Module 3 Physics in Action
Imaging & Signalling

T test booklet

Name:

Target Grade :

Date	T test	%	Corrections made

Progress tracker

Shade in squares to indicate your level of performance in each test. Do this in the order they were taken.
(for the purposes of this grades are based on % marks where A* 90, A 80 , B 70 etc..)

If you have to shade off the chart it is hopefully above rather than below

TG +2																
TG +1																
Target grade																
TG -1																
TG-2																

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3 Simon needs glasses for reading. Without glasses the nearest he can comfortably focus is 1.0 m away. He would like a normal reading distance of 0.25 m. This is illustrated in Fig. 3 below.

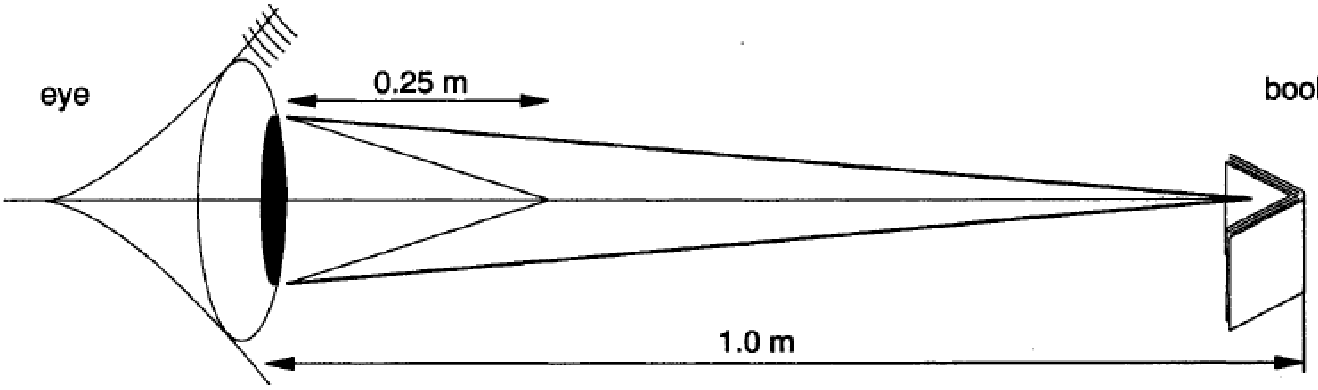


Fig. 3 (not to scale)

(a) What is the difference in curvature between the wavefronts arriving at his eye from these two distances?

difference in curvature = ... dioptre [2]

(b) What power is needed for his reading lenses?

power of lenses = ... dioptre [1]

2860Jun01

4 Jon measures the focal length *f* of a convex lens. He repeats the measurement several times. The mean value of the measurement is 0.125 m. The range over which the measurements vary due to experimental uncertainty is ± 0.005 m.

Jon correctly records the final result with the equation

$$f = 0.125 \pm 0.005\,\text{m}.$$

(a) The minimum value for *f* indicated by this equation is 0.120 m.

Write down the maximum value for *f* indicated by this equation.

maximum value for *f* = ...m [1]

(b) Jon calculates the power P of the lens using the relationship

$$P = \frac{1}{f}.$$

For the mean value $f = 0.125\,\text{m}$ $\quad P = 8.00\,\text{D}$.

Calculate the maximum value of the power corresponding to the minimum value of the focal length 0.120 m. Consider sensible **significant figures**.

maximum power = ...D [1]

(c) Complete the equation below to indicate the range of values within which the power can be expected to lie.

P = 8.0 ± .... D [1]

2860 Jan04

7 This question is about a beam of light emitted by an LED.
Light waves are emitted from a diode junction encapsulated in a curved plastic lens as shown in Fig. 7.1.

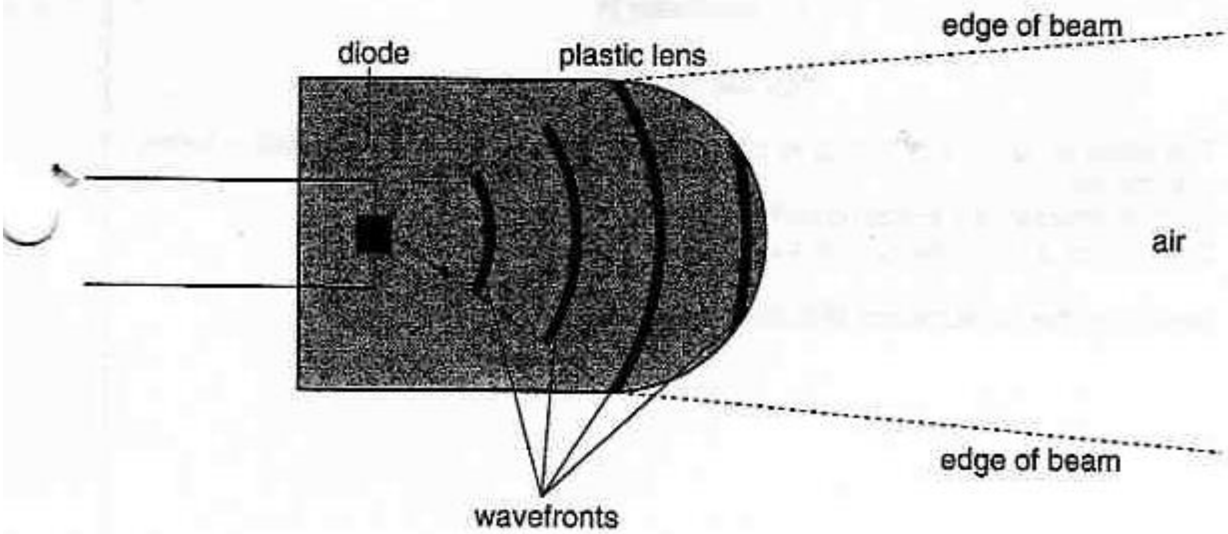


Fig. 7.1

Complete Fig. 7.1 to show **three** successive wavefronts in the beam after they have completely emerged from the plastic lens into air. [2]

2860Jun03

9 A slide projector produces a magnified focused image of a slide as shown in Fig. 9.

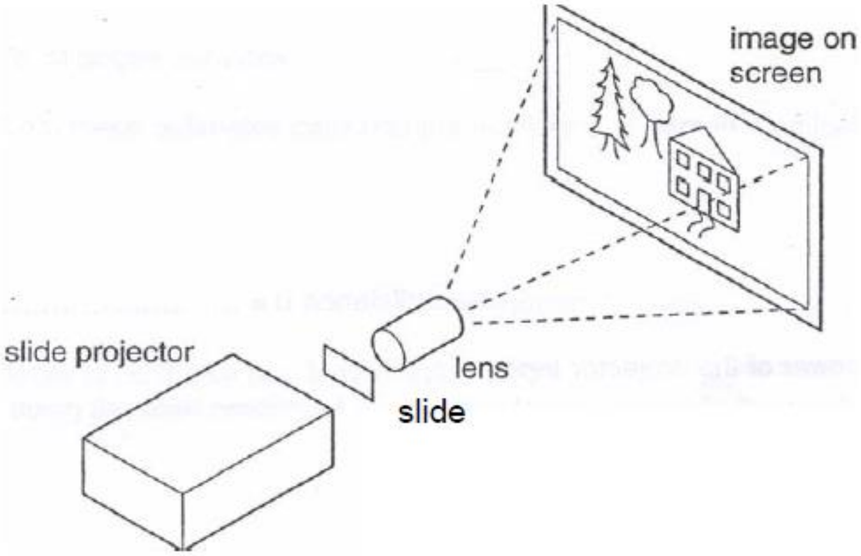


Fig. 9

(a) State the type of lens required for the projector.

[1]

(b) The image on the screen is projected the correct way up.
How must the slide be placed in the projector to achieve this?

[1]

(c) The width of the slide is 35 mm. If the image on the screen is to be 1.75 m wide, what is the magnification?

magnification = ...[2]

(d) The image is 4.0 m from the projector lens.
Calculate the object distance u from the slide to the lens.

object distance u = ...[2]

(e) Calculate the power of the projector lens.

power of lens = ... D [3]

3 The equation describing image formation by a lens is:

$$\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$$

(a) Complete the following explanation of this equation in words.

The curvature of the wavefronts leaving the lens is equal to

....

plus the ....

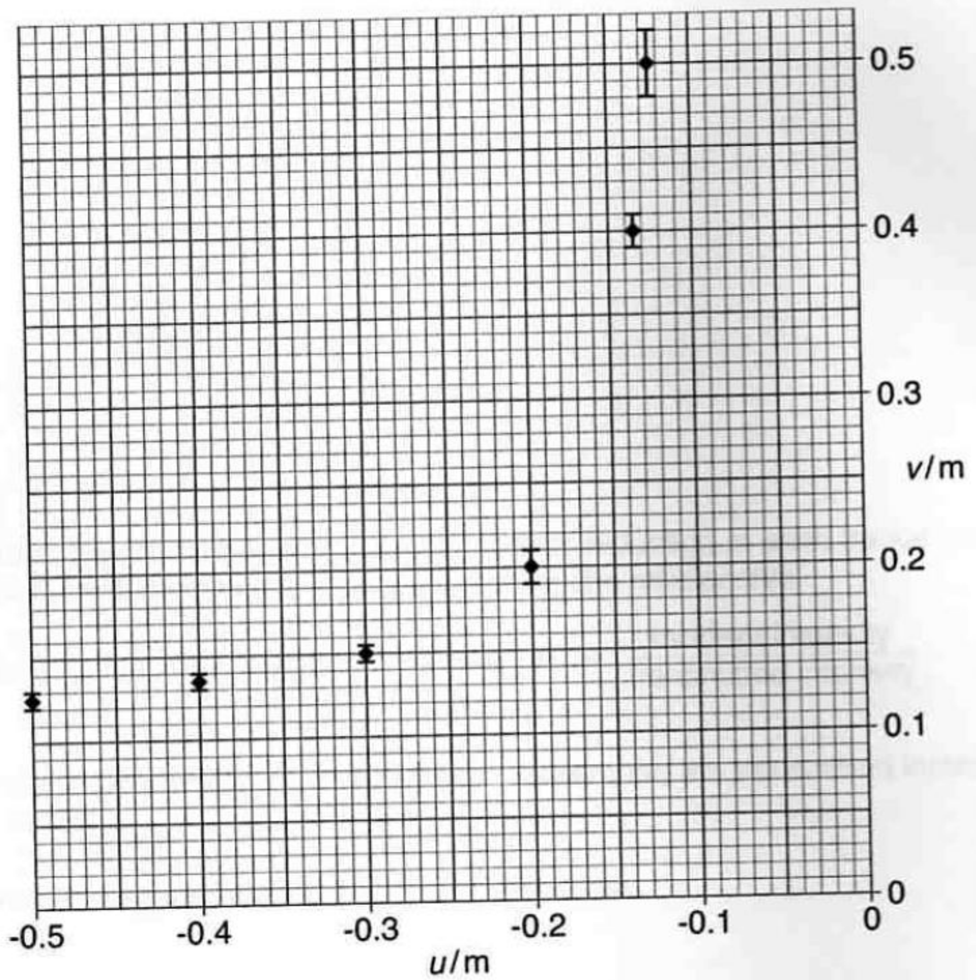
[2]

(b) State where an object should be placed so that the image distance is approximately equal to the focal length.

[1]

11 A student uses a lens to form the image of a lamp filament on a screen.

(a) She obtains values of image distance *v* for different values of the object distance *u*. She plots a graph as shown below.



(i) The uncertainty (spread) in *v* values is indicated by the vertical error bars. The uncertainty in the *u* values is negligible.

Plot the point from the student's data given in the table below.
Include the error bar, to show the uncertainty.

object distance *u* / m	image distance *v* / m	uncertainty in *v* ± *v* / m
–0.150	0.300	0.010

[2]

(ii) Draw the curve of best fit for the data points on the graph above. [1]

(b) **(i)** Suggest a practical difficulty that could lead to the uncertainty in the measurement of v.

(ii) Suggest how this difficulty might be overcome.

[2]

(c) **(i)** The student uses the data to calculate the focal length of the lens using the relationship

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}.$$

Complete the row in the table below for the curvatures of the wavefronts entering and leaving the lens, and for the curvature added by the lens. [1]

object distance u / m	image distance v / m	curvature entering lens $\frac{1}{u}$ / D	curvature leaving lens $\frac{1}{v}$ / D	curvature added by lens $\left\{\frac{1}{v} - \frac{1}{u}\right\}$ / D
–0.150	0.300			

(ii) For **one** other data point on the graph, show that the curvature added to wavefronts by the lens is **approximately constant** by completing the row in the table below.

[1]

object distance u / m	image distance v / m	curvature entering lens $\frac{1}{u}$ / D	curvature leaving lens $\frac{1}{v}$ / D	curvature added by lens $\left\{\frac{1}{v} - \frac{1}{u}\right\}$ / D

(iii) Calculate the focal length of the lens used in this experiment.

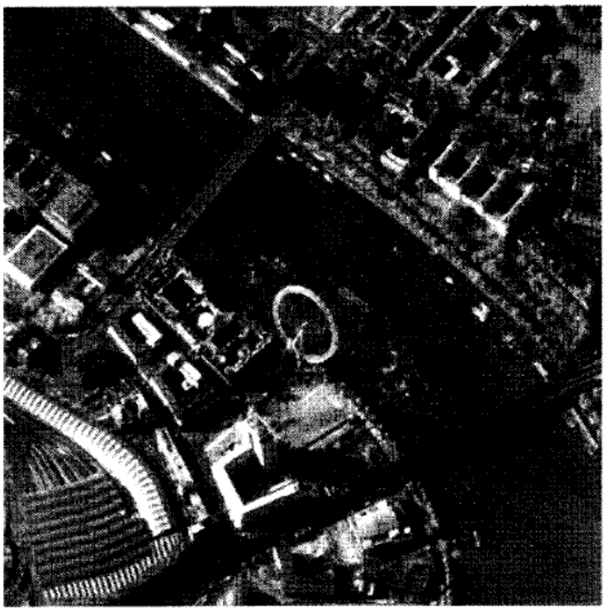
focal length = ... m [1]

(iv) Suggest how you could use the student's data to estimate the uncertainty in the value of the focal length.

[2]

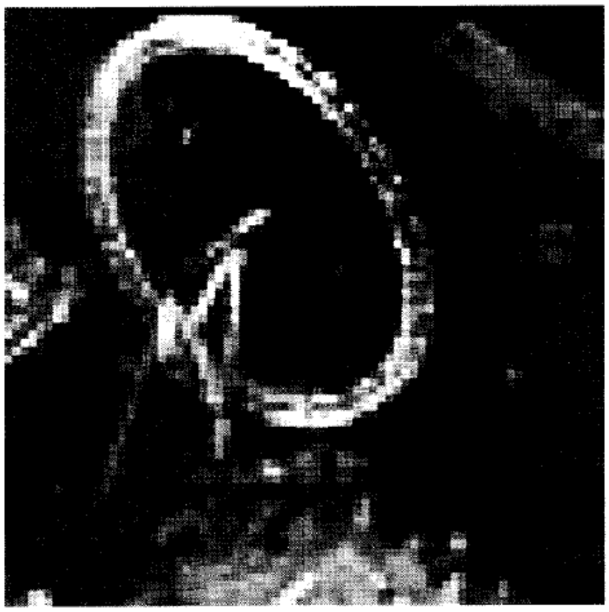
[Total: 10]

9 The London Eye was photographed from a satellite 200 km above the Earth.
Fig. 9.1 is the original image which is 400 × 400 pixels. Fig. 9.2 is a magnified view of part of the original showing 75 × 75 individual pixels.



400 pixels

Fig. 9.1



75 pixels

Fig. 9.2

(a) Estimate the number of pixels along a diameter of the image of the London Eye.

pixels along diameter = ... [1]

(b) The London Eye is about 135 m in diameter.

Estimate the resolution of the image. Give your answer to 1 significant figure.

resolution is about .... m / pixel [1]

(c) Explain why both images in Fig. 9.1 and Fig. 9.2 have the **same** resolution.

[1]

(d) The original image Fig. 9.1 has 400 × 400 pixels and a greyscale of 8 bits per pixel.

Calculate the amount of information stored in the original image Fig. 9.1.

information = ... bits [1]

(e) The convex lens in the satellite camera forms a real image 0.16 m behind the lens. The satellite camera is focused on the ground 200 km directly below the satellite, as shown in Fig. 9.3.

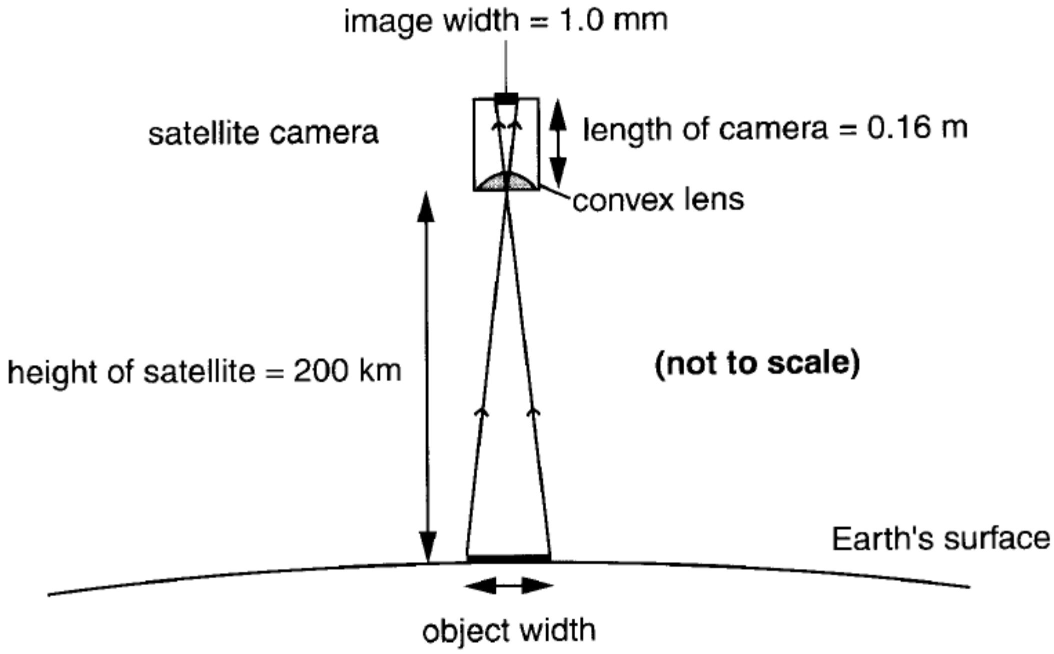


Fig. 9.3

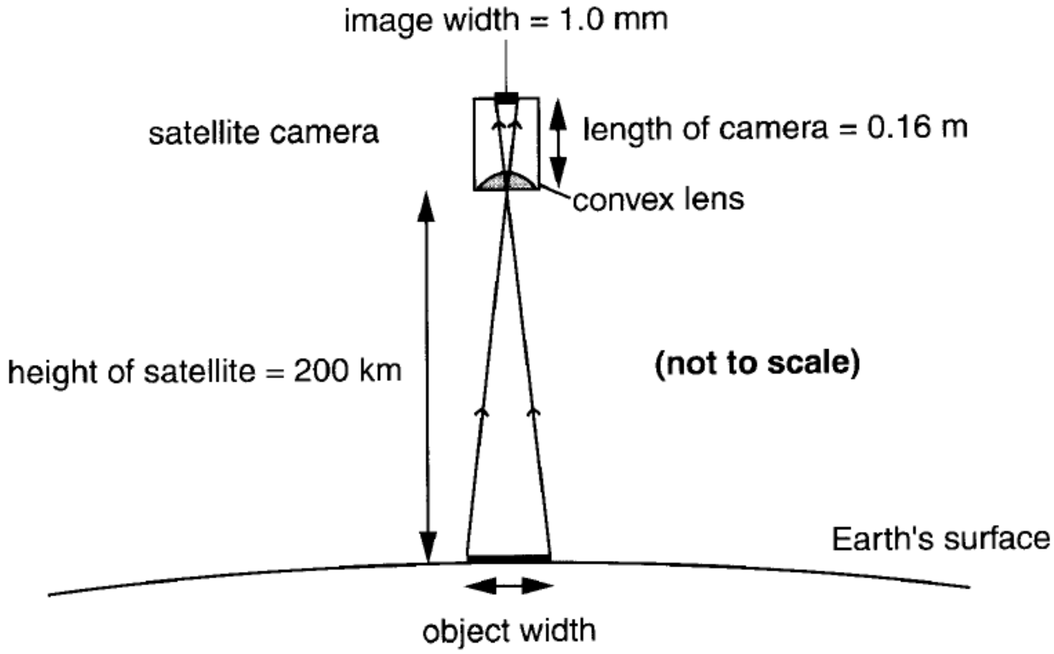
(i) Show that the magnification is 8×10^{-7}.

[1]

(ii) Calculate the width of object on the Earth's surface that would produce an image that is 1.0 mm wide in the camera.

width of object = ... m [1]

(e) The convex lens in the satellite camera forms a real image 0.16 m behind the lens. The satellite camera is focused on the ground 200 km directly below the satellite, as shown in Fig. 9.3.



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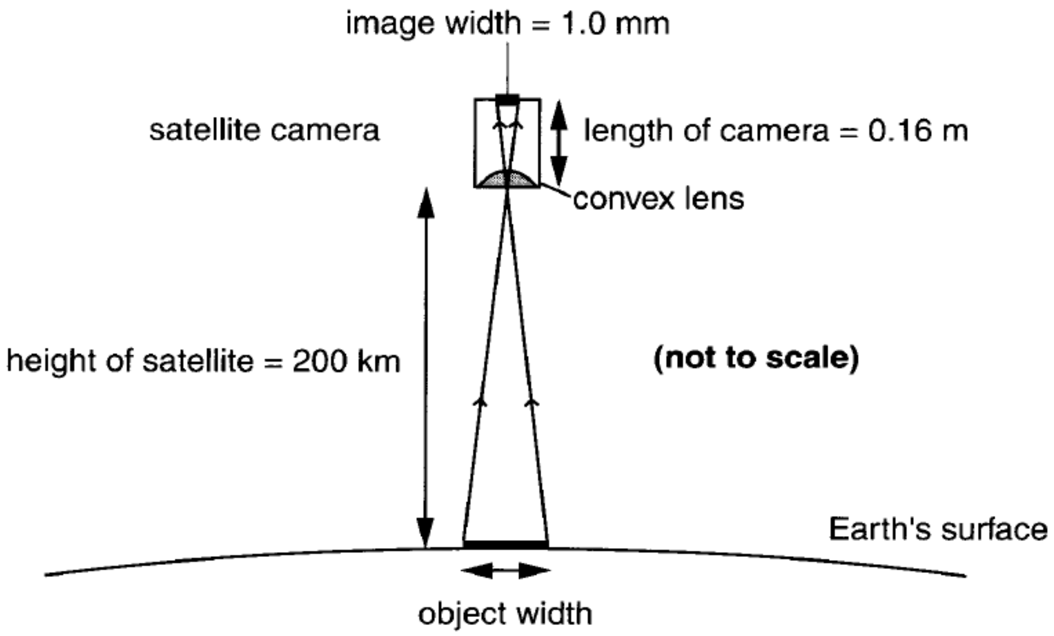


Fig. 9.3 (repeated)

(iii) Using the geometry of Fig. 9.3, explain why the ratios

$$\frac{\text{image distance}}{\text{object distance}} \text{ and } \frac{\text{image width}}{\text{object width}} \text{ are equal.}$$

[1]

(f) Using the lens equation

$$\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$$

explain why, for this camera, the image distance v is very nearly equal to the focal length f of the lens.

[2]

8 This question compares sending information by fax and by e-mail.

(a) A fax system converts an A4 page into an array of black (1) or white (0) pixels. There are 10 pixels per mm.
A letter **M** may occupy a square of side 2mm as shown magnified in Fig. 8.

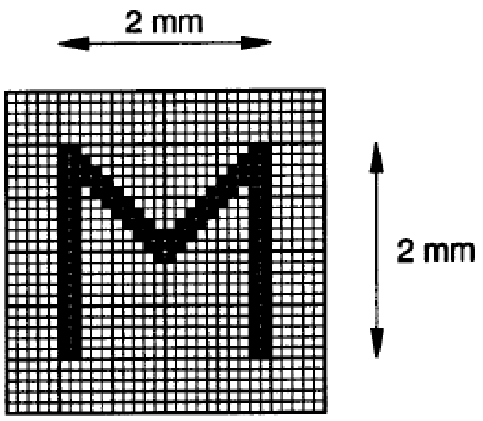


Fig. 8

(i) How many pixels are there in the 2 mm × 2 mm array?

number of pixels = ... [1]

(ii) How many bits are needed to code for each black or white pixel?

number of bits / pixel = ... [1]

(iii) How many bits are needed to code a letter (such as **M**) which occupies this area? (Assume no information compression is used).

number of bits = ... [1]

(b) **(i)** In e-mail, the letter **M** will be coded by a one byte international code. How many bits make a byte?

number of bits / byte = ... [1]

(ii) Each keyboard character (letter, number, punctuation etc.), has its own one byte code. How many different characters can be coded in a one byte code?

number of characters = ... [1]

(c) Compare and comment on the efficiency of coding information using fax and e-mail.

[2]

2 The charge coupled device (CCD) sensor in a digital camera has an array of pixels 1536 wide by 1024 high. Each pixel value is stored as an eight-bit number.

Show that the information stored in one complete image recorded by the CCD is greater than 1 Mbyte.

[3]

5 An overhead projector uses a converging lens to produce a magnified image of a transparency, as shown below.

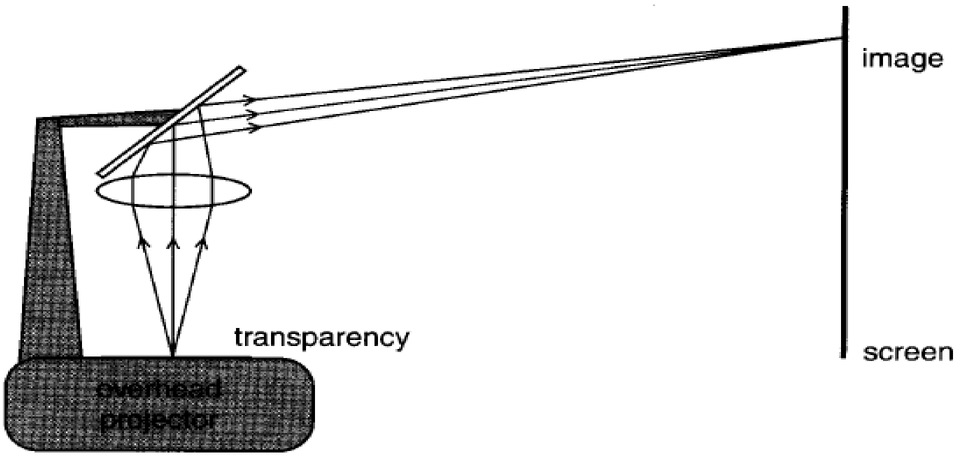


Fig. 5.1

The transparency is 0.20 m wide, and the image is 1.20 m wide.

(a) Calculate the linear magnification of the system.

linear magnification = ... [1]

(b) The image distance $v = 2.40$ m from the projector lens.

Use your answer to **(a)** to calculate the object distance u of the transparency from the lens.

[2]

14 This question is about an imaging system, producing data that can be stored and displayed by a computer.

(a) State your own example of such an imaging system.

Describe **three** pieces of information that could be obtained from the image.

example

information

1.

2.

3. [4]

(b) (i) State the kind of waves or radiation used in the imaging system.

[1]

(ii) Describe how the data for the image are obtained.
You may find it useful to use a labelled diagram.

[3]

(c) (i) Explain the meaning of the term *image resolution* using your example.

Estimate a typical resolution for the image you have chosen.

(ii) Discuss **two** factors that might limit the resolution in your imaging system.

[5]

11 Fig. 11.1 and 11.2 show images captured by cameras aboard the Mars Global Surveyor satellite.
Fig. 11.1 shows the 140 km-wide Holden Crater.
Fig. 11.2 shows the region indicated inside Holden Crater photographed using a much higher resolution camera.

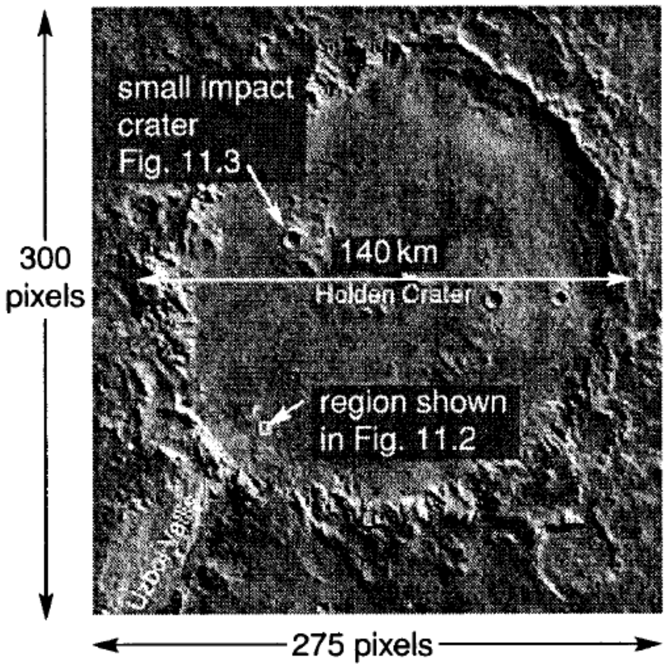


Fig. 11.1 (low resolution)

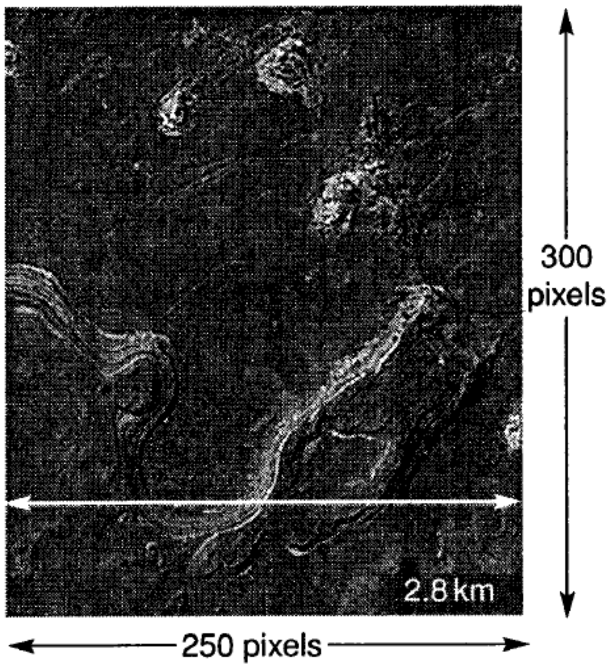


Fig. 11.2 (high resolution)

(a) **(i)** Estimate the resolution of the image shown in Fig. 11.1.

resolution = ... m pixel^{-1} [2]

(ii) Estimate the ratio

$$\frac{\text{resolution of Fig. 11.1}}{\text{resolution of Fig. 11.2}}.$$

ratio = ...[1]

(iii) Suggest and explain **one** way in which the resolution of this imaging system could be improved.

[2]

(b) The images shown in Fig. 11.1 and 11.2 have been processed to reduce noise.

(i) State what is meant by *noise* in an image.

[1]

(ii) Explain how some of the pixel values could have been altered to reduce the noise.

[1]

(c) Physicists analysing the image are trying to find the shape of an impact crater.
Fig. 11.3 shows a magnified image of the small impact crater indicated in Fig. 11.1. The crater wall casts a shadow inside the impact crater.

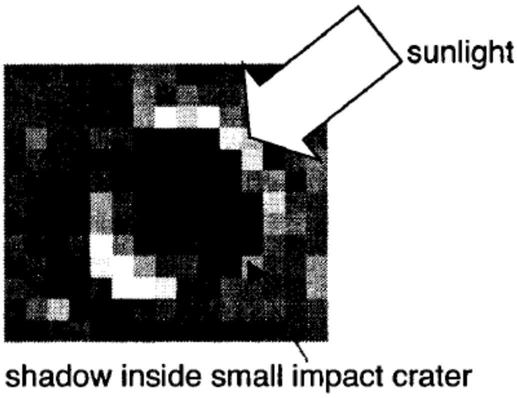


Fig. 11.3

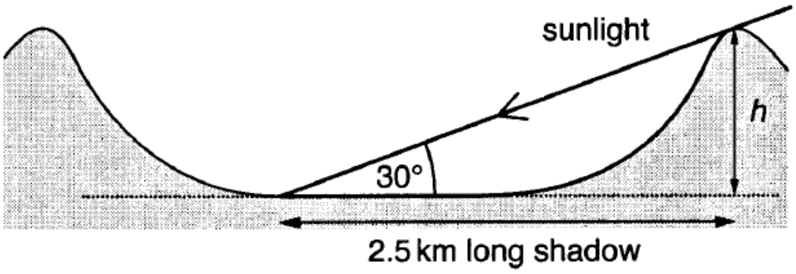


Fig. 11.4

The Sun is at an angle 30° above the horizontal causing the shadow about 2.5 km long, as shown in Fig. 11.4.

Estimate the height *h* of the crater rim above the crater floor, making your method clear.

h = ...m [2]

[Total: 9]

7 This question is about the fixed focus disposable camera, shown in Fig. 7.1.

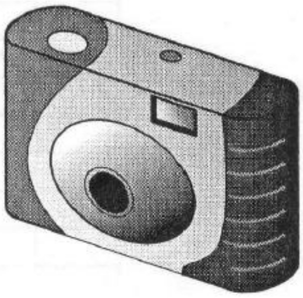


Fig. 7.1

(a) Fig. 7.2 shows three wavefronts of light moving towards a lens from a very distant object.

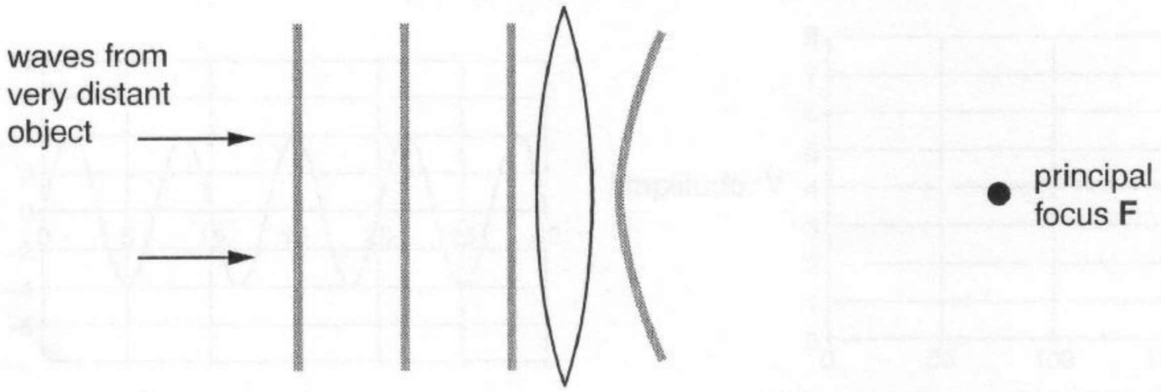


Fig. 7.2

On Fig. 7.2, draw the wavefronts of light after passing through the lens, as they move towards **F** the principal focus of the lens.
One wavefront has been drawn for you. [1]

(b) The focal length *f* of the camera lens is 12.5 mm.

Calculate the power of the lens, in dioptres.

power = ... D [2]

(c) **(i)** The camera is used to photograph a very distant object.

The film is 12.5 mm behind the lens.

Using the equation $\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$

explain why the image is in focus on the film.

[3]

(ii) Calculate the distance of the image from the lens, when the object is 2.00 m in front of the lens.

Give your answer to an appropriate number of significant figures.

image distance = ... mm [3]

(d) An advertisement for the camera states that the depth of field is from 2.0 m to infinity(∞). The depth of field is the range of object distances which give a reasonable focus on the film.

Suggest how your answer to **(c)(ii)** supports this statement.

[1]

[Total: 10]

2 A portable MP3 player has a memory of 64 Mbytes.
A song requires about 2 Mbytes of memory for storage in the MP3 player.

(a) Estimate the number of songs that the MP3 memory can store.

number of songs = ... [1]

(b) The same song on a CD is sampled at 44.1 kHz using 4 bytes per sample.
The song lasts for 150 s.

(i) Show that the information stored on the music CD is about 26 Mbytes.

[2]

(ii) Suggest **one** way in which the amount of memory needed to store a song can be reduced.

[1]

5 Fig. 5.1 shows an analogue voltage signal varying in time. It is sampled every 1.0 ms for conversion into a digital signal.

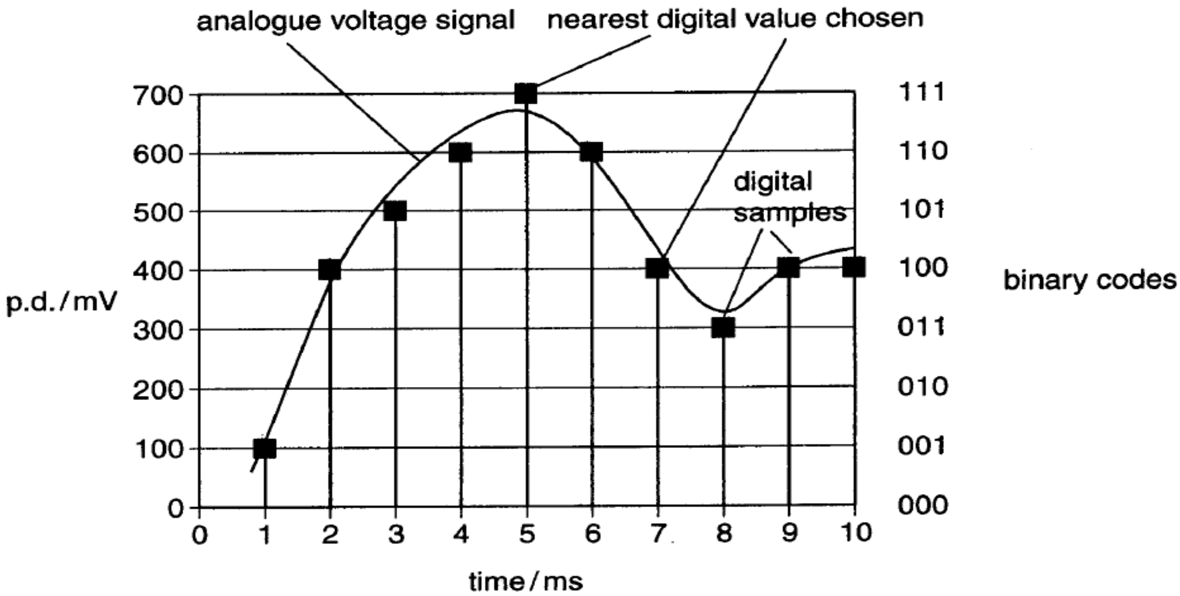


Fig. 5.1

(a) (i) State the number of bits used for the binary code of each sample in Fig. 5.1.

number of bits per sample = ... [1]

(ii) State the number of different signal levels defined by this number of bits.

number of signal levels = ... [1]

(b) Fig. 5.1 illustrates that the digital signals, introduced during digital sampling, can differ from the analogue signal.

(i) State the largest difference (measured in mV) that could be introduced in this example.

largest difference = ... mV [1]

(ii) Suggest **one** way in which these differences could be reduced to make the sampling more accurate.

[1]

7 A spectrum analyser displays the intensity of sound in five ranges from low (bass) to high (treble). Fig. 7.1 shows the display.

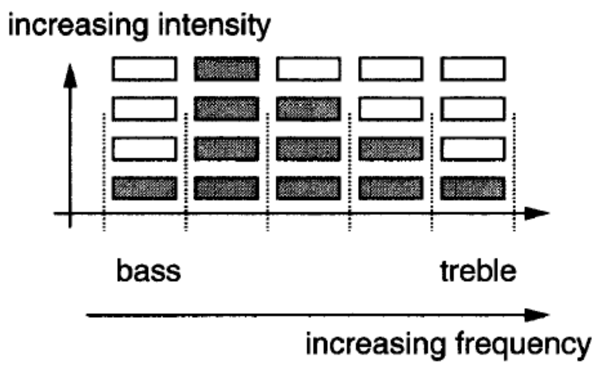


Fig. 7.1

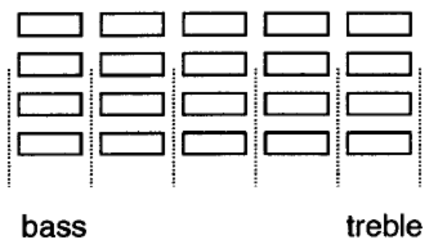


Fig. 7.2

More bars on the display shown in Fig. 7.1 light up when the sound in that frequency range is more intense. The lit up bars are shown as shaded.

Fig. 7.1 shows the display at one instant during the playback of a song on an audio system.

The listener then **boosts the bass** and **filters out the treble**.

Sketch on Fig. 7.2 a possible appearance of the spectrum analyser after this change, at the same instant of the new playback of the song.

[2]

8 This question is about converting an analogue musical sound signal into a digital signal so that it may be written to a CD.

This is for high fidelity (good quality) sound reproduction.

The graph Fig. 8.1 shows part of the analogue waveform and the digital sampling points.

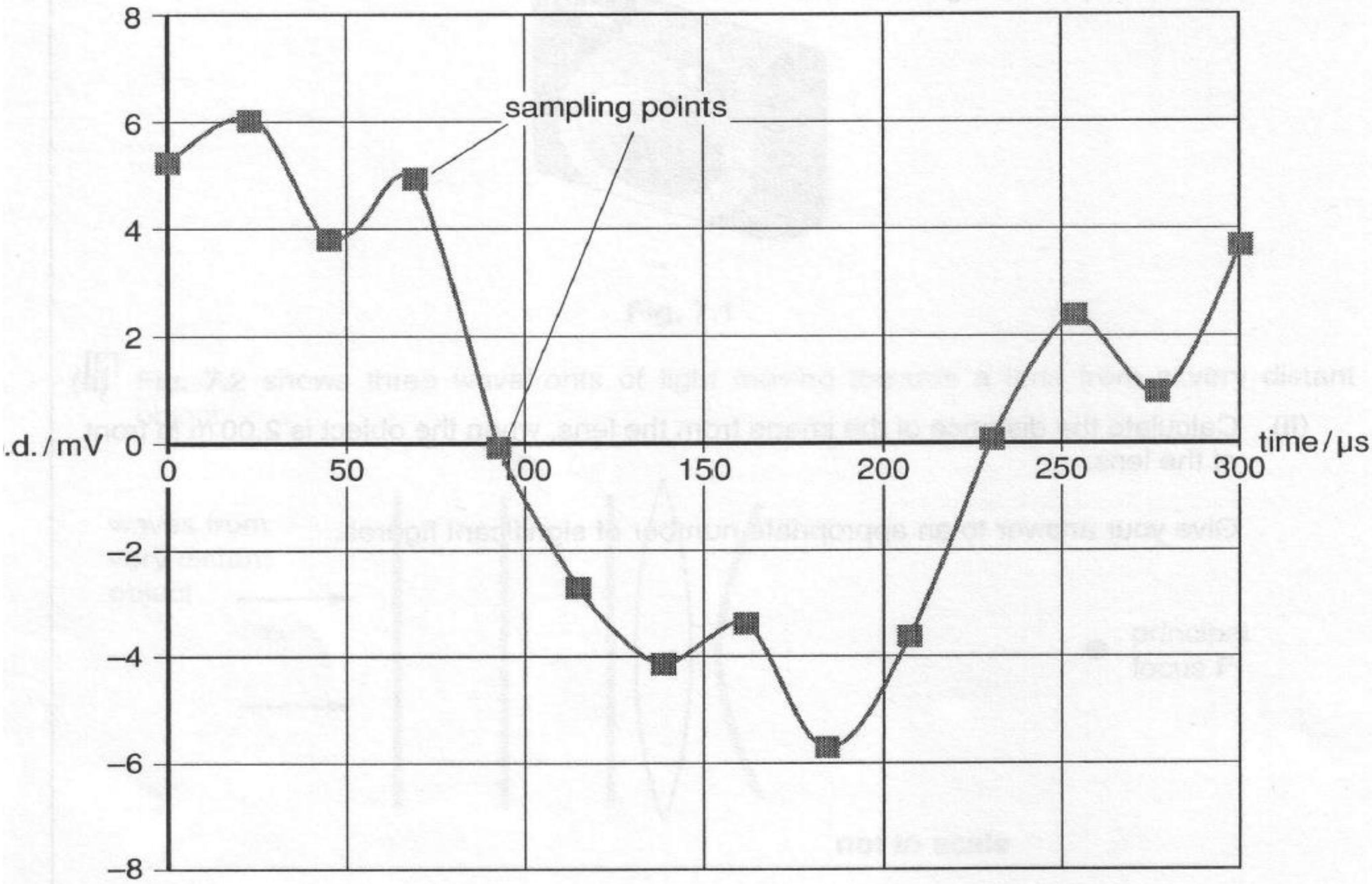


Fig. 8.1

(a) **(i)** The sampling rate is 44 kHz.

Show that the time between samples is between 20 μs and 25 μs.

[2]

(ii) The system uses 16 bit sampling.

Show that the number of voltage levels coded by 16 bits is about 66 000.

[1]

(iii) The signal voltage covers a range of 16 mV (between ± 8 mV).

Calculate the voltage resolution of this system.

voltage resolution = ... μV [2]

(b) A telephone line uses 8 bit sampling at an information rate of 64 kbits per second.

Explain the **disadvantages** of this sound reproduction system compared with the high quality system described in **(a)**.

[3]

[Total: 8]

7 Fig. 7.1 shows two waveforms displayed on an oscilloscope screen.
One is the original analogue signal from a recording of a dolphin whistling.
The other is the result of digitising it to the nearest of 8 binary coded levels.

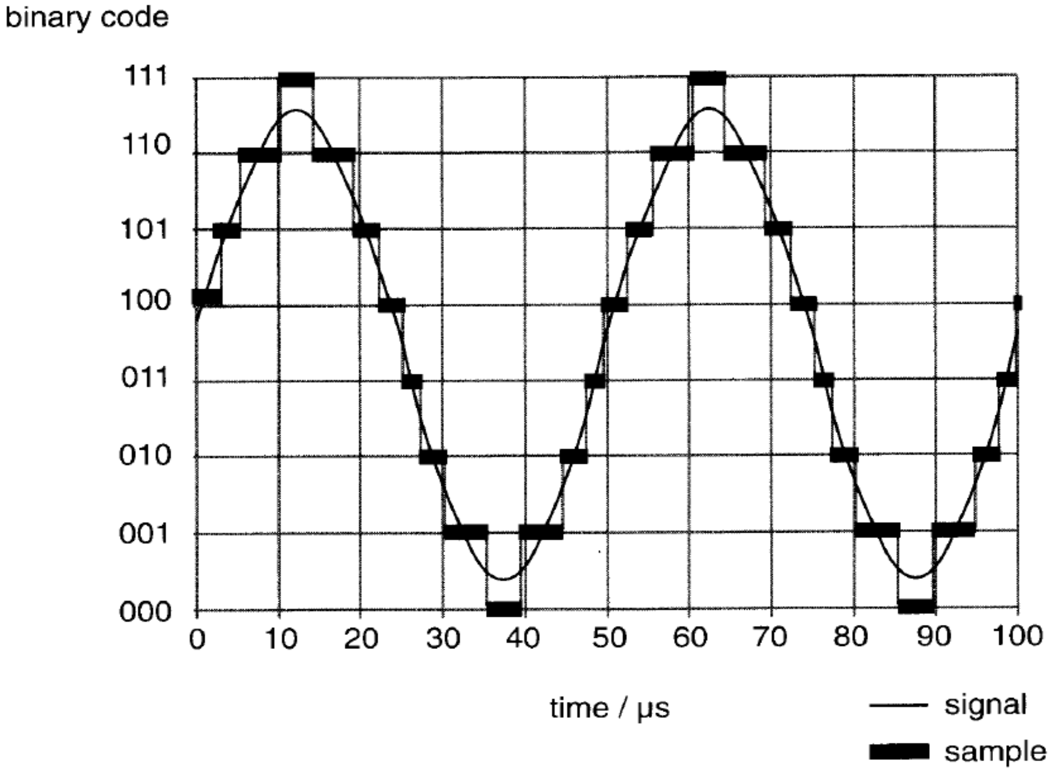


Fig. 7.1

(a) **(i)** Read from the graph the time period T in microseconds for one complete cycle of the dolphin whistle.

T = ... μs [1]

(ii) Calculate the frequency f corresponding to this time period T.

f = ... Hz [1]

(b) **(i)** State the number of bits per sample needed to code for the 8 binary levels.

number of bits = ... [1]

(ii) The waveform is sampled every 1.0 μs.

Calculate the rate at which information is digitised in this sampled waveform.

information rate = ... bits s^{-1} [1]

5 Fig. 5.1 shows an analogue voltage signal varying in time. It is sampled every 1.0 ms for conversion into a digital signal.

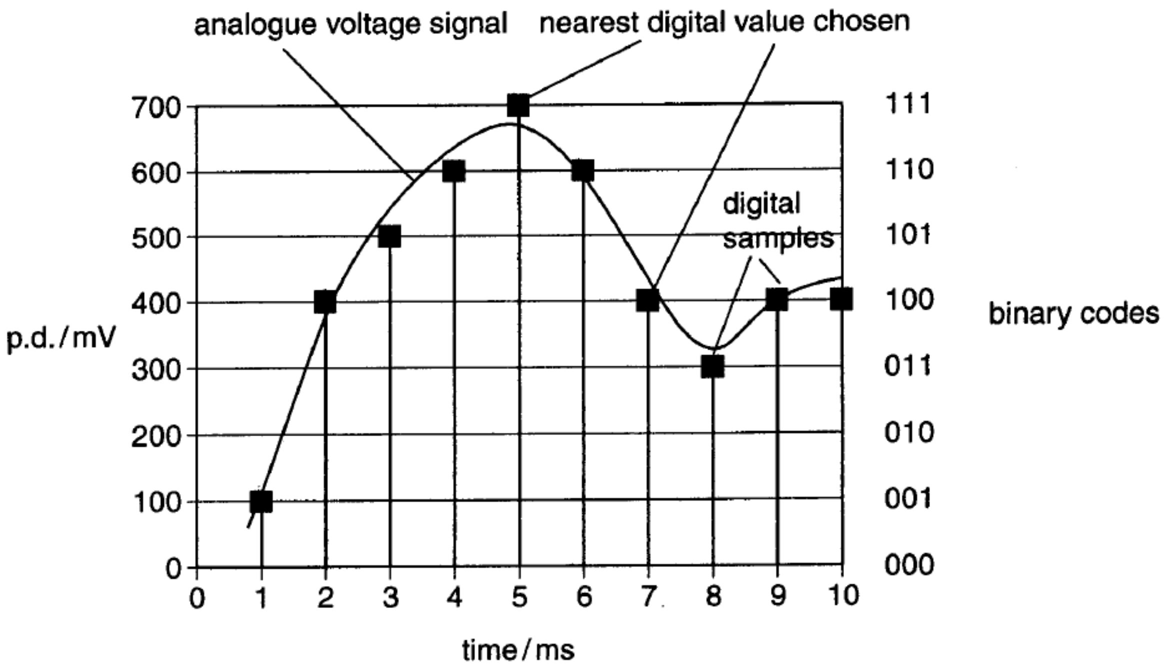


Fig. 5.1

(a) **(i)** State the number of bits used for the binary code of each sample in Fig. 5.1.

number of bits per sample = ... [1]

(ii) State the number of different signal levels defined by this number of bits.

number of signal levels = ... [1]

(b) Fig. 5.1 illustrates that the digital signals, introduced during digital sampling, can differ from the analogue signal.

(i) State the largest difference (measured in mV) that could be introduced in this example.

largest difference = ... mV [1]

(ii) Suggest **one** way in which these differences could be reduced to make the sampling more accurate.

[1]

5 Figs. 5.1 and 5.2 show the frequency components (spectra) of two sounds from a voice recognition system.

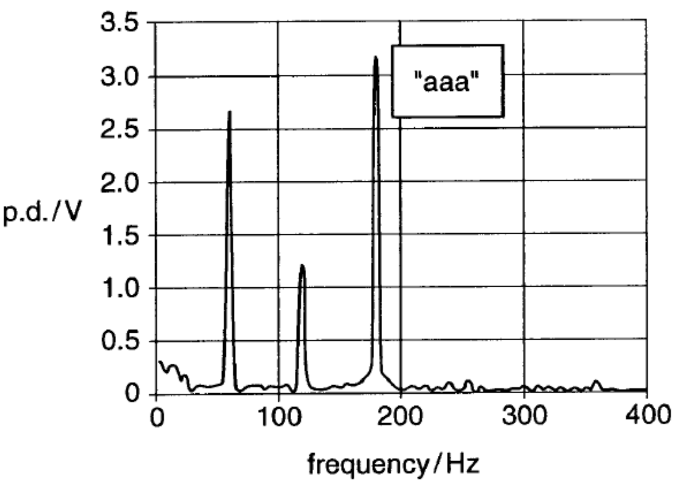


Fig. 5.1

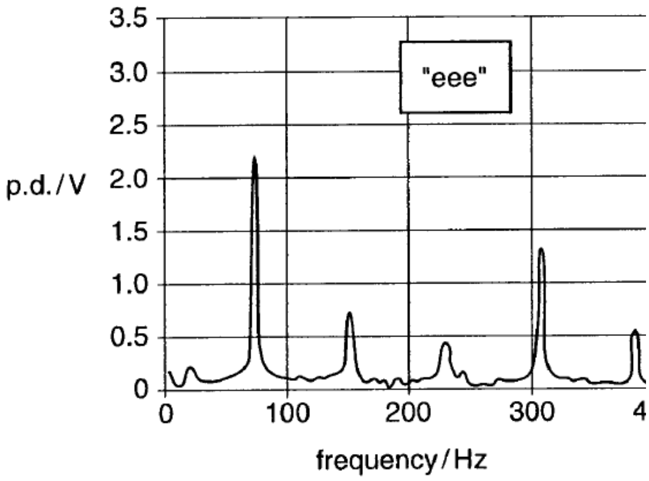


Fig. 5.2

(a) In Fig. 5.1, the voice was making an "aaa" sound, in Fig. 5.2 an "eee" sound.

Describe **two** differences between the sound spectra that would help you to distinguish between the sounds, by inspecting the spectra.

[2]

(b) The fundamental frequency component waveform of the "eee" spectrum at 77 Hz is shown in Fig. 5.3.

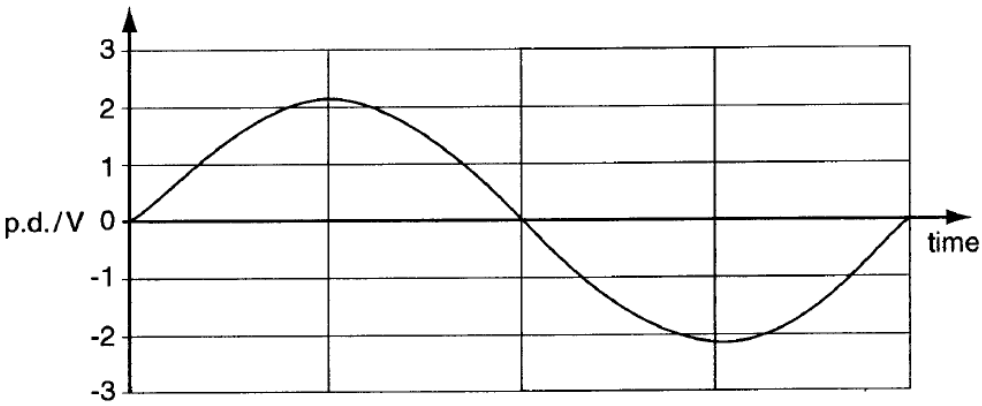


Fig. 5.3

Using information from Fig. 5.2, draw on Fig. 5.3 a waveform for the fourth harmonic component at 308 Hz at **four times** the fundamental frequency. [2]

6 This question is about the relationship between analogue waveforms and their frequency spectra.

Fig. 6.1 (a) shows the waveform of a pure sound and Fig. 6.1 (b) its frequency spectrum.

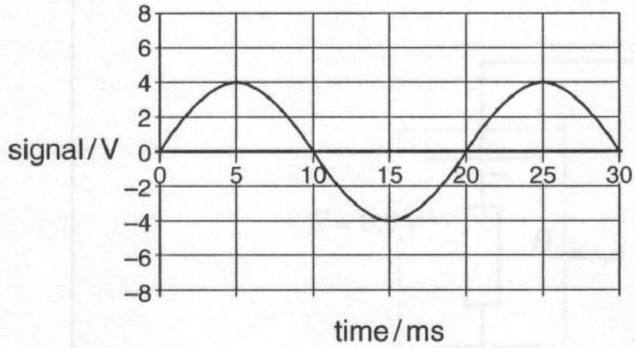


Fig. 6.1 (a) waveform

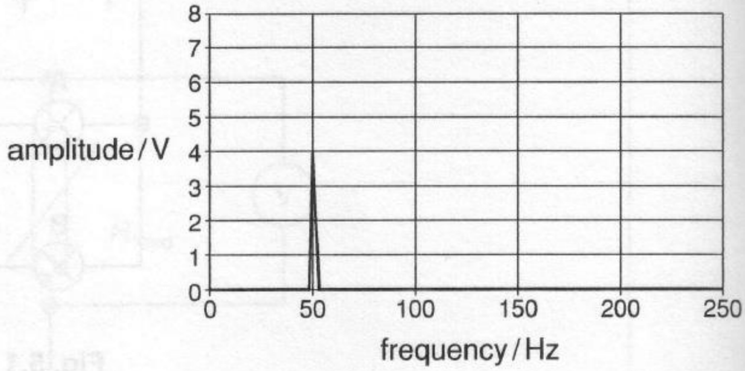


Fig. 6.1 (b) frequency spectrum

Fig. 6.2 (a) and (b) below show the waveform and frequency spectrum of a higher frequency sound.

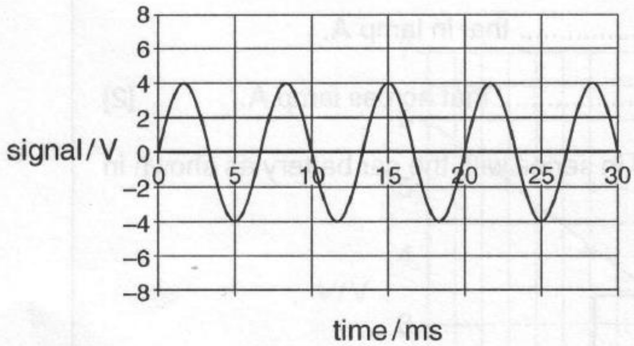


Fig. 6.2 (a) waveform

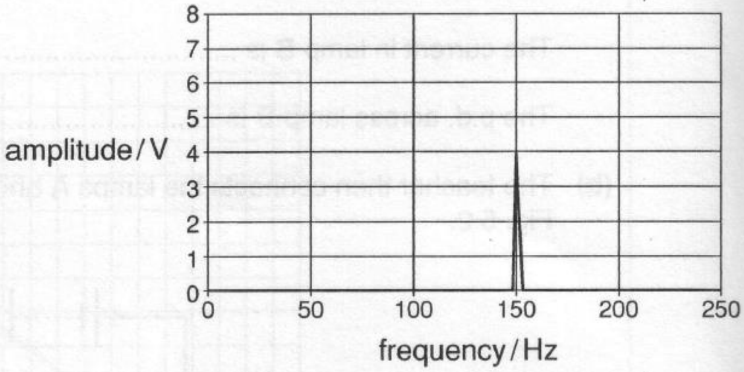


Fig. 6.2 (b) frequency spectrum

The waveforms of Fig. 6.1(a) and 6.2(a) are to be added to produce a combined waveform.

(a) On Fig. 6.3 (a), sketch this combined waveform. [3]

(b) On Fig. 6.3 (b), draw the frequency spectrum of the combined waveform. [1]

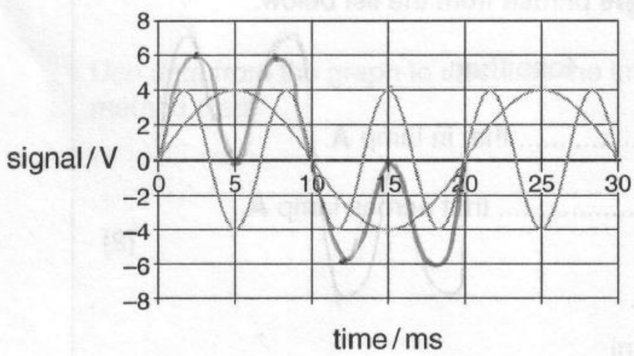


Fig. 6.3 (a) waveform

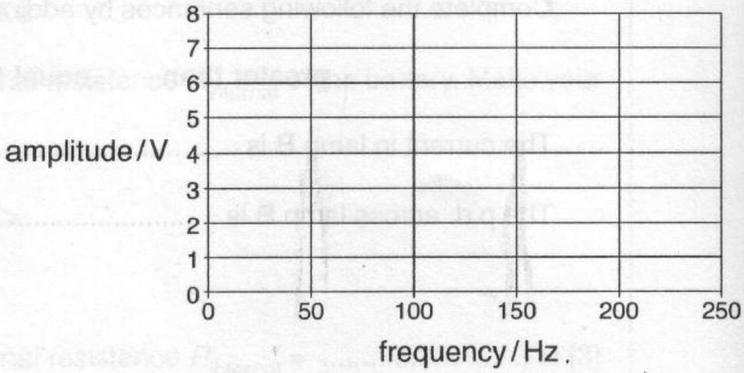
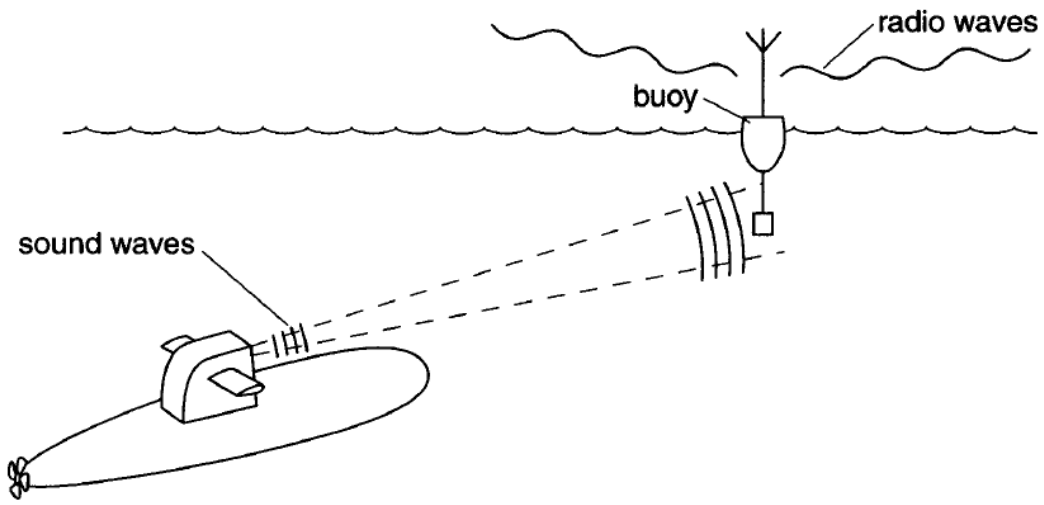


Fig. 6.3 (b) frequency spectrum

9 Radio waves cannot be transmitted through water, but submarines can now transmit and receive e-mails, without having to surface.



An 'acoustic modem' on the submarine transmits sound waves through water, at a frequency of 8.0 kHz. The waves carry information at 2.4 kbit s^{-1} to a radio buoy. The information is relayed from the buoy to shore by radio waves. The buoy can also receive radio signals, and transmit the information as sound waves back to the submarine.

(a) Show that the wavelength of the 8.0 kHz sound waves in sea water is about 0.2 m.

speed of sound in sea water = 1500 m s^{-1}

[3]

(b) The sound waves travel 5.0 km from the submarine to the buoy.

Calculate the time taken for the sound waves to travel this distance.

time taken = ... s [2]

(c) A typical e-mail message contains 1500 bytes of information.

Calculate the time taken to transmit the e-mail at 2.4 $kbit\,s^{-1}$.

time to transmit = ...s [2]

(d) Suggest and explain reasons why a live two-way video picture link **cannot** be supported by this underwater signalling system, although still pictures **can** be transmitted.

[3]

[Total: 10]

2 A clarinet plays a musical note. The note is recorded, as shown in Fig. 2.1.
It shows the waveform over a time interval of about 40 ms.

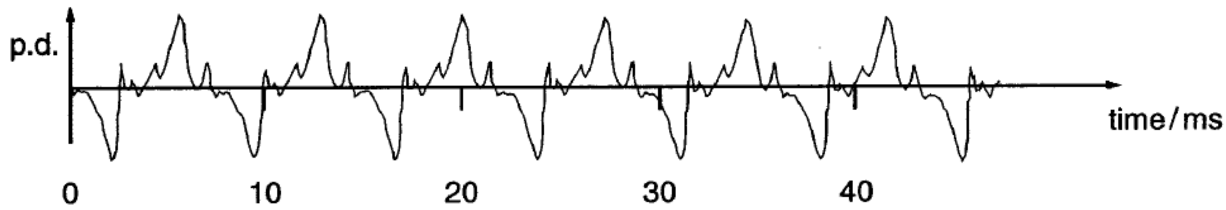


Fig. 2.1

(a) Draw on the waveform of Fig. 2.1 a box enclosing exactly **one** complete oscillation of the lowest frequency component of the note. [1]

(b) Use Fig. 2.1 to estimate the time period of this lowest frequency component of the note.

time period = ... ms [1]

(c) Calculate the frequency of the lowest frequency component of the note using your value for the time period from **(b)**.

frequency = ... Hz [1]

7 Fig. 7.1 shows an analogue signal from which digital samples are taken for transmission. The reconstructed analogue signal at the receiver is also shown.

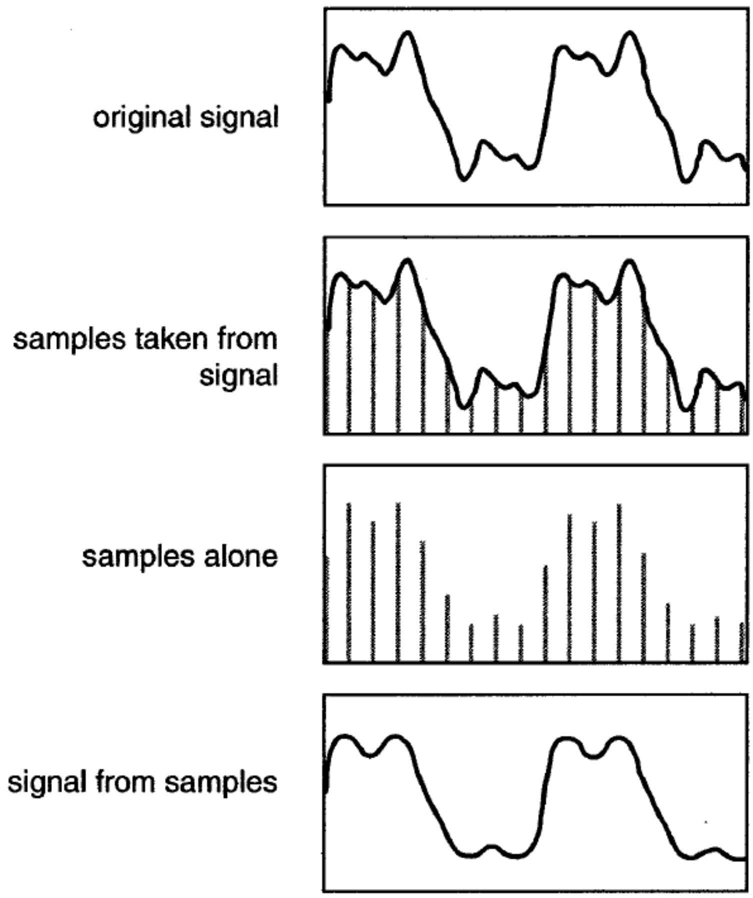


Fig. 7.1

(a) The diagrams show that the reconstructed signal is not exactly the same as the original signal.

State a difference between the signals.

[1]

(b) Suggest how to improve the quality of the reconstructed signal.

[1]