Answers to Coursebook questions – Chapter 8.1

1 **a** $3 = 1 \times 2^1 + 1 \times 2^0 = 11$

b $10 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 1010$

c $18 = 1 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 10010$

d $31 = 1 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 = 11111$

2 **a** $110 = 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 6$

b $1100 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0 = 12$

c $0101 = 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 5$

d $11110 = 1 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 30$

3 **a** **i** An analogue signal is a continuous signal that can have a numerical value that is any number between two extreme values.

ii A digital signal is a discrete signal that can take only 2 values, 0 or 1.

b **i** Suppose you speak into a microphone. Your voice creates an analogue signal. If the microphone is connected to an oscilloscope, what you see on the oscilloscope screen is a representation of the analogue signal.

ii Light falls on the collecting area of a digital camera. Electric charge builds up in each pixel of the camera. The values of the charges in each pixel are turned into binary numbers. The sequence of 0s and 1s that are created is a digital signal representing the charge in the pixels.

4 We read off the values of the signal from the graph and round. We then express the answer as a binary number.

Time/ms	**Signal strength/mV**	**Binary code**
0.0	0.0 = 0	000
0.1	2.0 = 2	010
0.2	4.2 = 4	100
0.3	5.8 = 6	110
0.4	6.8 = 7	111
0.5	7.0 = 7	111
0.6	6.8 = 7	111
0.7	5.8 = 6	110
0.8	4.2 = 4	100
0.9	2.0 = 2	010
1.0	0.0 = 0	000

The digital signals are shown in the answers (see page 809 in *Physics for the IB Diploma*).

5 **a** We convert the binary numbers into decimals.

Binary code	**Signal strength**
1100	12
1001	9
0010	2
0000	0
0010	2
1000	8
1110	14
1111	15

b and **c** The digital signals and the reconstructed analogue signal are shown in the answers (see page 809 in *Physics for the IB Diploma*).

6 A simple estimate without getting into mathematical details involving calculus is the following. Imagine that each spiral is in fact a circle and that the next circle has a radius that is larger by 1600 nm. Then the radius of each spiral (circle) is part of an arithmetic series with first term zero and common difference 1600 nm.
From mathematics, $r_n = r_1 + (n-1)d$. The nth circle has radius 6 cm and so the number n of spirals is found from $6\times 10^{-2} = (n-1)\times 1600\times 10^{-9}$, i.e. $n \approx 3.75\times 10^{4}$.
The length of each spiral (circle) is $C_n = 2\pi r_n$ and so is also part of an arithmetic series.
The total length is (summing an arithmetic series)

$$L = 2\pi\left(\frac{n}{2}(0+(n-1)\times 1600\times 10^{-9})\right) \approx 7\times 10^{3}\ \text{m}.$$

(This can be improved by assuming a thickness for the spiral and taking into account the hole at the centre of the CD; these do not change the answer in an appreciable way.)

7 The number of bits is $44100\times 32\times 4.0\times 60 = 3.39\times 10^{8}$ bits
or $\dfrac{3.39\times 10^{8}}{8} = 4.23\times 10^{7}$ bytes or about 42 Mbytes.

8 The number of bits is $44100\times 2\times 16\times 80\times 60 = 6.77\times 10^{9}$ bits
or $\dfrac{6.77\times 10^{9}}{8} = 8.47\times 10^{7}$ bytes or about 847 Mbytes.

9 **a** The signal to be recorded is first turned into a digital signal, i.e. a series of 0s and 1s. For every 1 a mark is made along a long spiral track on the surface of the CD.

b The laser shines down on to the boundary between a pit and a land. The beam is reflected from both the pit and the land and is received at a sensor. The part of the beam that is reflected from the land travels an extra distance of 2d before getting to the sensor where d is the pit depth. There will be destructive interference if the path difference is half a wavelength, i.e. if $2d = \dfrac{\lambda}{2} \Rightarrow d = \dfrac{\lambda}{4}$

c $d = \dfrac{\lambda}{4} = \dfrac{680\times 10^{-9}}{4} = 170\times 10^{-9}\ \text{m}.$

10

There is a problem with this question in that the data given are not mutually consistent. A consistent version is as follows:

A CD has an inner radius of r_1 and an outer radius of $r_2 = 6.0\text{ cm}$. The rate of rotation at a spiral of radius *r* is *f*.

a Show that $f \propto \frac{1}{r}$.

b The rate of rotation at the outer radius is 200 rpm and at the inner it is 500 rpm. Calculate the inner radius of the CD.

c The playing time of the CD is 80 min.

i Estimate the speed at which the pickup sensor of the CD moves,

ii the number of revolutions the CD makes during playback and

iii the separation of two consecutive spiral tracks for this CD.

Answers

a The speed of rotation is $v = \frac{2\pi r}{T} = 2\pi r f$.

Since the speed is constant we have that $f \propto \frac{1}{r}$.

b So if the outer radius where the frequency is 200 rpm is 6 cm the inner one where the rate of rotation is 500 rpm must be $r_1 = 6.0 \times \frac{200}{500} = 2.4\text{ cm}$.

c **i** The sensor must cover a distance of $6.0 - 2.4 = 3.6\text{ cm}$ in 80 min and so its average speed is $\frac{3.6}{80 \times 60} = 7.5 \times 10^{-4}\text{ cm s}^{-1}$.

ii The average rotation rate is $\frac{200 + 500}{2} = 350\text{ r.p.m}$ and so in 80 minutes the number of revolutions is $350 \times 80 = 28000$.

iii The sensor covers a distance of 3.6 cm after 28 000 revolutions. After each revolution the sensor moves a distance equal to the separation of the tracks and so the separation is $\frac{3.6}{28000} = 1.3 \times 10^{-6}\text{ m}$.

11 **a** $\lambda = \dfrac{740 \times 10^{-9}}{1.52} = 487 \times 10^{-9}$ m .

b $d = \dfrac{\lambda}{4} = \dfrac{487 \times 10^{-9}}{4} = 122 \times 10^{-9}$ m .

12 It is diffraction. The tracks on the CD act as the slits of a diffraction grating. Depending on the angle at which one looks at the CD, different wavelengths of light suffer constructive interference and those wavelengths lend their colour to the CD.

13 The main reason is the fact that the pit length is much shorter, which means that more data can be stored on the same length of the spiral track.

14 These include the fact that different parts of the recording may be accessed instantly without sequentially going through the recording from the beginning, that the recording may be played on a computer, that it may be sent electronically etc.

15 The laser beam must be able to detect the pit/land boundary. A general principle of resolution says that to resolve anything of size *d* the wavelength used must be of the same order of magnitude or smaller. Since the length of a pit can be as small as 850 nm for a CD (and smaller in the case of a DVD) the wavelength used must be smaller than this. Otherwise, the laser will not be able to 'see' the pit itself, let alone the pit–land boundary. So to get large storage capacity means smaller pits, and that in turn means smaller wavelengths.

16 Because the recording makes marks on the vinyl that are directly proportional to the sound signal being recorded.

17 It is analogue. The film records the intensity of light incident at various points on the film.

18 They are both digital storage devices with direct access and both use magnetic properties to store the data. The floppy disc has a very limited storage capacity and is much more susceptible to damage.

19 Advantages include: the large amount of data that can be stored, the ease with which the stored data can be transferred both physically and electronically, the fact that the stored data can be manipulated and edited and also the fact that digital storage is safer (and more secure) and can last longer.

