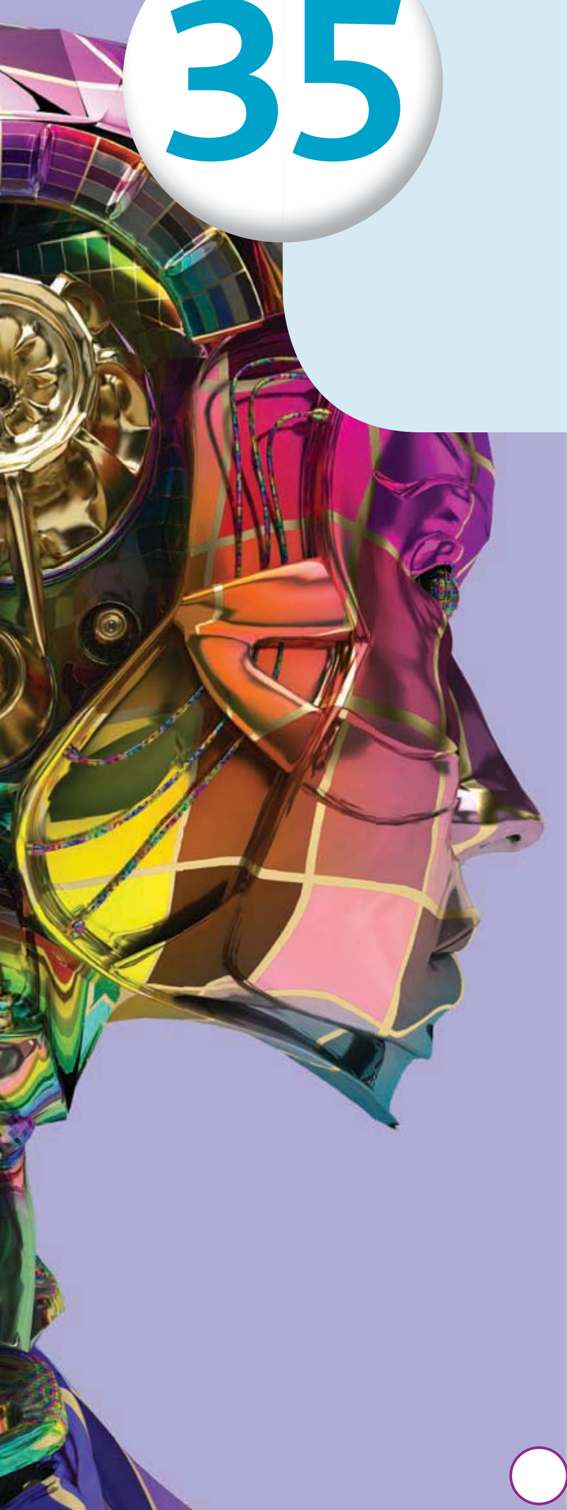

35 External hardware devices

SPECIFICATION COVERAGE

3.7.4 External hardware devices

LEARNING OBJECTIVES

In this chapter you will learn:

- how a digital camera works
- how a barcode reader works
- how RFID works
- how a laser printer works
- how magnetic, solid state and optical disks work
- the applications of each of these devices.

INTRODUCTION

In Chapter 32 we looked in detail at the main internal hardware components. This chapter considers external hardware including a range of input, output and storage devices. The definition of external hardware includes the hard disk as it is a form of secondary storage that is external to the processor.

There is an enormous range of devices that are available for computer systems and as AS- and A-level students you do not need to know how all of them work. In this chapter we concentrate on those devices that are stipulated in the specification as you must understand the main characteristics, purposes, suitability and principles of operation of these: the digital camera, barcode reader, laser printer and RFID.

Digital camera

A **digital camera** is a device for recording still and moving images in digital form that can then be processed further using specialised software. In common with other devices, the camera is taking analogue data, in this case light waves, and converting them into binary (0s and 1s). It does this in the following way:

- When a photograph is taken the shutter opens and lets light in through the lens.

KEYWORD

Digital camera: a device for creating digital images of photographs, which can be printed or transferred onto a computer to be manipulated and stored.

KEYWORDS

Charge coupled device (CCD): in digital cameras it is a sensor that records the amount of light received and convert it into a digital value.

Complementary metal oxide semiconductor (CMOS): is an alternative technology that performs the same functions as a CCD.

- The light is focused onto a sensor, which is usually either a **charge coupled device (CCD)** or a **complementary metal oxide semiconductor (CMOS)**.
- The sensors are made up of millions of transistors, each of which stores the data for one or more pixels. (A pixel is a picture element or individual dot, and the whole image will be made up of millions of pixels.)
- As the light hits the sensor, it is converted into electrons and the amount of charge is recorded for each pixel in digital form.
- With light, all colours can be created from red, green and blue (RGB). Therefore to record colour, the camera will either have three different sensors, or use three different filters – one for red, one for green and one for blue.
- The data are typically stored on removable storage devices, usually referred to as flash memory, which uses programmable ROM (see solid state disks later in this chapter).
- Data are usually stored in compressed files, for example, TIFF, JPG or PNG.
- RAW files can also be generated, which are uncompressed and therefore contain all of the data from the original photograph.
- This digital data can now be decoded and manipulated using specialised software.

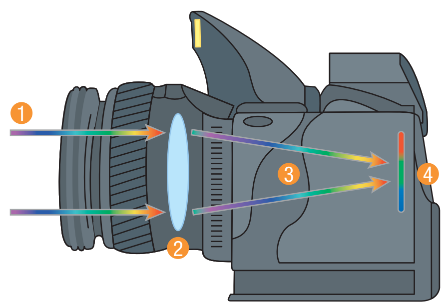

Figure 35.1 The workings of a digital camera

KEYWORD

RGB filter: red, green and blue filters that light passes through in order to create all other colours.

Light is let in through the shutter (1) and focused by the lens (2). It is directed through **RGB filters** (3) before being focused onto the CCD or CMOS sensor (4).

Figure 35.2 shows how the light is passed through the RGB filters to enable all possible colours to be created.

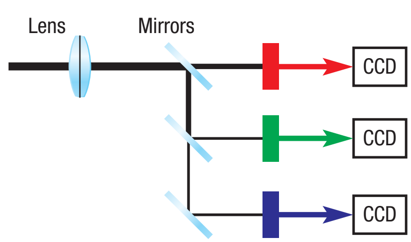

Figure 35.2 Red, green and blue (RGB) filters

The capability of digital cameras is often quantified in terms of how many megapixels it uses to record images. For example, a 12 megapixel camera will create an image made up of 12 million separate picture elements. This means that the sensor is breaking the image down into very small units and taking separate readings for each unit. The consequence is that the image can be recreated very accurately without blurring or pixellation. This creates high resolution images and is useful if the image is going to be printed and enlarged.

Figure 35.3 shows an enlarged area to demonstrate the effect of pixellation.

Figure 35.3 The effect of pixellation

However, for many users, a lower resolution is sufficient as it is more likely that the image will be taken using a smart phone and then transmitted over a mobile network. Lower resolution images will not be as accurate a reflection of the real image but they do have much smaller file sizes, making it more suitable for this application. Software can be used to alter the resolution of the image to make it suitable for the way in which the image is being used. It does this by compressing the image and many of the common file types used in digital photography such as JPG and TIFF are examples of compressed files. All of the original data collected by the camera's sensors are still available in the original file, which is said to be in raw format.

KEYWORDS

Compression: the process of reducing the size of a file.

Resolution: the number of pixels used to create an image.

Compression and **resolution** were covered in detail in Chapter 26.

Barcode reader

KEYWORD

Barcode reader: a device that uses lasers or LEDs to read the black and white lines of a barcode.

Barcode readers are one of a series of input devices that use scanner technology. These work in the following way:

- A light, usually an LED or laser is passed over an image.
- Some form of light sensor is used to measure the intensity of light being reflected back. This is converted into a current effectively generating a waveform. This could be achieved using a photodiode or a CCD sensor in the same way as a digital camera.
- White areas reflect most light and black areas the least, making it possible to use the waveform to distinguish the patterns of black and white bars.
- The waveform is analogue and therefore needs to be converted into digital form using an analogue to digital convertor.
- The encoding will convert the black and white into binary codes, for example, black = 0 and white = 1.
- The signal is decoded into a form that can then be interpreted by software.

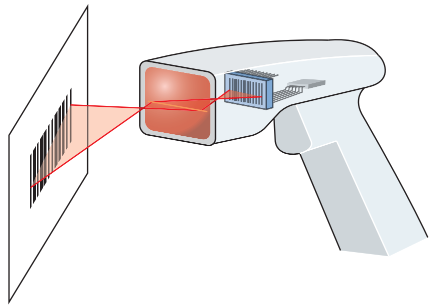

Figure 35.4 A barcode reader and barcode

Figure 35.5 A barcode

Figure 35.6 A QR code

There are many different types of barcode. Perhaps the most common is the UPC (universal product code) barcode, which uses a series of black and white lines of different widths with a printed number underneath. The lines are one of four widths and are encoded to represent the values 1 to 4. They are designed to be read reliably by a machine. The numbers are there as a manual over-ride and include a check digit.

Barcodes are used primarily for inputting product details at the point of sale. Typical uses include food, electrical products and books. Barcodes on food products are passed over a scanner built in to the checkout. Products that are physically bigger than food items, such as those sold in DIY stores, are more difficult to scan so hand-held scanners tend to be used. There are different classifications of barcodes, a common iteration being the European Article Number (EAN) which is standard for food products sold in the UK. The encoded data in the barcode is linked to a point-of-sale (POS) database system that matches the code to a particular item or product, where price details are also stored.

More recently, the same technology has been applied to codes that are made up of blocks of black and white symbols rather than lines. One example is the QR code, which has been widely adopted as it can be read with a scanner embedded within a smart phone and can contain a wider range of information than a barcode.

RFID

Radio frequency identification (RFID) is a technique where small wireless tracking devices or tags are embedded onto or into other items. The tags, which are typically about the size of a grain of rice, can be attached to almost anything and will contain data about the item being tracked. Typical uses include tagging pets or livestock or tracking products through a production line. Increasingly, RFID is being used in retail environments to tag products or to enable customer payments.

> **KEYWORD**
>
> **Radio frequency identification (RFID)**: a microscopic device that stores data and transmits it using radio waves – usually used in tags to track items.

RFID works in the following way:

- The tag, which can be microscopically small, contains a chip, which contains the data about the item and a modem to modulate and demodulate the radio signals.
- The tag also contains an antennae to send and receive signals.
- Tags can be either active, which means they have their own power source in the form of a small battery, or passive, which means that they will pick up electromagnetic power when they are in range of a RFID reader.

- Signals and therefore data can be transmitted in both directions using radio frequencies. This may be over a short or long distance depending on what the tags are being used for and how they are powered. The typical range of RFID tag is between 1 and 100 metres.
- Tags may be used simply to track the physical location of the tagged item or the item may transmit data back.

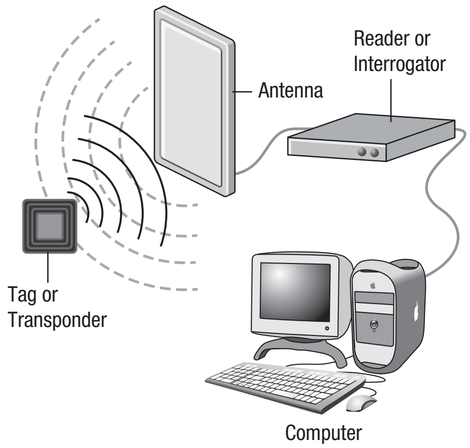

Figure 35.7 An RFID tag system

RFID is a relatively new technology and it is being put to various uses, some of which are controversial. Applications include:

- tracking individuals, particularly vulnerable adults such as Alzheimer's patients
- use in electronic passports to keep track of where people travel
- tags have been added to credit and debit cards to allow users to make contactless payment via RFID in a shop
- transport and distribution companies can use RFID to track shipments and deliveries
- tags have been added to high value items, for example artworks in museums or equipment in hospitals.

Laser printer

A **laser printer** works in the same way as a photocopier to produce high quality black and white and/or colour images. In fact, many laser printers are now 'all-in-one' combining the functions of scanning, copying and printing. They work in the following way:

- A rotating drum inside the printer is coated in a chemical which holds an electrical charge.
- The laser beam is reflected onto the drum and where the light hits the drum the charge is discharged, effectively creating the image on the drum.
- As the drum rotates it picks up toner which is attracted to the charged part of the drum.
- Paper is passed over the drum and by charging the paper with the opposite charge to the toner, the toner is attracted to the paper and away from the drum.
- The paper is heat treated to fuse the toner onto the paper.

KEYWORD

Laser printer: a device that uses lasers and toner to create mono and colour prints.

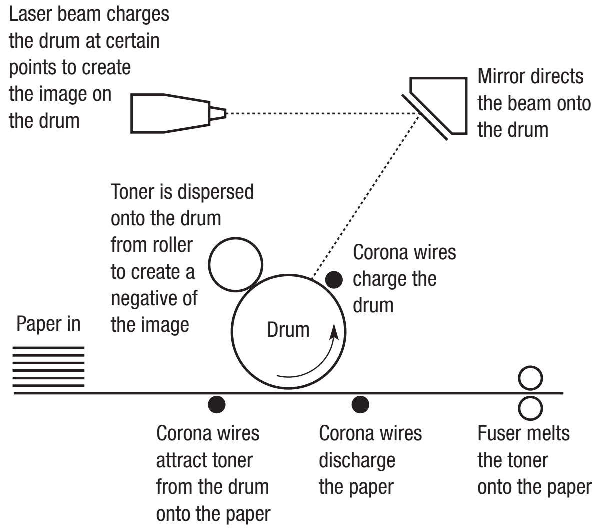

Figure 35.8 The workings of a laser printer

To achieve colour printing, four different coloured toners are used, and the process of transferring the toner to the drum is repeated for each colour. In some printers, a transfer belt is used to hold the four-colour image and therefore transfer it just once from the belt onto the paper, rather than having to pass the paper round the drum four times. Using light on a screen, creating all possible colours needs three primary colours: red, green and blue (RGB). When printing, four colours are needed: cyan, magenta, yellow and black (CMYK).

The cost of laser printers and toner cartridges has been reducing over recent years making them a common choice for personal and business users. Laser printers vary in size from small home printers costing around £100 through to large commercial machines that can cost tens of thousands of pounds.

One of the main advantages of laser printing is the speed, with home printers typically printing around 20 pages per minute with an output of a few hundred pages a month. A typical commercial laser printer can produce 200 pages per minute and is designed to print millions of copies a month.

Magnetic hard disk

Within a computer system, main memory or the Immediate Access Store (IAS) is used to store programs and data. It gives the user high speed access to applications and data, but is only temporary so the contents will be lost when the computer is switched off. To get around this there needs to be some form of permanent storage. There are a number of devices, known as secondary storage devices, that will permanently store data.

Hard disks are constructed of hard metallic material and are hermetically sealed. This is to protect them from being corrupted by dust or other debris. Most hard disks are in fact made up of a number of disks arranged in a stack. The disks are coated with a thin film of magnetic material. Changes in the direction of magnetism represent zeros and ones.

KEYWORD

Hard disk (HDD): a secondary storage device made up of metallic disks that stores data magnetically.

Hard disks spin at speeds between 3600 and 12 500 rpm as a series of heads read from and write to the disks. The heads do not actually touch the surface of the disk but float slightly above it by virtue of the speed at which the disk spins. There is an actuator arm which moves the head across surface of the disk as it spins. The combination of the rotating of the disks with the lateral movement of the arm means that the heads can access every part of the disk surface.

The surface of the disk is organised into concentric tracks and each track is split into sectors each of which can be individually addressed by the operating system. Because the head assembly can read any one of several disks, a cylinder reference is also used to identify which of the disks in the stack is being addressed.

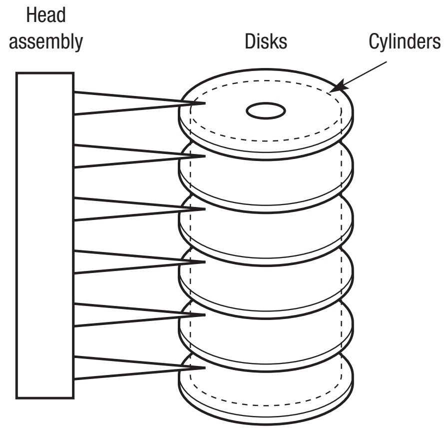

Figure 35.9 A magnetic hard disk array

Each sector has the same capacity and a large file will be stored over a number of sectors. The operating system groups sectors together into clusters to make storage easier to manage. There will be many occasions when a whole cluster is not needed. For example, a file may require five whole clusters and only part of a sixth. In this case, the whole cluster is allocated to the file even though it is not needed. This means that the disk is likely to have redundant space on it.

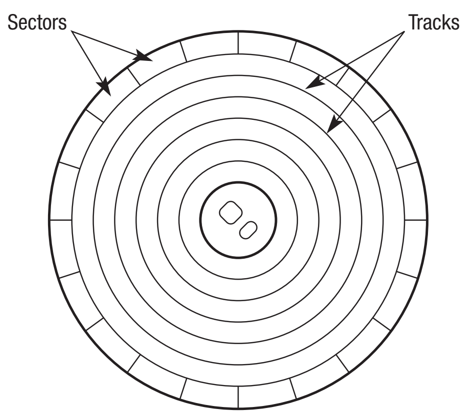

Figure 35.10 Tracks and sectors on a magnetic hard disk

The typical capacity of a hard disk at the time of writing is 1 TB. As hard disks are created with larger capacities there is an issue with the speed at which data can be retrieved from the disk. This is a feature of the physical speed at which it can spin along with the rate at which data can be transferred. In terms of relative speed, magnetic hard disks enable faster access than optical disks, but slower access than solid state disks.

Optical disk

Optical disk is a generic term for all variations of CD, DVD and Blu-Ray that use laser technology to read and write data. An optical disk is made up of one single spiral track that starts in the middle and works its way to the edge of the CD. The laser will read the data that are contained within this track by reading the pits and lands in combination with a sensor that measures how much light is reflected.

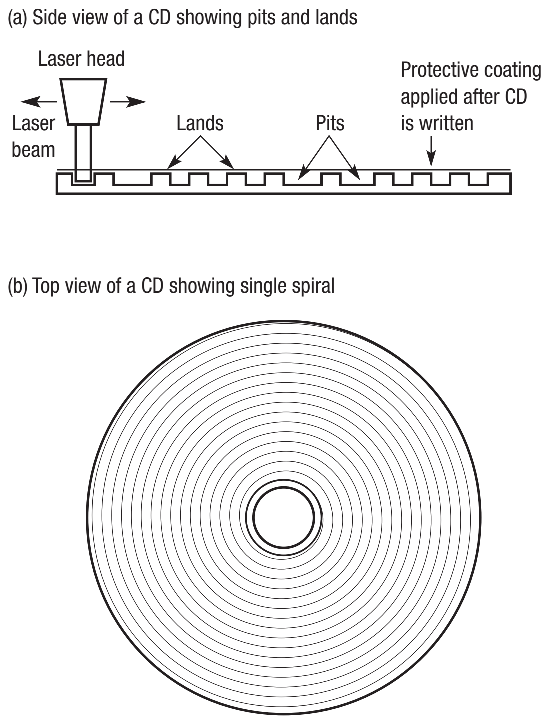

Figure 35.11 The workings of an optical disk

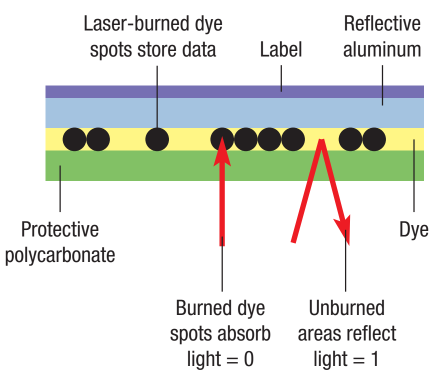

Figure 35.12 The workings of a writeable optical disk

For read-only optical disks, when data is written it is encoded as of a series of bumps, or pits and lands within the track on the disk. A protective layer is then put over the surface to prevent any corruption of the data. The pattern of pits and lands are used to represent data. When the CD is read, the pits and lands are read by the laser which then interprets each as different electrical signals. In turn the electrical signals can be converted into binary codes.

For writeable optical disks, rather than using pits and lands the disk is coated with a photosensitive dye, which is translucent. When writing to the disk, the laser will alter the state of a dye spot that is coated onto the surface making it opaque. The dye reflects a certain amount of light. A write laser alters the density of the dye and a read laser interprets the different densities to create binary patterns which in turn can represent data. Write lasers are higher powered than read lasers.

Solid state disk (SSD)

High-speed access to memory is achieved using memory cards, made up of semiconductors. As these are entirely electronic and have no mechanical parts, high-speed data transfer can be achieved. However, the problem is that they are volatile, which means that as soon as the power is lost, they lose their data. This is why hard disks are used as they use magnetic memory, which is non-volatile so is not lost when the power is switched off. However, access times for magnetic hard disks are relatively slow as the disk has to spin and an arm has to move across the surface of the disk until the data is found. This is known as latency.

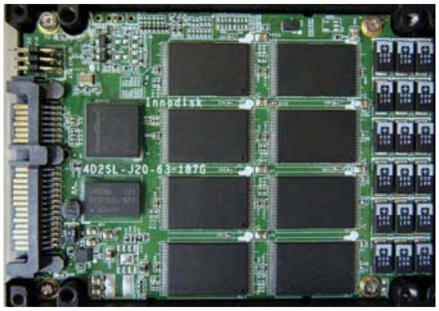

Figure 35.13 Inside a solid state disk

A relatively new development is the solid state disk, also known as a solid state drive, which is made up of semiconductors, but is also non-volatile, meaning that data is not lost when there is no power. A common implementation of this is the flash drive or memory stick, but this technology is also used to replace hard disks in computer systems.

The term solid state disk is misleading is there is no actual disk, instead they use programmable ROM chips, similar to memory cards, hence the alternative description as a drive rather than a disk. However these are stored inside a unit that looks like a hard disk and commonly uses a type of memory called NAND memory. This organises data into blocks in a similar way to a traditional hard disk as described earlier, with a **controller** being used to manage the blocks of data.

KEYWORDS

Controller: in SSDs a controller is needed to organise data into blocks for storage purposes.

Block: in data storage it is the concept of storing data into set groups of bits and bytes of a fixed length.

Floating gate transistor: in SSDs it is a type of non-volatile transistor that stores data even without a power source.

Blocks of a set physical size will be made up of binary data. When reading and writing, data can only be accessed in blocks. On a traditional hard disk, blocks will be allocated to different clusters on the disk. With SSD, blocks are allocated to particular semiconductors. The advantage of this is that data can be added and deleted in blocks to different areas of the drive, so that only small parts of the drive have to be erased and written to. This enables very fast access times.

The semiconductors are able to retain their data due to the type of transistor used. It uses what is a called a **floating gate transistor**, which is able to trap and store charge. A floating gate transistor contains two gates: a floating gate and a control gate. A thin layer of oxide is placed between the two gates, effectively trapping the charge inside the floating gate even when the power is turned off.

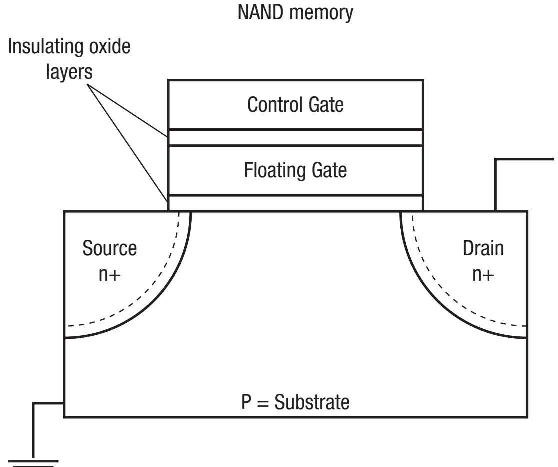

Figure 35.14 The workings of 'flash' memory

As there are no moving parts, SSDs are considered to be more reliable than HDDs as there is less chance of mechanical failure. Also, as there are no physical sectors, an SDD never needs to be defragmented, which means that its performance will not degrade over time as the disk gets full and it won't take longer to find the blocks of data.

Storage devices compared

In this chapter we have looked at three main types of secondary storage. In addition to knowing how they work, you should also have a good understanding of where you would use one type rather than the other and be able to make comparisons between the capabilities of each. Table 35.1 shows a relative comparison.

Table 35.1 Comparison of HDD, SSD, CD/DVD and Blu-ray

	Hard disk (HDD)	Solid state disk (SDD)	Optical disk (CD/DVD)	Optical disk (Blu-ray)
Typical capacity	High (1 TB)	Medium (500 GB)	Low (900 MB to 1.7 GB)	Low to medium (25–50 GB)
Relative cost	Medium	High	Low	Low
Easily portable	External disks are available	External disks are available	Yes	Yes
Relative power consumption	High	Low	High	High
Relative speed of access	Medium	High	Low	Low
Latency	High	Low	Very High	High
Fragmentation		None		
Reliability	Good	Very good	Fair	Fair
Relative physical size	Large	Small	Large	Large

The differing characteristics of each device lend themselves to particular applications. HDD and SSD are broadly comparable in terms of what you would use them for, which is as the main secondary storage device in a PC or laptop.

SSD enable access times up to 100 times faster than HDD and are physically smaller, lending themselves perfectly for use in laptops. However, the relative cost per GB compared to HDD is higher and the largest capacity is limited to about 1 TB (at the time of writing), although this will inevitably increase over time. This has implications for business and organisational users who may require large amounts of storage capacity.

Large-scale users may consider a hybrid implementation where some aspects use SSD and others use HDD. For example, the operating system and applications could be run from computers using SSD and the data storage could be handled using HDD.

Optical disks are a cheap form of portable storage and lend themselves to creating inexpensive back-ups of important data and programs. Original copies of software are also generally stored on optical disks as they are easily transportable and can be stored safely off-site. However, their very limited storage capacity means that they are only generally suitable for small-scale back-ups, normally of home systems. Access time is also very slow on an optical drive, again limiting their use to back-up purposes.

Practice questions can be found at the end of the section on page 298.

KEY POINTS

- Digital cameras work by directing light into sensors made up of millions of cells and then converting this data into digital form.
- Digital cameras are often compared in terms of the number of pixels that they use to create an image.
- Three colours (red, green, blue) are needed to create all possible colours.
- Laser printers work by transferring toner off a drum and onto paper with electrical charge.
- Four print colours (cyan, magenta, yellow and black) are required to create all possible colours.
- RFID tags are tiny devices that can be attached to anything and transmit a signal containing data that can be picked up by a reader.
- Optical disks such as CDs and DVD use lasers to read pits and lands on the surface of the disk that are encoded to represent data.
- Magnetic hard disks are made up of an array of metallic disks that are read by a reading head that floats across the surface.
- Solid state disks used programmable ROM chips.

TASKS

1 What are the key differences between the way an HDD works and the way an SSD works?

2 What is the purpose of an RGB filter?

3 Identify the most appropriate storage device in the following scenarios. Justify your choice.
   a) Creating a back-up of a school network each night.
   b) Transferring a document from home to school.
   c) Creating a back-up of all the work on a stand-alone computer.
   d) Storing a feature-length movie.
   e) Storing a number of audio files.

4 Explain how a digital camera turns analogue data into digital data.

5 Explain the common formats that are possible for digital images. Why are the different formats available?

6 How does RFID work and what are the possible applications of it?

7 How do laser printers work?

STUDY / RESEARCH TASKS

1 Explain the difference between DVD-ROM, DVD-R and DVD-RW.

2 How do USB 'sticks' work?

3 Research the latest specification for SSDs. What is the limiting factor on the storage capacity of this type of drive?

4 Provide a detailed comparison of inkjet and laser printers in terms of speed, quality, initial cost and ongoing costs.

5 Will increasing the number of megapixels on a digital camera always lead to a better quality image?

Section Seven: Practice questions

1 Processors use the fetch–execute cycle.

a) Describe in full sentences how the fetch–execute cycle works in relation to the main registers: Current Instruction Register (CIR), Memory Address Register (MAR), Memory Buffer Register (MBR), Program Counter (PC) and Status Register (SR).

b) Explain the three types of buses used in a computer and what they do during the fetch–execute cycle.

c) An interrupt will suspend execution of the current program by the processor. What is an interrupt?

2 Explain the difference between the Von Neumann and Harvard architectures.

3 Write assembly language instructions that would perform the same task as the pseudo-code below. Use the registers r1 and r2 to store the variables A and B.

```
If A = 1 THEN
  B ← 2
ELSE
  A ← A + 1
ENDIF
```

4 Two alternatives for data storage are hard disk drives (HDD) and solid state disks (SSD).

a) Describe the key principles of how each work.

b) State two advantages of HDD over SSD.

c) State two advantages of SSD over HDD.

5 Explain how the following can lead to faster execution of programs:

a) increasing the clock speed

b) modifying the width of the data bus

c) utilising cache memory.

6 'Police officers would be able to respond faster to emergency calls and spend more time on the street if they made better use of modern technology.' Why might some people object to police officers using new technology?

7 Name the most suitable storage medium for each of the following.

a) Backing up a 30 Kb email message

b) Backing up 2 Gb of data

c) Distributing a software package requiring 500 Mb of storage space.