy, in case there is no available internet connection. Any changes made locally will be synchronised when the connection is next available.

Advantages

The **capacity** offered by cloud storage can expand as your needs change — this is much more difficult and costly with other storage methods.

Your files can be accessed from anywhere in the world, provided there is a stable internet connection. This makes sharing files much easier and enables a greater scale of collaboration.

Cloud storage offers a safe way to **back up** your files; the provider takes responsibility for maintaining and protecting the data you store with them.

Disadvantages

The fact that cloud storage requires an internet connection can also be a disadvantage, because it means that it requires a relatively stable connection to work properly. This can exclude some people who cannot access or afford such a connection.

It can also be **slower** to access your files than on a storage device directly connected to your computer.

Storing your files online carries some risks. For example, malicious individuals might gain access or steal your data. You can also lose the data if something happens to the provider's servers or hard drives.



The figures given below were correct at the time of writing (2020). However, rapid developments in storage technology will inevitably mean that the figures cited in this section will be out of date. If you write about capacity, it is better to talk in relative terms.

	Typical capacity	Notes
Magnetic hard disk	1TB	Max. capacity is around 16TB
Solid-state disk	256GB	Max. capacity is around 8TB
CD	Standard form is 700MB	
DVD	Standard form is 4.7GB	Dual-layer: 8.5GB Double-sided: 9.4GB
Blu-ray Disc	Standard form is 25GB	Triple-Layer: 100GB



A **magnetic disk** is often referred to as a **hard disk**. This was to differentiate it from floppy disks (also magnetic), which were commonly used in the 1980s.

An HDD is a hard disk drive. The drive is a mechanical device with many moving parts. In theory, this means that it is more likely to fail. However, HDDs are sold as sealed units, so the disk medium and drive mechanism are well protected from contamination and wear and tear. Data is represented on the disk surface (a metal platter) by magnetised dots. Binary data is represented through the two states of 'magnetised' and 'not-magnetised'.

The read-write process requires the disk to spin at a high speed. The speed of rotation is a crucial factor in measuring the rate of data access for a magnetic disk. The faster the disk spins, the quicker the data can be retrieved. Standard drives spin at 5,400 rpm (revolutions per minute) and 7,200 rpm. Higher-specification drives (well suited for use as storage for servers) can spin at 15,000 rpm.

Standard HDDs have read-write access speeds of between 80 and 200MB/s (megabytes per second). The variation is determined by a range of factors, including how the disk has been configured, the size of the file, and how fragmented the disk or file is. **Fragmentation** occurs when there is insufficient **contiguous space** to store the file. If a file is fragmented, then each part of the file will be in a separate location with a link to the next location; the file will be read by following the links until an end-of-file marker is reached. If a disk is nearly full, it will take longer to find space to write file segments, and it will take longer to access a file that is spread across several locations.

The main advantages of a magnetic hard disk are its capacity and cost. This traditional format still offers greater capacity at a much lower unit cost than SSDs. However, the gap between the technologies is narrowing fast.

Magnetic hard disks are best suited to desktop and laptop devices where low purchase cost is the most important selection criterion.

Principles of operation

The disk unit usually comprises one or more metal platters with a magnetic coating. Each platter is double-sided and the number of platters will determine the total storage capacity of the disk. Binary data is stored on the platters as a series of polarised states. Each polarised state represents 1 or 0.

Each platter is broken down into a set of concentric **tracks** and the tracks are further broken down into **sectors**. A contiguous group of sectors is called a **cluster** (also called a **block** or **allocation unit**). This is the smallest unit of storage that can be addressed by the file system and will vary in size depending on the size of the disk and how it is formatted.

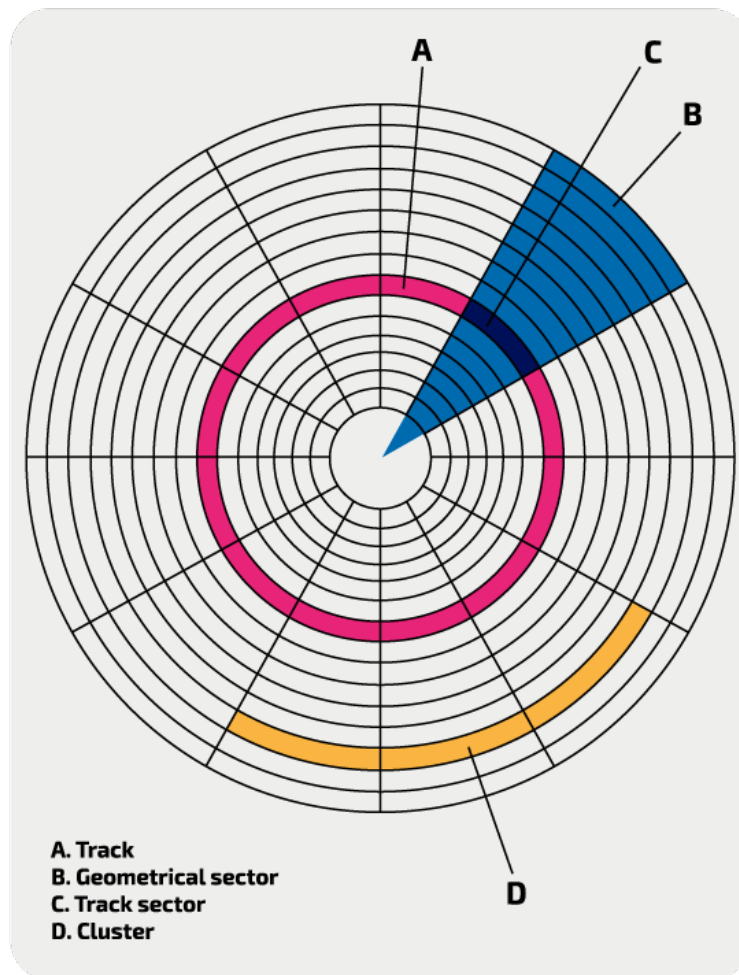


Figure 4: Disk structures:

A. Track; B. Geometrical sector; C. Track sector; D. Cluster

Heron2/MistWiz via Wikimedia Commons (<https://commons.wikimedia.org/wiki/File:Disk-structure2.svg>), [Public Domain]

The location of each file is recorded in a **file allocation record**. This allows the file to be retrieved, and free space to be identified for new files to be stored. When the disk is fairly full, it is common for files to be split across many blocks that are non-contiguous. This requires the file allocation record to keep track of not only where the file segments are, but also the order in which they should be reassembled. If this record is lost or corrupted, the file data will still be present on the disk, but it will be impossible to access it in a meaningful way, unless the record can be rebuilt.

A Level

Solid-state disk

The abbreviation **SSD** stands for **solid-state disk**, but it is also sometimes interpreted as **solid-state drive** or **solid-state device**. An SSD is an electronic device that uses flash memory, and has no moving parts.

Compared to magnetic hard disks, SSDs offer many advantages. The main advantage is speed of access and write access speeds for a standard SSD are in the range of 200–500 MB/s. Despite the fact that some operations will take longer than others, these timings are relative, and SSDs will always outperform magnetic or optical drives.

The absence of moving parts means that mechanical failure is far less likely. The reduced likelihood of failure through day-to-day bumps and knocks make an SSD a better choice of drive for portable devices. The lack of moving parts also reduces the amount of energy consumed, which, in turn, reduces the amount of heat generated in a computer system.

However, while an SSD is robust, it does have a limited lifespan. The number of times that an SSD can be written to is finite, and memory cell 'leakage' can be a problem if devices are not powered up from time to time. As a result, they are not suitable for the long-term archiving of data.

At the time of writing (2020) SSD storage is still more expensive per GB than magnetic storage. High-end computer systems will sometimes have large-capacity solid-state disks, but this will add significantly to the overall cost of the device.

SSDs are usually built into a physical enclosure that mirrors those used for magnetic disk drives. This allows computers to be upgraded by swapping the original drive, or by connecting an additional drive.

SSDs are particularly suitable for storing files that are read or changed frequently. Having your operating system on an SSD will likely dramatically improve the time that it takes for your system to go through its boot sequence. If there are applications and data that are accessed frequently, it may be beneficial to store these on SSDs too.

It is becoming increasingly common for computer systems to have both magnetic and solid-state disks. Having an SSD as an additional drive is a sensible upgrade for a computer system. A small SSD can be used to store the operating system and files (including applications) that are used frequently. Files (including applications) that are used less frequently can be stored on the larger magnetic disk.

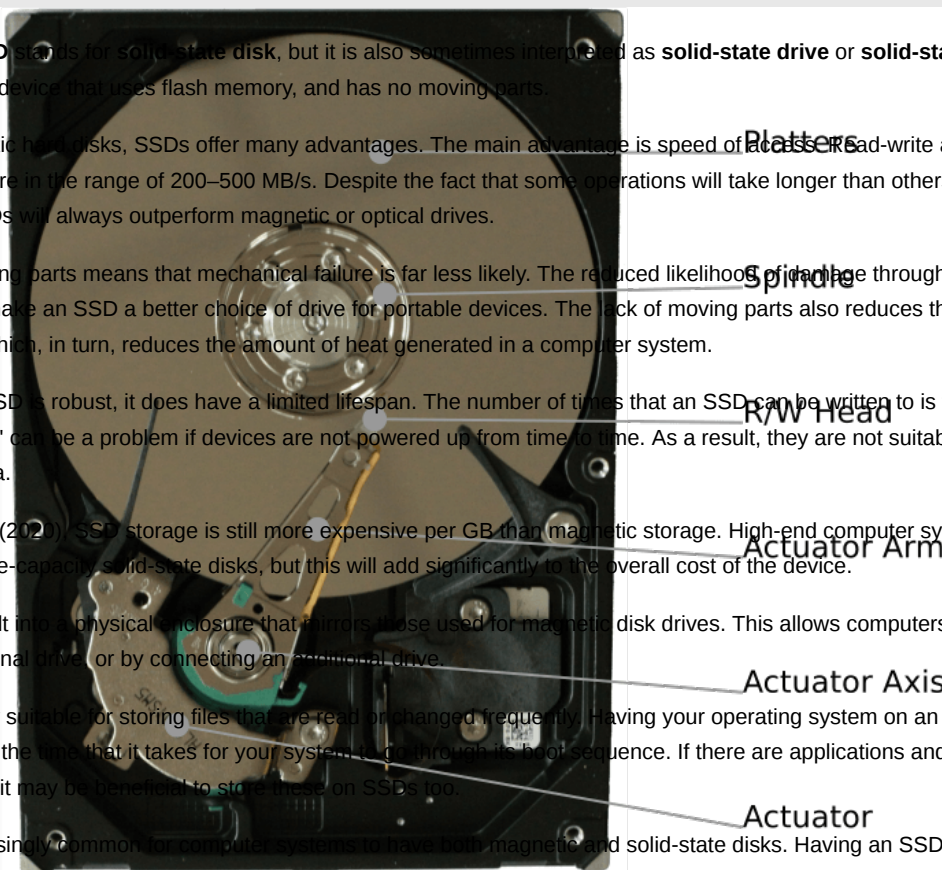


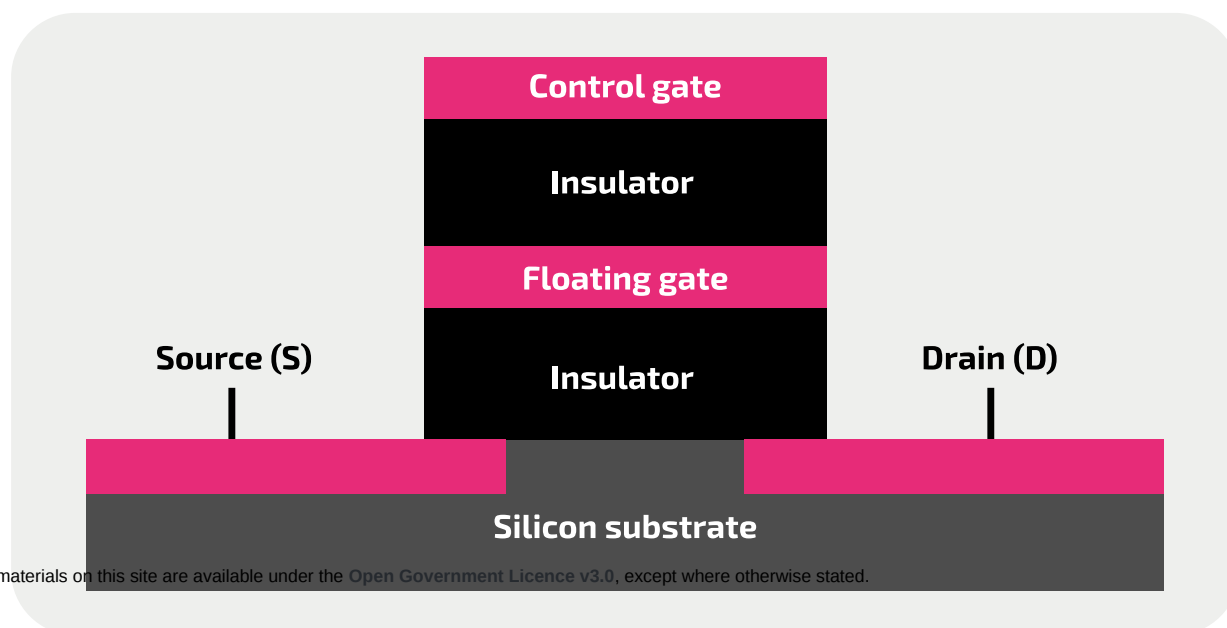
Figure 5: Magnetic hard disk drive

Principles of operation

Erwan velu via Wikimedia Commons (<https://commons.wikimedia.org/wiki/File:Harddisk-top.png>), [CC BY-SA 3.0 (

<https://creativecommons.org/licenses/by-sa/3.0/deed.en>)]

Solid-state disks are made up of a controller and a bank of millions of NAND 'flash' memory cells.



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Figure 6: SSD memory cell

Cyferz via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Flash_cell_structure.svg), [CC BY-SA 3.0 (

<https://creativecommons.org/licenses/by-sa/3.0/deed.en>)]

The diagram shows a simple memory cell design. Each cell has a floating gate transistor that allows an electrical charge to be trapped. A charged cell represents a 0, and a cell with no trapped charge represents a 1.

NAND flash cells are organised in terms of **pages** and **blocks**. A **page** is a cell within a grid, and each row of cells is a **block**.

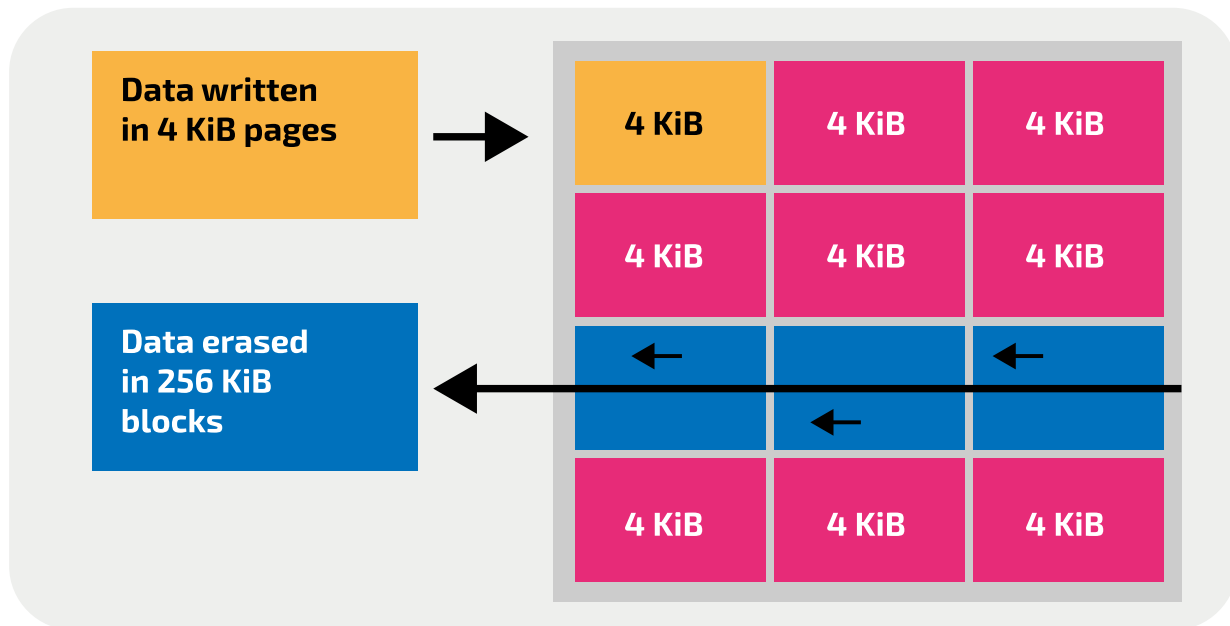


Figure 7: Blocks and pages

Dmitry Nosachev via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:NAND_Flash_Pages_and_Blocks.svg), [CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/deed.en>)]

Data is read from an SSD by page. It can also be written a page at a time, as long as the surrounding cells are empty. If a file is to be updated, this cannot be done in situ. The relevant block containing the pages must be copied to main memory and updated. It will then be written to a new area of the disk and the original block(s) will be erased.

SSDs become slower as they fill up. A new empty drive will be full of pages that can be written to immediately. When the disk is nearly full, writing and updating will become relatively slow operations as a result of having to copy out, then rewrite existing pages within a block.

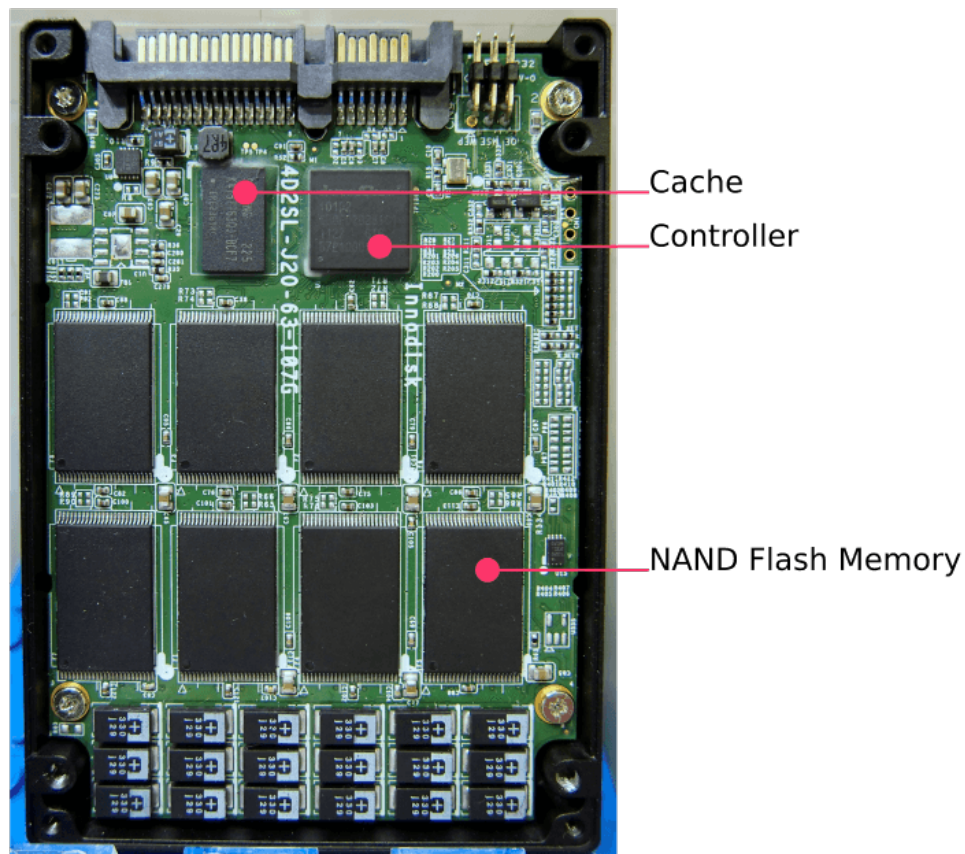


Figure 8: Solid-state disk

Ordercrazy via Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Embedded_World_2014_SSD.jpg), [CC0 (<https://creativecommons.org/publicdomain/zero/1.0/deed.en>)]



Optical discs are a large family of different disc types, the most common of which are CD (compact disc), DVD (digital versatile disc), and Blu-ray Disc. When discussing optical storage, the word 'disc' is usually spelt like this ('disc'), in contrast to other types of disk storage.

CD-ROM and DVD-ROM

'ROM' is 'read-only memory'. These discs are usually mass-produced and used for distributing music and films. Each CD or DVD is 'mastered', usually pressed from a mould, in a single operation. In a factory environment, tens of thousands of copies can be made every day.

CD/DVD-ROMs were, and in some cases still are, used as a means of delivering application software. They are light and easily transported, and need little physical space. However, this use of optical discs is declining. High-speed broadband and cloud distribution mean that software is usually distributed via the internet.

CD-R and DVD-R

'R' stands for 'recordable'. These discs can also be described by the acronym 'WORM' ('write-once read-many'). This type of disc was once popular for archiving data, such as photos. **Archiving** means making a permanent copy, so it requires a storage medium that cannot be overwritten.

CD-RW and DVD-RW

'RW' stands for 'rewritable'. This type of disc was once popular for backing up computer files. **Backing up** means making a temporary copy, so it requires a storage medium that can be overwritten at some point in the future. Today, most systems are backed up to high-speed digital tape or cloud storage.

Speed ratings

The speed rating of an optical disc is expressed as a factor relative to a base figure. For CDs, the base figure is the speed that is required to read a music (audio) CD. The speed rating of DVDs is based on the speed that is required to play a (video) film. The base rating in each case is expressed as **1×**.

The actual speed achieved when reading and writing data files to optical storage is based on two factors: the speed rating of the disc and the speed rating of the disc drive. If a disc has a read speed rated as 16× but the drive itself is rated as 8×, the lower of the two values would be used. The same protocol applies for writing to optical discs.

Format	Rating	Transfer rate
CD	1×	150kB/s
DVD	1×	1.3MB/s
Blu-ray Disc	1×	36MB/s

Longevity

CD/DVD-ROMs are fairly robust, although they are susceptible to scratching if the surface is not kept protected.

For any of the disc types, exposure to heat may cause the polycarbonate and/or metallic layers to warp.

Many optical discs that have a layer of chemical dye are susceptible to damage by light: extended exposure to sunlight can affect the dye, which degrades the layer, thereby increasing the chances of data being misread. Any chemical layer will degrade over time.

However, the biggest problem with optical discs is the availability of drives to read them. Most computers are no longer shipped with optical disc drives, and they are fast disappearing from music players and cars. If you have valuable data stored on CD or DVD, it might well be advisable to copy it to cloud storage.

Principles of operation

An optical disc is made up of a set of layers, the composition of which depends on the type of disc. The base is usually polycarbonate, and provides the main structure of the disc, and there is always a thin aluminium reflective layer on the disc's surface. Recordable (R) and

rewritable (RW) discs also have a chemical layer (a dye) on top of the reflective layer.

Each disc has a continuous track of data arranged in a spiral (rather than a series of concentric tracks, like in a hard disk). Data is stored in the form of pits (troughs) and lands (peaks) in the structure of the disc.

Reading

When you read from an optical disc (e.g. play a CD), a laser beam is used. The data is read serially, and the disc rotates at varying speeds, depending on the data being read — it rotates faster nearer the centre. To read the data, the light from the laser is shone onto the surface of the disc. The light from the beam reflects off the aluminium layer and hits an optoelectronic device that detects any changes in light. The pits and lands reflect different amounts of light, and the electronics in the drive interpret the changes as data bits.

Writing

To write to a recordable (R) or rewritable (RW) disc, the laser in the optical disc drive is used at a higher intensity (than that used for reading). The light will 'burn' tiny dots into the chemical layer to alter the amount of light reflected. This creates a readable surface representing binary values.

With rewritable (RW) discs, the chemical dyes that are used allow the burning process to be reversed. This means that data can be erased and the disc can be written to again.

A Level

Virtual storage

Users often have access to storage that is not installed as part of their own computer system.

Network attached storage (NAS) is usually provided in the form of a dedicated stand-alone device that is installed as part of a LAN. There are small NAS devices for home networks, and much larger devices for business use. When network attached storage is used, the user will see the drive listed alongside their local storage. They do not need to be aware of its physical location, although they will lose access in the event of network (or device) failure.

Cloud storage is facilitated by the internet, and is usually owned and managed by commercial organisations. A popular business model, at the time of writing, is to provide a certain amount of cloud storage (typically 1GB) free of charge, and then to charge per GB for additional storage needs.

Cloud storage has had a huge impact on the way that we store files, and the way that we move data between devices. In particular, it has affected the market for portable storage devices such as optical discs and USB flash drives. Nowadays, it is quite rare to get an optical disc drive as standard when you buy a desktop or laptop computer.

Cloud storage can be configured so that it automatically synchronises with local drives. This means that there is always a local copy, in case there is no available internet connection. Any changes made locally will be synchronised when the connection is next available.