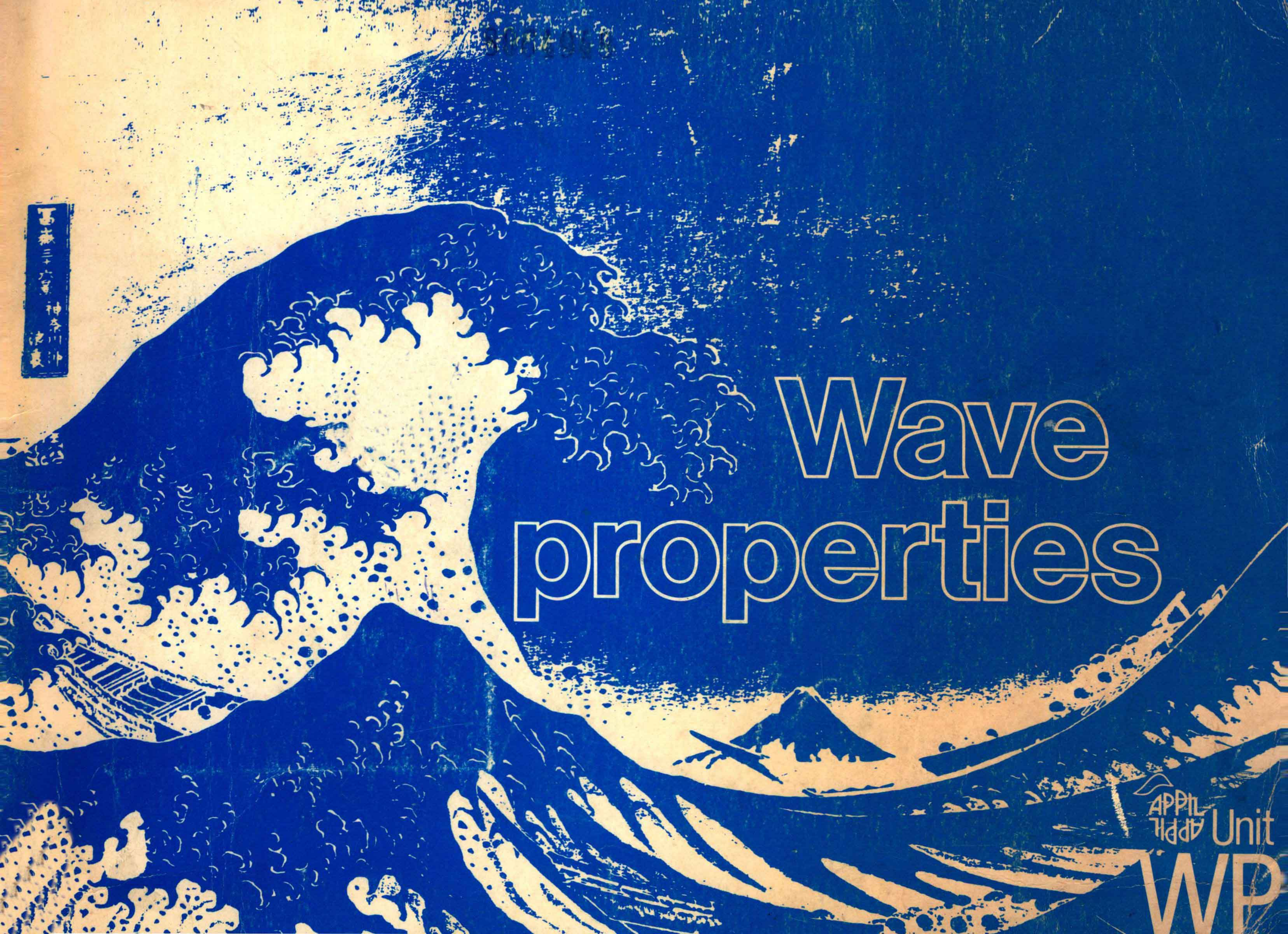
Wave properties



APPIL Unit WP

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Wave properties

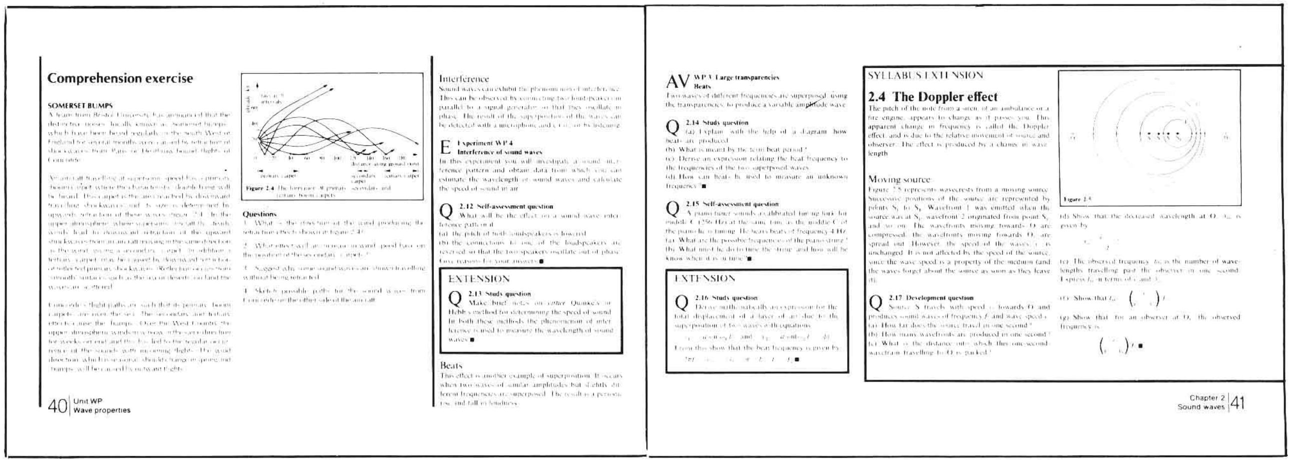
Advanced Physics Project for Independent Learning

Student's Guide

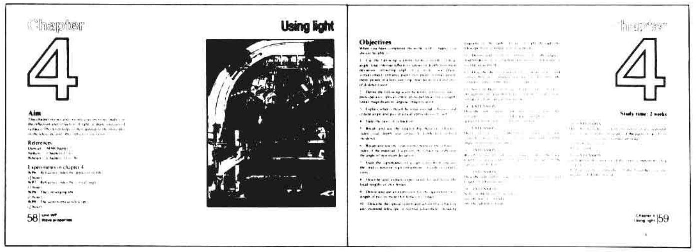
John Murray
in association with
Inner London Education Authority

How to use this student's guide

This is a programme for independent learning. It is not a textbook: it is a guide to using texts, experiments and other resources to help you to learn about waves.



Objectives



What is to be learnt is stated at the beginning of each chapter — a general statement of what you will be doing, and more detailed objectives to be achieved. The *objectives* are particularly important, because they tell you what you should be able to do when you have finished working through the chapter, and so give you extra help in organising your learning. You will probably wish to refer to them when you have finished each chapter.

There are sections of text in this guide which are to be read as in any other book, but much of the guide is concerned with helping you through activities designed to produce effective learning when you work independently. For a fuller explanation of the way APPIL is written you should read the Student's Handbook. What follows is a brief summary.

Q Self-assessment questions
These test your understanding of the work you have done, and will help you to check your progress. They are not intended to be difficult: you should be able to answer most of them quite easily.■

The answers to self-assessment questions are given at the end of the book, but if you look at the answer before you have tried the question you will not be involved in the learning process and your learning may suffer.

Q Development questions
These are included to involve you in a proof or idea which is being developed in the text.■

The answers to these questions are in the text or, for questions marked with an asterisk, at the end of the book. Involving yourself in the development helps you to learn: just looking at the answer is not so effective.

Q Study questions
For these you will need to use resources apart from this guide: for example, textbooks or experimental results. General references are given to basic books at the start of each chapter. You are not expected to consult all the references given, but you should always use more than one when possible.■

This type of question usually requires longer answers than the others. These answers, in many cases, form a basis for your notes for the final examination and are therefore very important. Full answers are not usually given in this guide, though hints and partial answers are sometimes given (these questions are marked with an asterisk). Your answers to study questions should be handed in regularly for marking.

EXTENSIONS

Extensions are provided for several reasons.

(a) To provide additional material of general interest, e.g. applications.

(b) To provide more detailed treatment of some topics.

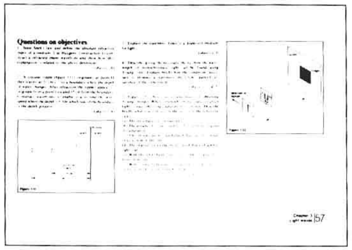
(c) To provide additional topics, or extensions of core material, to cover the requirements of a particular examination board. In this case, the section is marked SYLLABUS EXTENSION and will be essential study for some students, although others may find it of value. You should consult your teacher if you are not certain whether a particular syllabus extension is appropriate for you.

Use of resources

Audio-visual aids. These are included to supplement your experimental observations.

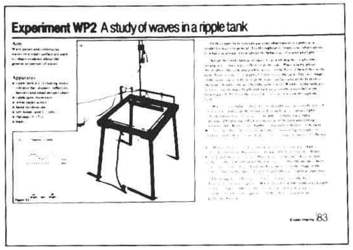
Background reading. This refers to books which are useful for a more detailed study of certain topics. They are also often interesting to read in their own right, and sometimes put the physics of the syllabus in its historical, social and technological context.

Questions on objectives



These are groups of questions which come at the end of each chapter, and are related to the objectives at the beginning of each chapter. Answering these will help you to tell whether you have achieved the objectives.

Experiments



These are a very important part of the course. The experiments in each chapter are listed at the beginning of the chapter, with an indication of the approximate *laboratory time* required for setting up the apparatus and taking readings. Each experiment is referred to in the text at the most appropriate time. You should aim to organise your work so that it can be done at that time. Full details of experiments are given at the end of the book. Record your results, graphically or in some other way, and your conclusions. There is no value in copying out the instructions given, but notes on special procedures, and any details which might be useful for revision, should be made.

Organising your time

In this programme of work there is a variety of activities. Some of them, like experiments, need a laboratory, and you will also need to use the library. You must, therefore, organise your time so that you can make the best use of the resources available.

When you start a chapter, look through it and see what activities are included, then allocate each activity a time on your work schedule. Make sure, for example, that you do the experiments when you are timetabled in a laboratory. Follow the sequence in this guide if you can, but this may not always be possible.

In the introduction, and at the beginning of each chapter, you will find the recommended time for completion of the work in each chapter. These times are given in units of one week. This assumes that you spend a minimum of 10 hours each week on physics, divided between class time, private study and home study. It is important to try to complete the unit in the stated time. The *progress monitor* will help you plan your time.

End-of-unit test

This is to enable your teacher to check the value of the course to you. You will be asked to do this test when you have completed the unit, and will be given details at the appropriate time.

Introduction to the unit

This is the first of two APPIL units in which you will study waves.

As this unit is one of the recommended starting points for the course, there is a preliminary section, 'Starting block', which reviews some of your earlier physics studies which are relevant to this unit, and includes a preliminary test and advice on how to fill any gaps in your knowledge.

Chapter 1 develops the idea of a wave model by studying the properties of mechanical waves, in springs and on the surface of water.

Chapter 2 introduces a study of sound waves which will be continued in the unit *Vibrations and waves.*

Chapter 3 considers evidence which supports the idea that light is a wave, and shows how some of the properties of light can be explained by assuming this wave model.

Chapter 4 extends your knowledge of the reflection and refraction of light, and shows how these properties are applied to the design of optical instruments.

Recommended study times

You should spend 6 to 7 weeks on this unit, divided roughly as follows:

Chapter 1 2 weeks
Chapter 2 1 week
Chapter 3 $1\frac{1}{2}$ weeks
Chapter 4 2 weeks

In independent learning, students progress through the text at different rates. If you remember your earlier studies of light and sound, you will find that you progress quickly through some parts of chapters 1, 2 and 4.

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Starting block

It is assumed in this unit that you have studied physics before, so the unit will build on and extend your present knowledge. Since you may have forgotten some of the things you learnt, or there may be a few things you are not sure about, this section is designed to help you to revise, re-learn or learn what you need to know to make the best use of this unit.

Start by reading the pre-requisite objectives: these are the things you need to be able to do before you begin work on the main part of the unit.

Then work through the preliminary test, which consists of questions based on the pre-requisite objectives. Work quickly through all parts of the test without reference to books or to any other person. The aim of the test is to enable you to check up on what you know now, so that you can find and fill up any gaps in your own knowledge.

Mark your own test when you have finished, following the marking instructions. Then read the directions for using your test result, and do any follow-up work that is recommended for you.

When you have done this, you will be able to start chapter 1 with the confidence of knowing that you are ready to tackle new work.

Pre-requisite objectives

Before starting this unit you should be able to:

1 Use the following scientific terms correctly: displacement, amplitude, frequency, wavelength, medium, wave, wave speed, period.

2 Interpret a graph of particle displacement plotted against time.

3 Use the following scientific terms correctly: reflection, refraction, real image, virtual image, angle of incidence, angle of reflection, normal, angle of refraction.

4 Recall the relationship between angle of incidence and angle of reflection when light is reflected from a smooth surface.

5 Recall the type and nature of the image formed by a plane mirror.

6 Sketch the paths of rays of light from an object, reflected by a plane mirror to the eye, showing how the image is located.

7 Recall the effect on a ray of light reflected from a plane mirror when the mirror is rotated about an axis perpendicular to the plane containing incident ray, normal and reflected ray.

8 State the meaning of refraction, and sketch the path of rays of light which pass from one medium to another (for example, from air to glass).

9 Recall the effects of a prism on a narrow beam of white light.

10 Use the following scientific terms correctly: converging rays, diverging rays, converging (convex) lens, diverging (concave) lens, focal length, erect image, inverted image, magnification, concave mirror, convex mirror.

11 Explain the difference between a real image and a virtual image.

12 Determine, by graphical construction, the positions, sizes and natures of the images formed by a concave mirror for different positions of the object.

13 Determine, by graphical construction, the positions, sizes and natures of the images formed by a converging lens for different positions of the object.

Preliminary test

There are three types of question in this test, coded as follows:

MC Multiple choice. Select the single best answer.
MR Multiple response. Select all the correct answers.
NUM Numerical answer (including diagrams). Work out the answer and write it down, including the unit where appropriate.

Part A Wave terms

Questions 1–3 *MC*
Which of the quantities (A–E) below is described in each of the questions 1–3?

A frequency
B wavelength
C period
D wave speed
E amplitude

1 The maximum displacement of a particle from its rest position.

2 The number of complete vibrations made in 1 second.

3 The distance between two adjacent crests of a wave.

Questions 4–6 *MC*
Figure P1 shows the waveforms of five notes (A–E), displayed one after the other on a cathode ray oscilloscope, without adjusting its controls.

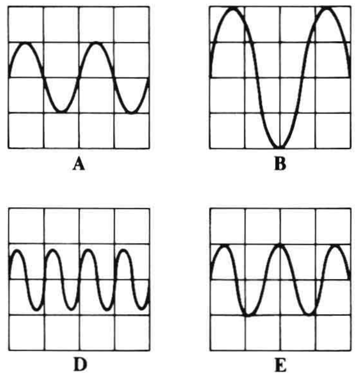


Figure P1

4 Which note has the largest amplitude?

5 Which note has the lowest frequency?

6 Which note has the highest frequency?

Questions 7 and 8 *MR*
The displacement–time graph, figure P2, shows how the displacement of a particle at a particular distance from a source of vibration varies with time. Which of the distances marked (A–G) are equal to the quantities in questions 7 and 8?

7 The period of the vibration.

8 The amplitude of the vibration.

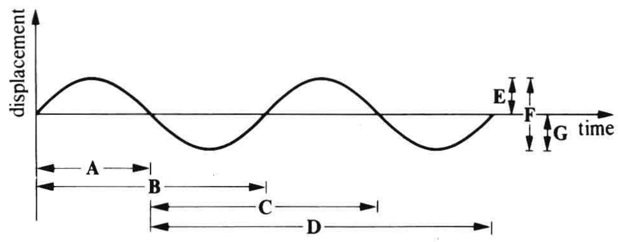


Figure P2

Part B Reflection and refraction

9 *MC* Which of the following (A–D) shows the image of a letter P placed in front of a plane mirror?
A P
B b
C q
D d

10 *NUM* A student faces a plane mirror, which is 5 metres in front of her. How far must she move so that she is 4 metres nearer to her image?

11 *NUM* A ray of light strikes a plane mirror so that the reflected ray makes an angle of 30° with the incident ray. The mirror is turned through an angle of 20°, first clockwise then anticlockwise, about an axis at right angles to the plane of the rays. For each case, what is the angle between the incident ray and the new reflected ray?

12 *NUM* An object O is placed between two plane mirrors which are arranged at right angles to each other. The object is 2 cm from one mirror and 3 cm from the other. Sketch a diagram showing the positions of the images that are produced.

13 *MC* Which of the diagrams (A–D) in figure P3 shows correctly the path of a ray of light passing through a glass block?

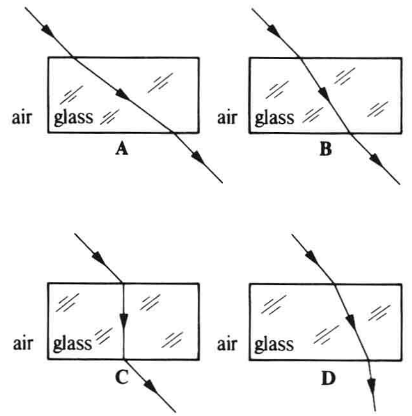


Figure P3

14 *MC* When white light is passed through a prism, which of the following colours is refracted through the smallest angle?

A yellow
B red
C green
D blue

Part C Mirrors and lenses

Questions 15–19 *MC*

From the descriptions of optical images (A–E) below, choose the correct description for the image formed in each of the cases specified in questions 15–19.

A real and diminished
B real and enlarged
C virtual and diminished
D virtual and the same size as the object
E virtual and enlarged

15 A plane mirror.

16 A convex driving mirror.

17 A camera lens used to photograph a distant object.

18 A concave mirror used as a shaving mirror.

19 A converging lens used as a magnifying glass.

20 *MC* An object is placed between a concave mirror and its principal focus. Which of the statements (A–E) correctly describes the image which is formed?

A virtual, erect and diminished
B virtual, erect and enlarged
C real, inverted and diminished
D real, inverted and the same size as the object
E real, inverted and enlarged

Questions 21–24 *NUM*

An object 3.0 cm tall is placed 30.0 cm from a concave mirror of focal length 10.0 cm so that it is perpendicular to, and has one end on, the axis of the mirror. Determine, by graphical construction, the answers to questions 21–24.

21 What is the distance of the image from the mirror?

22 What is the height of the image?

23 Is the image erect or inverted?

24 Is the image real or virtual?

Questions 25–27 *MC*

Figure P4 shows a converging lens with five possible *object* positions (A–E) marked on the axis. Select from these the correct object position for each of the types of *image* described in questions 25–27.

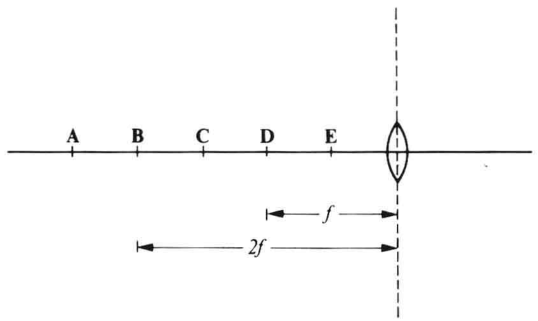


Figure P4

25 Virtual and erect.

26 Real and diminished.

27 Real and enlarged.

Questions 28–32 *NUM*
Figure P5 is a ray diagram (drawn to scale) illustrating the formation of the image of an object 1.0 cm tall, placed 9.0 cm away from the lens.

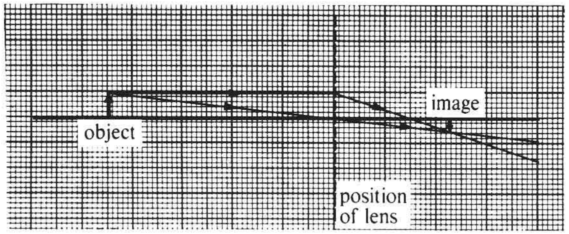


Figure P5

28 What type of lens is used?

29 What is the focal length of the lens?

30 How far is the image from the lens?

31 Is the image real or virtual?

32 What is the magnification of the image?

Questions 33–36 *NUM*
An object 4.0 cm tall is placed 6.0 cm from a converging (convex) lens of focal length 18.0 cm. The object is perpendicular to, and has one end on, the axis of the lens. Determine, by graphical construction, the answers to questions 33–36.

33 What is the distance of the image from the lens?

34 What is the height of the image?

35 Is the image erect or inverted?

36 Is the image real or virtual?

Marking

Compare your answers with those given below, and give yourself one mark for each fully correct answer. To be fully correct, only the one right answer should be given for multiple choice questions, all the right answers and no wrong ones for multiple response questions, and the unit as well as the number for numerical questions. Add up your marks for each part of the test separately.

Answers

Part A *8 marks*
1 E
2 A
3 B
4 B
5 C
6 D
7 B, C
8 E, G

Part B *6 marks*
9 C
10 2 metres
11 70°, 10° (figure P6)

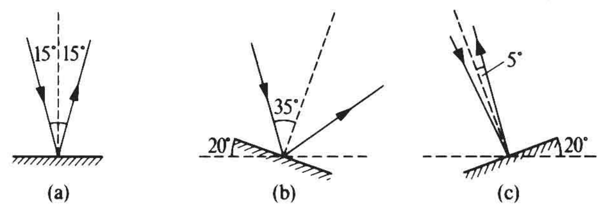


Figure P6

12 Figure P7 shows the positions of all three images.
13 B
14 B

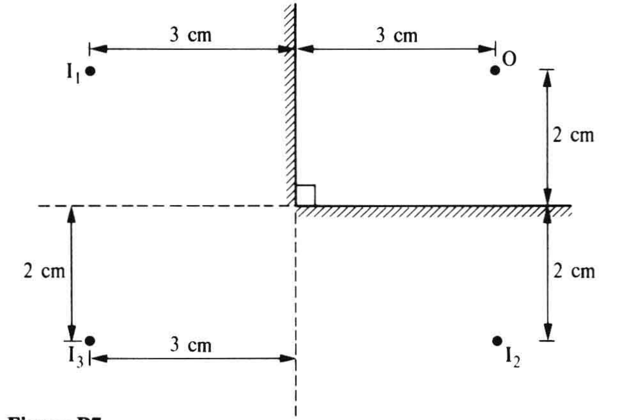


Figure P7

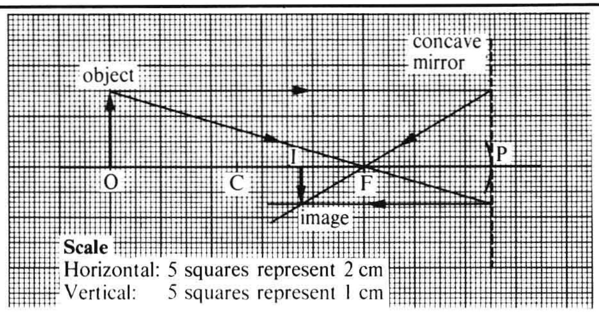


Figure P8

Part C *22 marks*
15 D
16 C
17 A
18 E
19 E
20 B
21 15.0 cm (figure P8)
22 1.5 cm
23 Inverted
24 Real
25 E
26 A
27 C
28 A converging (convex) lens.
29 3.0 cm
30 4.5 cm
31 Real
32 0.5
33 9.0 cm (figure P9)
34 6.0 cm
35 Erect
36 Virtual

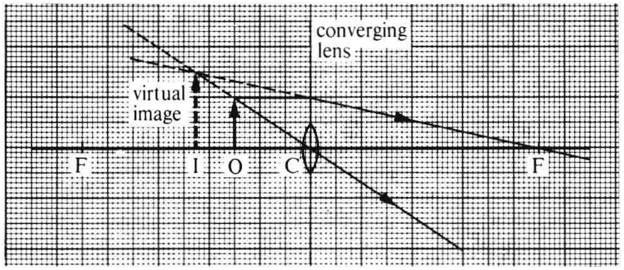


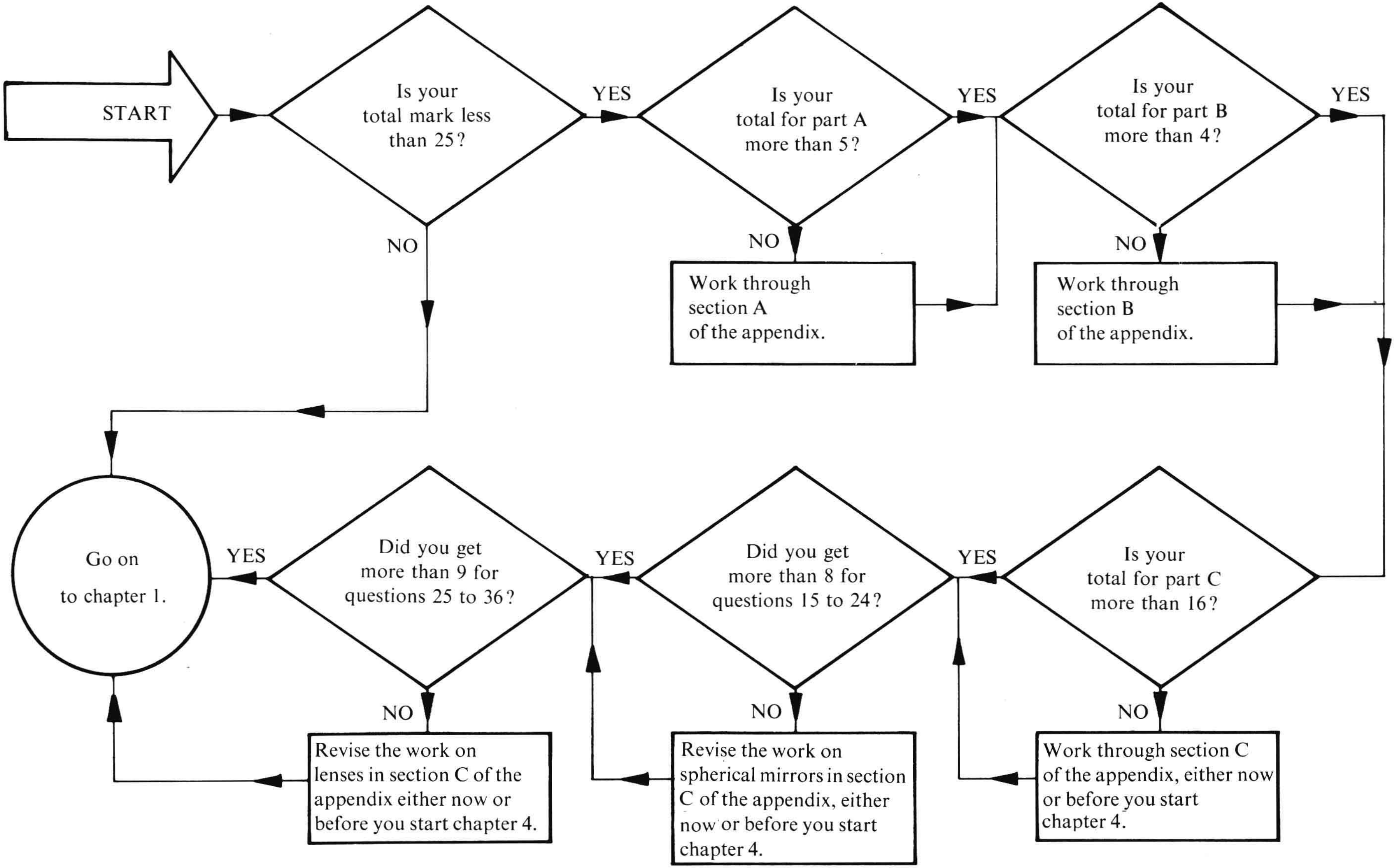
Figure P9

Using the test results

The pre-requisite objectives were tested as follows.

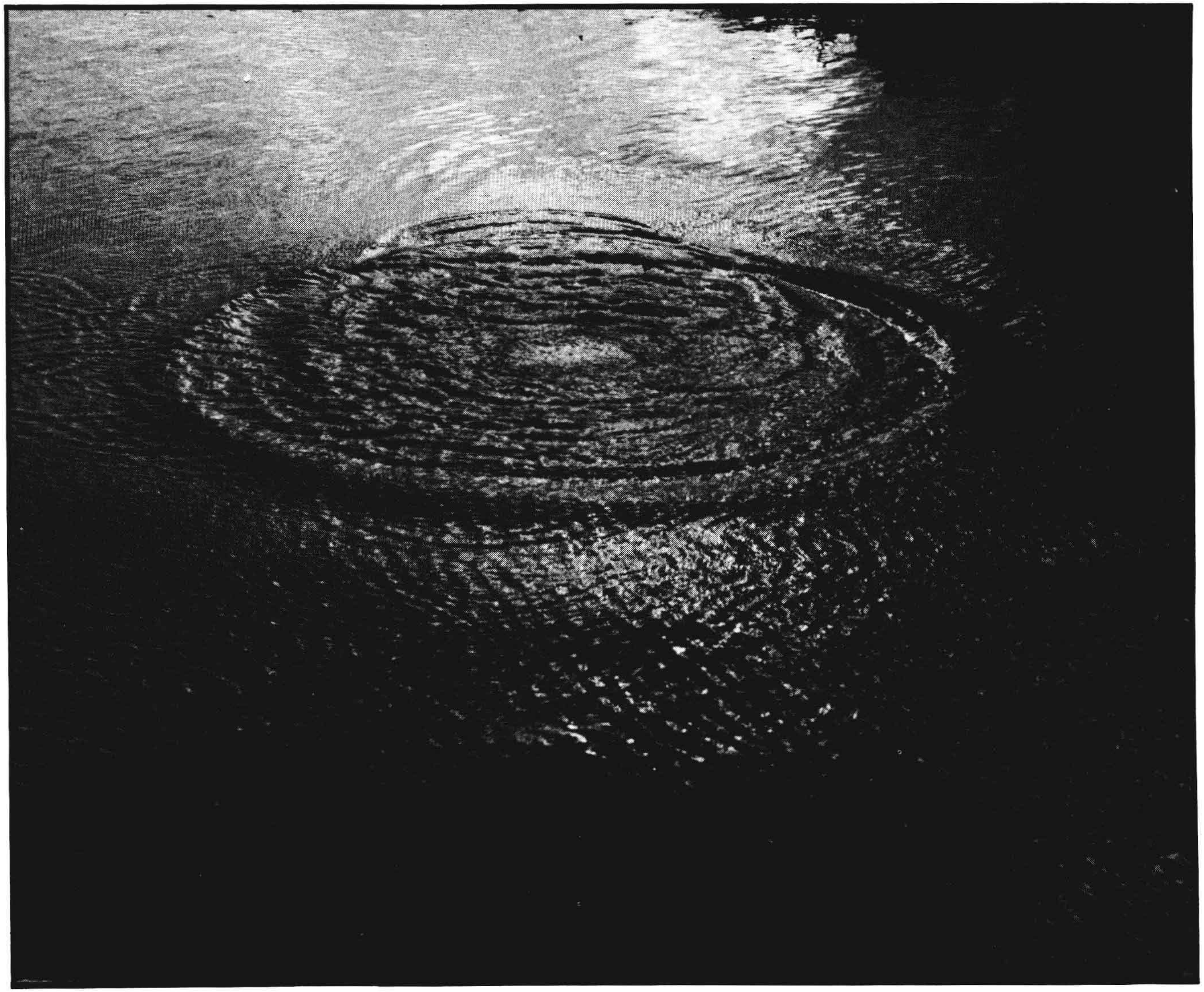
Objectives 1 and 2	Part A
Objectives 3, 4, 5, 6, 7, 8 and 9	Part B
Objectives 10, 11, 12 and 13	Part C

Your marks in the preliminary test indicate whether you need to do some follow-up work before starting chapters 1 and 4. The flow chart will direct you along your own personal route through any necessary revision sections.


START
Is your total mark less than 25?
YES
NO
Is your total for part A more than 5?
YES
NO
Work through section A of the appendix.
Is your total for part B more than 4?
YES
NO
Work through section B of the appendix.
Go on to chapter 1.
YES
Did you get more than 9 for questions 25 to 36?
YES
Did you get more than 8 for questions 15 to 24?
YES
Is your total for part C more than 16?
NO
Revise the work on lenses in section C of the appendix either now or before you start chapter 4.
NO
Revise the work on spherical mirrors in section C of the appendix, either now or before you start chapter 4.
NO
Work through section C of the appendix, either now or before you start chapter 4.

Chapter 1

Waves and wave models



Aim

In this chapter a model of wave motion will be developed by studying the properties of mechanical waves in springs and on the surface of water. This wave model will form the basis for your study of the wave properties of sound and electromagnetic radiations.

Chapter 1

Study time: 2 weeks

Objectives

When you have completed the work in this chapter you should be able to:

1 Use the following scientific terms correctly: phase angle, phase difference, wave pulse, diffraction, wave train, interference, superposition, mechanical wave, electromagnetic wave, progressive wave, sinusoidal wave.

2 Define the following terms: wavelength, wavefront, amplitude, period, frequency, angular frequency, dispersion.

3 Distinguish between longitudinal and transverse waves, and give examples of each.

4 Derive, recall and use the relationship between wave speed, frequency, and wavelength.

5 Recall examples of reflection of waves, with and without phase change.

6 Predict the forms of the reflected wavefronts when plane or circular waves are reflected from straight or curved barriers.

7 Give qualitative explanations of the refraction and diffraction of waves, with suitable examples.

8 State the principle of superposition.

9 Explain qualitatively, using diagrams, how an interference pattern is produced by superposition of waves from two point sources of the same frequency, and give examples of this phenomenon.

10 Describe, with diagrams and/or graphs, the relationship for a progressive wave between
(a) displacement and time, for a particular point in a medium,
(b) displacement and distance, at a particular instant.

11 SYLLABUS EXTENSION
Outline how an equation of the form $y = a \sin(\omega t - kx)$ can be used to describe a sinusoidal progressive wave, and indicate the physical meaning of the variables and constants in this equation.

Experiments in chapter 1

WP 1 Observing wave pulses
($\frac{3}{4}$ hour)
WP 2 A study of waves in a ripple tank
(1 hour)

References

Akrill	Chapters 16, 17
Bolton	Chapter 6
Duncan FWA	Chapter 6
Nelkon	Chapter 24
Whelan	Chapters 12 and 14

1.1 Mechanical waves as a wave model

Waves are very common, varied and important phenomena. Animals, including man, explore their environment through sound and light waves. We communicate by waves; indeed, it is difficult to think of any method of communication, ancient or modern, which does not use waves. Waves also provide the most important means of transferring energy, including the energy of the sun, which is so vital to man's needs on earth. When a wave transfers energy and momentum from the wave source to places around it, we describe it as a *progressive* or *travelling* wave.

In science, models are used to help in explaining observations and predicting effects. A model may be a diagram, a constructed object, a physical situation, or even a mathematical equation. We use models in everyday life. A London underground map is a good model of the underground system. It is certainly not an exact replica of the rail system. For one thing, it is not drawn to scale and the actual lines and trains are not red, brown, yellow or blue as the map suggests. Nevertheless, it is a good model because it can *explain* why if we travel on a certain line we will pass through King's Cross at regular intervals and it can *predict* that if we get on a particular train we can end up in the Essex marshes!

No one can see a *wave* of light, and it is not easy to observe the effects produced when sound travels through air. A wave model helps us to visualise and explain what is happening when waves like light, sound, X-rays, and so on, are produced and transmitted. The wave model will be developed by observing waves in springs, and on the surface of water. These are *mechanical waves*, which are produced when some part of an elastic medium is displaced from its equilibrium position, for example, when a stone is dropped on to a water surface or a loudspeaker makes particles of air vibrate.

Q **1.1 Development question***

Figure 1.1 shows the cross-section of a water surface just after a small stone has been dropped on to it.

(a) How does this diagram support the fact that water is almost incompressible?

(b) What forces act to move particles in the water which are some distance from the stone?

(c) Sketch a section through the water surface a moment after that shown in figure 1.1, marking the reference lines O, X and Y.

(d) What happens to the original kinetic energy of the stone?

(e) Suggest a reason why the water does not immediately become calm again.■

Note. Answers to development questions are sometimes given at the back of the book, as in this case, but are often incorporated in the question or in the following text.

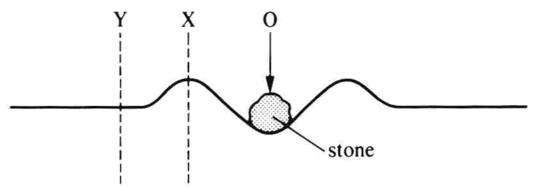


Figure 1.1

Elastic is the term used to describe 'springiness': the capacity of a substance to return to its original shape and size after being deformed. When a particle in an elastic medium is displaced from its equilibrium position, forces act on the particle which will tend to restore it to its original position. Because the particle has inertia (resistance to change in motion), it will overshoot the equilibrium position and oscillate. All the particles in the medium are interconnected by forces, and the displacement of one particle will change the forces acting on other particles close to it. These particles will then be displaced. This interaction between the particles causes a disturbance to spread through the medium and produces a transfer of energy. The moving disturbance is a wave, and the energy transfer can be detected (for example, by a floating cork for water waves or a microphone for sound waves).

A mechanical wave, therefore, transmits mechanical energy through a material medium which has inertia and elasticity.

Electromagnetic waves form a second group of waves. These include light, radio and X-rays. In chapter 3 you will study some evidence that light has wave properties, but a study of the nature of electromagnetic waves and explanation of how they can transmit energy through a vacuum will be deferred until the unit *Vibrations and waves*. However, many of the properties of these complex three-dimensional waves can be understood by studying a simple kind of wave – a one-dimensional wave pulse in a long spring or rope.

1.2 Wave pulses

When you slam the door of a room, the air in the doorway is compressed rapidly. This single compression travels as a disturbance across the room and gives a sudden push to the curtains. The air particles have not travelled across the room in that time, but energy has. This short-duration wave is called a pulse.

Q **1.2 Self-assessment question**

(a) In an obstacle race a competitor has to crawl under a tarpaulin sheet, causing a bump to travel along the sheet. Is this moving disturbance a progressive wave pulse? Explain.

(b) If you look down on a line of cars queuing at traffic lights, you will observe a 'pulse of starting' move along the line of cars when the traffic light changes to green. Which way does the 'pulse of starting' travel, and what does its speed depend on?■

A distinction must always be made between the movement of the particles of the medium and the movement of the wave pulse through the medium.

E **Experiment WP1**

Observing wave pulses

Different types of wave pulse can be observed moving along a stretched spring, and the pulse speeds can be estimated.

Q **1.3 Self-assessment question**

Figure 1.2 shows a series of pictures taken at regular intervals illustrating how a pulse of compressed coils moves along a slinky spring.

(a) Which way does the 10th coil from the left move between instant 2 and instant 4?

(b) Is this coil moving at instant 5? If so, in which direction?

(c) Is it possible to say in which direction this coil is moving at instant 7? Explain.■

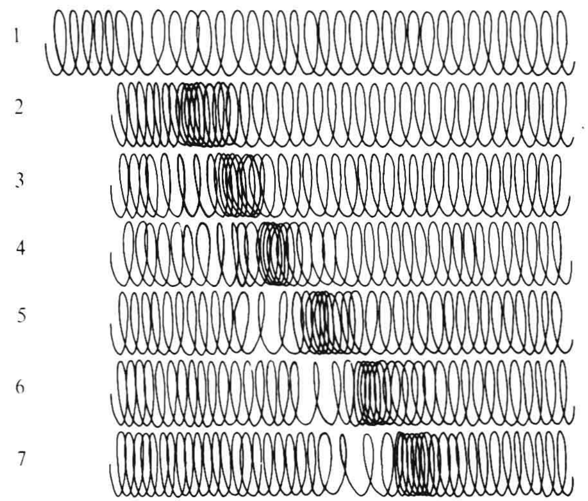


Figure 1.2