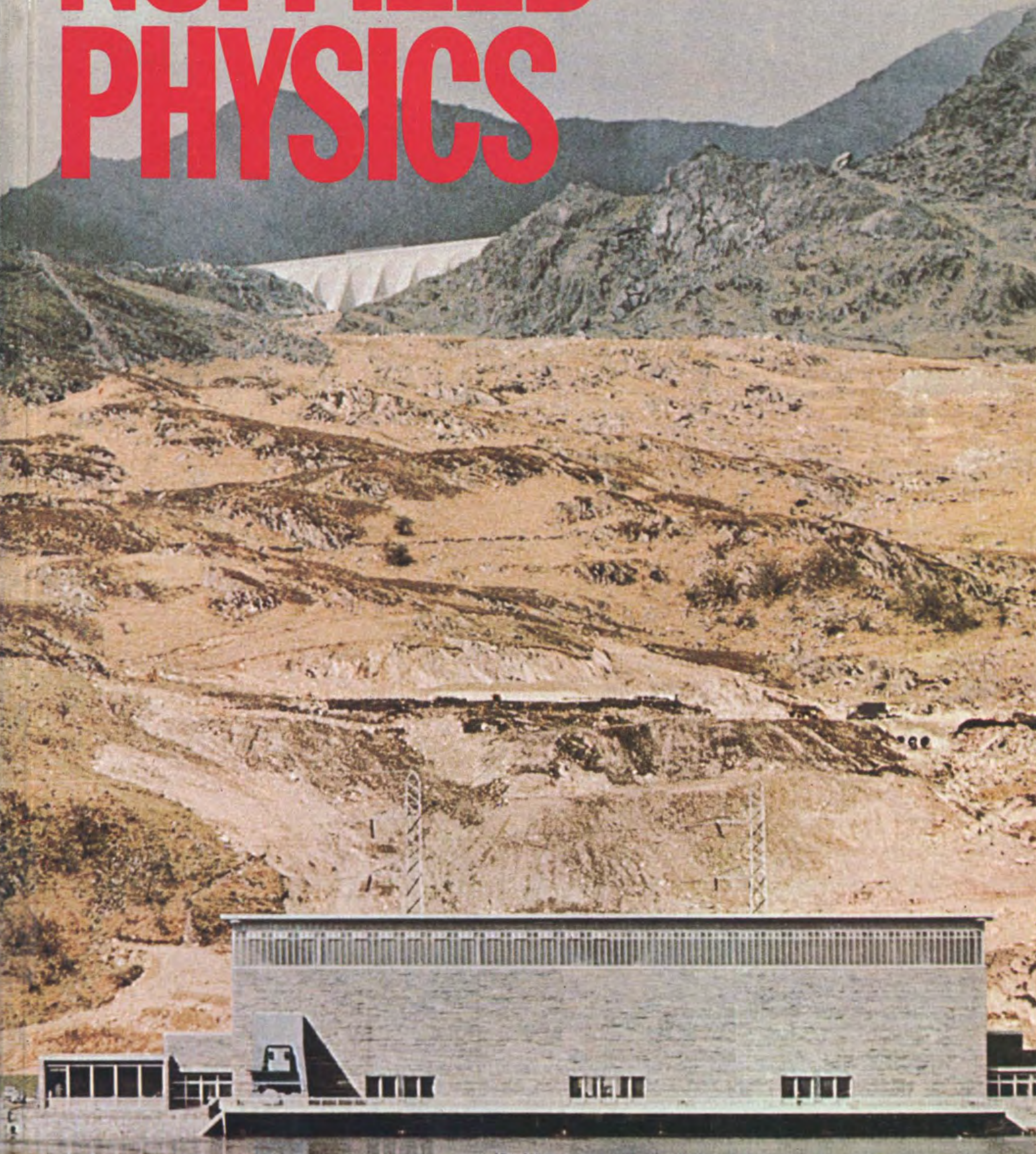
REVISED

NUFFIELD PHYSICS

Pupils' Text Year 3



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Nuffield Physics
PUPILS' TEXT
YEAR 3

General Editors
Eric M. Rogers
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NUFFIELD PHYSICS PUPILS' TEXT YEAR 3

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Foreword

In the early 1960s the Nuffield Foundation commenced its sponsorship of curriculum development in the sciences. Specific projects can now be seen in retrospect as forerunners in a decade unparalleled for interest in teaching and learning, not only in, but far beyond, the sciences. Their success can best be measured by their undoubted influence and stimulus to physics amongst teachers—both convinced and not-so-convinced.

The examinations accompanying the schemes of study, which have been developed with the ready cooperation of the Schools Certificate Examination Boards, have provoked change and have enabled teachers to realize more fully their objectives in both classroom and laboratory. The changes continue and the nation is currently engaged in discussion of further alterations to the pattern of examinations. Whatever the outcome, we are confident that these Nuffield studies will continue to make important contributions to the teaching and learning of science. In these volumes we have attempted to produce materials to meet the needs of particular classroom situations. Where curriculum development is not capable of adaptation and renewal, it impedes, rather than encourages, innovation and it commits the very sin it sets out to avoid.

The opportunity for local curriculum study has seldom been greater and the creation of Schools Council and teachers' centres has done much to contribute to discussion and participation of teachers in this work. It is these discussions which have enabled the Nuffield Foundation to take note of changing views, to correct or change emphasis in the curriculum in science, and to pay attention to current attitudes to school organization. We have learned of many, particularly those in the Association for Science Education, who, through their writings, conversations, and contributions and in other varied ways have brought to our attention the needs of the practising teacher and the pupil in schools.

This new edition of the Nuffield physics material draws heavily on the work of the editors and authors of the first edition published in 1966. An immense debt is owed to them. The physics programme was inaugurated in May 1962 under the leadership of Donald McGill. It suffered a severe setback with his tragic death on 22 March 1963, but those who were appointed to continue the work have done so in the spirit in which he initiated it, and in the direction he foreshadowed. He was succeeded as organizer by Professor E. M. Rogers. Together with the associate organizers, John Lewis at Malvern and E.J. Wenham at Worcester, the assistant organizer, D. W. Harding, and the deviser of the *Questions Books*, the late H. F. Boulind, the teams of teachers led by Eric Rogers produced teaching ideas that have influenced profoundly curriculum discussions and physics at a time of major educational change.

The new edition contains a preponderant part of the original material in edited versions. Their contribution in providing a firm basis for these further developments is gladly acknowledged here. It is a pleasure to praise the part played by the large number of teachers who have helped in discussion, feedback and persuasion but it is once more to Eric Rogers who, with an extraordinary vitality, has led and completed this work, that we especially record our thanks.

Lastly I should like to acknowledge the work of William Anderson, our Publications Manager, his colleagues and of course our publishers, the Longman Group Ltd., for their continued assistance in the publication of these books. The editorial and publishing contribution to the work of the projects is not only most valued but central to effective curriculum development.

K. W. Keohane
Coordinator of the Nuffield
Foundation Science Teaching
Project

General Editors' Preface

A dozen years ago the Nuffield Foundation, following requests from teachers who suggested changes in O-Level Physics teaching, gave a large grant for studies of needs, development of apparatus and the provision of printed materials to offer a new teaching programme to schools who liked to try it.

The essence of that programme, as it emerged from consultations, visits to schools, discussions in groups of teachers—was a change from teaching hampered by insistence on rote learning towards even more learning for understanding which, it was felt, would provide greater chances of pupils' learning of science being transferred towards long-lasting benefits.

By now, pupils of many schools have tried that programme—we believe with enjoyment and some success. As pupils reached the end of the five years to face an O-Level Examination, the teaching proved justified by the admirably relevant Nuffield Physics papers produced by the Oxford & Cambridge Schools Examination Board (acting on behalf of all Boards). The number of candidates for that Nuffield O-Level Physics Examination is now over 20,000 each year.

Those Nuffield papers were set with the aim of testing the teaching and learning that we suggested; and they received sympathetic marking which looked for understanding in candidates' answers.*

Many teachers have followed some general suggestions:

1 Let pupils work in the lab in small groups, often pairs, and leave them alone to make their own mistakes and find their own solutions, except where rescue is needed. That seems to us near to professional science.

2 Use stimulating questions as principal learning aids to encourage discussion, reasoning, and imagination.

In making the revision for this new edition we received a general directive from the Foundation; that we should try to maintain the same standard of enquiry, and learning of science for understanding, and not change the programme in a way that would 'lose the Nuffield spirit'. The Foundation recognized the changes in school structure but considered that other programmes, such as Nuffield Secondary Science, provide better for other levels of treatment than a heavily diluted version of our programme could do.

We started the revision by consulting some 200 teachers, some of them in person, many by profuse enquiry forms. We also visited a considerable number of schools to see Nuffield classes in their present form. Again, those visits influenced us very profitably in our revision.

We changed Dr Henry Boulind's excellent questions for thinking and understanding to

*Two small examples may illustrate that:

(i) The Board prints on the front of the Examination paper all the formulae likely to be wanted—this is an assurance to both teachers and pupils that just 'memorizing formulae' is not so important. Candidates realize that memorizing definitions and formulae is not very profitable. On the other hand, the Examiners expect a candidate to understand the origin and uses of some formulae and their limitations—like a capable craftsman. And they expect a candidate to be able to describe physical quantities and relationships in his or her own words.

(ii) In marking scripts for O-Level, the Nuffield Examiners have not felt themselves restricted by a fixed marking scheme. They read with a flexible attitude, looking for good knowledge, imagination, and interesting suggestions too—which they reward with bonus marks.

simpler wording, but retained their essential enquiry. In response to pleas from teachers, and to the needs of the new school structure, we added progress questions to provide a different and easier approach.

Our most important change of all in the revision has been the production of the *Pupils' Text* in four volumes, to provide young scientists with help for experiments and some discussions of ideas, also thinking questions and progress questions. Thus this book should act for many of them as a complete substitute for work cards.

On behalf of teachers and pupils who will use these books, we owe thanks to many people: to our consultant teachers, without whose advice we could not have envisaged the needs of the project; to Professor R. A. Becher, who was our chief inspiration and guide in the original project, to whom we still turn for wise advice; to Professor K. W. Keohane as our coordinator with counsel concerning physics and teaching and people; to John Maddox, Director of the Foundation, for past interest and care, and now special encouragement.

Both teachers and pupils will owe much to the four teachers who constructed the 'progress questions'—forged and tempered them: Margaret Fawcett, Reinet Fremlin, Gwen Jones, and Hilda Misselbrook.

Where some apparatus has a pleasing successor thanks should go to Philip Baillie of Worcester, who tried out designs.

During revision we have kept closely in touch with the Examiners who frame the questions and organize the marking. We could not even recommend the programme as viable without the continuing loyal support of the Examining Board.

Publishing *Teachers' Guides* and now *Pupils' Texts* together has raised many problems of editing and printing. We owe a special debt to Hendrina Ellis for her long work of perceptive guidance and help. And to William Anderson, Publications Manager of the Nuffield Science Teaching Projects, for management, advice and, above all, wisdom of words.

Our work of producing these books has involved consulting, editing, sketching pictures, trying experiments, writing chapters: all these have depended on Elizabeth Aldwinckle, on her insight and full understanding of the project. She has transformed rough drafts to clear material, has collected, corrected, given wise criticism, and has seen the project through with constructive skill and care.

All who have contributed hope that this new form of the programme will enable many of the next generation to enjoy physics and remember it all their lives.

Eric M. Rogers
E. J. Wenham
General Editors

TO THE PUPILS WHO USE THIS BOOK

Welcome to Physics

This book is meant to help you learn some physics. Physics is *doing* experiments and *thinking* about them. If you do the experiments (by yourself or with a partner) you will learn how scientists *find* things out.

If you read the explanations here and try some of the questions you will learn how scientists *think* things out.

So, if you enjoy *doing* experiments and *thinking* about them, you will understand some science and you will have a good chance of keeping that understanding all your life.

Best of all, while you are in the lab pretend you are a professional physicist; 'a scientist for the day'.

These Nuffield Books

Two books came before this but you may not have used them; so this book offers you a fresh start. There are two more books ahead of this for you if you wish to continue physics next year. And there is an A-Level programme with many books and advanced experiments after that.

In this book there are some choices of things that may be left out or put off till later.

Experiments, Demonstrations, Questions

The experiments are here for you to find out some science yourself. They are things for you to do, by yourself or with a partner. Each time there is an experiment, the instructions in this book will suggest what to try.

Those instructions will give you enough help to get the experiment started; but they will not be like a cookery book. They will not tell you everything you should do. You will need to think and plan and try things yourself, as a good scientist.

Demonstrations You will need plenty of time for your own experiments. So your teacher will show you some experiments as demonstrations. Those will save time and give you more time for your own experimenting. Watch those demonstrations carefully. They can tell you a lot.

The questions are here to help you to think about the science you are learning. And they will help you to understand what you are learning. These questions and your own experiments are your chief 'learning aids'. So it would be a pity to mistake the idea of the questions and think they want difficult answers with many scientific words. The questions are to show you what you can do, not to tease you with things you can't do.

You will be able to answer some of the questions at once. But others may seem too difficult at first. If you find a question too puzzling or too hard, try another one.

You will find that some questions have no simple answer. That is intentional: just see what you can do.

And some questions are simply meant to start a discussion: they ask, 'What do you think?'

Some questions will ask about things you have already learnt in science. Others bring in new topics. And some questions will ask about things which are unfamiliar but which are linked with what you have already heard about. Some questions are just problems to test your ingenuity.

There are too many questions for you to be able to tackle all of them. You will have to pick and choose. You will find some more interesting or provoking than others.

Before you start answering questions, see the special pages of 'Help in answering the questions'.

The pages of this book are your work-sheets to help you to learn.

HELP IN ANSWERING THE QUESTIONS

Here are imaginary questions—not real physics questions but ones we have made up so that we can tell you about answering our questions. Some questions are clear and easy like this:

Question A. When you throw a stone into a pond, it makes a round ripple. Does that ripple spread outwards and grow wider as time goes on? Or does it shrink?

Answer A. *'It grows wider.'*

Sometimes one such question leads to another, like Question B.

Question B. How do you know your answer to Question A is right?

Answer B. *(i)* You could say: *'I've seen ripples'* or *'I tried that in my ripple tank.'*

(ii) You might say, *'It's obvious'*, or *'It's common sense.'* If you say that, aren't you really saying, *'I've seen it'?* (Common sense is just the things you have seen and know.) Then answer *(i)* would look a little better than *(ii)*.

(Of course you might never have been near a pond or ripple tank and have only heard about ripples. Then, *'I am guessing'* might do, but a better answer—more like a scientist—would be, *'I don't KNOW but I've been TOLD ripples grow wider.'* But, do you know anyone who hasn't thrown a stone into a pond?)

Sometimes a question has an extra part which is more advanced, like Question C. That takes some thinking and needs physics that you know.

Question C. Can you invent a way of making a round ripple which shrinks to a central point instead of growing? If so, describe it in a few words.

Answer C is not given here. Question C is left as a puzzle for the future. You should be able to answer it when you have finished your experiments with a ripple tank—soon in this year's work. Wait until you see it. Answering this question will need some remembering and thinking and guessing. There won't be many as puzzling as that.

Many questions, particularly at the beginning of the year, just need ordinary knowledge. Always look for a common-sense answer first. Don't try to make up a complicated 'scientific' answer with long words instead. Things you already know, with some of the science you are learning, will bring you success and praise for your answers.

Some questions are not so definite. They ask for discussion, or that want your opinion about something. You should try using imagination as well as things you know. Question D is like that. You might even meet it in an exam; but there too you will succeed with ordinary thinking—and extra thinking might bring you some extra reward.

Question D. Suppose you are at the bottom of a hill and must get to the top as quickly as possible, at all costs. Which will get you there quicker, running up the hill or cycling?

Answering Question D. If you meet a question like that you should not think it wants you to find a strange scientific answer, such as some special argument about energy, or a discussion of changes of momentum, which you might not even have met so far. (If the question did expect you to give special scientific reasons it should say so clearly like this: 'Discuss the energy-changes in the two methods and from those calculate the power involved.')

Question D does not say that. It simply wants an ordinary answer from the things you know. Remember that, when you meet questions in science. Think first if an ordinary answer will do.

You should not worry and think you *have* to give extra comments or experimental results. The simple answer that we mentioned here is enough, unless the question asks for more.

But if you think of some extra things you should write them down. They are the result of thinking things out with the help of all the ordinary things you know—and that is what scientists try to do.

Answer D. The good answer is the obvious one: '*Cycling is quicker.*'

You might add, '*because I can make the bicycle tyre move faster than I can make my feet move,*' and that should get an extra mark—giving a reason is usually a good idea.

You might be cunning and add a special exception: '*If the hill is very steep, like a road straight up a mountain, I might not be able to pedal my bicycle. In that case, running or walking uphill would be quicker; because if I had the bicycle I should have to walk it with me. I should have to make the bicycle climb as well as myself.*' (That should get a bonus mark or two.)

If you wanted to make an extra good impression, you might do an experiment then say '*I have tried cycling up a hill which is not very steep, and then running up the same distance. 100 metres took about 15 seconds on my bike, and about 40 seconds running.*'

And if you wanted to be specially clever and ingenious you would make experiments with steeper and steeper hills. You might come to the conclusion: '*The steeper the hill, the less the advantage cycling has over running.*'

Question E. (THIS IS NOT A PHYSICS QUESTION. It is just a riddle; but it gives you an example of the way our questions ask for ordinary thinking.)

Think about all the men with beards, in the United Kingdom. Suppose you have counted the number of BLIND MEN with beards and the number of SEEING MEN with beards.

a. Why are there more SEEING MEN with beards than BLIND MEN with beards?

b. Out of every 1000 BLIND MEN there are, say, 500 with beards. Out of every 1000 SEEING MEN there are, say, 300 with beards. Why is the fraction (or proportion) of blind men with beards greater than the fraction of seeing men with beards? That is, why do blind men have beards more often than seeing men?

Answer E a. Just common sense: '*There are more of them, more seeing men than blind men.*' (Remember the riddle 'Why do we get more wool from white sheep than from black sheep?' Answer: 'Because there are more white sheep.')

That answer is just ordinary knowledge. If you aim at a simple answer you will get it. It is so simple that you may fear it is only leading you up to a harder question (b). But don't let that fear trick you into thinking that (b) needs a strange, complicated answer.

Think about part **E b**. If ordinary thinking doesn't help you to guess why beards are more welcome to blind men, try turning the story the other way round, and think about CLEAN-SHAVEN men. Ask 'What makes a CLEAN-SHAVEN face less easy for BLIND MEN than for SEEING MEN?' Now can you answer (b)?

Answer E b. *Shaving is rather harder or at least more risky.* (If you add, '*But in a country where every man uses an electric razor, the story might be untrue*', you should hope for a bonus mark.)

INTRODUCTION

CHAPTER 1

WAVES

Wave behaviour experiments with ripple tanks

Introduction

Doing Physics means finding out about things: how springs stretch, how electric currents make lamps light or make magnets pull things, ... Scientists do experiments, they *try* things to find out; then they think about what they find, so that they know more about what happens. They enjoy knowing; also, they can invent new things.

It is not much fun to be *told* about Science. You should see real experiments and do some yourself—so that you know what it is like to be a Scientist.

You will soon be doing many experiments yourself. But, to begin a new term at school, your teacher may show you some physics demonstrations. We call them 'Demonstrations' when a teacher shows them to you; and 'Experiments' when you do them yourself, often working with a partner.

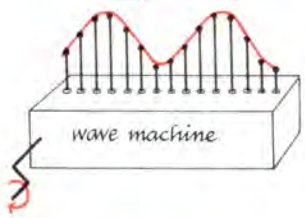
Optional Introductory Demonstrations 0

You may see a few of the following, as samples of things to come. If you see some of them, look at the descriptions which follow below. Do not worry if you do not see these now. You will see most of them later.

0a A Machine that shows a Wave Travelling Along

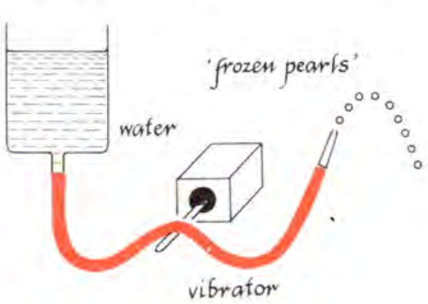
Watch what happens. Does something move along? Does the whole machine move along, like a train running along the railway line? What happens to the wave-speed if we make the motion more violent?

(Questions like those are part of Science, they are the *thinking* that goes with *doing*. Scientists say, 'We ask questions of Nature'—that's the doing of experiments—'and we find out how Nature behaves'—that's the result they get out by watching and thinking.)



0b 'Frozen Pearls' of Water

Water from a small tank squirts out of a tilted glass tube; and you see the stream of water making a 'parabola' (the curve that a stone follows when you throw it in the air). The water stream comes out in separate drops, because the rubber tube that carries the water from the tank to the jet is squeezed by a vibrating electromagnet.



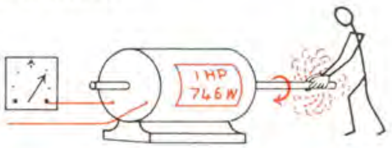
The magnet is driven by alternating current, 50 Hz (cycles per second), so the drops of water come out regularly, one per cycle, 50 per second. They follow each other too rapidly for you to see them as separate drops in the fast-moving stream but there is a trick to make them look 'frozen', fixed at rest in the air! If this demonstration is shown, you will see how that trick is done. Later, you will use it yourself for several experiments. It is called 'stroboscopic' illumination or viewing.

Wait until you see it done, and then try thinking about the way it works. You may think like this: suppose we have the experiment in a dark room and light up the stream of water drops by a special lamp that makes very short bright flashes of light, regularly, exactly 50 flashes a second. *What would we see? What would we see if the flashes come a little slower, only 49 a second?*

0c The Current taken by a Big Electric Motor

An ammeter in series with the motor will show the current that is being used. Watch how the current changes when we make the motor do a job of work, like hauling up a load.

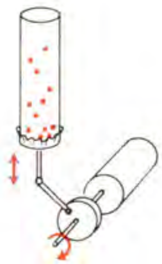
For a demonstration, it is easier to make large demands of the motor by holding its axle with a gloved hand. *What happens then, instead of a load being raised? What happens to the current when the gloved hand holds tighter and exerts more force? Why wear a glove?*



0d A Teaching-model of Air Molecules in Motion

When we think about things that happen in experiments, we often invent a picture to help our imagining and to suggest more experiments. We call such a picture a 'model'. Just as a model aeroplane is not a true plane that carries people, our scientific idea-models are not necessarily true; they are useful thinking-pictures which may or may not be true. When we get down to atoms, any real details are far too small to see directly so we have to say 'all our descriptions of atoms are just idea-models'. We might call them '*thinking-models*'.

We sometimes picture the air around us as made up of tiny particles, 'molecules' of oxygen, nitrogen, carbon dioxide, etc., all in rapid motion, whizzing about, colliding with each other, and bombarding our skin and the walls of the room. That is a *thinking-model* for air.



Then, in thinking about those molecules that we have imagined, we make a guess: *perhaps* the pressure of air is simply made by molecules hitting and bouncing, 'molecular bombardment'. Then we can make predictions about air pressure, to be tested by experiments.

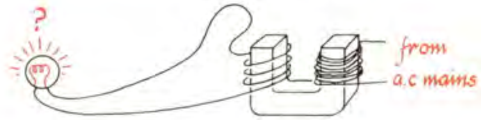
The molecules of our thinking-model are far too small to see, but we can make it easier to imagine their behaviour if we construct a toy with visible 'molecules' which are small metal balls. The balls are in a tall transparent tube. A rubber sheet at the bottom of the tube is pushed up and down rapidly by a small electric motor, and that keeps the balls in motion. See that in action, and watch what the balls do.

That toy is a model of a model: it is a *teaching-model* to show what our scientific thinking-model is like. We might pretend it is a scale model, but scaled *up* enormously in size, instead of scaled *down* like a model aeroplane.

When that teaching-model is running, can you see the balls exerting pressure? What would happen if you put more balls in the tube? (Do you need to try that, or can you guess the answer by thinking?)

0e An Alternating Current Transformer Lights a Lamp

This is something to enjoy seeing, without any explanation until later. The transformer is a block of iron shaped like the letter U, with a coil of wire, called the 'primary' coil, on one leg. That primary is connected to the main a.c. supply.



Watch while a 'secondary' coil of loose wire is wound, turn after turn, round the other leg. The ends of the secondary are connected to a small low-voltage lamp.

What would happen if some of the secondary turns were wound on backwards (for example, counter-clockwise instead of clockwise)? Is this something to guess, or should you ask to see it done?

Waves

We shall do some scientific experiments with waves, many of them experiments that you do on your own or with a partner.

Why worry about waves? Because various kinds of waves do interesting, useful things for you. You will understand those things better if you know how waves behave.

Questions and Experiments 1: Waves

Here are some experiments to try or to see, with questions to read and think about at home.

One of the quickest and easiest ways of sending a message is by waves.

When you talk or play music, sound waves carry your message through the air to other people.

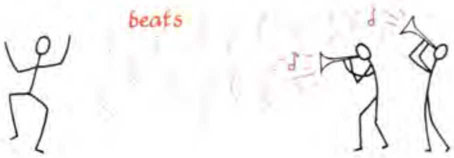
1a Sound: Echo and Speed

Clap your hands, or give a loud shout in a long corridor and listen for the echo. *How does sound travel so fast? Can sound waves in air travel faster than the wind?*

1b Sound: Beats

Listen to two musical sounds of almost—but not quite—the same note. *What do you hear?* The strange throbbing is called 'beats'. *Can you guess how the two sounds manufacture beats?*

Sound waves drive your ear drums in-and-out. *What must they carry to you to do that?*



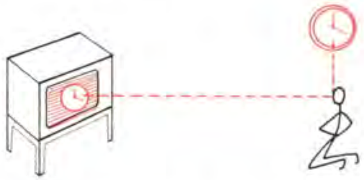
1c Sea Waves

At the seaside you will find great waves coming in from storms far out to sea—often telling you about a storm beyond the horizon. *How do those waves travel to you?*

If you have a chance watch sea waves rolling a stone up the beach; or let them hit you. *What must they carry to move things or do damage?*

1d Radio

The signals of radio and television come to you as waves. These are not waves of water or air; they are waves in electric and magnetic fields.

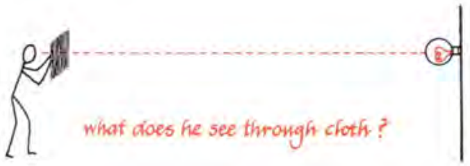


Listen to time signals on the radio, or watch a clock on television. *Do the signals arrive noticeably late if you are far away from the broadcasting station?*

Those signals bring in a tiny stream of energy which triggers a lot more energy from the mains or batteries.

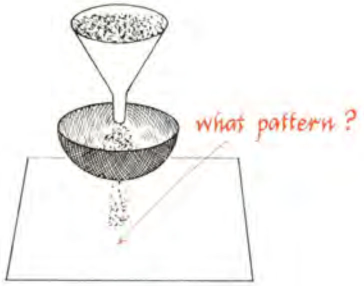
1e Light

We shall argue about light. Is it also a wave motion travelling just like radio waves, a very rapid, very tiny disturbance in electric and magnetic fields?



(*i*) Look at a small bright lamp through a scrap of closely-woven cloth. (Or look at a street light through an umbrella at night.) *Why do you see extra patterns?*

(*ii*) Instead of light through cloth, pour a stream of sand through a fine-mesh strainer. *Does the sand make an extra pattern of heaps or just one small mountain?*



What makes the difference between light and sand patterns? Is it that light IS a wave motion?

1f Radiation Visible and Invisible: Energy

All the colours of visible light, and infra-red, etc., carry energy. (Think of energy here as something that does the useful job of warming things.)

Hold your hand near a glowing fire or near an electric heater. *What do you feel?*

How does energy get to us from the Sun, to grow our food and help to keep us warm?

1g Radiation: Red-hot Heater and Curved Mirrors

You may have seen this demonstration in an earlier year. If not, see it now or later this year.

An electric heater is placed in front of a curved mirror. Several metres away, another mirror faces the first one. Hold your hand near the second mirror (at the 'right' place). *What do you feel?*

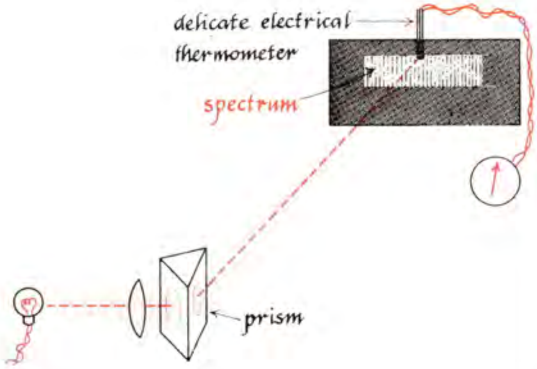
Some energy seems to go across from one mirror to the other.

Ask someone to put a sheet of cardboard in quickly as an obstruction near the heater. What do you feel? *Does the supply of energy stop almost at once or only long after, as it would if air currents carry the energy? How could energy get across there, so far away?*

1h Radiation: Energy among Colours

(You may have seen this demonstration in an earlier year. If not, see it now or later this year.) A prism (wedge of glass) spreads white light out into a band of colours. A specially delicate thermometer is used to explore along the band, to see if energy is arriving there.

How does energy get there, so far away? Quite apart from energy and heating, give suggestions about *what makes the difference between one colour and another.*



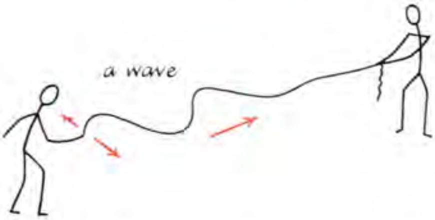
Waves in general So waves usually travel fast. And sometimes they make strange 'extra patterns'. And each kind of wave carries energy.

Thus waves are very important. You will need to know about them if you want to understand the science of sound and music, or the behaviour of radio waves. In a later year you may see how we use wave ideas in our most modern 'thinking-models' of atoms.

In the case of light, there has been a great dispute between two rival *theories* or *'thinking-models'* for light. One of those describes light as a stream of bullets, a *particle model*; the other is a *wave model*. And, to understand what the dispute is about, you will need to know how waves behave, how they travel, and what they can do. Make some waves yourself and watch what they do.

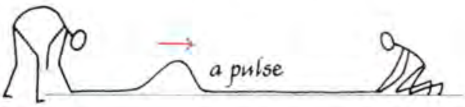
Experiment 2
Transverse Waves on a Rope

Send waves along a taut rope.

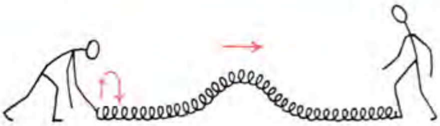


Work in pairs. Your partner should hold the other end while you jerk the rope up-and-down or to-and-fro sideways.

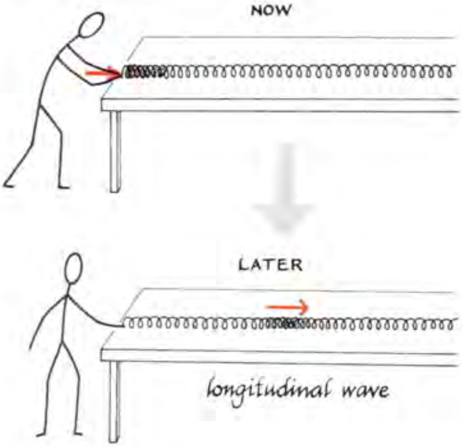
To make a single 'pulse', hold your end near your ankle and whip it sharply against your ankle.



Demonstration 3a
Examples of Wave Motion: Slinky (or Rubber Tubing)



You may see a demonstration of waves on a long, wide spring ('slinky') or on a long rubber tube. As well as transverse (sideways) waves, you may see longitudinal (forward and backward) waves on the spring.

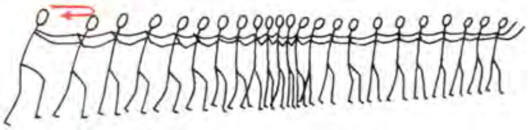


Experiment 3b
Waves in a Human Army *(OPTIONAL)*

If you like, form a line of all the members of the class and try letting a transverse wave travel down the line. In this case it is quite clear that the wave carries some energy.

The class may also try a longitudinal wave.

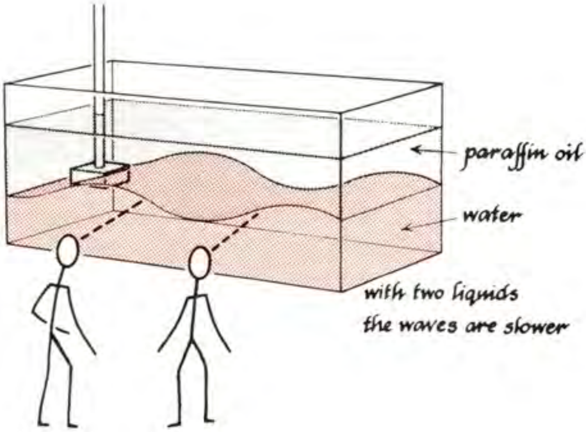
transverse wave



longitudinal wave

Demonstration 3c
Watching Water Waves

What really happens to the stuff that carries a wave? You can see how the pieces of rope move when a rope carries a wave, but what happens with water waves? This is interesting for the waves in the sea. It also gives important help in a later study of waves of light.

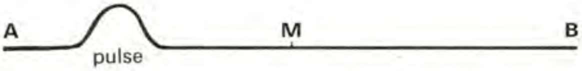


Watch some waves in liquid from one side, so that you can see what the liquid itself does.

Progress Questions

WAVES

1. Lay a long rope out straight on the floor. Tie one end B to a table leg. Mark the middle point M with chalk or cotton. Hold the loose end A and stand facing the rope. Give the loose end of the rope a quick shake to the left. This will make a 'pulse' on the rope. The pulse goes along the rope towards the table leg.



a. When the pulse gets to the middle of the rope, M, is it still on the same side of the rope (the left), or has it shifted over to the other side?

b. Is it bigger, the same, or smaller?

c. Draw two pictures; *(i)* to show a pulse just setting off: and *(ii)* when it gets to M.

d. What does the chalk mark on the rope at M do when the pulse goes past?

2a. Two boys, A and B, hold a long rope and keep it taut. Boy A moves his hand quickly up and down, once. Sketch the rope showing the wave (pulse) that A makes travelling along from A to B.

b. What can the boys do, *with the same rope*, to make the wave travel faster?

c. Suppose the boys tie a piece of paper to the rope at some place C. Does the paper move along with the wave? What does it do as the wave travels past?

3. Ann holds one end of a long rope, and Bill holds the other end. Ann sends a pulse along to Bill.

a. Draw a picture to show what you would see just before the pulse reaches Bill.

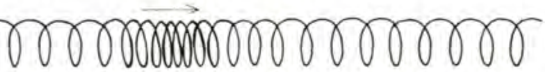
b. Bill feels a force when the pulse reaches him. Put an arrow on your picture to show which way he feels the force.

4. Suppose you sent pulse after pulse down a very long rope, with a chalk mark, M, near the middle.

a. Sketch what the rope would look like with that series of pulses.

b. Describe how the chalk mark would move.

5. This diagram shows a different sort of pulse, in a stretched-out 'slinky' spring.



a. How do you make this sort of pulse?

b. Describe—with sketches if you like—anything special you saw with this sort of pulse.

6. Home Experiment. Set up a lot of blocks of wood standing on the table in a line (like dominoes or toy soldiers). Arrange them so that when you push one block, it falls over, hitting the next one as it falls. You can see one kind of wave there. Do the wooden blocks travel along with the wave?

A chain reaction is something that happens and continues because one bit of it starts up the next bit, and that starts the next, and so on. The motion of blocks falling over is a kind of wave: it is also a kind of chain reaction.

A coal fire, or a firework, burns with a chain reaction—one piece of burning stuff lights the next and that lights the next and the burning continues.

Sometimes a chain reaction grows larger and larger: that is an explosion. You can make an explosion model with blocks of wood or dominoes. Set them up on the table so that one block hits two blocks as it falls over, and EACH of those hits two more as they fall over, and so on. Try that.

7. A small toy boat is floating quite still in the middle of a pond.

a. How could you make a pulse in the water, to go across the pond?

b. What will happen to the little boat as the pulse passes it?

c. Suppose you send a whole lot of pulses one after each other. What will happen to the boat?

8. This is what happens when the bow-wave from a motor boat meets a little boat.

a. Which way is the *wave* moving?

b. Which way does the *little boat* move?

c. Does the wave carry the little boat along with it? (Yes? No?)

Questions

WAVES

9. *Example A* in the table below shows one kind of wave-motion (moving waves) together with:

the way it is started;

what it is that 'oscillates' (that is, moves to and fro);

whether it oscillates *across* the direction of wave travel (that is, at *right angles* to it) or *along* the direction of wave travel.

Copy *Example A* and add two other examples, *B* and *C*. Think of two other kinds of wave that you have seen or heard about. Do *not* include sound or light.

	Example A	*Example B*	*Example C*
Wave:	A LONG STRETCHED STRING		
How set up:	string plucked sideways		
What oscillates:	particles of the string		
Oscillation direction:	at right angles to wave travel		

10. There are two ways by which you can communicate with another person, two ways of sending him a 'signal'.

(i) You can make some object travel from you to him (for example you can touch him, or attract his attention by throwing a stone at him, or send him a letter).

(ii) You can signal by some form of wave-motion.

Suggest some way in which you could communicate with someone else by using the two wave-motions you chose for *B* and *C* in your answer to Q.9. (Note that these do *not* include sound and light.)

Your answer should describe the apparatus you would use (however crude) and say how you would send a message, however simple the method.

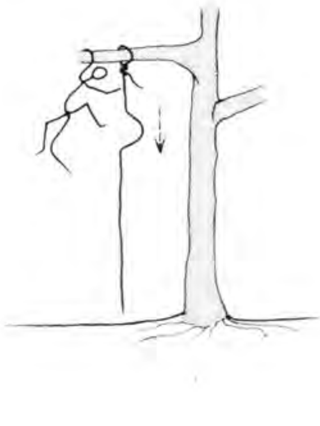
11. A *pulse* is a wave that lasts a short time. For example there is a clap of thunder and the window curtains flutter, or a vase falls off the mantelpiece —a sound-wave pulse did that. A pulse is often quite violent; but it does not continue as a long series of waves.

a. How could the driver of a shunting engine demonstrate a pulse along a train of goods wagons? Say what the wagons do.

b. How could you demonstrate a pulse, given a smooth flat table and a number of coins? Say what happens to the coins.

c. Explain how you would demonstrate a pulse in which the particle movement is *at right angles* to (across) the direction the pulse travels. Assume you are given coins, rubber bands. What else would you need?

12. *(ADVANCED)* A flexible rope hangs down from a branch of a tree. The bottom end of the rope hangs loose just above the ground. A monkey hanging on the branch gives the rope a push and starts a pulse which travels down the rope. Sketch the rope showing the pulse a short time after it has reached the bottom of the rope.



13a. Suppose you hold one end of a 'slinky' spring. and the other end is fixed to a massive wall. You send a pulse along the spring. What happens when the pulse reaches the fixed end, and afterwards?

b. *(i)* How would you show the same thing happening to a pulse made by a stone thrown into still water?

(ii) Give a sketch of what you would see.

14. Suppose a 'slinky' spring hangs vertically with the lower end fixed to the floor. A pulse sent down it from the top is reflected and goes back up.

a. What difference would it make if the lower end were loose and immersed in water?

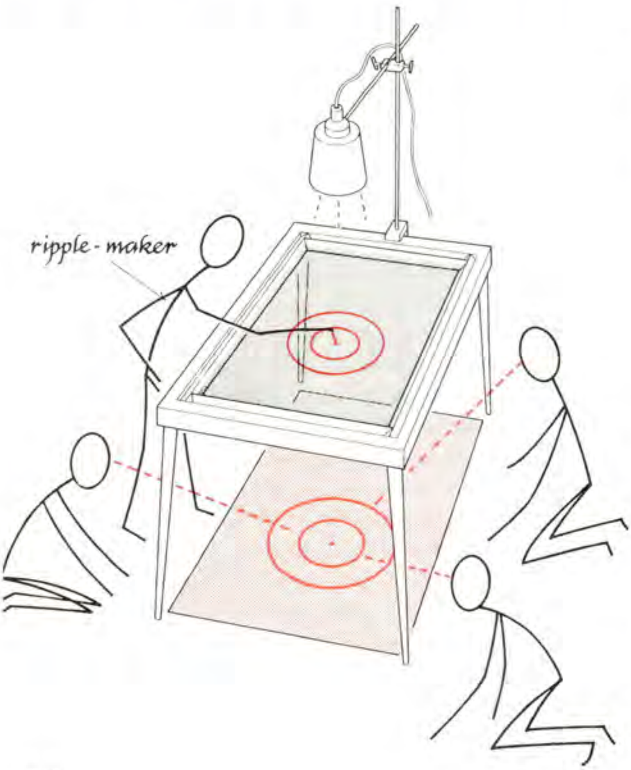
b. What if it were immersed in thick treacle?

RIPPLE TANKS

Now investigate waves yourselves.

Experiment 4
Ripple Tank (A Series of Experiments)

You are going to try many experiments with a shallow pond, to see what it can show you about the way water waves (ripples) behave. The pond is a tray with a glass bottom. Then a lamp above can cast the shadow of the waves on the floor below.



GENERAL INSTRUCTIONS FOR RIPPLE-TANK EXPERIMENTS

Fill the tank with water to a depth of about $\frac{1}{2}$ centimetre.

Make sure it is standing firmly on the floor. Make sure it is level, so that the depth of water is the same everywhere.

Place a bright electric lamp above the tank, and white paper on the floor, so that you can see the shadows of ripples.

THE NEXT FEW PAGES WILL SUGGEST THINGS TO TRY. Try them one after another. Watch and find out all you can about the way ripples behave.

You do not need to take notes. You will have a chance to make notes later when you come to answer questions.

4a Exploring the Behaviour of Ripples

Try your own experiments. Use a finger to start a single ripple, which we call a 'pulse'. Just try any things you can think of and watch.

How else can you start a ripple?

Note. When you look at ripples, look directly at the shadows on white paper under the tank—do not look at those shadows *through* the water in the tank or you may have a double picture.

NOTE. If you jog the whole tank and make it vibrate, you will see square patterns of waves, like a tartan plaid cloth. Those are nice to look at but too complicated to help you learn about waves. Be very careful NOT to make those patterns.

EXPERIMENTS 4b–4e
RIPPLE TANK WITH SINGLE PULSES

Continue the ripple-tank experiments. Go straight on from one experiment to the next in the series 4b, 4c, . . . Take your time to try things carefully and watch what happens.

You will need to empty your tank at the end of the class period; but at the next period and the next with the ripple tank you will be much quicker at setting it up and filling it; so that you can get on with the experimenting on your own and gather more and more general knowledge of ripples.

4b Circular Pulses

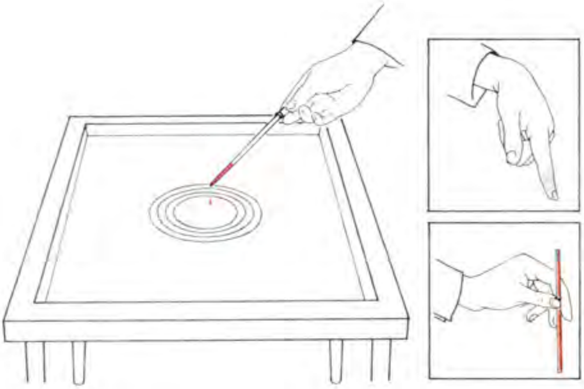
Start a single pulse near the middle of the tank, using a finger or a pencil to touch the water. (Or use a drop of water from an eye dropper.)

Watch what the pulse does.

Make several pulses, one after another, all starting from the same place.

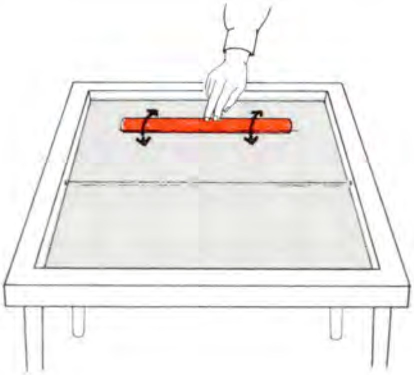
Does the water travel along with the wave?

Invent your own way of finding out the answer to that question. If you cannot find a test, leave that until a later day.



4c Straight Pulses

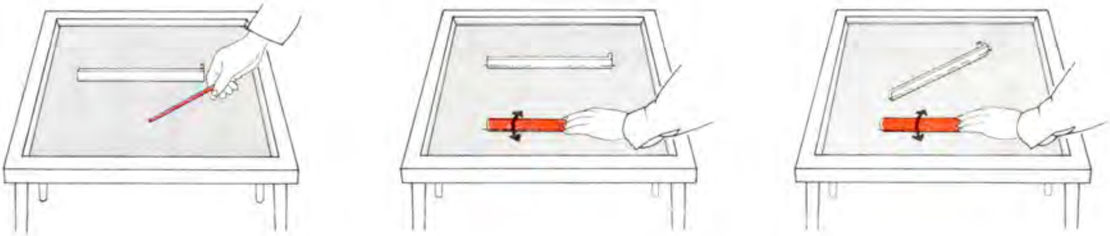
Dip a ruler (or roll a long wooden rod) in the water and give it a *very small* quick push to make a straight pulse.



4d A Pulse meets a Wall

Put a long barrier of wood or metal in the water, like a sea wall.

(i) Start a circular pulse near the wall and see what happens.



(ii) Then make a straight pulse that will hit the wall head-on. (Place the ruler or rod that makes the ripple PARALLEL TO THE WALL.)

(iii) Make a straight pulse that will travel and hit the wall in the *slanting* direction. Avoid a 45° direction.

In each case we say the wall or barrier 'reflects' the ripple, meaning it bounces the ripple back.

4e Curved Wall Reflects Ripples

Bend a stiff tube to make a curved wall the shape of a parabola. Try using that wall to reflect any ripples you like.

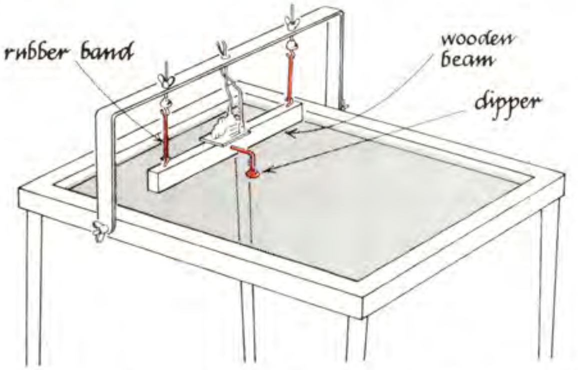
(A parabola is the path of a ball thrown outward and upward in the air. Try that out and watch it. A parabola is drawn for you here in your book, on page 15. Bend your tube to match that.)

EXPERIMENTS 4f–4h
RIPPLE TANK WITH VIBRATOR
TO MAKE CONTINUOUS WAVES

4f A Train of Waves

A little motor with an off-balance load on its axle moves a small dipper up and down, regularly, to make a train of waves.

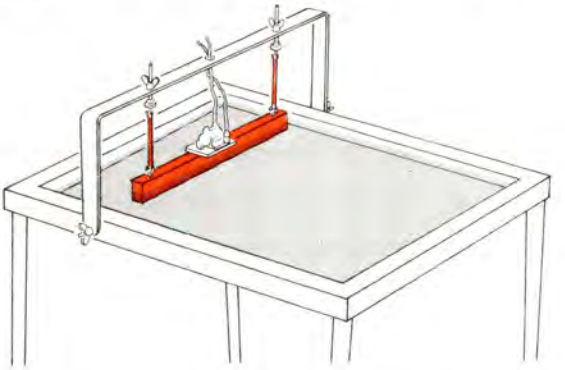
Connect the motor to a battery and watch the patterns.



(i) Use a small ball as dipper. The ball should *just* touch the water. (Raise and lower it a little until you get ripples to travel right across the tank.)

(ii) Let the ripples hit a straight barrier.

(iii) Try making the dipper vibrate up and down faster or slower. *What change(s) do you notice?*



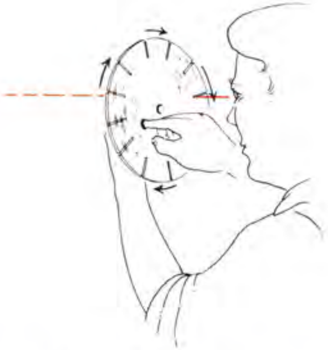
(iv) Remove the ball dipper and lower the wooden bar (with the motor on it) so that the bar almost touches the water. RAISE AND LOWER THE BAR A LITTLE UNTIL YOU GET RIPPLES THAT TRAVEL RIGHT ACROSS THE TANK.

(v) Let the straight ripples hit a straight wall. Then try a curved wall.

'Freezing' a moving pattern A train of ripples moves too fast for you to see clearly all the things it does. There is a way to 'freeze' the ripple pattern, to make it seem to stand still. Look at it through a spinning disk with a hole which only lets you have a glimpse of the waves from time to time. This is called a stroboscope.

The description that follows explains how a stroboscope works.

Suppose you have a wheel with one crooked spoke. If the wheel is spinning you see a blurr of spokes. But suppose you shut your eyes and only open them for a glimpse once every revolution of the wheel—just when the crooked spoke is at the top. Those glimpses will show you the wheel and its spokes 'frozen'—and you will see the crooked spokes looking quite stationary at the top.



That is called stroboscopic viewing; watching something by glimpses spaced at just the right intervals so that the motion seems stopped.

Suppose you take your glimpses a little longer apart. The spokes of the wheel will advance a little from glimpse to glimpse; so you will think the wheel is moving slowly forwards. *If you take your glimpses closer together, what will you think the wheel is doing?*

You may have seen such things in films when a car or cart is moving quite fast but the spokes of its wheels seem to have a queer motion slowly forwards or even backwards. That is because the film is shown to you frame after frame, like glimpses.

You could view a train of waves stroboscopically, taking glimpses at the right rate. To understand how you could do that, think about a long single line of soldiers marching ahead. Suppose you stand where you can watch them march past but keep your eyes shut most of the time. The sergeant keeps them marching 'left . . . right . . . left . . . right . . .'. You shut your eyes and only open them for a glimpse each time the sergeant starts to say 'left' 'le- . . . le- . . . le- . . .'. *What will you see in that series of glimpses?* From one glimpse to the next the soldiers all 'move on one'. So you will see a fixed pattern.

Experiment 5
Introduction to Stroboscopes

Instead of opening and shutting your eyes, you can have a stroboscope disk, a round piece of cardboard with a slit near the edge. Keep the strobe disk spinning with a finger while you hold it in front of your face and look through it. You catch a glimpse each time the slit comes round in front of your eyes.

Use your own hand stroboscope (strobe disk) to view an arrow that is kept spinning by an electric motor. Even though it is spinning quite fast, you can 'freeze' the arrow.

Questions

STROBOSCOPE

15. You have a stroboscope disk which you can turn by a handle, and the disk has only ONE slit in it.

a. Describe the kind of picture you see if you rotate the disk at two revolutions per second and look 'through it' at a car travelling along a straight road some distance away.

b. Suppose the car travels at 50 kilometres per hour ($\approx$ 13 metres per second $\approx$ 30 miles per hour or 44 feet per second). How far does the car travel between one 'glimpse' that you get and the next?

c. Now suppose you speed up the disk so that it rotates *four* times per second. What is the time interval between glimpses? How far does the car travel between one glimpse and the next?

d. If the disk has TWO slits in it, at opposite ends of a diameter, and you rotate it only TWICE per second, the result is just the same as in (c). Why is this?

16. A spoked wheel has *eight* spokes, and it rotates *once* per second. It is viewed through a strobe disk that has *one* slit and rotates *once* per second. The wheel appears to be at rest, not rotating at all.

a. Why does the wheel appear to be at rest?

b. If the strobe disk rotates *eight* times per second, the wheel also appears stationary. Why?

c. *(ADVANCED)* The wheel also appears stationary when the disk rotates *twice* a second; also *four times* a second. Why is this?

17. A strobe disk has twelve slits and rotates 15 times in 3 seconds.

a. How many times does it rotate in 1 second?

b. How many glimpses through the slits does it give in 1 second?

c. What is the time interval between one glimpse and the next?

d. Suppose you want to use that strobe disk to give a time interval *twice* as long as in (c). How would you alter the disk?

e. How could you *double* the time interval between glimpses *without altering the disk in any way?*

18. A ball rolls in a straight line along a level table. Its speed is 120 centimetres per second. It is viewed through a strobe disk which has 10 slits and rotates 3 times per second.

a. How many glimpses of the ball do you get in 1 second?

b. What is the time interval between one glimpse and the next?

c. How far does the ball travel in the time between one glimpse and the next?

19. Suppose that, instead of looking at the rolling ball (Q.18), you use a camera and take a photograph of it through the strobe disk. You leave the shutter of the camera open while the ball rolls.

a. Draw a sketch showing what you expect the photo to look like.

b. Explain briefly why it looks like that.

20. Suppose in another experiment, you see that the distance the ball moves *between one glimpse and the next* gets smaller and smaller, from one to the next. This might be due to:

A. the ball slowing down,
B. the ball speeding up,
C. the disk slowing down,
D. the disk speeding up.

a. Which of these suggestions, A, B, C, D, *could* be correct?

b. Explain why (in one or two sentences).

21. A wheel has 8 spokes all alike. A boy looks at it through a strobe disk with 10 slits. When the disk rotates 4 times a second, the wheel seems to be at rest.

a. How many glimpses of the wheel does he see in 1 second?

b. How long is the time interval between one glimpse and the next?

c. What is the *longest* time the wheel can be taking to make one complete rotation and still seem to be at rest?

d. What is, therefore, the *smallest rate* of rotation the wheel can have? (Give your answer in revolutions per second.)

22. Suppose the wheel of Q.21 continues to turn at the same speed but the strobe disk is slowed down *slightly*.

a. What does the boy see now?

b. Explain why.

c. What does the boy see if the strobe disk is speeded up slightly from the rate which made the wheel seem to be at rest?

d. Explain why.

23. *(ADVANCED)* Suppose the wheel (Q.21) rotates at *twice* the 'smallest rate' for freezing the motion. Then the spokes again appear to be at rest. Why is this?

24. Suppose the wheel (Q.21) has *one* of its spokes painted white. The stroboscope is rotating at the smallest speed which makes the spokes appear at rest. What will you see? You will not see one clear white spoke. You will see several faint ghostly ones instead.

a. The white mark is *not* clearly visible. Why not?

b. What is the smallest rate of rotation of the strobe disk if you can see the white mark clearly and it appears to be at rest?

25. The games master at a school wishes to take 'slow motion' pictures of pupils while they are batting, bowling, jumping, running, diving, etc., in order to help them to correct faults.

He has a film projector which runs at 16 frames per second, and a film camera whose speed can be varied. He says that he wants to show pictures at half actual speed, and to do this he proposes to set his camera for 8 frames a second instead of 16.

a. Is he right?

b. If not, what would you tell him to do? Explain why you are right and he is wrong.

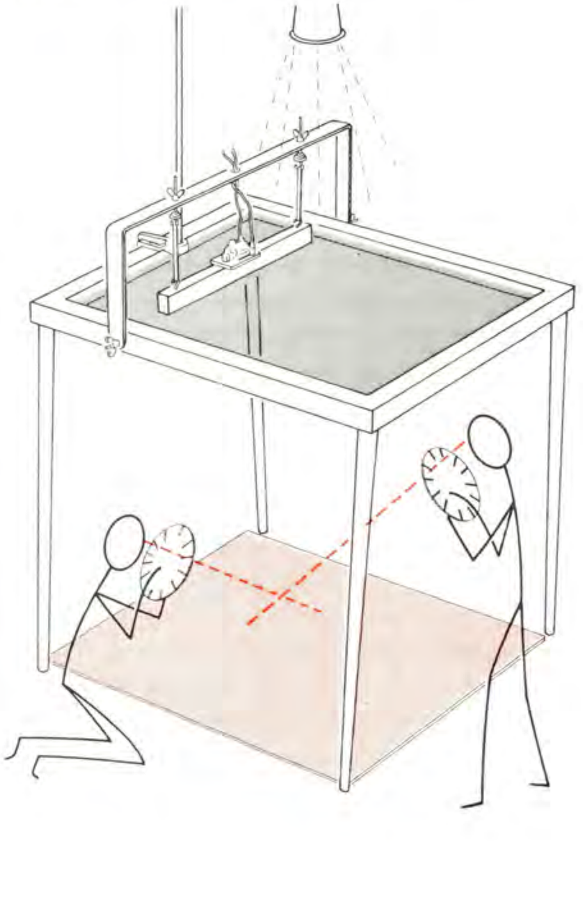
c. What would happen if he did it his way?

26. An astronomer is making a special study of the surface of the Sun. He wishes to make a ciné film, showing changes in the Sun's corona—that is the region just outside the Sun's surface. In the corona there are great jets of red hot gases which are thrown out in spurts from the surface. They rise many thousands of kilometres and fall back. The astronomer wants to take pictures so that one 3-minute film will show changes that actually take three days. The film will be run at the rate of 16 frames per second. How often must the astronomer take a photograph (one frame) to get three days of pictures into three minutes?

You can do that with water ripples. Arrange the glimpses so that between one glimpse and the next each wave-crest moves ahead to the place where the next wave-crest was.

4g 'Freezing' the Wave Pattern

Try watching the shadow of a train of ripples through a hand stroboscope. *Can you 'freeze' their motion?*



4h Measuring Wavelength of Ripples

When the pattern is 'frozen' try to measure its 'wave length'. That is the distance from crest to crest, from one complete ripple to the next.

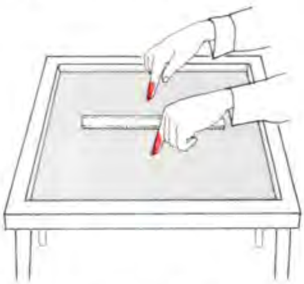
Change the vibration rate. *What happens to the wavelength?*

EXPERIMENTS 4i–4n
USING A RIPPLE TANK
TO ANSWER QUESTIONS

(These are experiments to do carefully, to make sure your ripple tank shows you a clear answer. You may want to compare your tank with another tank nearby.)

4i Where from?

QUESTION: You saw a round pulse bounced back by a straight wall. Where did the reflected pulse SEEM to have started from?



Try that again in your ripple tank. Put the wall near the middle of the tank. Start the round pulse by a finger near the wall.

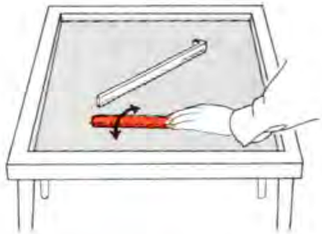
When you know *where the reflected pulse seems to come from*, try starting a pulse from that place as well. To do that, make a pulse with a finger of your *left* hand. Let that pulse spread and hit the wall and bounce back. With a finger of your *right* hand mark the place that the bounced-back pulse *seems to come from*. (If you like, put a small coin there in the tank so that you can remember that place.) Then start a pulse from that place with your right-hand finger.

Now keep those fingers in the same positions and start pulses with *both* those fingers *at the same time*. Your left finger will start the main wave and your right finger will start a wave like the one that bounces back from the wall.

Watch.

4j A Question about Reflection

QUESTION: Can you find a simple story to describe what happens to straight waves when they meet a flat wall?



Let the waves meet the wall in a slanting direction: and look at the direction of the reflected waves.

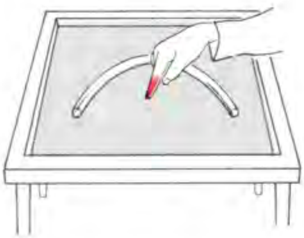
Do you see anything about *angles* there? (There is no need to measure angles. This is just a suggestion for looking at the pattern.)

4k Parabola

(i) QUESTION: What happens to a straight pulse when it hits a curved wall that has the shape of a parabola?

If you did not see a clear answer to this question in earlier experiments, try it now carefully.

(ii) QUESTION: Now try the reverse of that question. Can you make straight ripples come OUT from a curved parabola-shaped wall? The straight waves are to be the *reflected* waves.



Find out what waves you must send in to the wall to make this happen. Try with a finger at various places in front of the wall.

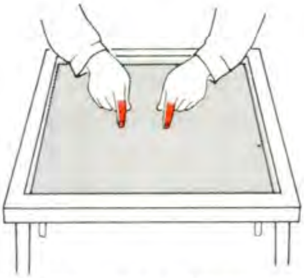
4l Puzzle: What does a Circular Wall do to a Pulse?

(Here is a puzzle question, simpler than the last one.) Use a reflecting wall that is part of a *circle*. Find out anything you can about the way

this curved wall reflects waves. Here, you are on your own to investigate the question and then look for an answer.

4m A Very Important Question: What happens when one Ripple crosses Another?

Do they upset each other? Do they come out from the encounter weaker or the worse for wear, or stronger, or just the same?

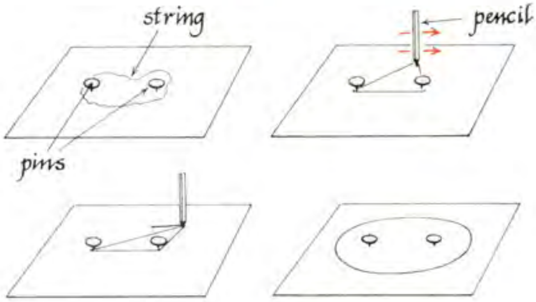


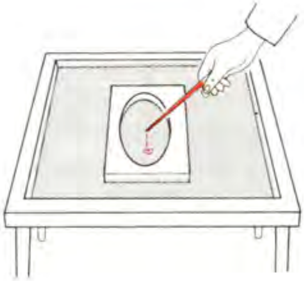
Make one pulse with a finger, and then start another pulse from a place some distance away, perhaps a little later. Watch the two pulses.

4n Ellipse Reflector

What can a reflecting wall in the shape of an ellipse do? If this special wall is available, ask your teacher to show what happens.

HOW TO DRAW AN ELLIPSE





Progress Questions

WAVES IN A RIPPLE TANK

27. Write some *careful* instructions to help someone new to use a ripple tank. Explain:

a. Where to put the lamp. (Does it matter very much?)

b. Where to look to see the pattern.

c. How to make a clear circular ripple.

d. How to keep the water smooth, without extra ripples which muddle the picture.

e. Any other special things you can think of.

28. You have a ripple tank with water already in it.

a. What do you see when you touch the surface of the water with one finger?

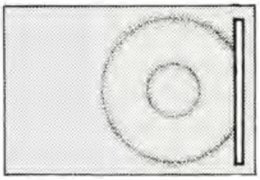
b. What do you see when you let a drop of water fall from a dropper?

c. You have a roller in the water in your ripple tank. What do you see happening if you give the roller a small roll and then stop?

d. Describe, or draw sketches, of anything else that you noticed with your ripple tank.

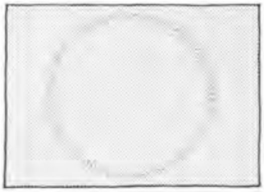
29. When a round pulse reaches a clean straight wall, it does not stop and disappear. The wall bounces it back. We say the wall *reflects* the wave.

Copy the diagram and sketch the reflected part of the ripple.



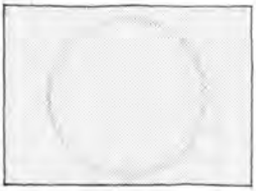
30a. How can you make a circular ripple (or pulse)?

b. Copy the drawing and show what the ripple will look like a moment later.

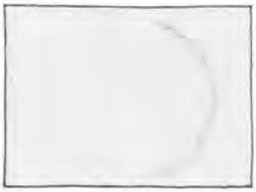


31a. Fig. A shows a round ripple in a ripple tank. Where did it start?

b. Fig. B is a picture of a round ripple in a ripple tank. But somehow part of it does not show in the picture. How could you find the place where it started? (HINT. Borrow a 1p coin.)

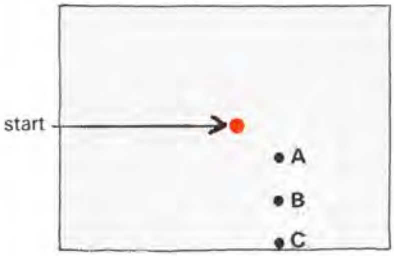


A



B

32. A finger dipped at some central place makes one pulse. Copy the diagram and mark all the pulse when a piece of it has had time to travel out to A. Also all the pulse when a piece of it has had time to reach B. Also when a piece of it has had time to reach C.



33a. When you made a small pulse (ripple) by dipping your finger in a ripple tank, what shape did it have as it moved out? Answer in one or two words.

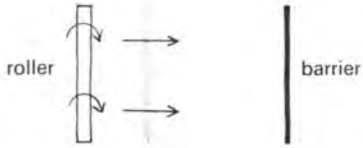
Also make a sketch (about as big as your hand) of a *square* tank, and show one ripple in it. You do not need to use special drawing instruments such as compasses. Borrow a coin.

b. Did the ripple change *size* as it moved out?

c. Did it change its *shape* as it moved out?

d. Say in a few words how you can make a straight ripple or pulse, with a ruler.

34. The roller has made a single straight pulse. The pulse goes across the ripple tank to a straight wall. The arrows show which way the pulse is going.



a. How can you use a roller to make a straight pulse?

b. Draw sketches to show the pulse:
(i) just before it meets the wall.
(ii) just after it has met the wall.

Put arrows on both sketches to show which way the pulse is moving in each case.

35. Have you watched a single straight pulse travel across a ripple tank? About how fast did the pulse go? (Was it at walking pace—about a metre a second—or much faster or slower?)

36a. You have seen waves in ropes and waves in water. What other kinds of waves have you heard of or seen?

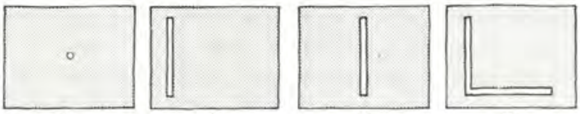
b. Are 'waves in hair' the same sort of wave? If not, what is the difference?

RIPPLE TANKS

37a. Drops of water fall into the ripple tank. Ripples go out in all directions and they look like circles. Suggest some way of testing whether they really are circular. (You should suggest you want a more accurate test than simply looking at them.)

b. Ripples are formed by a 15 cm ruler held horizontally and dipped into the water. Are those ripples circular? Are they straight? Sketch their shape as seen from above.

38. Figs. A to D show some pictures of a ripple tank with different things starting a ripple. Copy each picture and show on your sketch one pulse that has travelled out a short way from the starting point.



A B C D

Fig. A. A finger dipped once at the centre of the tank.
Fig. B. A wooden bar or ruler dipped once near the lefthand side of the tank.
Fig. C. A wooden bar or ruler dipped at the centre of the tank.
Fig. D. Two wooden bars glued together to make a shape like letter L, dipped once.

39. Draw a series of pictures like a comic strip to show what a pulse does when it is started *in each of the following ways.*

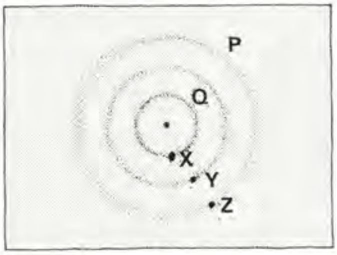
a. A finger dipped once at the centre of a circular reflecting wall (Fig. A).

b. The circular reflecting wall is cut in half, so that there is only a semicircle (Fig. B). A finger is dipped in the 'centre' as shown.

A B

40a. Suppose you have a motor-driven dipper that dips in a ripple tank every $\frac{1}{4}$ second. The diagram shows a snapshot of the ripples it makes. Why does the ripple at P look fainter than the ripple at Q? (HINT. Use the word 'energy' in your answer.)

b. Use a piece of paper as a rough ruler to measure the spacing of successive ripples. How does the *radius* of a ripple, in this snapshot, change from X to Y to Z? What does that tell you about the way ripples travel?



41. If you put bits of paper (or some dust) to float on the water of a ripple tank, you can see how the water itself moves. What did you see the water do? Did it move along with the wave? If so, did it move as fast as the wave? Or did it do something quite different?

42a. How would you show, by doing an experiment with a ripple tank, that two waves pass through each other *without change?*

b. What would be a similar effect with waves in a 'slinky' spring?

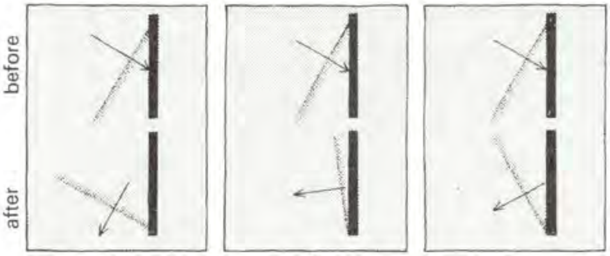
c. What happens to ripples when they arrive at a sloping beach in the tank?

d. What would be a similar effect with waves in a 'slinky' spring? Suggest a way of making that happen with a 'slinky' spring.

43a. What happens when two balls of steel or glass are rolled in opposite directions along a grooved plank so that they meet head-on?

b. In what way is this different from what happens when two *waves* meet head-on?

44. A straight pulse goes across a ripple tank and hits a straight wall. But it arrives at an angle with the wall.



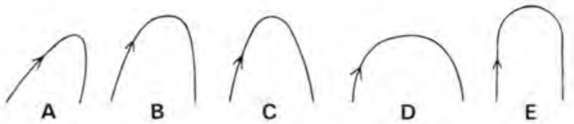
A B C

a. Which pair of sketches, A or B or C, best shows what happens?

b. Explain how you decided which was correct.

PARABOLA

45a. *The Shape of a Parabola.* Throw a small stone (or a ball or a piece of chalk) upward and outward. Watch its path. Which of the pictures, A, B, C, D, or E, is nearest to the shape of that path? (NOTE. The path of any small dense projectile is called a parabola.)



b. *Parabolic reflection.* Describe the things a parabola-shaped reflector can do to ripples.

46a. Describe a simple stroboscope ('strobe disk') such as you have used with a ripple tank.

b. When you look at ripples through a stroboscope they can be made to appear at rest. Explain how this happens.

c. Suppose a strobe disk is rotating at the correct 'no motion' or 'freezing' speed. What do you expect to see:
(i) if the rotation is speeded up slightly?
(ii) if the rotation is slowed down slightly?

47. A stone is dropped in water. The ripples spread farther and farther. They get smaller and smaller in height and finally vanish. Why do they get smaller? Give *two* reasons.

48. *(ADVANCED)* A bugle player stands and plays in an open field. Various people listen to his 'tune'.

To the people farther from him his tune sounds fainter than to people near him. Why?

49. *(ADVANCED)* A round pulse in water usually spreads outwards.

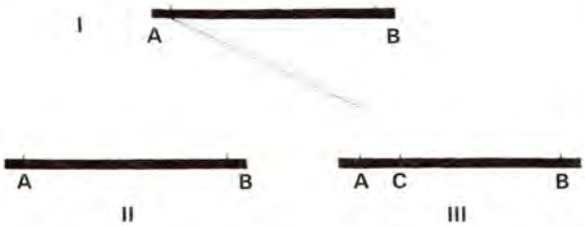
a. How can you make a round pulse that travels inwards?

b. What does such a pulse do after reaching the centre?

50. *(ADVANCED)* In fig. I, the sloping line AX represents a part of a straight ripple produced by a vibrating straight bar. The lefthand side of the part of the ripple has just reached a point A on a straight reflecting surface AB. A little later the righthand side will reach B. The angle between the ripple crest and the reflector is 25°.

a. Copy fig. II; and show the position of the ripple crest when the righthand side has reached B. Mark on it an angle which you think is equal to 25°.

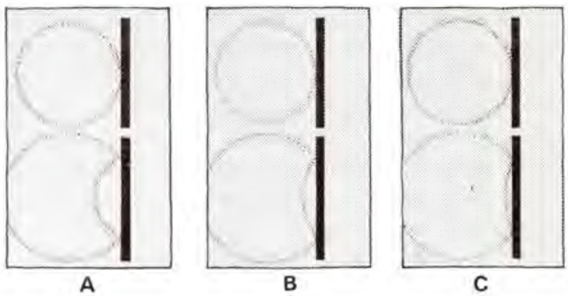
b. Copy fig. III and show an earlier position of the ripple crest, when it has just reached C (that is, before it has got as far as B).



51. The arrow Y in the diagram shows the direction in which the wave front travels.

Copy the diagram. On your copy:
(i) Add a line Z at right angles to the reflecting surface AB.
(ii) Add an arrow R showing the direction of travel of the reflected ripple.
(iii) Mark in two angles on the diagram which are equal.

52. A circular pulse meets a straight barrier.



a. Which drawing shows best what you would see a short time later?

b. What did you look for in the drawings?

53. This drawing shows a circular ripple and a barrier.

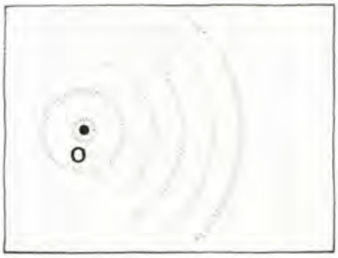
Where would you put the point of a pair of compasses to draw the reflected part which has been missed out of the drawing?

RIPPLES AND RAYS

54. *RAYS.* When ripples move out from a 'source' (starting point) you can draw lines-of-travel like the one in fig. A. We call these lines 'RAYS' (from the Latin for spokes of a wheel).

A

B



a. Fig. A shows straight ripples made by a ruler dipping in a ripple tank. Copy this sketch and add more RAYS to show how these ripples travel from left to right. Put arrow heads on the rays.

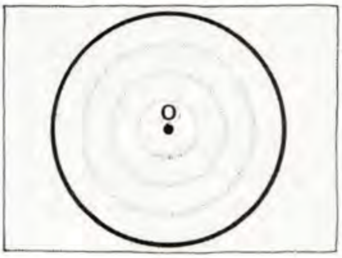
b. Round ripples travel out in a ripple tank from a dipping finger at O. Copy fig. B and add some RAYS which show how the ripples travel.

c. *(i)* Round ripples start from O at the centre of a circular reflector (see fig. C). The RAYS for those ripples travelling *out* will be the same as in (b), so you need not draw those. But draw the RAYS for the ripples *reflected* from that round wall.

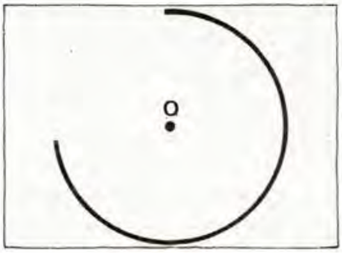
(ii) Where do those reflected RAYS pass through a focus point? Do they stop there or do rays and ripples continue?

(iii) Try continuing the RAYS. Then guess what they show the ripples would do. Using your guess draw the later stages of reflected ripples. That will be easier if you draw the round reflector with a gap in it like fig. C *.

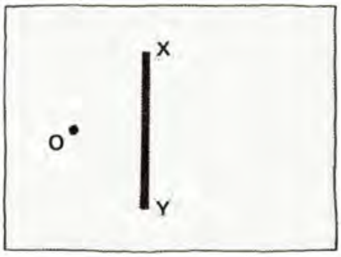
C



C*



D



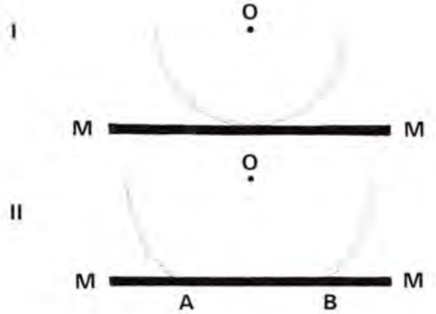
d. *(i)* Ripples start out from a dipping finger at O and meet a straight wall XY. Copy fig. D and draw the RAYS for the ripples travelling out.

(ii) Draw the RAYS for the reflected ripples. Where do the reflected rays *seem to come from?*

REFLECTIONS OF RIPPLES

55. Fig. I shows a round pulse spreading out from a source at O. The pulse has just reached a reflecting wall MM. A little later the pulse has reached the position in fig. II.

a. Copy fig. II. Draw in the position of that part of the ripple between A and B *which has already been reflected.*



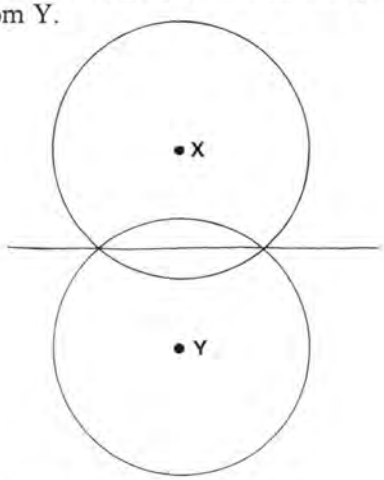
b. Suppose you think that this reflected part is part of a circle. Where do you expect the centre of that circle to be? Mark the centre D on your diagram.

c. What can you say about the distance of that centre D from MM? Is it larger than the distance of O from MM, or the same, or smaller?

56. A boy set up a straight wall across a ripple tank. He dropped in drops of water at two places X and Y, at the same time. The pulses made the pattern shown in the diagram.

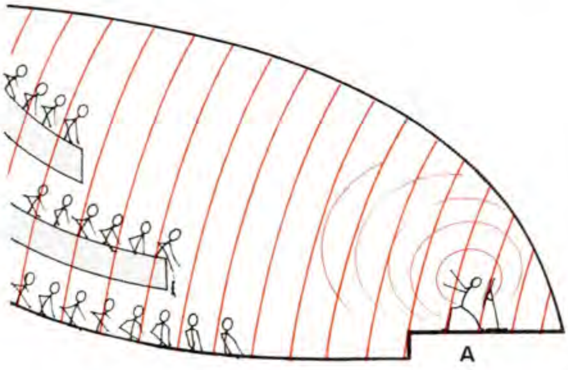
a. What can you say about the distances of X and Y from the wall?

b. Copy the diagram. Draw over the pulse that came from X with a coloured pencil or ink. If you have another colour, use that on the pulse that came from Y.



57. A reflecting wall bent to the shape of a parabola is put in a ripple tank. You could find a place for your finger to start a pulse so that after being reflected by the wall the pulse is a straight one. Draw the RAYS for several stages of that ripple: starting out from the right place, hitting the reflecting wall, and continuing after being reflected.

58. The sounds of music and people's voices travel out as waves in air. Architects who design concert halls and theatres sometimes use a ripple tank before they start the building to see what sound waves would do.

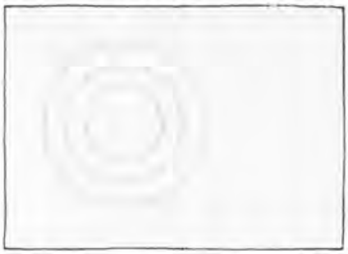


The diagram shows a theatre with its ceiling in the shape of (part of) a parabola. The actor, A, stands at just the right place for the reflected waves to be straight waves, so that they travel out to all parts of the audience. The diagram also shows waves from an actor's voice.

a. Copy the diagram and add RAYS, from the actor to the ceiling and from there to the audience.

b. When this shape of ceiling was tried for a cinema, it was a great success. The loudspeaker was placed where the actor is in the sketch and all the audience heard very well indeed. But when it was tried for a concert hall, it was not a success. The violinist at A complained bitterly about something. He said he was disturbed. Guess what the trouble was. (HINT. Remember that waves can travel both ways.)

59. Here is a strange picture of a round ripple growing smaller as it travels.



a. How could you make a ripple which does that? (Guess!)

b. Copy the diagram and draw rays for the ripple.

c. On your sketch continue those rays to show later stages of the travel of the ripple. (Use the rays to help you to guess what the ripple will do in later stages.)

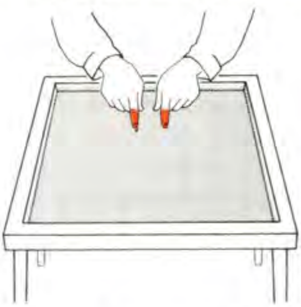
EXPERIMENTS 4o–4v
SPECIAL RIPPLE-TANK EXPERIMENTS TO LOOK AHEAD

(These are OPTIONAL EXTRAS now. You will not need to know the things they show until a later year.)

4o Waves from a Pair of Sources, using two Fingers *(OPTIONAL NOW)*

This is a first attempt at something you will meet again.)

Use two fingers of one hand as a pair of sources near each other to make two sets of ripples. Try making a pair of pulses (single ripples).

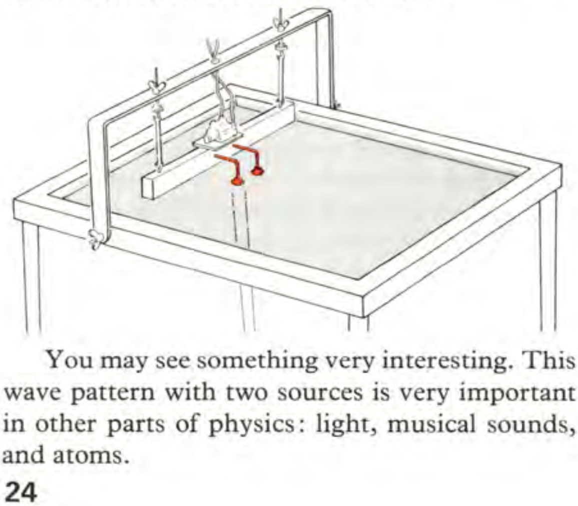


Then move your hand up and down regularly and make two streams of continuous ripples.

It is difficult to see the pattern because you cannot dip your fingers in and out regularly or fast enough. *What should you use instead of fingers?*

4p Waves from a Pair of Sources, using the Vibrator *(OPTIONAL NOW)*

Use the motor-driven vibrator with a pair of small dippers attached to the wooden bar. The dippers should be 2 or 3 centimetres apart. RUN THE VIBRATOR AS SLOWLY AS POSSIBLE.



You may see something very interesting. This wave pattern with two sources is very important in other parts of physics: light, musical sounds, and atoms.

At this stage you do not have to see the right pattern at all costs or make a note of the pattern. It is something interesting to see now: and meet again later.

(You will find another method, suggested after Experiment 4q.)

4q Waves passing through a Gateway *(OPTIONAL NOW)*

You have seen what happens when ripples meet a barrier. *What happens when there is a hole in the barrier that lets ripples through?*

(i) Wide gateway. Arrange the vibrator and bar to make straight ripples. Place two pieces of wall about 5 centimetres from the vibrating bar, with a wide gap between them—about 10 centimetres.

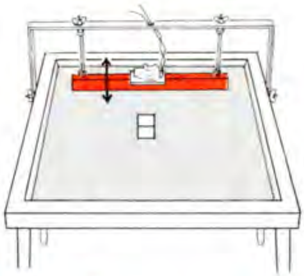
Look at the ripples that get through.

(ii) Narrow gateway. Use the same arrangement as above but move the barriers so that the gap between them is only 1 or 2 centimetres.

Keep the vibrator running *very slowly*. Watch the waves that come through.

4r What does a Very Short Wall do to Waves? *(OPTIONAL ADVANCED EXTRA EXPERIMENT)*

Try placing a small obstacle 2 or 3 centimetres wide near the vibrating bar. This may show what a tiny island does to waves in the sea. (A weighted piece of plastic foam will do well.)



4s Two Narrow Gateways to act as a Pair of Sources *(OPTIONAL NOW)*

Let straight waves from the vibrating bar meet a wall with two very narrow gaps 2 or 3 centimetres apart. Those ripples make the water in each gap bounce up and down so that beyond the wall the waves seem to start from the two gaps. (The same thing can be done with sound waves, and you may also see it with light.)

4t Waves that change their Speed *(OPTIONAL ADVANCED EXPERIMENT)*

Ripples travel with a different speed in shallower water. But they also die away soon, because their energy is taken away by water friction.

If you level your tank and adjust things very carefully you may be able to see what happens. Or you may just watch a demonstration.

To MAKE A PATCH OF SHALLOW WATER, put a sheet of glass in the tank. (Put some small bits of metal under the glass so that you can take it out again easily.) Pour in water until it *just* covers the glass. Then take out a little water, leaving a *very* shallow layer of water above the glass. (The tank must be very carefully levelled for this.)

Lower the vibrating bar until it just touches the water. Run the vibrator *very* slowly.

(i) Arrange the glass sheet so that the ripples meet its edge head-on. *What happens to their speed? What happens to their wavelength (distance from crest to crest)?*

(ii) Turn the glass so that the waves will meet it in a slanting direction. Now watch carefully what happens to them.

4u Estimating Wavelength, Frequency and Speed of Ripples *(OPTIONAL ADVANCED EXPERIMENT)*

Run the vibrating bar as slowly as possible. 'Freeze' the pattern of ripples, by viewing it through a hand stroboscope.

(i) Measure a batch of WAVELENGTHS (say 10) on the paper on the floor. (Remember that the wavelength is the distance from crest to crest.)

(ii) Estimate roughly how many vibrations the bar makes in one second. Count vibrations in groups of 4, for several seconds. (A scrap of paper touching the motor's axle will make sounds that are easier to count.) Or use a hand stroboscope. Calculate the FREQUENCY (the number of complete vibrations in each second).

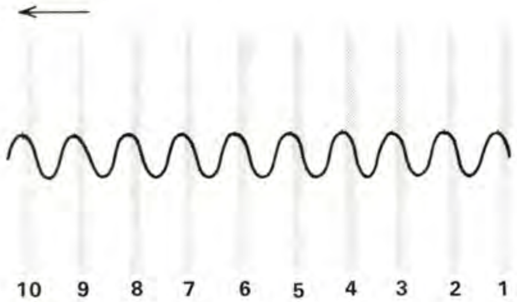
(iii) Estimate the ripples' SPEED by timing one crest across the paper.

These will be rough measurements, but they may be good enough to offer a test of a formula that connects WAVE-SPEED, WAVELENGTH, and FREQUENCY.

Questions

REFRACTION OF WAVES

60. The diagram shows a set of straight ripples in a tank. The ripples came from a vibrator on the right of the diagram. When a stroboscope is used at the proper rate the ripples seem to be frozen in the positions shown. A flat glass plate rests on the bottom of the tank, so the water above it is shallower. The ripples are parallel to the edge of the plate.



a. Look at the diagram. Where do you think the edge of the plate is situated? Is it between crest no. 2 and crest no. 3, or between 8 and 9, or where?

b. Is the plate in the righthand part of the tank or the lefthand part?

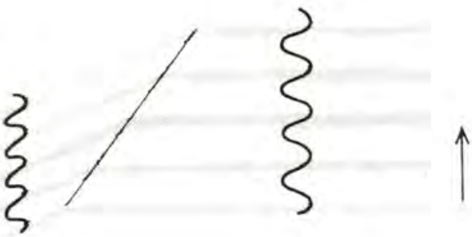
c. Do the ripples on the right and the ripples on the left have the same frequency? (Remember that the stroboscope makes *all* the ripples seem to be at rest.)

d. What is the wavelength on the right? (Measure the diagram with a centimetre ruler.)

e. What is the wavelength on the left? (Measure the diagram.)

f. If the speed of the ripples is 21 centimetres per second on the right, what is the speed on the left?

61. Here is a diagram of a series of straight ripples coming from a vibrator at the bottom of the page. In the tank there is a straight-sided glass plate which makes the water above it shallower.



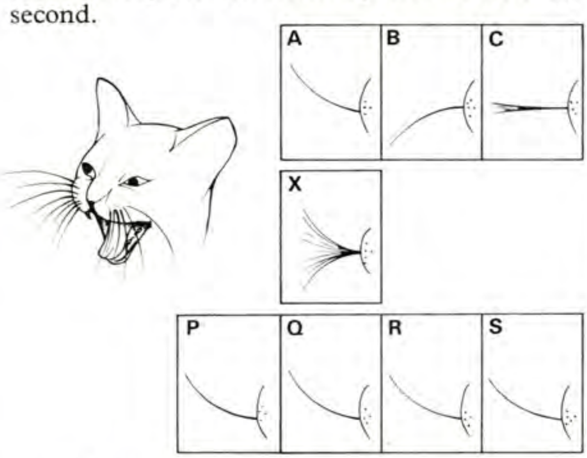
a. Where is the edge of the plate? Copy the diagram and mark that edge on it.

b. Find, by measuring on the diagram, the wavelength in the shallow part.

c. Draw some 'rays'—that is, some lines showing the direction-of-travel of the ripples in each part of the tank.

d. What happens to a ray when it meets the shallower water at the edge of the glass sheet?

62. An angry cat has one long whisker which trembles with fury. The end of the whisker makes twelve complete vibrations up and down every second.



Each of the pictures, A, B, C, is a snapshot of the whisker taken with a flash bulb. The picture X was taken with a long exposure.

a. The pictures P, Q, R, S, are photos of the vibrating whisker taken by a specially slow ciné camera. How many photos a second was it taking? (There may be more than one right answer. Choose the easiest.)

b. You have a stroboscope with 12 slits and you make it go round once a second. Suppose you could look through it at the whisker (still trembling 12 times a second). How many glimpses of the whisker seen through the slits would you get in one second? What would you see? (Answer in words or with a sketch.)

DIFFRACTION OF WAVES

63. The diagrams show three arrangements of walls placed, each one in turn, in a ripple tank. In each case a straight vibrator, near the bottom of the page, sends a series of straight ripples to the walls.

a. Fig. A shows a wall with one very narrow gap. A ripple reaches the wall and the gap. A little later the ripple has travelled a further distance of 3 centimetres. Copy the diagram and sketch in the position of this ripple. (You may use compasses if you like.)

b. In fig. B the gap is about 5 centimetres wide. Copy fig. B. Sketch in roughly what you think would be the shape of a ripple which has travelled 3 centimetres beyond the gap.

c. In fig. C there are 11 narrow gaps in a row. The two end ones are 5 cm apart. Treat each gap as a single small hole like the one in fig. A. Copy fig. C and sketch the ripples when they have travelled 3 cm beyond the wall and gaps.

d. Can you find from this any new idea about ripples and what they do? If so, describe that in one or two sentences.

64. The diagrams show straight waves coming up to barriers with holes in them. Copy them and draw in what happens on the *far* side.

INTERFERENCE OF WAVES

65. A single vibrator has its dipper immersed in a ripple tank. The ripples it forms are circles as usual. A second vibrator is then set up, about 5 centimetres from the first. The two vibrators move up and down *together*, 'hand in hand' so to speak ('in phase'). Describe briefly (with a sketch if you can) the ripple pattern produced by the two vibrators together.

66a. Suppose the same thing as in Q.65 could be arranged with waves of light. What would you hope to see?

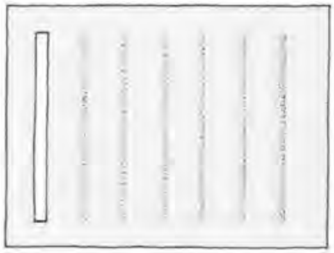
For example, the two vibrators might be replaced by two flash-lamp bulbs, and the ripple tank replaced by a white wall.

b. Do you think any such effect would actually be observed with the bulbs and the paper? Why not? (Either give a practical answer, e.g. 'I've tried it and . . .', or 'I've seen something similar and . . .', or give a theoretical reason; or give both.)

67. Astronomers tell us that when we see a star, we are really seeing what it was like hundreds of years ago. Can you explain this?

WAVELENGTH

68a. This diagram shows what you see on the screen when you look at straight ripples with a stroboscope. Sketch this diagram. (You may make it larger.) Mark one wavelength on your copy.



b. Does the wavelength get larger or smaller when the motor is speeded up?

69. Copy and complete:

The distance between one peak (or trough) in a wave is called the . . . of the wave.

The number of peaks (or troughs) that come out and go past any point in a second is called the . . . of the wave.

When you make the frequency higher, you get [/*more*/*less*/] peaks in a second, and they are [/*closer together*/*further apart*/] so the wavelength is [/*longer*/*shorter*/].

70. How did you use a stroboscope to help you measure 'one wavelength' of the ripples you made in a ripple tank?

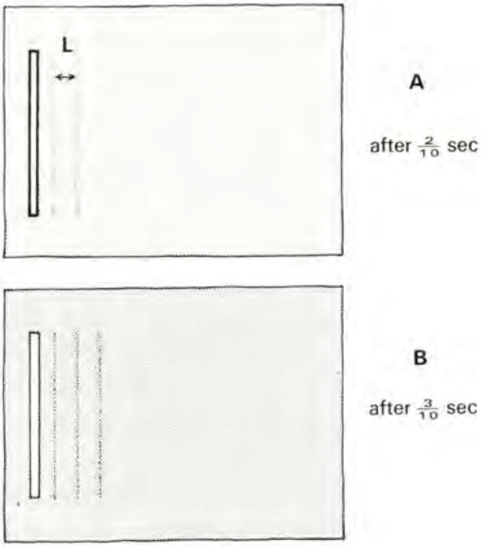
71. The vibrator in a tank has just been started. These diagrams show the waves going forward.

The wavelength (labelled L in the diagram) is 4 cm, and the vibrator goes up and down 10 times in every second.

a. How far forward does the front wave go in $\frac{1}{10}$ sec?

b. How far forward does the front wave go in 1 sec?

c. Look at your answer to (b) and say what the speed of the wave is, in cm per sec.



72a. Copy out the sentences below, filling in the blanks in each.

(i) The distance between the crests of two adjacent ripples (or between the troughs) is called the . . ? . . of the ripples.

(ii) The number of ripples passing a given point in a given time is called the . . ? . . of the ripples.

b. If we used a centimetre ruler and a stop-watch measuring seconds, what would be the units for each of those quantities that you named in the blanks in *(i)* and *(ii)*?

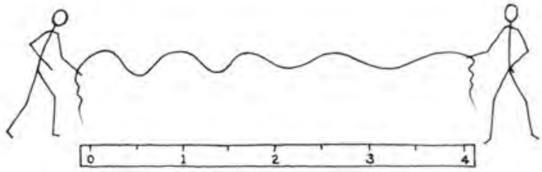
73a. Suppose you are given a stroboscope, a centimetre rule, and a stop-watch. How would you measure the wavelength and the frequency of ripples in a ripple tank?

b. How would you *calculate* the speed of the ripples from your measurements and wavelength and frequency?

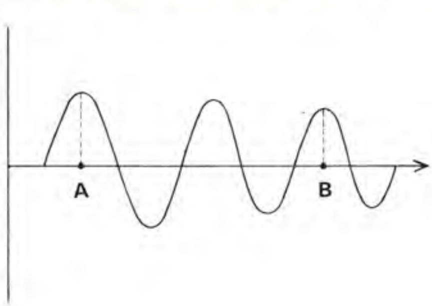
c. How would you *measure* the speed of the ripples directly? (Suppose they travel fairly slowly.)

74. Two boys hold the ends of a rope and keep it taut. One boy moves his end of the rope up-and-down, up-and-down . . . regularly so that a train of waves travels along the rope. Here is a snapshot of the rope.

What is the wavelength of those waves? Is it roughly $\frac{1}{2}$ metre, 1 metre, or what? Use the scale shown (reduced) on the picture.



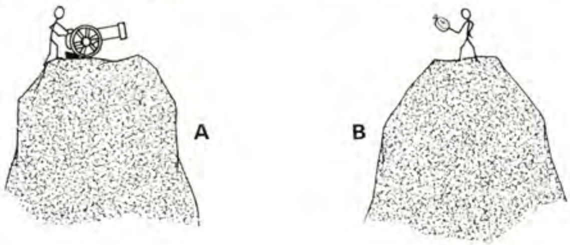
75. Radio comes to you by electric waves. Although we cannot see or hear an electric wave, we can make a graph of the electric force in it (at an instant), plotted against distance away from the broadcasting power. The diagram shows such a graph. Suppose the newspapers tell you the wavelength from that broadcasting station is 300 metres. What is the distance between A and B?



76. Here is a sketch of a ripple tank, with ripples being made regularly every $\frac{1}{4}$ second by a vibrator. What is the wavelength of these ripples, judged by the scale of cm which is actually *IN* the water?

SOUND WAVES

77. Water waves take time to travel from one place to another, and so do sound waves. This is a way of finding the speed of sound waves.



A has a gun. When he fires it, B *first* sees a flash, then *hears* the bang. B has a clock. He starts it when he sees the flash and stops it when he hears the bang.

a. A and B are 1600 metres apart—about 1 mile. B finds the time between the flash and the bang is about 5 sec. What is the speed of the sound waves in metres per second?

b. This is not a very reliable experiment. Point out some things which can go wrong and try to suggest improvements.

c. What about the light—does it reach B in no time at all, or take a very short time? Can you give a reason for your answer?

d. During a thunderstorm you can count the seconds between seeing a flash and hearing the thunder. Suppose you count 10 seconds: how far away is the storm?

78. Scientists think that sound travels as waves.

Use your knowledge about ripples and waves in water to help you understand more about sound.

a. Water waves need *water* to travel in. Sound can travel through *lots* of things. How could you show sound travelling in *(i)* air, *(ii)* a length of string (you can have two tin cans too, if you like!), *(iii)* wood? Give some other examples if you can.

b. When water waves go along, they make the water go up and down—so a little boat or stick goes up and down, too. When sound waves go through air into your ear, they make your ear drum vibrate. So what do you think the air does when a sound wave goes through it?

c. When water waves meet a barrier, they bounce off it.

(i) What do you think is happening when you shout, and then hear an echo?

(ii) What sort of surfaces make good echoes?

(iii) How does the echo change as you go further away? Why is this?

79. You can make water waves with all sorts of different frequencies. When the frequency is higher (more vibrations every second) the waves get closer together (the wavelength gets smaller).

You can have waves of sound with all sorts of frequencies, and wavelengths, too. Often the wavelength is related to the size of the source in some way.

a. A bassoon is much longer than a piccolo. Which of them makes waves with the higher frequency?

b. Do high frequency waves 'sound' *high* or *low* in pitch when you hear them?

c. Which has the higher frequency, a note from a double bass, or a note from a violin?

80. Sound waves travel in air about 340 metres per second ($\approx$ 1100 feet per second). A brass band at the head of an army plays a tune with regular drum beats to keep the soldiers in step. Suppose you stand a long way off to one side, so that you can see all the long column of marching soldiers at a glance. And suppose you notice that the soldiers at the back of the column are exactly *out of step* with the soldiers at the front. If so, how long is the column?

(This is a question that could have several answers. Give the shortest column that could show this.)

OTHER WAVES

81. Tidal waves have speeds of about 200 metres per second. How long would it take a tidal wave to reach a place 160 km (160 000 metres) away?

82. When there was an earthquake in New Zealand sensitive instruments in England recorded it about 21 minutes later. If New Zealand is 14 000 km from England, about how fast did the earthquake wave travel?

CHAPTER 2

OPTICS

Images and rays; lenses and instruments

RAYS OF LIGHT, CAMERAS, TELESCOPES, EYES, AND SPECTACLES

Introduction

This is a section about telescopes, spectacles, and eyes: the physics of seeing, and the instruments that help you to see things larger or better, and cameras to take pictures.

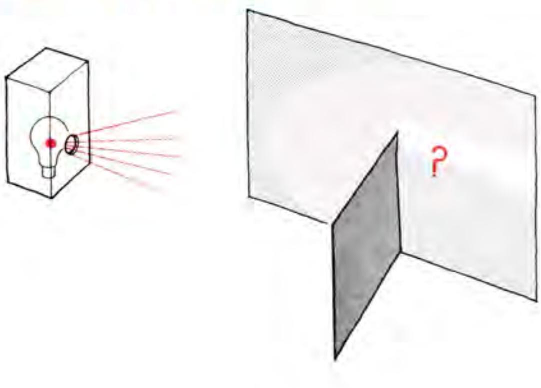
You see things by using light which travels straight to your eyes from the thing that you are looking at. *Rays* are the path along which light travels. A sunbeam is a very thick 'ray' of sunlight.

What do your eyes do with the rays that reach them, to see things? How do magnifying glasses and telescopes make things look larger or nearer? These are questions you will soon be able to answer. They belong to the part of science called 'Optics'.

You may begin with your own experiments in the lab. Or you may see some of the following demonstrations for a start.

Preliminary Demonstrations 6

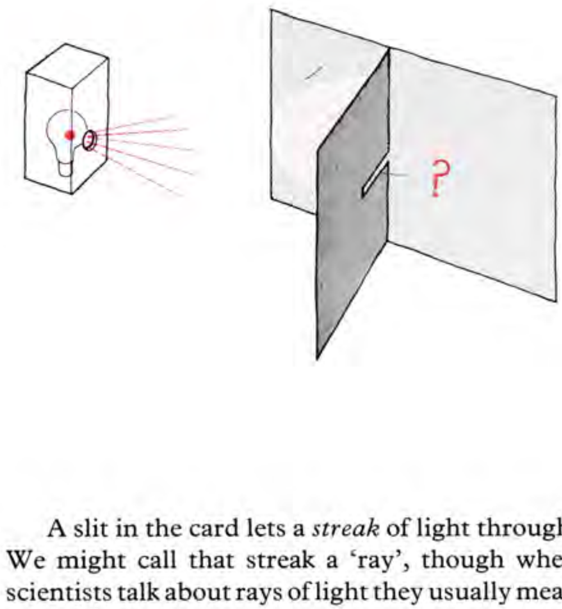
6a Shadow on a Wall



A small bright electric lamp sends light splashing across a white wall. Where a card stops the light its straight edge casts a long shadow.

What does that tell you about the light rays from the lamp that just graze the edge of the cardboard? Do they scatter in all directions or just go on? Do they go straight on?

6b 'Ray' of Light

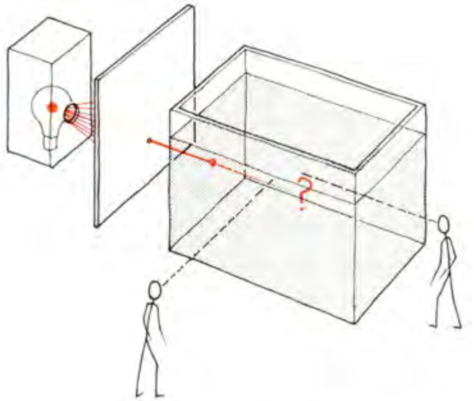


A slit in the card lets a *streak* of light through. We might call that streak a 'ray', though when scientists talk about rays of light they usually mean very thin lines.

What can you say about the path of that thick 'ray'? Is it straight, curved, crooked?

6c Ray of Light in Water

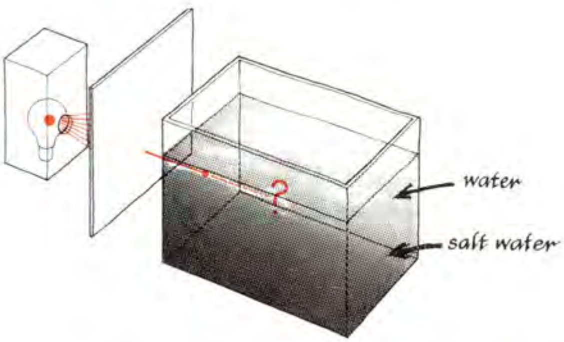
You can see the path of a thick ray of light through a tank of water if you add a little milk (or a special dye), to scatter some of the light out to your eyes.



What path do you see in the water?

[6d A Strange Ray

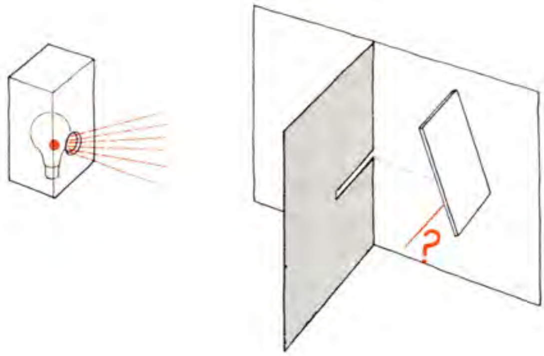
On a later day, you may see Experiment 6c specially set up to show a thick ray of light behaving in a very odd way. Some water is put in the bottom of the tank; then salt water is poured in under it. Where the salt water and fresh water meet, they mix slowly; and soon there is a variation of saltiness in the middle region.



See what happens to a ray of light directed along the middle layers. Also view it from the end, looking *along* the ray.]

6e Reflecting a Ray

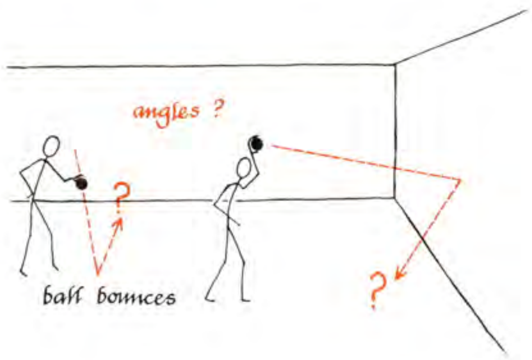
A flat mirror catches a ray and sends it away in a new direction—all on a wall. The mirror reflects the ray.



Can you see any connection between angles in this picture on the wall? (Just see a ray of light being reflected. There is no need to make measurements now or to write down exactly what happens. You will have a better chance in a later experiment.)

6f 'Reflecting' a Ball

Throw a rubber ball fast against a hard floor or a hard massive wall. Watch its path. You could say the ball is 'reflected'.



Ideas *Could you guess anything from that, about light? Could light be a stream of elastic bullets, like tiny rubber balls?*

Before you accept this hint, remember that you have seen reflection happening in the ripple tank.

Could light be waves like water ripples, but in open space? This is something to think about later.

Either of those ideas about light is just a guess at present. Even if we knew that one of the ideas must be a true description, could we ever decide which one? What is the use of arguing about such ideas? Is that one of the interesting things that scientists do?

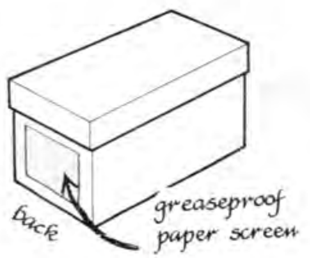
Pinhole Camera and Lens Camera

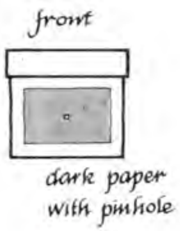
Experiment 7
Home-made Camera

Make a special kind of camera for yourself, that has a pinhole in front instead of a lens.

It may not be useful for taking snapshots; but you will be able to see how it works. And you could make one just like it at home, to explain to your family.

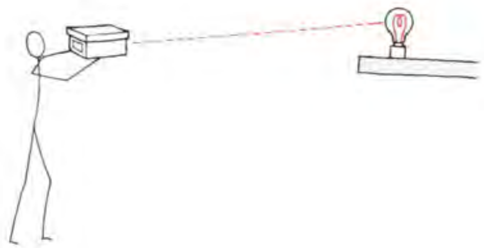
The camera is a small cardboard box with a piece of thick paper in front, where you can make a hole with a pin. The back has a large square hole cut in it and is covered with kitchen waxed paper. Then you can look at a bright picture on it from behind.





7a Using your Pinhole Camera

(i) Stand about 2 metres from a large bright electric lamp. Make a small hole with a pin in the front of your camera and point it towards the lamp. Hold the camera *at arm's length* and look at the translucent back.



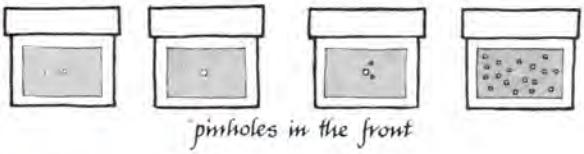
(It would be wrong to hold the camera close up against your face. You are trying to look at a picture that is formed on the back of the camera. So you need to hold it as far off as you would hold a book to read it.)

(ii) Try moving nearer to the lamp, then farther away. Watch what happens to the picture.

(iii) Make the pinhole bigger, about as big as the head of a pin. A blunt pencil-point will do that.

(iv) Make several small pinholes near the large one.

(v) Now make a whole 'pepper' of many pinholes in the front and see what the camera now shows on the back.

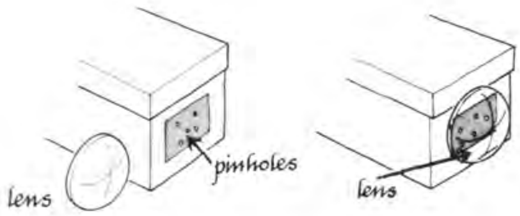


7b Improving the Camera

Ask for a lens. (This should be a large bulgy lens like a weak magnifying glass. Its power should be about +7 D. Soon you will understand the meaning of that description of the power of a lens.)

(i) Stand about 2 metres from the lamp. Point your camera with its pepper of pinholes at the lamp as before; and hold the lens up against the pinholes on the front of your camera.

Try sliding the lens in across the front: then OUT, so that it does not cover the pinholes; then IN so that it does cover them. Watch the picture as you slide the lens in.



Now you have a lens camera. The cameras that you buy in shops are made like this; but they have a film for catching and keeping the picture, instead of the waxed paper at the back. And they have a shutter in front to let the light in for the short time of taking a snapshot.

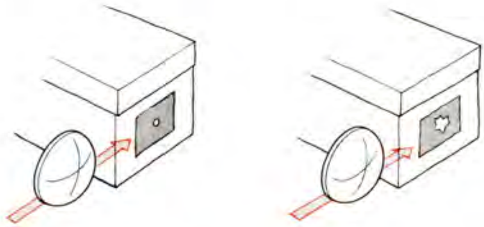
What does the lens do to all the many pictures made by the pepper of pinholes? What does the lens do to the many rays of light that go through the many pinholes?

(ii) Move nearer to the lamp and farther away. *Is the lens equally successful at all distances?* If not, find the *best* place to stand, and stay there while you try Experiments 7c and 7d.

7c A Brighter Picture

(i) Make a large hole with a pencil, and put the lens over that. Look at the picture of the lamp.

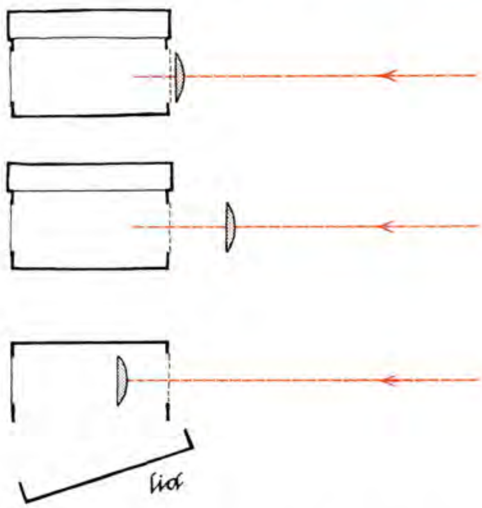
(ii) Make a very large hole by pushing your thumb through the paper front of the camera and put the lens against that.



7d Focusing your Lens Camera

Holding the lens camera that you now have, move nearer to the lamp and farther away and watch the sharpness of the picture.

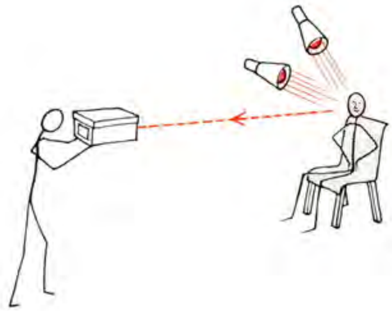
Move much nearer to the lamp. Try to improve the sharpness of the picture *by holding the lens somewhere else*, not just up against the front of the camera, but farther out.

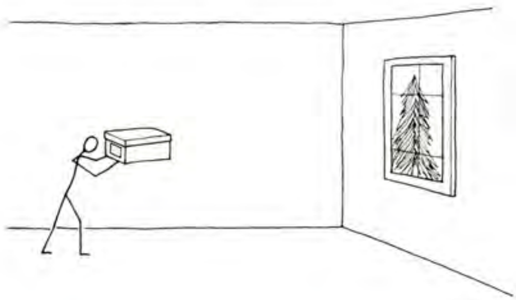


If you take the lid off your box and hold the box upside down, you can still hold it with one hand while you hold the lens somewhere *inside* the box. *Is that any help, for focusing at some other distances?*

7e Using your Lens Camera

Shine bright light on someone's face. Point your camera at the illuminated face. Then point the camera towards an open window with fields or buildings beyond. (HINT. To focus the camera for those objects, you may have to hold the lens *inside* the box. If so, take the lid off and hold the box upside down.)





7f Advanced Optional Experiment Investigate Depth of Field

Put a new front on your camera.

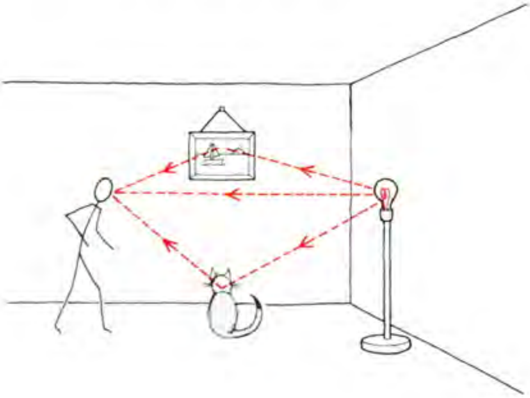
(i) Make a large pinhole. Hold the lens against it and find the range of distances from the lamp for which your camera makes a fairly sharp image.

(ii) Repeat that with a large hole, then with a still larger hole.

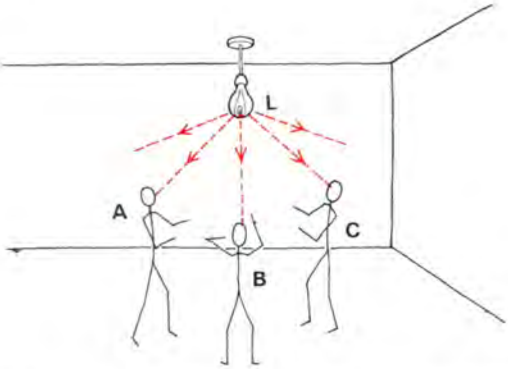
What do Rays of Light do? How Does a Camera Work?

Seeing things A camera 'sees' things in much the same way as your eyes do.

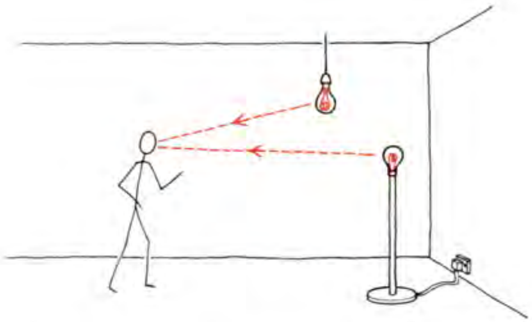
When you look at an object, you use rays of light that come straight to your eye from each different part of the object. Some parts may be sending out their own light—for example, a bright lamp filament or a candle flame. Other parts may be reflecting or scattering to you some of the light they receive from somewhere else—from a lamp or the sky or the Sun.



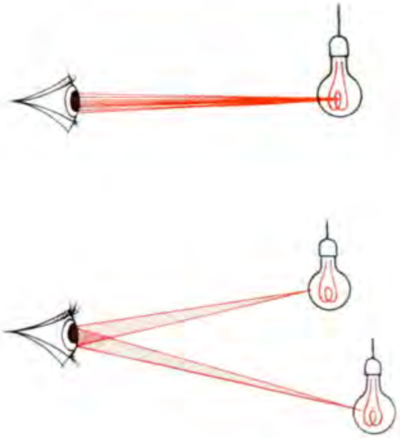
Rays also go out in all other directions. Look at the stars at night: they send light to your eyes, but they also send light everywhere else—to other stars, for example. If there is a lamp at L, *you* see it by the ray LA, *I* see it by ray LB, *someone else* by ray LC.



When your eye looks at *two* objects *two* lots of rays go into your eye.



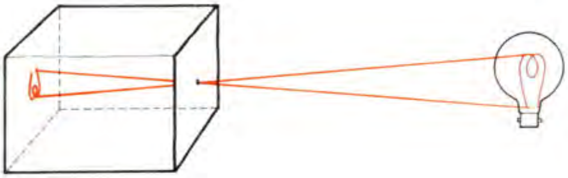
In diagrams, *we shall only draw the rays that enter your eye pupil*. Even then we cannot draw *all* the rays that get in from each point you look at. We just draw a cone that contains them all. Then we fill each cone with shading to show that it is full of rays.



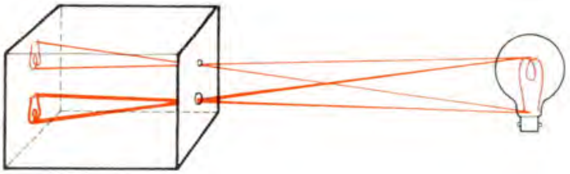
Camera focuses rays With a camera, rays of light come straight from each point on a bright filament, or a brightly lighted face, or whatever else is the object that you are photographing.

The picture on the back of your pinhole camera is made by those rays which go straight through the pinhole—while the front wall of the camera stops all other rays.

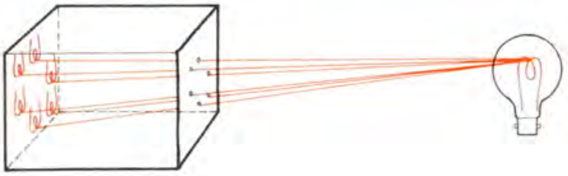
The sketch shows rays of light from just two specimen points on a lamp filament contributing to the picture at the back. Each point on an object provides rays for a little spot in the picture at the back, a spot slightly larger than the pinhole. So with a small enough pinhole you get a fairly sharp picture. (See diagram on next page.)

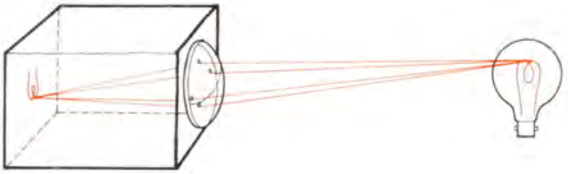


With a large pinhole, you no longer get a point-for-point copy of the object; you get a patch-for-point copy—rather a fuzzy picture—as in the sketch.



When you have several pinholes, each lets through rays of light from every part of the object. So each pinhole leads to a whole picture of the object.



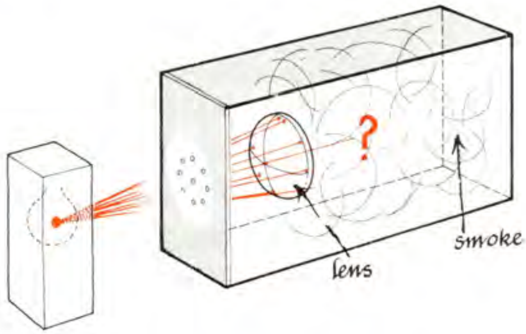


What does the lens do when it makes that wonderful single picture? Look at the diagram and imagine what the lens does. For light that starts *from a single point*, the lens seems to collect up the rays that go through different pinholes. It bends them so that they all run together through a point. We call that point the IMAGE.

To know what the lens really does, you must let a lens receive many rays of light and see how it deals with them.

Demonstration 8
Lens and Rays in a Box of Smoke

Light from a small bright lamp shines through a window into a large box.* A metal sheet stops the light, except for some thick 'rays' which go through holes in the plate. Those rays go straight from the lamp into the box and straight on until they meet a lens. See what the lens does to that fan of rays spreading from the lamp.



The smoke in the box scatters some of the light to you, so that you can see the path of the rays; but of course those rays are there anyway, even without the smoke.

Later on, you may see what a flat mirror does to rays in the smoke box. And you may see a curved mirror—a concave silvered bowl—changing the path of the rays.

*You need not have a special box, if you do not mind putting a lot of smoke in the air in the lab. Just make some smoke around the lens and look at the rays without any box.

Progress Questions

CAMERAS

1. This box could be used as a 'pin hole camera'.

a. Copy the sketch, and label:
(i) the pinhole,
(ii) the screen where you saw the picture.

b. *(i)* What was the screen made of in your camera?
(ii) What were the sides of the box made of? Could light get in through the sides?
(iii) What bright thing did you look at?

c. Make a labelled sketch to show clearly how to arrange the bright *object*, the pinhole camera, and your eyes so that you could see a picture on the screen.

2a. Draw a sketch of the object you used with your pinhole camera.

b. Draw what you saw* on the screen of your pinhole camera:
(i) with one small hole, when you held it a long way from the object.
(ii) with one small hole, when you held it nearer to the object.
(iii) with *two* small holes, a long way from the object.
(iv) with 10 small holes, a long way from the object.

3. When you used a pinhole camera:

a. Was the picture on the screen the same way up as the object, or upside down?

b. How did the picture on the screen change when you took the camera nearer to the object?

c. How did the picture on the screen change when you made the pinhole much *bigger* using a pencil or even your thumb?

4. When you first used a lens over the holes in your camera, you were changing it from a pinhole camera to a lens camera. Then:

a. Draw what you saw on your screen when a lens was slipped in front of the camera, covering the pinholes.

b. What did you see on your screen when you moved the lens back and forth?

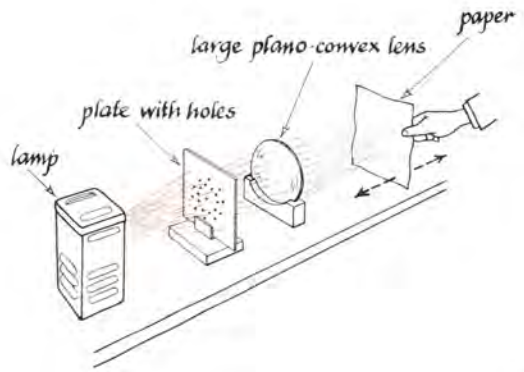
5. Copy and complete, using the correct word from each square bracket.

When you use a pinhole camera and want to see a shorter picture on your screen, you must use a [/*much larger*/*smaller*/] pinhole.
If you want to see a *brighter* picture on your screen you must use a [/*larger*/*smaller*/] pinhole.

*What you see on the screen is just called a picture, not an image. We use the word 'image' when a lens bends rays to form a sharp, focused, image.

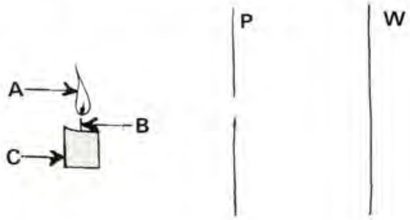
Class Demonstration 9
Lens and Real Image: Catching Rays in Open Air *(OPTIONAL)*

Arrange a sheaf of rays to hit a lens, as in the smoke box, but just in the open air. Catch the rays on a sheet of paper and investigate their paths by running along with the paper.



Questions

PINHOLE CAMERAS



6. The diagram shows a candle ABC in front of a sheet of metal with a very small pinhole P. W is a waxed-paper screen. The distance from W to P is the same as the distance from B to P.
A is a bright yellow point in the flame;
B is a dark point on the wick, giving out very little light;
C is a fairly bright point on the white wax.

a. Copy the diagram. Draw a single ray from A through the pinhole P to the screen W. Put a label, A^1, where that ray arrives at the screen.

Draw rays from B to C in the same way. Put labels B^1, C^1 where they meet the screen.

b. In drawing those rays, what have you taken for granted about the way rays of light behave?

c. What does your sketch let you predict about the picture on the screen? (Does it tell you what it would look like? Does it tell you what size?)

d. Do your predictions agree with what you saw in your experiments with a pinhole camera?

7. Look at Q.6. Suppose the candle and the pinhole are kept at the same places. In what way will the picture on the screen W be changed if:

a. The screen W is moved closer to the pinhole P?

b. W is moved farther from P?

c. There are *two* pinholes instead of one?

d. There is a single pinhole, but it is twice as big?

8a. Try this walk under trees on a sunny summer day. There are patches of sunlight on the ground where sunshine gets through chinks between the leaves. These patches are *round*, even though the leaves are sharp-pointed or jaggy. Why are they round?

b. Why do the round patches have blurred edges?

c. During a partial eclipse of the Sun, you see just a part of the Sun—when you see the Sun as a crescent, like a new Moon. Then the patches of sunlight under trees have a different shape. What shape do you expect them to have when there is an eclipse like that?

d. Give a reason for your answer to (c).

9. An electric light bulb is 7.5 cm in diameter. It is placed 100 cm from the front of a pinhole camera, and the distance from the pinhole to the screen at the back of the camera is 20 cm. How wide is the image of the bulb on the screen? Find out *either*:
(i) by drawing a diagram to scale and measuring it;
or (ii) by drawing a *rough* sketch and calculating by proportions.

PINHOLE CAMERA AND LENS CAMERA

10a. A certain pinhole camera has five pinholes instead of just one, all in a line. Draw a diagram like that in Q.6 but with five pinholes. Draw a ray from the point A, through each of the pinholes, to show the five positions of pictures of A on the screen.

b. Now suppose you place a positive lens in front of the five pinholes in (a) above, with its centre on the central pinhole of the five. Draw a fresh sketch.
(i) Draw rays from A, through the lens, to go through the pinholes, to show what may happen on the screen. (See the NOTE just below.)
(ii) In what way is the picture at the back different now?

c. What happens to the picture if you poke a finger through the pinholes to make a big round hole, as wide as the distance between the first and fifth pinholes; and then put the lens in position?

(NOTE: You may suppose that the lens is of exactly the right power to 'focus the images' of the pinholes on the screen. However, the questions could be answered for *any* positive lens.)

11. A long-sighted person who needs to wear glasses for reading cannot read print without his glasses under normal conditions. However, if he needs urgently to read, say, a telephone directory, and has not got his glasses, he may succeed if he looks at it in a very bright light. And he finds no difficulty at all in reading it if he peers at the print with one eye, through a pinhole in a piece of card.

a. How do you account for this?

b. Something similar occurs when a person wishes to take close-up pictures with a cheap camera with 'fixed focus': explain what he has to do to get a satisfactory picture.

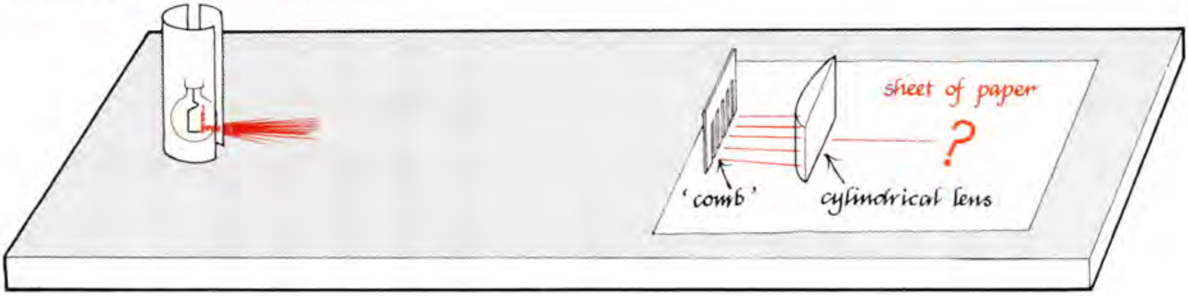
12. *(Optional Advanced Problem)* A camera with a lens whose aperture has 10 millimetres *radius* (area $= \pi \times 10^2$) needs exposure $\frac{1}{5}$ second for a certain picture. If you have a pinhole camera instead, with a pinhole of *radius* 1 millimetre (area $\pi \times 1^2$), how long should the exposure be for a similar picture? (Remember that the light gets in through a round hole in each case. It is the *area* of the hole that tells you how much light gets in.)

13. You go to a lesson in which a film is shown, but when the projector is switched on and focused the picture is too large for the screen. It overlaps all round.

Suppose the screen cannot be made bigger. You can help to show the film properly by making *two* adjustments. What are they?

14. *(Optional)* An enlarger is an instrument that is used to make large photographic prints from small negatives. It is like a camera but it is used differently. Describe how it is used. Explain why the distances from its lens to the object and to the image are different from the usual distances for a camera.

Experiment 10
Model of Rays and a Camera
(A first experiment with 'ray streaks')



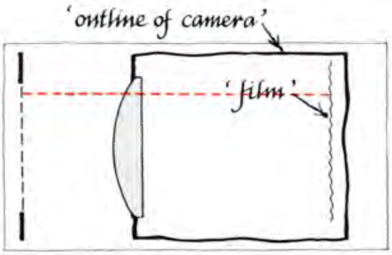
Use a bright lamp with vertical filament as your 'object' for the 'camera' to photograph. Place a comb so that it lets through a fan of 'thick rays' of light that spread out across white paper on the table.

Place a cylindrical* lens (of power +7 D) on the paper. The lens must stand upright on its flat end.

Place the lamp about 1 metre from the lens. Keep the comb quite near the lens so that many streaks (or thick rays) of light hit the lens. Raise or lower the lamp until you have bright streaks right across the paper.

See how the lens bends all the rays that strike it to pass through an 'image', which is the place for the camera film.

Draw an outline of a camera box on the paper, with the lens at the front. Mark a place for the 'film' at the back.



Then borrow another lamp and place it beside your lamp. You will see how those two object-points make two image-points on the 'film' in your camera. You might imagine they are the head and the toes of a person being photographed.

Now move one lamp closer to the camera and see how you get a patch *on the film*, instead of a point. A patch like that for each point on the original object would make a fuzzy 'out-of-focus' picture.

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* A later note explains the use of *cylindrical* lenses.

Keep the lamp in the close position. Make the front opening of your lens narrower by pushing in some small barriers to stop the outer rays getting through. See what that does to the out-of-focus patch on the film.

We call that 'reducing the aperture' of the camera lens. Photographers call it 'stopping down' the lens.

Comparing Cameras

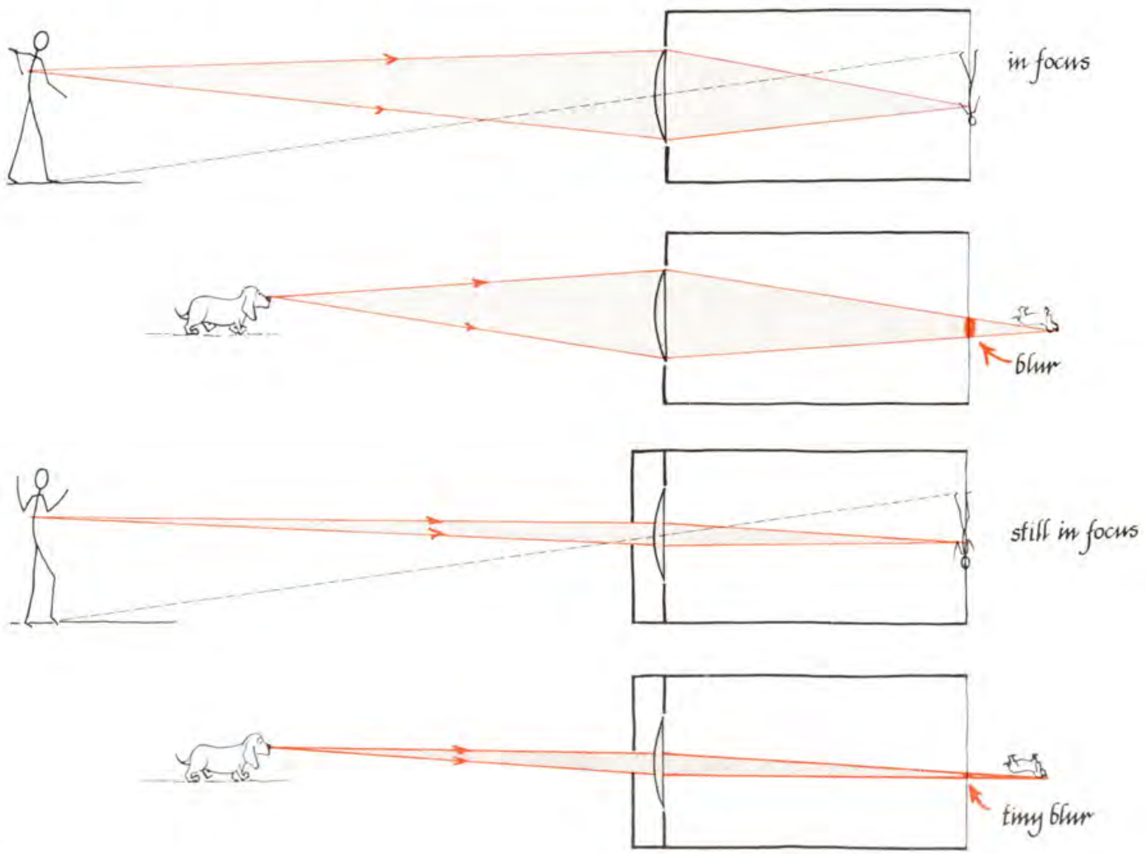
Cheap cameras: 'fixed focus' A cheap camera which has a very small opening of lens is often said to have 'fixed focus'—it is claimed to be in focus for all distances. More expensive cameras have an arrangement for moving the lens nearer to the film or further out, according to the distance of the object being photographed.

Can you see now why a cheap camera with its very small aperture does not need focusing? When an object is out of focus the lens fails to produce an exact point-image on the film for every point of an object: but the blur patch is not very big.

When you had a small hole just in front of the lens, or behind it (just a large pinhole), you used only a small part of the lens to take light into your camera. If you were a camera manufacturer you could save money by putting just that small piece of lens in a 'fixed focus' camera.

Expensive cameras You can also see the advantage of an expensive camera. Although it needs careful focusing, its wide lens takes in much more light. That light which goes into the camera makes an impression on the film which can be developed by chemicals into a picture. With a wide lens there is more light to make the picture, so you need not hold the shutter open for so long a time. *What are the advantages of a short exposure?*

In the days of your great-great-grandfather, when photographic materials were not very sensitive, a person having his portrait taken with a camera had to hold still for a minute or two. And a picture of a fast express train . . . ?



A Lens forms Images

Light from any small bright object travels straight out until it meets a lens; then the lens bends the rays so that they travel to an image. The lens makes an image-point for each point on the original object. So the image is a 'point-for-point' picture of the object.

A camera lens makes an image of the object which you want to photograph and you place the film just at the image. Perhaps the image exists there anyway, whether the film is there or not, whether the camera box is there or not, whether you are there or not. Perhaps you could see the image by letting your eyes receive rays of light that have come to the image AND PASSED STRAIGHT ON THROUGH IT.

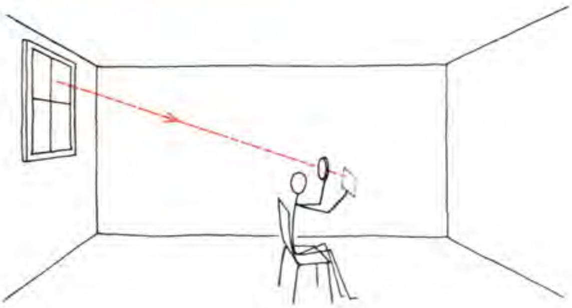
That is a new suggestion that goes beyond what you saw with your camera. Science makes progress by thinking of new suggestions like that, and then testing them.

Experiment 11
Viewing a Real Image formed by a Lens

You should have a weak magnifying glass for this. Share one with a neighbour; or, better still, have one all to yourself. (It should be a lens of power about $+7$ D, in the way opticians describe the strength of a lens. This is the lens you added to your pinhole camera. Other lenses would do, but they may be less comfortable to use.)

See whether your lens forms images without the camera box. Try this in a half-dark room with a bright window (or a large electric lamp) as object.

11a Image on Paper

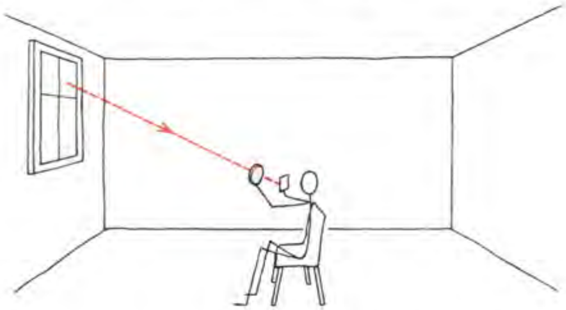


Sit or stand WITH YOUR BACK TO THE WINDOW. Hold a piece of paper at arm's length in front of you. Hold the lens nearer to you, so that the light from the window goes over your shoulder, and through the lens, and reaches the paper. Move the paper nearer and farther until you catch a sharp image of the window (or lamp) on it. There is the image that you saw on your camera screen. You no longer have the box; but the paper is like the back screen.

11b Image in Mid-Air

Now take away the paper. *Does the lens still bring the rays of light to an image where the paper was?* You will have to go round behind where the paper was, to look. So you had better turn round yourself and face the window; and start again.

Hold the lens at arm's length towards the window. Then hunt for the image with a scrap of tissue paper, somewhere between the lens and your face. The tissue paper will catch the image, just as the back screen of your camera did. You will see the image faintly through the tissue.



Then move the paper sideways until the image is at the edge of it, half off the edge. Go on looking at the image. Stare at it with both eyes. It is still there in mid-air, just where it was on the paper. We call such an image which you can catch on paper a 'real' image.

If you are not successful, ask a partner to hold the scrap of paper and catch the image on it. Then he should move the paper a little to one side so that the image is half on the paper and half off it. He should point to the image with his finger or try to pinch it with finger and thumb. And you should go on staring at his finger. Keep both eyes open. If you wag your head a little from side to side, that may help.

In this experiment and many later ones, remember that you see a thing clearly with your eyes when the thing is some distance in front of you. You can't read a book crammed against your face. So you must hold your head some distance back from the place where the paper caught the image. Then look at that place and focus on it, to see if the image is there.

What does that image look like? Is it bigger or smaller than life? Is it the right way up or upside down (erect or inverted)? The answers to those questions are things to remember.

Lenses of different powers The diagram shows slices through lenses of different shapes and powers. The power of each is marked in 'dioptres', the spectacle-maker's units (metres $^{-1}$). There are several 'positive' lenses. Any of those could be used in a simple camera. There is one 'negative' lens.

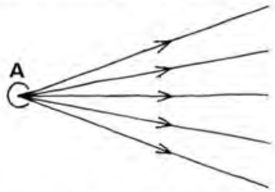
When you first meet a lens you can find out something about its power by feeling the shape of its faces. *If its faces are very bulgy, strongly curved, does that mean it has a large power or a small power?* (After you have touched the faces of a lens be careful to clean it, or dirt will scatter light and make the lens do a poorer job.) You will soon have a much better way of judging the power of a lens without touching its faces.

Progress Questions

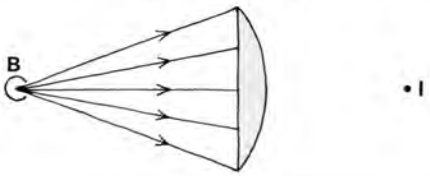
LENSES AND RAYS

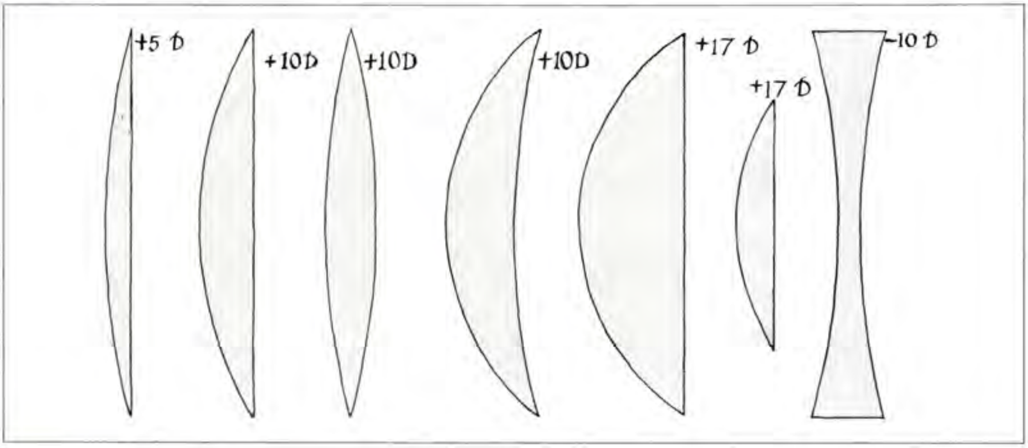
15. You saw a big positive lens in a box full of smoke. Just outside the box there was a bright lamp with a very small filament from which rays ran into the box. Make a sketch to show what happened to those rays *inside* the box.

16. Fig. A shows streaks (rays) of light spreading out from a small lamp.



Copy fig. B and complete it to show the difference the lens makes. (Pretend that you know that this lens makes an image near the point I.)





Experiment 12
Comparing Short Cameras and Long Cameras

Take a window as object, or the bright filament of a distant lamp. Instead of a camera box just hold the lens in your hand and catch the image on a piece of paper, or on a wall.

Try using the lens you used before ($+7$ D). Change to a much weaker lens (such as $+2\frac{1}{2}$ D).

Which lens makes the larger image, for a camera picture?

Which lens needs a longer camera?

What kind of lens would you expect to find in a tiny camera used by a spy to make secret photographs?

Questions

LENSES AND IMAGES

17. A pupil in a lab holds up a lens to catch light from a window. He holds a screen of thin paper at the right place to catch a sharp image of the window. He stands behind and looks.

a. What is the image like? (Is it the same size as the window? Is it the same way up as the window? Does it have the same colours as the window?)

b. If there are some trees and flowers outside the window, do they show on the image?

c. Could the pupil still see the image if the thin paper screen is taken away?

d. While he is looking at the image, the pupil sees a small upside-down 'person shape' moving across the screen from left to right. Where was the person walking? Which way was he walking?

e. The pupil then notices the image of a tree which is farther away outside the window. The picture on the thin paper screen is blurred. The pupil wants to move the lens to get the tree's image 'in focus'. Must he move the lens *away* from the screen, or *towards* it?

18. This is the same arrangement as in Q.17, except that the lens is thinner, less bulgy.

a. The pupil wants to catch a sharp image of the window on the thin paper screen with this lens. Must he hold the screen nearer this lens for the other lens, or farther away?

b. What difference will the new lens make to the image?

19. Rewrite the following, with the correct words where there is a choice:

The [/*nearer*/*farther*/] a distant object is [/*to*/*from*/] a positive lens, the farther away the image. The [/*nearer*/*farther*/] the object is [/*to*/*from*/] the lens, the smaller the image.

20. The teacher says, 'Use the positive lens to form an image of that end window. Catch the image on a sheet of paper. Now take the paper away and look at the image.' Your partner tries this, but at once says, 'I can't see any image.' You notice that he has put his head where the sheet of paper was. The teacher says, 'No, hold the lens at arm's length.' Your partner says, 'That's no use, I have tried looking at the lens; and I have tried looking at the window. I still can't see any image.' Why can't he see an image? Where ought he to look?

21. *A Puzzle.* A boy holds a positive lens and catches the real image of a window on a sheet of paper. At first he holds the lens with two fingers on its edge. Then he holds it with a finger and thumb, so that the thumb blocks off quite a lot of the lens. He is surprised to see that the image is *just as clear as before*, and the *whole of the image is there on the paper*. The image is every bit as sharp, but not quite so bright.

a. Why is no part of the image cut off by his thumb?

b. Why is the image not quite so bright when his thumb is there?

A problem Suppose you wish to look at something $\frac{1}{2}$ kilometre away, a cow in a field or a bus in the street. You can use a lens to make an image of that object, as in a camera. But without a film or anything else at the back, the rays go straight on through the image and you could let them enter your eye. You could look at the image directly. The image is very small, much smaller than the actual size of the cow or bus: the image is close to you. You can march right up to it and look at it with a magnifying glass. Then you have a telescope.

Telescope

Before you learn more about rays and lenses and images and how you see things, just make a telescope yourself.

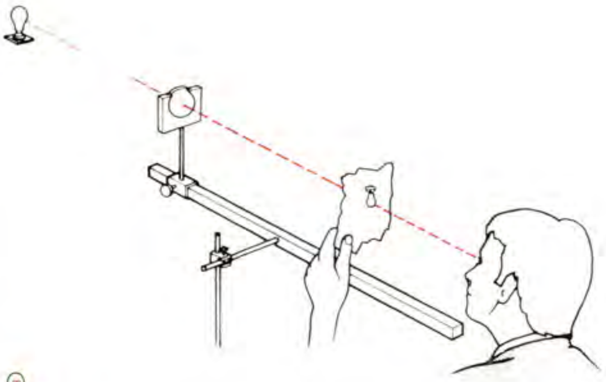
You may need some help at this stage: but if you can make your telescope work on your own you will learn more about the optics that lies ahead. You will have an opportunity later to set up your own telescope more carefully, and focus it; and to measure how much it magnifies. So you should try this quickly. You need not take notes or make sketches until the later telescope experiment.

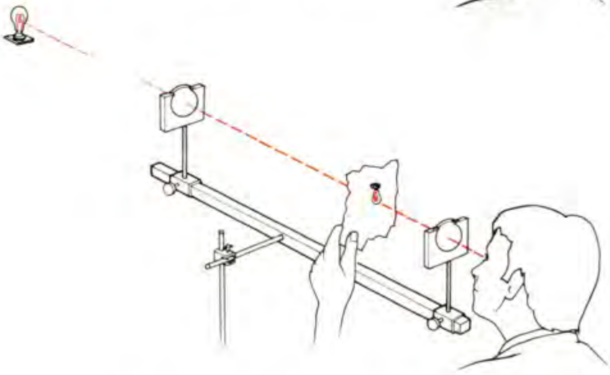
Experiment 13
Making your own Telescope

Use a positive lens to form an image of the distant object that you want to look at. Then use a strong lens as a magnifying glass to look at that image. That is all you need, except for a rod to support the lenses.

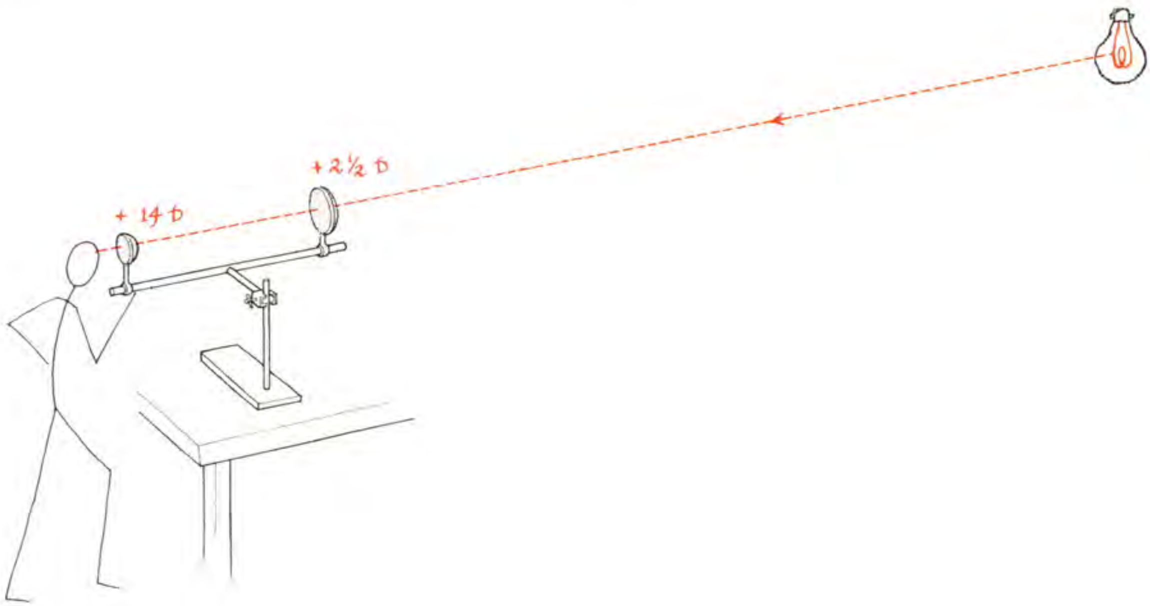
The first lens, nearest the object, is called the objective. Use a weak lens ($+2\frac{1}{2}$ D) for that. Use a strong lens ($+14$ D) for the magnifying glass, which is called the eye-piece.

Set up objective and eye-piece in holder on the telescope rod. For comfort, raise the rod to shoulder height, so that you can stand upright and look through your telescope without bending your neck.





Point your telescope at a bright electric lamp far across the room. Catch the real image of the lamp on a scrap of tissue paper (like the back of your pinhole camera). Bring up the magnifying glass and hold it so that you see the tissue paper magnified and in focus. Take away the tissue paper and you will be looking through a telescope at the lamp.



Ask your teacher for help, if you need it. But doing good science means making your experiments go yourself; so you should try to succeed on your own, before you ask for help.

A partner can help you to succeed. He should hold the scrap of tissue paper and move it until he has caught the image of the distant lamp, while you move the eyepiece until you can see the details of the tissue clearly magnified. Then he should remind you, again and again, to watch the place where the scrap of paper is. You should keep your eyepiece focused there while he takes the piece of paper away (or half away), leaving you to look at the image there.

For comfortable use, the eyepiece should give you an image to look at which is far away. It should be as far back as the object itself.

It is quite difficult to focus your eyes on something far off in mid-air when you don't know quite where it is. And your partner can help with that. He should point to the distant object and say, 'the image is back THERE'.

What should you do with your other eye (the eye that is not looking through the eyepiece)? The best thing of all is to behave like a professional telescope or microscope scientist and teach the other eye to be 'blind' for the moment while you are using the instrument.

Until you have learned how to do that, cover the other eye with a hand or an eye-patch. (If you just close the other eye by tightening up the muscles round it, you will also tighten up the muscles round the eye that you are using for the eyepiece. That will make it difficult to see well.)

When you have made the telescope work, so that you can see the distant lamp, open the other eye and use your two eyes to get the telescope properly focused.

The eye at the eyepiece looks through the telescope at an image of the distant lamp; while the other eye, the naked eye, looks straight at the distant lamp. *Can you see them both together clearly? If you can, does the telescope picture of the lamp look larger than the picture seen by the naked eye?*

If they are not both in focus at the same time, move the eyepiece forwards or backwards a little until you do see both clearly *at the same time*.

The naked eye is the one to pay attention to when you are trying to focus a telescope with both eyes open. It is not easy at first to keep both eyes open and see those two different things. Your partner can help. He should stand beside you and tell you to keep both eyes open. He should say 'Remember, the naked eye is looking at something far across the room. Keep on paying attention to the NAKED EYE and move the eyepiece until your telescope-eye sees something clearly at the same time.'

Your partner should also watch your eyes and if you try to shut one eye he should say, 'Open both eyes with wide-eyed surprise.' That will help you to raise your eyebrows and keep your eyes wide open; and that in turn will help you to succeed.

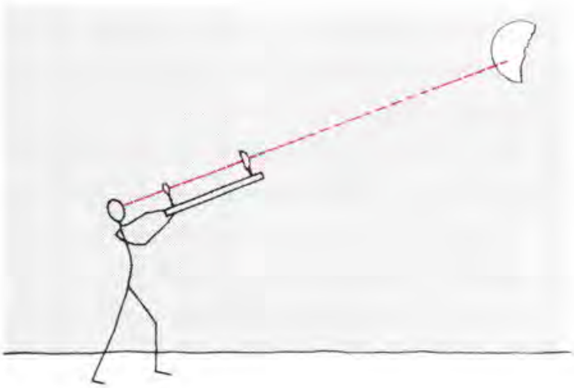
Once you have learned to focus your telescope you will find that it grows easier and easier; and you can soon use your telescope for many things.

If you see only a little of the lamp (a small field of view) try pulling your head a little farther back from the eyepiece. There is a good place for your eyepiece-eye which gives you the widest picture. Move your head back and see if you can find that place.

AS SOON AS YOU HAVE MADE YOUR TELESCOPE WORK, ASK YOUR TEACHER TO COME AND LOOK AT IT. THEN YOUR PARTNER SHOULD HAVE HIS TURN WITH IT. LET HIM MAKE A COMPLETELY FRESH START.

Use your telescope to look at some books the other side of the room, to see whether the printing on their covers looks larger. Open a window and look at things outside.

If you have a chance, take your telescope home, direct it at the Moon; and see what you can make out. (Full Moon makes too much glare; but at half Moon you will see the sunlight catching mountain tops.)

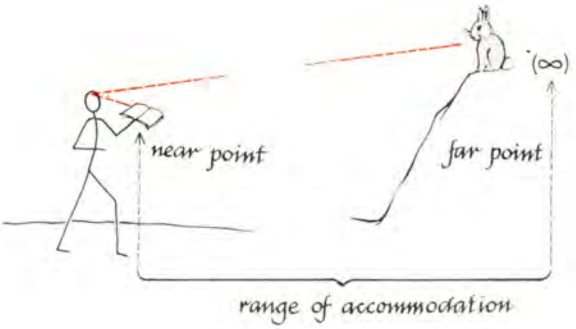


What your eyes can do: Accommodation

Your eyes are a super-camera with 3-D stereo, colour vision, and adjustable focusing. Find out what they can do.

Experiment 14
Your Range of Clear Vision

Look at a book and move it nearer and farther to find your own nearest point for comfortable seeing. (If you wear spectacles you may keep them on; but you will find it interesting to repeat the investigation without your spectacles. See the note on spectacles later on.)



You already know your *farthest* limit of clear seeing: a tree across the fields or a bus at the end of the street. We call that 'infinity'. What is your *shortest* distance for comfortable vision? Bring a book closer and closer until you can no longer focus it sharply. (You may need to cover one eye so that you can use the other eye without squinting.)

Record your range.

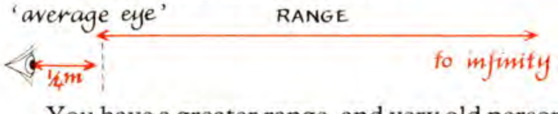
Look at the book, then look up quickly at the other side of the room. You are changing the power of your eye lenses as you focus near and far. We call that change of focusing 'ACCOMMODATION'. With a camera, you change the focusing by moving the lens in or out a little; but with your eyes you make a lens inside stronger or weaker.

Your variable focusing At your age, most people's eyes have a huge range from 'infinity' (bus, mountain, or stars) right in to somewhere very close, perhaps 10 centimetres from their face. Yet you do not hold a book as close as that: it might be uncomfortable for your arm to hold and it would certainly be uncomfortable for your two eyes to concentrate on the print, because they would have to turn inwards rather sharply. Also, print might even seem too large for quick reading, if you held the book so close. Books are printed for comfortable reading when they are held about $\frac{1}{4}$ metre away.

As you grow older, your near point for comfortable seeing will move farther away. When you are much older, 40 to 45, it will be about $\frac{1}{4}$ metre away. It is said that an eye-doctor can tell your age from your range of accommodation, about as accurately as a veterinary sugeon can tell the age of a horse from his teeth.

Average eye

Because $\frac{1}{4}$ metre is comfortable for reading and is the closest distance for clear seeing for middle-aged people, we imagine an 'average eye' with a range from $\frac{1}{4}$ metre to infinity. We use that for our work in designing telescopes, etc.



You have a greater range, and very old persons have a more restricted range—that is why many old people need two lots of spectacles (or else bifocals).

So the average eye is just a useful standard like an average meal or an average amount of homework.

A question for guessing ahead *What do a short-sighted man's spectacles really do when they change his seeing to that of an average eye?* Soon you will know a clear answer to this question. At this stage, can you make a courageous guess?

Eyes and Spectacles

Short sight and long sight Some people have extra strong eyes so that their range for comfortable seeing is closer; for example, from 15 to 40 centimetres (6 inches to 16). And things beyond 40 centimetres (all the way out to a tree, bus, or mountain at infinity) would be too difficult to focus; they would look fuzzy. So we call them short-sighted.

Such a person could read a book because the convenient distance, $\frac{1}{4}$ metre, is within the range for *his* eyes. But he would need spectacles for looking at things far away.

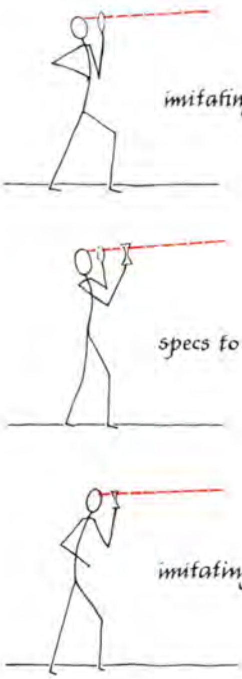
A long-sighted person has a range which starts farther out, for example from $\frac{1}{2}$ metre out to infinity (and, in a certain sense, 'beyond infinity'). So he can see a distant view or stars without spectacles; but he needs spectacles to read a book held at $\frac{1}{4}$ metre.

Spectacle wearers have their lenses designed to add just the right amount of lens POWER, so that the combination {spectacle lens + eye} has the same range as someone of the same age who does not need spectacles.

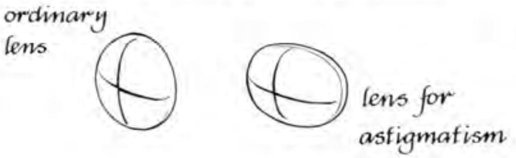
Spectacles are image-formers Spectacles, like all other lenses, form images. They take the object that you want to look at and move it, *optically*, to an image for you to look at instead. The image is then at a place where it is comfortable for your eyes to see it.*

Experiment 15
How does the World Look Without Glasses?

To a short-sighted person? If you are short-sighted, you already know. If not, ask for positive lenses, +7 D, and hold them in front of your eyes. Can you read a book? Can you see a distant view clearly?



*Many people need an extra piece of help from their spectacles for for clear seeing, because they have what is called 'ASTIGMATISM'. That just means that their eyes have a front surface shaped more like a rugger ball than a soccer ball. It is common and harmless. It is corrected by spectacles with a surface that is curved more strongly in one direction than another.



Ask for a 'spectacle lens' to correct your temporary short sight. Hold that in front of your eye, with the +7 D lens still there.

To a long-sighted person? If you are long-sighted, you already know. If not, ask for negative lenses, −7 D, and hold them in front of your eyes. Can you read a book? Can you thread a needle? Can you read a newspaper at arm's length? Can you see a distant view clearly?

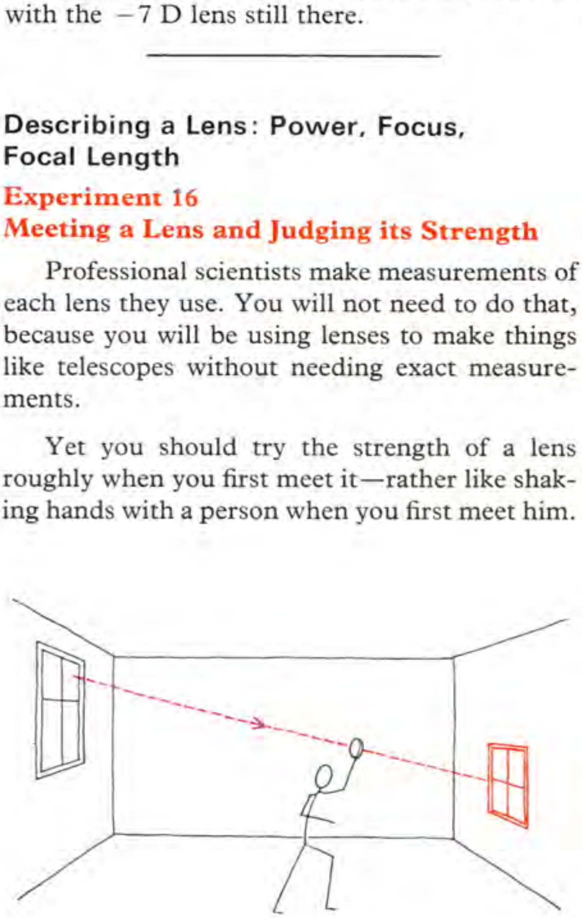
Ask for a spectacle lens to correct your temporary long sight. Hold that in front of your eyes with the −7 D lens still there.

Describing a Lens: Power, Focus, Focal Length

Experiment 16
Meeting a Lens and Judging its Strength

Professional scientists make measurements of each lens they use. You will not need to do that, because you will be using lenses to make things like telescopes without needing exact measurements.

Yet you should try the strength of a lens roughly when you first meet it—rather like shaking hands with a person when you first meet him.



Contact lenses take the place of the front window of the eye, for bending rays of light. So, contact lenses with spherical faces can usually 'remove' astigmatism.

If you have astigmatism, you should keep your spectacles on for optical experiments. If you have little or no astigmatism, you may take your spectacles off for some of our experiments.

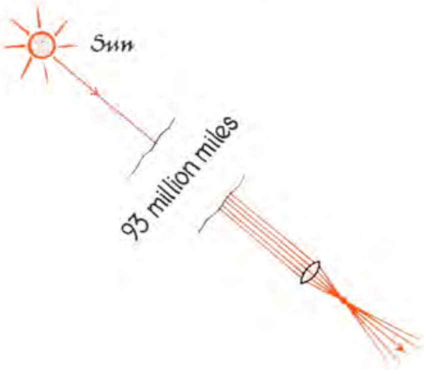
If you find an old spectacle lens and try using it to form an image of a window or the Sun, it may make something like an image but with streaky lines instead of a clear sharp shape. Then that may be a lens made for a person with astigmatism. You should not use it for your optical experiments because it will complicate things.

Take the lens to a wall opposite a window or lamp. (Or hold a sheet of paper in one hand and hold the lens in the other hand towards a window or a lamp.) Move the lens until you catch an image of the window (or lamp) on the wall or paper.

Look at the distance from lens to image and measure it roughly. We call that the 'FOCAL LENGTH' of the lens.

You could do the same thing using the Sun instead of the window. Let the lens form an image of the Sun on a piece of paper. In bright sunlight, the paper will soon catch fire. You are using the lens as a burning glass.

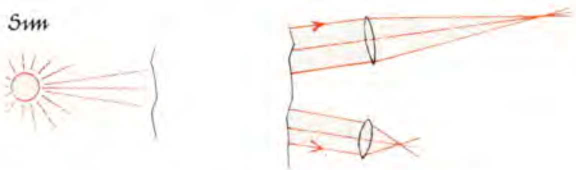
Focus The image of the Sun is like a burning fire in a hearth, so it is given the Latin name for a hearth, 'focus'. When any object is far away, like the Sun, the image is *at* the focus of the lens, F. The distance from lens to focus is called the 'FOCAL LENGTH', (f). The stronger the lens, the shorter the distance it needs to bring rays to a focus at an image, the shorter its focal length.



In your work with telescopes and spectacles and eyes, you will not need to use the focus for drawing diagrams; and you will not find the focal length very important, except as a rough measurement that tells you how strong a lens is.

So when you meet a lens it is good to make a rough estimate of its focal length; but then you need not worry about it.*

Power of a lens We call $\frac{1}{f}$ the POWER of the lens. When f is measured in metres, $\frac{1}{f}$ is measured in units which are $\frac{1}{1\ \text{metre}}$; and the spectacle-makers call these 'dioptres', D for short.



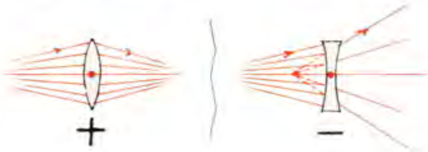
If f is 2 metres, the power is $\frac{1}{2}$ D or 0.5 D.

If f is 0.2 metre (= 20 cm) the power is $\frac{1}{0.2}$ or 5 D.

If the power is 5 D, f is $\frac{1}{5}$ or 0.2 metre.

The lens you used for the camera has power 7 D. *What would be the value of its f, roughly? (Does that fit fairly well with the length of your camera box?)*

Positive and negative lenses The + or − sign in the power of a lens tells us which way it bends rays: + to make them converge more; − to make them splay out more.



Positive lenses make a real image of a window or the Sun or a distant lamp.

Negative lenses will fail to make an image on paper or walls. (To estimate their focal length you would have to proceed in a roundabout way.)

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*In some methods of teaching optics, the focal length and the 'principal focus' of a lens play important parts in calculations and constructions. Here we shall not use them. Instead, we treat the way in which lenses make rays form images as the important behaviour. And we shall use images to explain the working of telescopes and other optical instruments, including your own eyes.

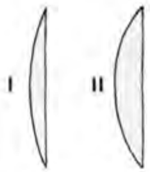
So you need not learn definitions of focus or focal length. You need not make measurements of focal lengths—except just for a quick estimate.

Which kind of spectacles will help a short-sighted man? Positive lenses or negative? Ask your neighbours if they are short-sighted. If someone is, ask him to see if his spectacles will form a real image of a window or the Sun. Long-sighted people need the *opposite* kind of spectacles.

Questions

LENS POWER

22. The diagram shows two lenses, I and II.



a. Which is the stronger lens, I or II?

b. Suppose each lens in turn is used to make a real image of a distant object. Which will make the larger image?

c. Suppose the two lenses I and II are held together so that light goes through both. If that combination is used to make an image of a distant object, will that image be larger than the image made by either lens, or smaller?

d. Which of those two lenses would you choose for the *objective* lens of a telescope to magnify as much as possible?

23a. If a lens has focal length $+25$ cm, what is its power in dioptres (metres^{-1})?

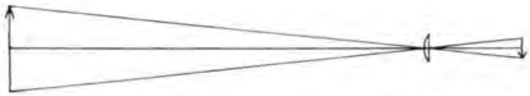
b. If a lens has power $+3$ D, what is its focal length?

c. If a lens has power -5 D, what is its focal length?

d. If a lens has focal length -2 metres, what is its power?

e. What is the power of a piece of flat window glass?

PUZZLES



24a. The diagram (not to scale!) shows a positive lens forming an image of a flagpole 5 metres high, 100 metres away. The image is 2.5 cm high. (The flagpole is so far away that the image is practically at the principal focus of the lens.) Calculate the power of the lens.

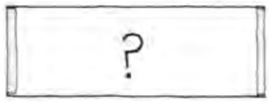
b. *(Advanced puzzle)* Suppose you are given a combination of several lenses mounted close together, like an expensive camera lens.

You do not know where to measure the focal length from, among the set of lenses. So you cannot measure f of the combination, by means of a distant window, and then find the power $\frac{1}{f}$.

How could you find the power of this lens combination? (Use (a) as a hint.)

(NOTE. This part (b)—with a hint from (a)—asks about the method used by optical experts for every kind of lens.)

25. *(This is a puzzle question, but it is not important. Try it if you have finished the other questions.)*

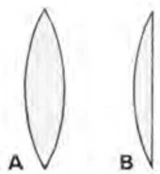


The diagram shows a cardboard tube about 15 centimetres long, closed at each end with pieces of flat glass. Somewhere inside there is a single positive lens fitted in the tube—but you do not know just where it is. You do not know the focal length of the lens; but it is more than 15 centimetres. How would you find the focal length of the lens *and* the position of the lens in the box *without taking the box to pieces?*

The only 'apparatus' provided is a bright window at one end of the room, a piece of white paper, and a ruler.

(HINT. Remember that light can go *either way* through the box.)

26. *(A Question for Guessing.)* Fig. A shows a slice through a strong positive lens of power $+10$ D. Fig. B shows that lens sliced in half. What power would B have? ($+5$ D, $+10$ D, $+20$ D, or can't say?)

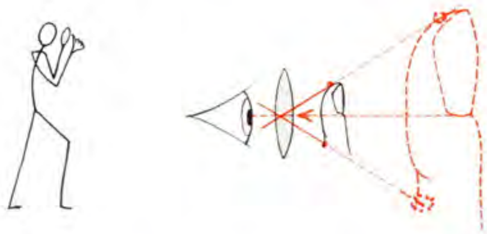


Virtual Images

Experiment 17
Magnifying Glass

The positive lens (+7 D) that you have been using to make real images will also act as a magnifying glass—as you know from your telescope experiment. Find out how it does that. Use it to look at your thumb.

(If you wear spectacles for reading, it is best to keep them on for this experiment.)



Hold the lens *very close* to your eye with one hand. Put the thumb of your other hand at the right place for looking at it with this magnifying glass. Move your thumb nearer and farther until you see it clearly in focus. Then whip the lens away and see whether you can still see your thumb.

Without the lens, you can see that your thumb is still there; but it looks fuzzy. It is too close for you to see it in focus. It is much closer than your eye's near-point of comfortable vision; and you cannot change the lens inside your eye enough to focus it.

Now put the magnifying glass back. You can see your thumb comfortably and it looks large. You are looking at an IMAGE of your thumb. *Where must that image be?*

You know that you can see things comfortably if they are anywhere in your own range (from, say, 15 cm out to infinity). You can see your thumb's image clearly with the lens. So it must be somewhere out in front of you, in your range.

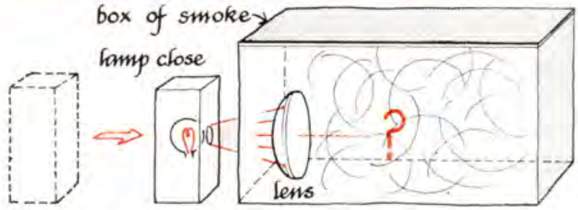
(If you had an 'average eye', your thumb's image would have to be somewhere between $\frac{1}{4}$ metre in front and infinity; but you will probably have to wait till you are about 40 for your range to have decreased to that.)

In any case, the image is out in front, on the same side as your thumb and farther away than your thumb. It could hardly be on *your* side of the lens, behind your head!

So now you have the lens making an image on the SAME SIDE AS THE OBJECT, *when the object is very close*. And that image is *farther away* from the lens than the object. We call that a VIRTUAL IMAGE.* Rays of light come straight from your thumb to the magnifying glass, are bent a little there, and continue forward on to your eye. The rays don't go back to the virtual image and *then* come to your eye. They only *seem to come from* the image. So you cannot catch a virtual image on a piece of paper.

Virtual images are a little harder to think about than real images. We shall come back to them when you watch lenses doing things with rays.

Demonstration 18
Virtual Image in a Box of Smoke



Put the big positive lens in the box of smoke. Use the bright lamp. Move lamp and lens much closer together. The rays from the lamp that meet the lens now splay out so strongly that the lens can't cope with them and bend them enough to make them pass through a real image. But it *does* bend them so that they *seem to come from* a virtual image back behind the lamp. Look and see where that virtual image seems to be.

That is how a magnifying glass treats rays from your thumb or anything else very close to it.

*Virtual is a useful word. It is not easy to define virtual but it has a clear flavour of '*not really, but as if . . .*'.

[If a large *negative* lens is available, you may see it making rays splay out in the smoke, so that they seem to come from a virtual image.]

[A flat (plane) mirror in the box will show how it makes an image; but you will see that better with ray streaks and can use the knowledge for your experiment with a candle (Experiment 22).]

Virtual images are common and important You have often seen virtual images all through your life (PUZZLE: where?); and you have been reading about them here and doing an experiment that made one.

What kind of image did your telescope EYEPIECE *make? Where was the final image?*

What kind of image do spectacles make for the person who wears them?

Where do you often see a virtual image at home?

The telescope Think about the telescope you made and use the word 'image' to describe what it did. *What did the first lens (objective) do? What did the second lens (eyepiece) do?*

You will have another turn with telescopes in a later experiment. But first you should try some experiments with rays of light splashing across paper on your lab table. There you will see the way a lens treats rays from an object and makes them pass through an image.

EXPERIMENTS WITH RAY STREAKS

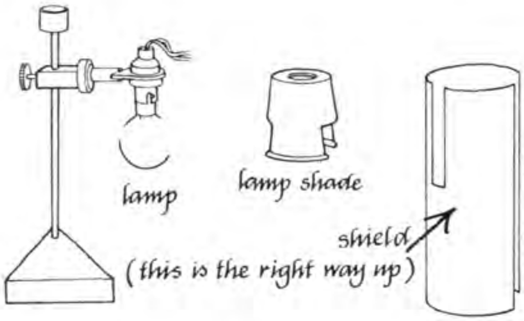
Learning more about lenses and light To understand how telescopes work and what spectacles do for your eyes, you need to know what happens to rays when they go through a lens. You need to *see* rays making an image.

Experiment 19 Ray Streaks
See What a Lens does to Rays

The experiments that follow, 19a, b, c, . . ., will let you see for yourself what lenses do with rays—not just what they 'ought' to do but what they really do. And you will be able to make models of telescopes, etc., with real rays.

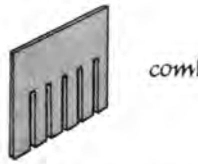
GENERAL INSTRUCTIONS FOR RAY-STREAK EXPERIMENTS

(1) Work in a fairly dark room. Use a very bright lamp with a vertical filament, as your 'object'.



(2) Place the lamp $\frac{1}{2}$ metre or more from a sheet of white paper on your table. Let light from the lamp splash out across the sheet.

(3) If the rays do not go right across the paper to the other end, raise or lower your lamp until they do. ADJUST THE HEIGHT OF THE LAMP FOR EACH EXPERIMENT SO THAT THE RAYS ARE AS BRIGHT AS POSSIBLE BUT STILL COVER THE LENGTH OF THE PAPER.

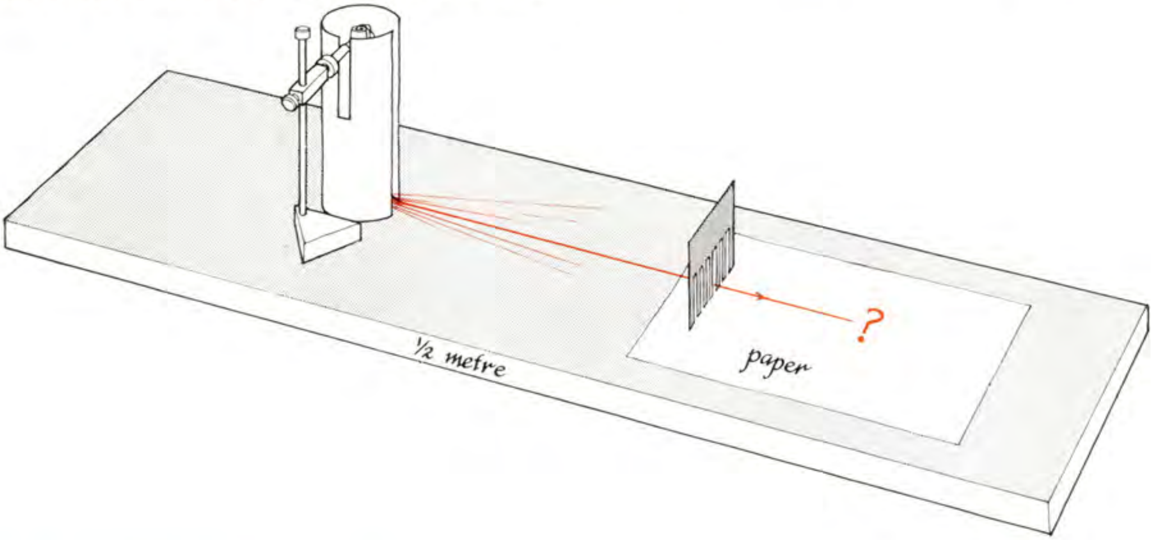


(4) Place a comb so that it lets through a sheaf of thick 'rays' of light which spread out across the paper.

(5) You will not need to make notes of these experiments with lenses and rays. They are in the half dark; and the best thing to do is just watch what happens, and remember some of the things you have seen.

19a Look at Rays

Set up your lamp and comb to make thick 'rays' of light on the paper. *Are the streaks straight or curved?* (If they look curved examine the lamp filament. A crooked filament may upset your experiments.)



19b Explore Lenses with Rays of Light

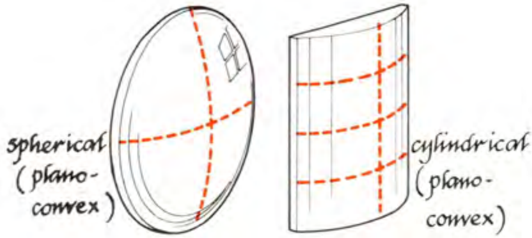
Put a cylindrical lens* on the paper to receive the rays. (Power +7 D is suitable.) Stand it upright on its foot.

Start with the lamp $\frac{1}{2}$ metre or more away.

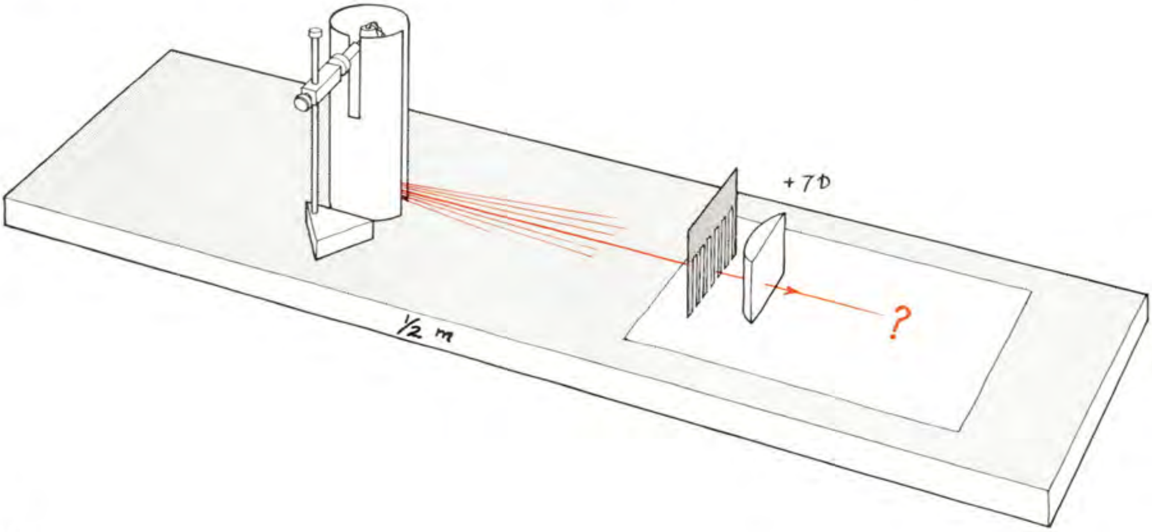
Try moving your lens in different ways.

Try other lenses.

If you like, borrow an extra lens from your neighbour and see what happens when rays go through *two* lenses in succession.



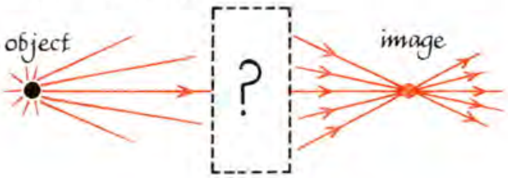
*We use cylindrical lenses for this. These are curved only one way, sideways, instead of ordinary lenses that are curved both sideways and up-and-down. With them the path of a ray can be traced right across the paper. With ordinary lenses, the ray would disappear under the paper when it passed through an image.

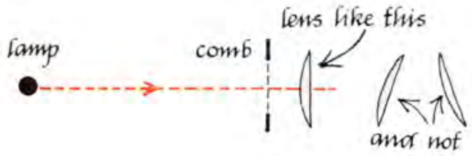


A series of experiments, 19c to 19l Now continue exploring with ray streaks. Go straight on from one experiment to the next, watching carefully what the rays do. You will learn more that way than if you stop to read the extra comments here or fill in a notebook. You can write notes later, when you have collected some knowledge of real rays.

19c Good Image with a Lens

Place the lamp $\frac{1}{2}$ metre or more away. If you arrange your weak lens (+7 D) carefully you will see it making an image. That is, you will see that it collects a fan of rays from the object lamp and bends them so that they all pass through one point. That point is the IMAGE of the lamp filament. The image is the place all the rays go through—where the rays 'focus', if you like.





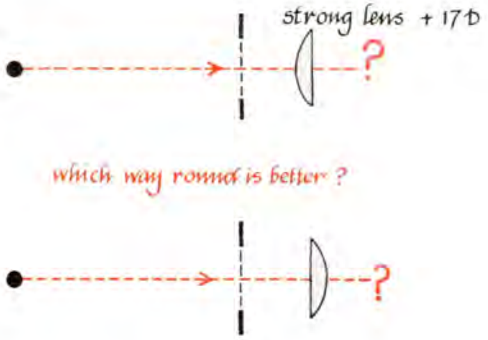
You will need to twist your lens so that the rays meet it head-on. Then you will see it making a proper image.

Try moving the lamp *sideways* while you watch what the image does.

Try moving the lamp to different distances from the lens.

19d Stronger Lens

Now ask for a stronger lens (+17 D). *Does that form an image properly?* Use two small barriers to shut off some parts of that lens.



Try turning your lens round so that rays meet the other face. Whichever way round you place the lens, you may see some 'disease'—some failure to make all rays go through an image.

That does not mean that the lens is *wrong* or that rays of light have developed *wrong* behaviour. It only means that real lenses do not do quite what we hope for. They do not make all rays pass exactly through an image point. With strong lenses that trouble becomes quite noticeable.

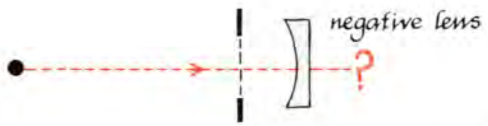
So when you use a strong lens, you should make it face whichever way gives less 'disease'. And you should limit it with side barriers so that it seems to form a fairly good image. Then the rays that do get through will meet and cross almost exactly at one image-point. Try that.

Modern cameras have very strong lenses. *How do they avoid this 'disease'?* That is done by putting several lenses together, arranging their shapes and distances so that the 'disease' caused by one is just compensated by opposite 'disease' from others. For modern microscopes, such 'compound lenses' are essential.

This 'disease' is called '*spherical aberration*'. (That is the professional name, but you need not remember it.)

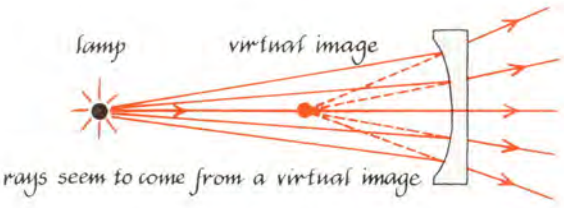
19e Negative Lens

Ask for a negative cylindrical lens (−17 D). Shoot a fan of rays at it. *Does your negative lens bend rays?*

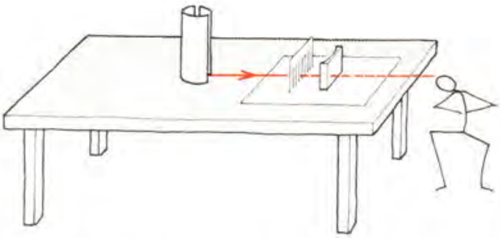


'Virtual' With a positive lens, you can see that the rays which start from the lamp are bent by the lens so that they pass through a new point, the real image of the lamp filament. See what your negative lens does to rays from the lamp. *Does it make them pass through an image point?*

Could you, instead, say that it makes them SEEM TO COME FROM an image point? If so, you would call that a 'virtual' image.* A virtual image is a perfectly respectable kind of image, only you cannot put your finger on it as you can with the real image. The rays don't actually pass through it.



If you like, go to the end of the table and look back towards the lens, looking along the rays that come out of the lens. *What do you see? Can you see the virtual image's position now?*



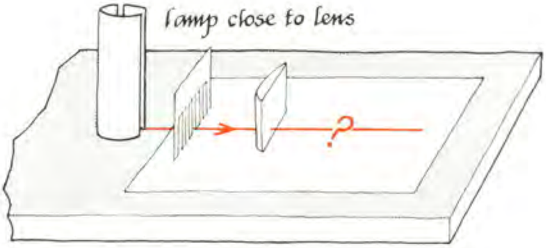
Try moving the lamp farther away and then nearer to the lens. *What does the image do?*

19f A Positive Lens CAN make a Virtual Image

You can also see a positive lens making a virtual image when the object is very close.

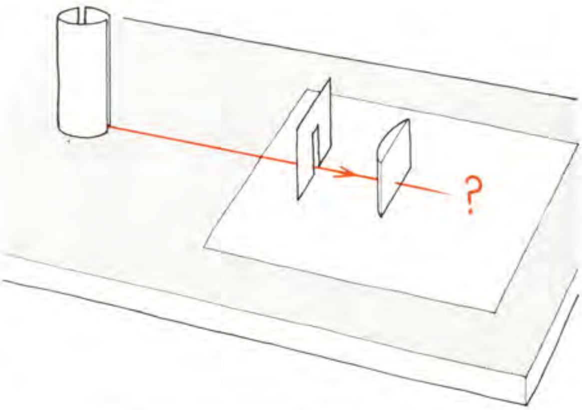
Set up your weak lens again (+7 D). Move the lamp and comb *very near* to it and see a picture of the lens making rays come from a virtual image of the lamp. Show your teacher the pattern when you have found it.

*Virtual is a useful word. It is not easy to define but it has a clear flavour of '*not really, but as if . . .*'.

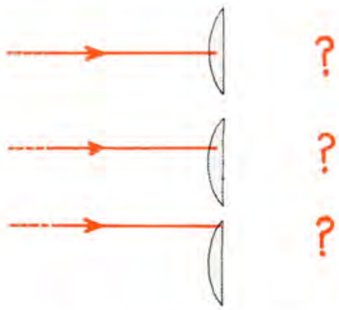


19g Single Ray hits a Lens

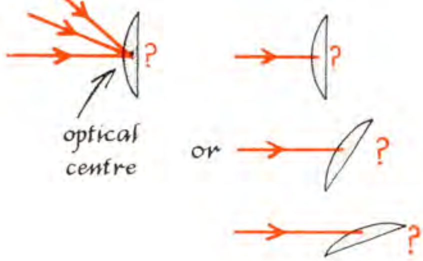
Replace the comb by a sheet of metal or card with one slit, so you have just one 'ray' of light.



Watch what happens when the ray hits various places on a positive lens (+7 D).



Find the place on the lens where the ray must hit it to go STRAIGHT THROUGH WITHOUT BEING BENT.



We call such a ray an 'undeviated ray' (meaning a ray not-bent-away-from-its path).

The part of the lens which lets a ray through without bending is called the 'optical centre'.*

Try firing a ray AT THE OPTICAL CENTRE from different directions. (That is easier to do if you just twist the lens.)

Undeviated rays are useful In drawing optical diagrams of rays, you should make use of undeviated rays, because they will help you to see how tall the image is compared with the object—they help you to see the *magnification*.

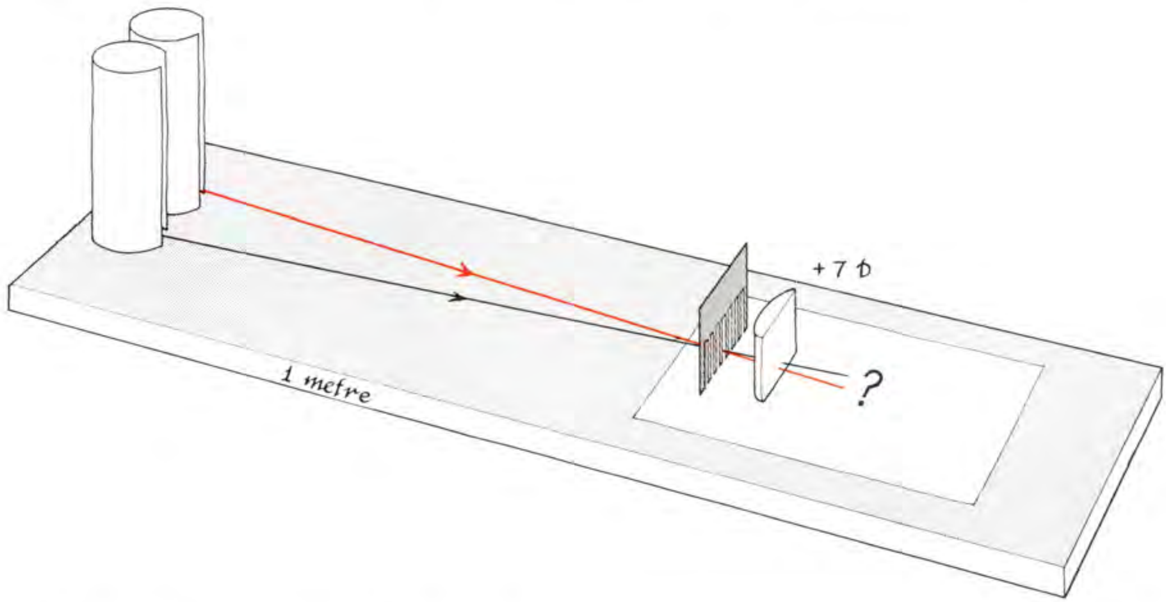
19h Two Object-Lamps and a Lens

Borrow a lamp from a neighbour and place two lamps very close together side by side a long way (about 1 metre) from your comb and weak lens (+7 D).

Size of image Pretend that the two lamps, A and B, are top and bottom of a tall object, and their images A′ and B′ are the top and bottom of the image of that object.

Make a sketch and think about an undeviated ray from A to A′, and an undeviated ray from B to B′.

If the image A′ B′ is a quarter as far from the lens as the object AB, how does its size compare with that of the object?
(HINT. Look for similar triangles.)

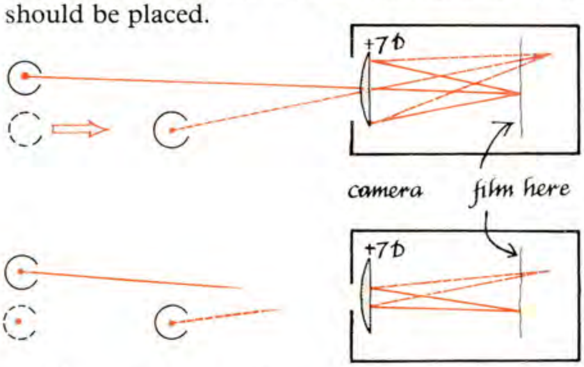


Those two lamps represent two points on some bright object. Look at the images.

You can make it easier to tell which rays come from which lamp if you put a piece of coloured glass or plastic in front of one lamp.

*With stronger lenses you will not find undeviated rays that go straight through a single optical centre. You can find rays that enter, then take a slanting path through the thick glass of the lens, then come out *parallel to their original direction*. Those are *called* undeviated rays because their final direction is the same as before they entered—they only stagger a little sideways.

Cameras Your two lamps A and B might be two object-points for a camera. Look at their images. You can see where the camera's film should be placed.

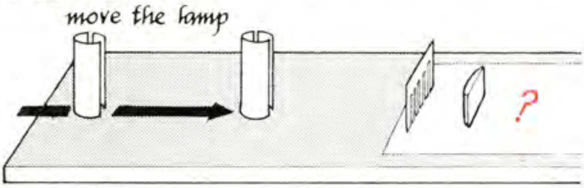


Now move one lamp, A, much nearer or farther—as if your camera were trying to take two objects at different distances. The lens still makes an image of lamp A, but does that image fall on the imaginary camera film? *What pattern do rays from lamp A make on the film?*

Bring in barriers to 'stop down' your camera's lens to a smaller aperture. *Does that shift the image position? Does it change the size of the out-of-focus mark on the film? How do cheap cameras manage to claim they have 'fixed focus'?*

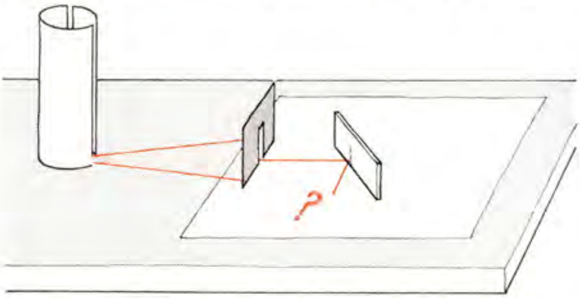
19i Object walks towards a Lens

Shoot a fan of rays at a weak positive lens (+7 D) from a lamp far away. Move the lamp nearer and nearer to the lens and watch how the image moves.



19j Flat Mirror and a Ray

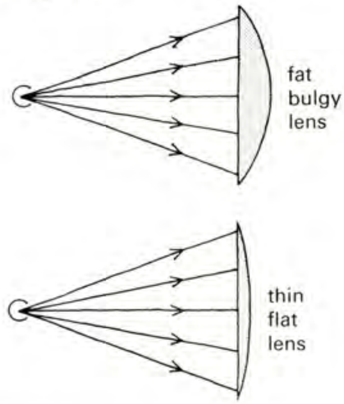
Hold a piece of flat mirror upright and shoot a ray at it. See what the mirror does to the ray.



Progress Questions

LENSES AND RAYS

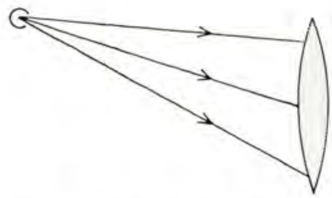
27a. Copy and complete these two diagrams so that you show the difference the shape of the lens makes to the pattern.



b. Which is the *stronger* lens?

28. Does a lens always bend *every* ray that passes through it?

Copy the diagram and complete it. Show what is most likely to happen to the rays after they pass through the lens.

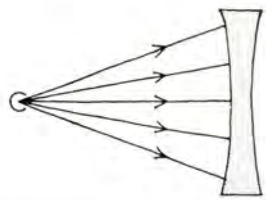


29. What is the name we give to an image we can cast on a screen—it is *real* or *virtual?*

What name do we give to an image we cannot cast on a screen but can see when we look through a lens?

RAY STREAKS

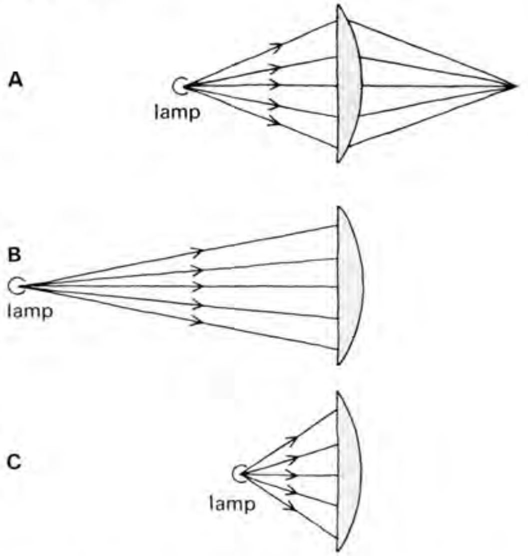
30. Copy and complete this to show the pattern you get.



Questions

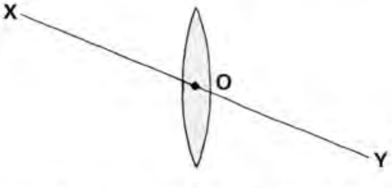
LENSES AND RAYS

31. Fig. A shows a lens collecting streaks of light from a lamp.



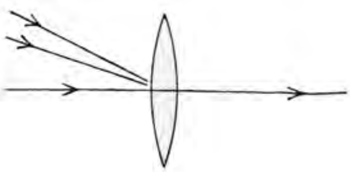
Copy all the diagrams carefully and show the difference in the pattern you get when you change the distances. (It is the *same* lens each time.)

32a. In the diagram the ray XY goes through the lens without being bent. What is the name for such a ray?

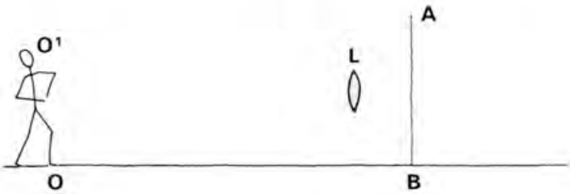


b. What is the name for the point O belonging to that lens?

33. The diagram shows three rays hitting a lens. One ray is continued through the lens. What happens to the other two rays which *go through the same point in the middle of the lens?* (Answer with words or a sketch.)



34. In the diagram a lens L forms an image of a man OO′ on a piece of paper at the place AB.



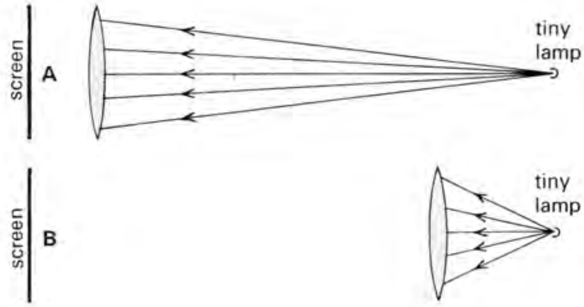
a. Where is the image of the top of the man's head?

b. Is the image upside-down or the right way up?

c. Where is the image of the man's feet?

The man is about 5 times as far from the lens as the piece of paper is on the other side. If the man is 200 cm tall, how tall is the image?

35. In both arrangements A and B the lens is the same. In both the arrangements the lens makes a clear picture of the tiny lamp on the screen. The lens has been moved from its place in A to a new place in B, but it makes a clear image in both cases.



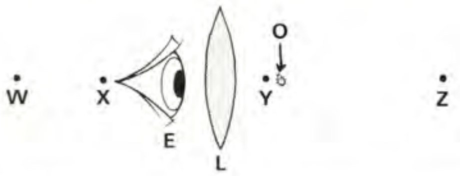
a. Copy the drawings (about twice as big). Complete them to show what the rays do after going through the lens.

b. Will the image in A be bigger or smaller than the object?

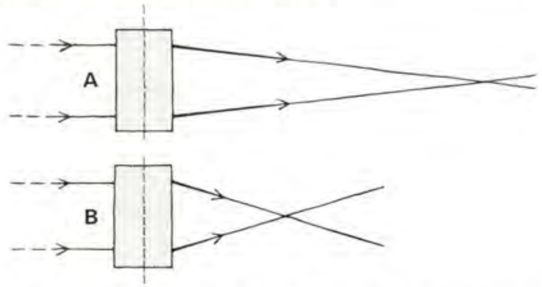
c. Will the image in B be bigger or smaller than the object?

d. The same tiny lamp was used for A and B. Draw the object and then draw the pictures you see on the screen in each case.

36. An eye E is looking at a small object O, with a magnifying glass L. Where is the image that the eye is looking at? At W, X, Y, Z or infinity?



37. A and B are two lenses *concealed in boxes*. Each box contains a glass lens (in the middle, along the dotted line). The boxes *look* alike but the lenses inside are different. The left and right faces of the boxes are open so that light can enter and come out. Rays of light from an object very far away pass into each box. They come out and come to a focus as shown in the sketches.



a. Are these lenses *thicker* or *thinner* in the middle than at their edges?

b. Are they 'positive' or 'negative', + or − ?

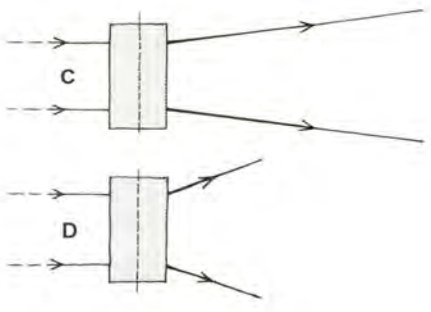
c. Do they make rays 'converge' or 'diverge'?

d. Which is the 'stronger'?

e. Which has the greater focal length, A or B?

f. Which would make the better magnifying glass? (This is a question to discuss in class. What does 'better' mean, here?)

38. The diagram shows two boxes, each containing a glass lens, at the dotted line. When rays from a very distant object pass through boxes, they come out as shown.



a. Which sort of lenses are these, positive or negative?

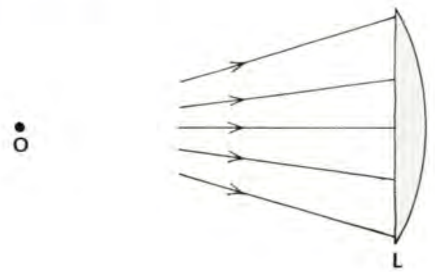
b. Are they *thicker* or *thinner* in the middle than at the edges?

c. Some people like to name lenses 'convex' or 'concave'. Which are these?

d. Are they 'converging' lenses or 'diverging' lenses?

e. By comparison with your answers to Q. 37, which of the lenses, C or D, has the greater focal length?

39a. The diagram shows rays spreading out (diverging) from a lamp and arriving at a positive lens L. The lamp is not drawn; but it is at the point marked O.



Copy the diagram and show what is likely to happen to the rays after they have passed through the lens.

(NOTE. You may *choose* any distance you like for the image, but note that (b) *(i)* and (b) *(ii)* below ask for different lenses with the object at the same distance from the lens; so it would be good to plan to get all the pictures on one sheet of paper.)

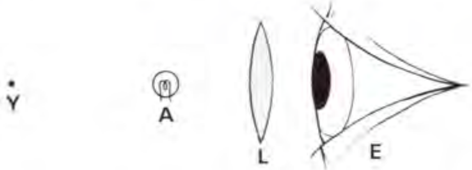
b. Now make similar diagrams for rays from a lamp arriving at *(i)* a *more* powerful positive lens, then *(ii)* a *less* powerful positive lens.

c. Next make a similar diagram with *two* positive lenses placed one after the other a few centimetres apart.

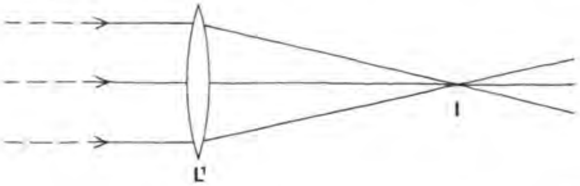
d. Make a diagram which shows what happens to the rays from O when they pass through a *negative* lens.

40. Repeat parts (a) and (d) of Q. 39, using a drawing in which the lamp, at O, is much farther away from the lens than before. This means that those rays which hit the lens are more nearly parallel to each other.

41. A is a tiny lamp. The lens, L, makes a virtual image of A at Y. E is the eye of a man looking at the virtual image. Does the man think he is looking at something at A or something farther away or nearer? (HINT. The eye uses the rays that get to it. Where do those rays seem to come from?)



42. Rays of light strike a lens L_1 and form an image I.



a. How far away is the source of light in the diagram?

b. Copy the diagram. Below that draw three parallel rays striking another lens L_2 which is stronger than L_1.

c. Draw the rays beyond L_2 to show where it forms an image.

d. Draw a lens L_3 which makes the parallel rays *spread out* as they leave the lens. Sketch those rays.

43. B is a tiny, very bright, lamp bulb which sends out light rays in all directions. The sketch shows five of these rays. L is a thin positive lens. S is a screen.

S has been placed where it catches a sharp image of B. (The lens, L, is supposed to be a very good lens which forms an almost perfect image.)

a. Copy the diagram leaving out S_1 and S_2. (No exact measurements needed.) Draw the five rays onwards to the lens and continue then beyond it in their new directions, until they reach the screen S.

(Do not try to draw the rays *inside* the lens. You can pretend it is very thin.)

b. Suppose the *screen* is moved from S to S_1, but the lamp and lens remain where they are. What do you expect to see on the screen in its new position S_1?

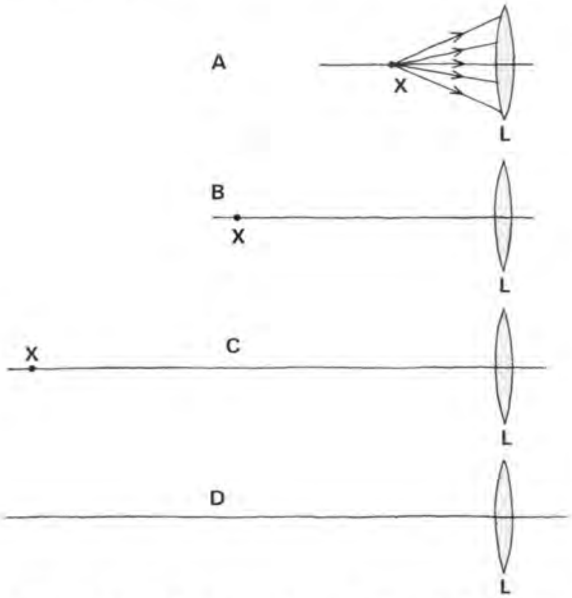
c. What do you expect to see if the screen is moved from S to S_2, an equal distance the other way? (That is, so that $SS_2 = SS_1$.)

44. *(This refers to the arrangement of Q. 43.)*

a. What would you see on the screen if it is moved only a tiny distance (a millimetre or so) from S towards the lens? What, if it is moved a tiny distance from S, away from the lens?

b. Explain what is meant by 'depth of focus'.

45. Fig. A shows a lens, L, and a tiny lamp, X. Five specimen rays show light going from X to the lens. In figs B and C, X is farther and farther away from the lens.

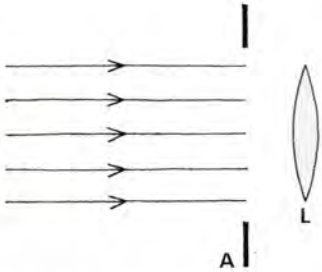


a. Copy figs B and C and on each add five rays from X to the lens, just like those in fig. A.

b. In fig. D, X is right off the paper, very far away, like a distant street lamp, or a star. Guess, and then draw, what the rays look like in D.

c. Write underneath your fig. D the following sentence, filling in the blank with *one* word: 'For all practical purposes, these rays are . . . ? . .'

46. L is a thin positive lens and A is a screen with a large hole in it. Light comes to A from an object a long way off, such as a street lamp 100 yards away, or even a star. Five rays entering the hole are shown in the diagram.



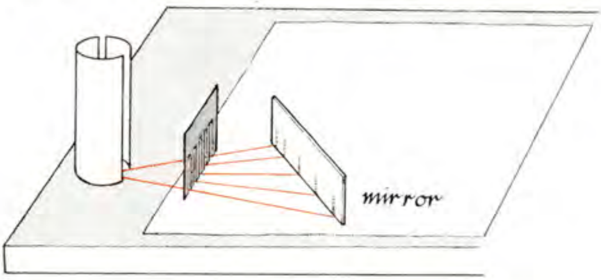
a. Explain why these rays have been drawn all PARALLEL to each other.

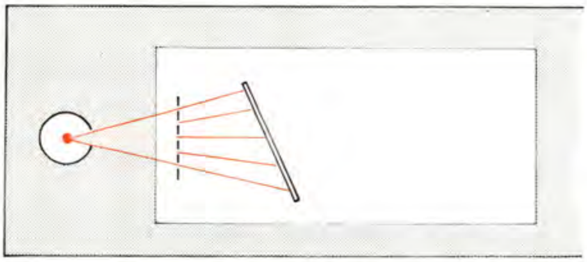
b. Copy the diagram. Continue the rays onwards to the right, to the place where a sharp image of the lamp or star is formed. Continue them, a little farther still.

c. If, instead of the distant lamp or star, we used a lamp a metre or so from the lens, would the image be *nearer* the lens than before, or *farther away?*

Experiment 19k Flat Mirror and a Fan of Rays

Place a piece of flat mirror upright on your sheet of paper. Move the lamp and comb quite close to it. See what happens to the fan of rays from the lamp when they hit the mirror.





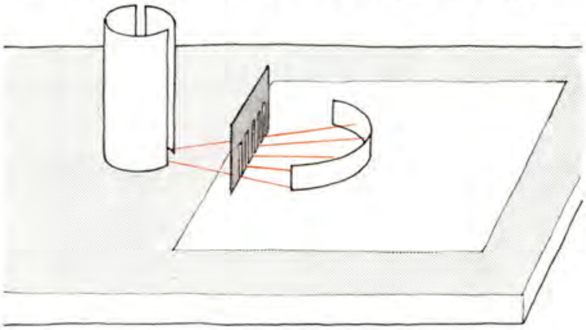
After they are reflected by the mirror, the rays do not seem to come from the lamp itself. *Where do they seem to come from?* Look at them from above. Then bend down and look along them. *Is there an image point? Is it real or virtual?*

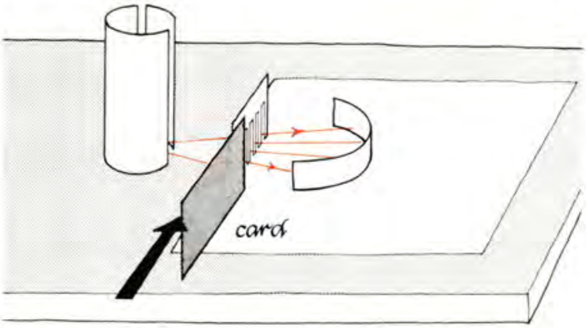
(There is no need to draw pencil lines on the paper or do some construction. Drawing would either be very slow or too rough to show the story clearly. Use your eyes and think about the rays instead. Simply look at the rays that reach the mirror and see that they come from the lamp. Then look at the rays which come *from* the mirror and try to decide where they all come from.)

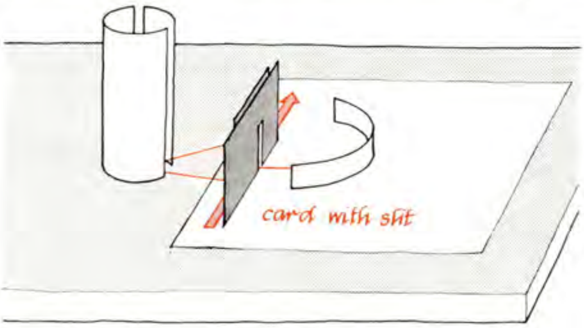
The reflected rays *do* seem to come from a special place: the 'virtual image' of the lamp.

19l Curved Mirror and a Fan of Rays

Shoot a very wide fan of ray-streaks from the lamp at a concave curved mirror. You should see a beautiful pattern. Raise the lamp enough to make the reflected rays travel back across the paper.







But the pattern will not tell you the mirror forms a good image of the lamp filament. For a good image you would have to limit the rays to a very narrow fan. Try doing that with two barriers.

Also return to the full fan and slide a card in from one side near the comb to cut off ray after ray.

If you like, cut a wide slit in a piece of card and move that across the full fan of rays from the lamp. Then a narrow sheaf of rays hits one part of the mirror after another. With such a narrow fan, you *can* see an image. *What does that image do as you move the slit across?*

Home Experiment H.191

If you enjoy seeing the patterns of this experiment you may want to show it at home. You could do that with the inside of a shiny soup or vegetable tin for the mirror (after you have cut away some of it). Use an ordinary comb to make the rays. You could use the Sun as a source of light or a clear electric light bulb on its side; or possibly you could borrow a transformer and lamp from school.

Cut out the top and the bottom with a tin opener. Then you need to make two cuts down the side so that you have half a cylinder. Bring the tin to school and ask your teacher to cut it with tin-snips.

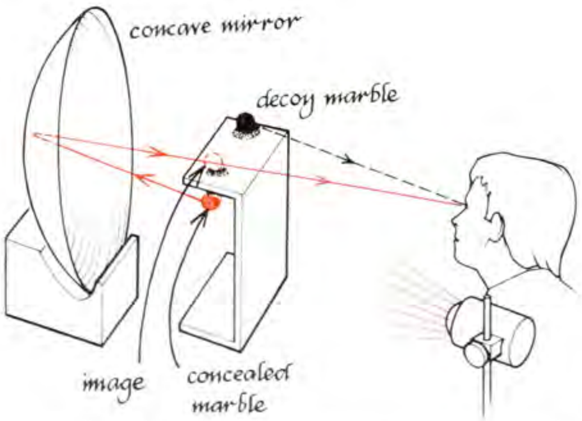
More Experiments with Mirrors

Demonstration 20
Curved Mirror in a Box of Smoke

If a large concave mirror is available, you may see how it reflects rays to form a real image in space.

Demonstration 21
Optical Illusion with a Curved Mirror

You may see the demonstration sketched. When an object is *at the centre* of a spherical mirror, or near it, the mirror forms a very good image, without the complicated 'trouble' (spherical aberration) that a curved mirror gives for other object-distances.



The coloured marble is placed a little way off the centre of the mirror. Its real image appears nearby. The marble may be concealed by a box round it, and yet send enough light to the mirror to make a visible real image.

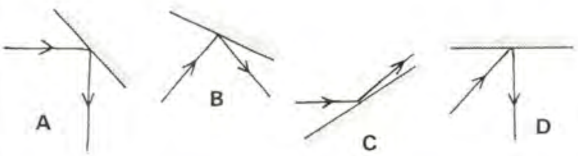
Then you can invite people to look at the real image. A grey marble is placed as a decoy beside that image so that the person who looks thinks he is seeing two marbles side by side. One is a real decoy marble, the other is just a real image of the concealed marble.

Ray Diagrams

Some people like to draw careful diagrams to show how rays of light go through optical instruments. If you would like to do this, find the special section in this book which shows, with pictures in colour, how to draw good diagrams.

Progress Questions

MIRRORS AND RAYS



47a. Which of these drawings is nearest to correct?

b. How can you tell?

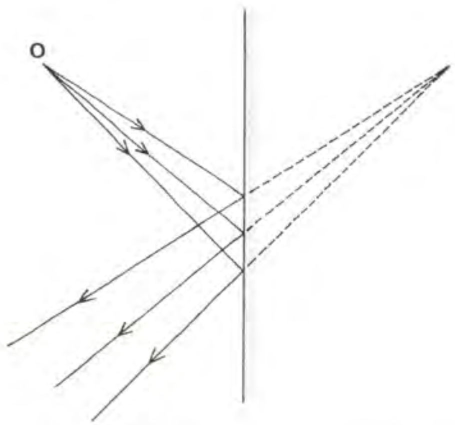
c. Copy and complete:
When light bounces off a mirror, we say it is [/*reflected*/*refracted*/].

48a. When you look at yourself in a mirror, where must you focus your eyes—somewhere *in front of* the mirror, or *on* the mirror, or somewhere *behind* the mirror?

b. Is the image made by a mirror a real or a virtual one?

MIRRORS AND IMAGES

49a. Copy this diagram carefully. O is the real light source. Label:
(i) the real reflected rays,
(ii) the image.



b. Draw in a (big) eye which is looking at the image.

c. Where must this eye focus—somewhere *in front of* the mirror, or *on* the mirror, or somewhere *behind* it?

d. Is the image real or virtual?

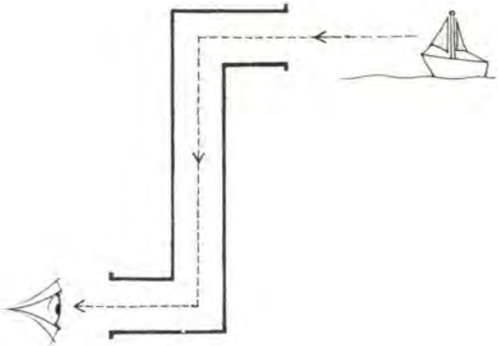
USES OF MIRRORS

50. Mirrors are often used either on their own or as parts of something else.

a. Make a list of uses. For each use, say whether the mirror is flat or curved.

b. For some (or all!) of your examples, explain *why* the mirror is used. (Make a sketch if it helps you.)

51. Here is a periscope with the path of a light ray drawn in.



Copy the diagram, and put in mirrors at the correct angles, so that the light ray is reflected as shown.

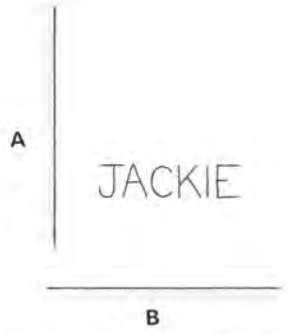
52. Think about this carefully. The diagram shows a mirror, an eye, and a coat button B. The eye is looking at the image of B in the mirror.

Where exactly will the image be?

Copy the diagram. Draw two rays going from the button to the mirror. Then show how these rays bounce towards the eye.

If you have drawn it correctly, both the bouncing rays should seem to be coming straight from the image of the button.

(If you find you have drawn your eye not quite in the right place, you may move it.)



53. Write your own name in capitals, and then draw what it would look like when seen in a mirror.

Your diagram should show where the mirror is, for example, at A or B or somewhere else.

54. Write very neatly ROBIN HOOD with ROBIN in blue and HOOD in red.

Then stand a mirror on the page just above the writing. Draw what you see in the mirror.

Questions

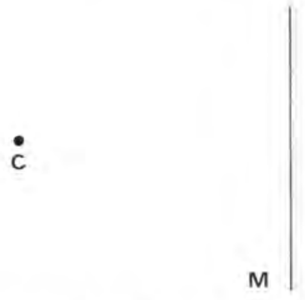
MIRRORS AND IMAGES

55. Think of the real images formed by some lenses.

a. How would you show that the images formed by a flat (plane) mirror are *not* real images?

b. What name is given to this type of image?

56a. A candle, at C, is placed in front of a flat (plane) mirror M. Many rays of light from the candle fall on the mirror. Copy the diagram and mark on it the point C′, which the reflected light *seems to come from*—that is, where the image of the candle is.



b. Now draw several rays from the original candle to the mirror and use your knowledge of the image-position (C′) to draw the paths of those rays after reflection.

57. Your diagram in answer to Q. 56 shows how reflected light appears to spread from a point behind the mirror. Describe briefly an experiment with a ripple tank in which something like that happened.

58. Describe briefly the experiment which leads to a Law about angles for reflection of rays of light.

59. *(Advanced)* Some very sensitive instruments for measuring tiny electric currents have their moving part so light that it would be upset if it had to carry a metal pointer. Those instruments use a ray of light reflected by a small mirror which turns instead of a solid pointer.

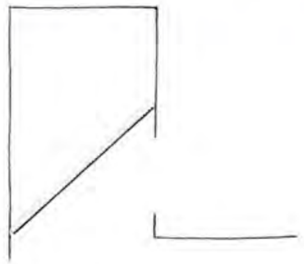
A narrow beam of light from a fixed lamp shines on the mirror. The light is reflected from the mirror to a centimetre scale 1 metre away from the mirror. That ray of light is as good as a long metal pointer for the instrument: how long? To choose the correct answer, think about the following argument.

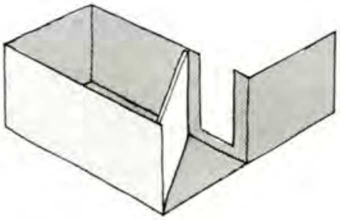
a. A ray of light falls on a plane mirror. That ray is kept fixed, but the mirror rotates a little. If the mirror turns through an angle of 1°, the *reflected* ray turns through 2°. How do you explain this?

b. You should have decided which was the length of the 'ray-of-light' pointer. That is *equivalent* to a real pointer of length ...?... ($\frac{1}{2}$ metre? 1 metre? 2 metres?)

[HINT. In (b), use information from (a).]

60. The diagram shows a large cardboard box which has had the lid removed. One end is cut open and bent back on the right, as shown. A hole is cut in the righthand side. A sheet of transparent glass is placed at 45°, as you see in the diagram.





The idea is to show (perhaps at a school 'open day' or 'parents' evening') the optical illusion of a candle burning in the middle of a beaker full of water.

a. Copy the PLAN diagram and show on it where you would put the beaker, and where you would put the candle, and where you would tell people to look. For the beaker (seen from above) put a large circle with a diameter about one-third the width of the box. For the candle put a small circle.

b. The candle has to appear to be exactly in the middle of the beaker. Draw a ray of light from the candle to the observer and another from the beaker to the observer.

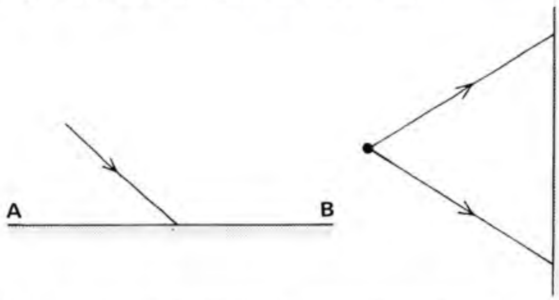
61. A man runs towards a plane mirror with speed 2 metres per second.

a. With what speed does his image approach the *mirror*?

b. How much closer to each other do the man and image go in each second?

c. The man stands still and the mirror is moved towards him at 2 metres per second. Does the mirror move away from the image? Or do they approach each other? With what speed?

62a. Copy the diagrams. Draw in the reflected rays in each carefully and accurately.

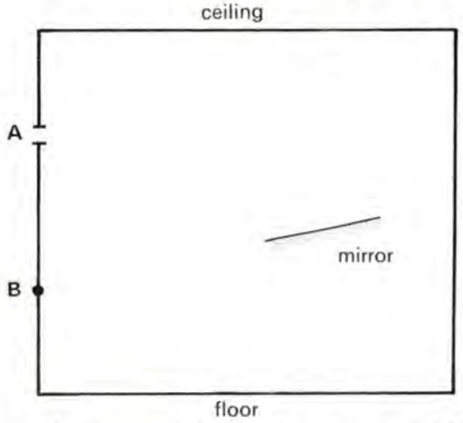


b. State any rule that helped to draw the reflected ray in A.

c. For B, you need not use that rule. There is an easier way. What is it?

63. Sunlight is coming in through a crack in the curtain at A. The mirror makes a patch of light on one of the walls.

a. Copy the diagram and mark the patch of light in the wall. Draw in the path of the light, too.



b. Draw the room, and show how you would have to place the mirror to get a patch of light on the wall at B. Draw in the path of the light, too.

REAL AND VIRTUAL

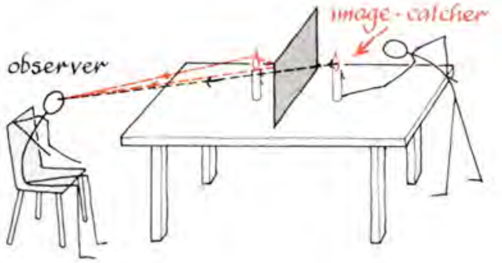
64a. Why is a real image called a *real* image?

b. You have often seen an image of yourself when you face an ordinary flat mirror. In what sense is that image of you less 'real' than the image a lens forms of you when your photograph is taken?

c. Describe briefly experiments you would do to show the difference between the image of a remote electric-light bulb formed by a positive lens and its image formed by a flat mirror.

Experiment 22
Candle and Flat Mirror

You have seen a flat mirror forming an image by reflecting ray streaks. *Where did that image seem to be? Was it real or virtual? (Did you ever see anything in your ripple-tank work that reminds you of this?)* Now look for the image of a candle placed in front of a mirror.



Set up a large piece of flat mirror vertical on the table. Place a candle (or a piece of chalk or some such object) in front of the mirror. Look *with both eyes* at the image that you see. Try to place another candle where that image is. This second candle is only an 'image catcher'. You are trying to place it where you think the image of the first candle is.

Hold your head out to one side of the mirror. Then you can look past the mirror at the catcher-candle with one eye, while you look at the image of the object-candle with the other eye. Or you may bob your head up-and-down and to-and-fro, trying to look at each in turn with both eyes.

When you are successful in placing the catcher-candle, ask your teacher to come and see.

Telescope

Now that you know about real images and virtual images, we can talk about telescopes in a more scientific way.

The simple telescope that astronomers use for looking at stars has two lenses. The light from an object far away first meets the 'objective' lens, which forms a *real* image of the object. That real image is much smaller than life; but it is nearby, so you can look at it with an eyepiece. The eyepiece is a strong positive lens, used as a magnifying glass to make a large *virtual* image of the real image.

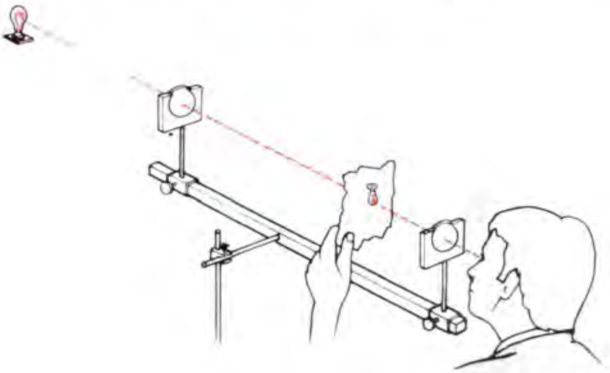
That final virtual image must be placed where the observer's eye can focus on it comfortably: anywhere from $\frac{1}{4}$ metre in front (for an average eye) to infinity.

If the observer is also taking notes in a book (held comfortably $\frac{1}{4}$ metre away) he may find it convenient to place the telescope's final virtual image $\frac{1}{4}$ metre away. Then he need not change the focusing of his eyes as he glances from telescope to notebook.

But for ordinary observing it is more comfortable to place the final virtual image as far away as the object. Then the observer can switch easily from looking through the telescope to looking with naked eyes. And he can even estimate the magnification* his telescope gives by using *one* eye for the telescope and *the other eye* naked to look at the distant object. Then he needs to have both eyes focused at infinity.

Experiment 23a
Astronomical Telescope (Second Look)

Set up your telescope again as in Experiment 13. Focus it, this time without any help.



Make sure your telescope-bar is up at shoulder height. Then you will not make your eyes ache by bending down to the bench with your head tilted back!

Point your telescope at a distant lamp and catch the image of the lamp on a scrap of thin paper.

Move your eyepiece lens until you see the scrap of paper in focus, magnified. Then take the scrap away and look at the virtual image of the lamp. Pull your *head* back a short way.

---

*You may hear the *magnification* called the telescope's *magnifying power*. But in scientific work MAGNIFYING POWER has special meanings, such as the best the telescope can do when both object and image are at infinity. It is safer to say MAGNIFICATION, which is the factor by which you gain in your actual use.

Move your eyepiece lens forward and back till you have placed the virtual image back where the object-lamp is. To do that, KEEP BOTH EYES OPEN. KEEP BOTH EYES FOCUSED ON THE FAR-AWAY LAMP while you apply one eye to the telescope. Move the eyepiece lens until you see the magnified image sitting on the real lamp both in focus.

If you are not successful, look back to the earlier telescope experiment (page 45) for hints of ways in which your *partner* can help you.

When you have succeeded, show your focused telescope to your teacher. Then let your partner have his turn, beginning all over again—do not let him use your focusing ready-made.

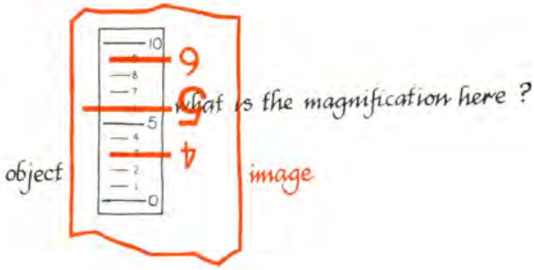
Experiment 23b
Telescope Magnification

Turn your telescope to look at a coarse scale posted on the wall. Make sure the final virtual image of the scale is back on the wall too. Then, look through the telescope with one eye while you look at the scale with the other, naked, eye. KEEP BOTH EYES OPEN. Estimate the number of spaces on the original scale covered by one space on the image. That is your estimate of the MAGNIFICATION.

Don't tell your partner, but let him have a try. Then compare notes.

Optional Advanced Experiment 23c
Re-focusing the Telescope

If you have time to spare and find you are good at focusing, try placing the final virtual image at a comfortable 'notebook distance', $\frac{1}{4}$ metre. For that, you will need to move the eyepiece and concentrate your attention on looking at things much nearer, just $\frac{1}{4}$ metre away.

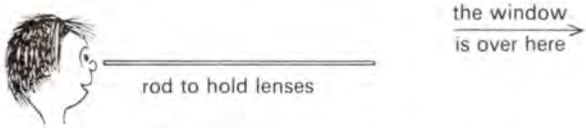


Hold a book in one hand $\frac{1}{4}$ metre from your face. Look at it with one eye while you look through the telescope with the other eye. Concentrate on seeing clearly with the naked eye, and move the eyepiece lens of the telescope nearer and farther till you see the image sitting on the book. It may help if you wobble your head from side to side while you are deciding if both book and image are in focus.

Progress Questions

TELESCOPES

65. When you make a model telescope, you use one fat bulgy lens, and one thin lens, not so bulgy, like A and B in the diagram.



a. Copy fig. C and draw in the lenses in the right places.

b. You move your eye lens so you can see a distant building as clearly as possible. What does the image of the building look like?

(i) Is it the right way up, or upside down?

(ii) Can you see it in colour?

(iii) Can you see the whole building in one look, or do you have to move your telescope to see all of it?

66. Make a list of people who use telescopes or binoculars (which are a special sort of double telescope) for their work. Try to say what each person wants to look at.

67. Go to the library and find out some more about proper telescopes. Write down at least three of the new things you learn.

68. Telescopes were invented over 350 years ago. Galileo heard about 'glasses to make far-away things look nearer' and at once started making a telescope. He had to make his own lenses by grinding blocks of glass. He made a different arrangement of lenses from yours.

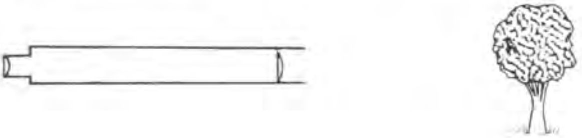
a. Look in books in a library to find out about Galileo's telescope (now called an 'opera glass'). In what way was it different from the one you made?

b. In what way was it better?

c. In what way was it poorer?

d. Read about the things Galileo did with his telescope. What did he discover with it?

e. Here is a diagram of your telescope pointed at a bird in a tree. Make a sketch like that of Galileo's form of telescope. (Show roughly the shapes of its lenses.)



Questions

TELESCOPES

69. *(Do not try this question until you have made a telescope yourself.)*

a. Make a sketch of how you arranged the lenses for your telescope so that you could see a distant building clearly.

b. When you moved your telescope to look at something much closer, you had to move the eyepiece lens. Which way did you have to move it, towards the object or away?

70. Suppose you have lenses of powers about +3 D and +20 D, and a bar to hold them at shoulder height. You also have tissue paper. You wish to make a telescope.

a. Which lens would you set up first, and whereabouts on the bar would you mount it?

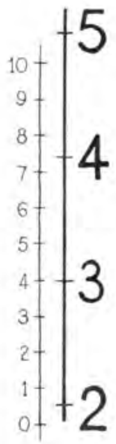
b. What would you do with the tissue paper?

c. Where would you put the second lens?

d. At what position would you expect to have your eye when looking through the telescope—up against one lens, or $\frac{1}{4}$ metre from it or where?

71. A vertical scale is drawn on the blackboard, with regularly spaced marks labelled 0 to 10. A boy makes a telescope from two positive lenses. He takes it to the end of the room to look at the blackboard, which is 10 metres away.

He keeps his *left* eye open and uses it to look at the board directly. He looks through the telescope with his *right* eye and adjusts the lenses so that he sees the image clearly. He then sees something like the diagram on the next page.



a. How far away from him is the image he sees through the telescope?

b. Why do you say it is at that distance?

c. What is the magnification that the telescope produces.

d. Something has been drawn badly wrong in this diagram. If the telescope were really made from two convex lenses, he could not have seen what is shown. Copy the diagram but put it right to show something he *could* have seen. (HINT. The *markings* are in the right place, but the *figures* are wrong.)

72. *(Optional Advanced Question)* **a.** What part of a telescope acts as a magnifying glass, and what 'object' does it magnify?

b. A telescope magnifies 4 times and the eyepiece has a focal length of 5.0 cm. What is:
(i) the focal length of the objective,
(ii) the distance between the lenses?

73a. The 'astronomical' telescope gives a final image that is upside-down, yet it is a virtual image, and we usually expect virtual images to be upright. How do you account for this?

b. *(Optional advanced question. For hints and help see the telescope in the instructions for ray-diagrams.)*

(i) How could a third positive lens be used in a telescope to make the telescope give an upright final virtual image the same way up as the object?
(ii) Where would you put that third lens in order to give a final image that is the same size as it is without the third lens?
(iii) If you are offered a choice between the two lenses, 5 cm or 25 cm focal length (+20 D or +4 D) for use as the third 'inverting' lens, which would you choose and why?

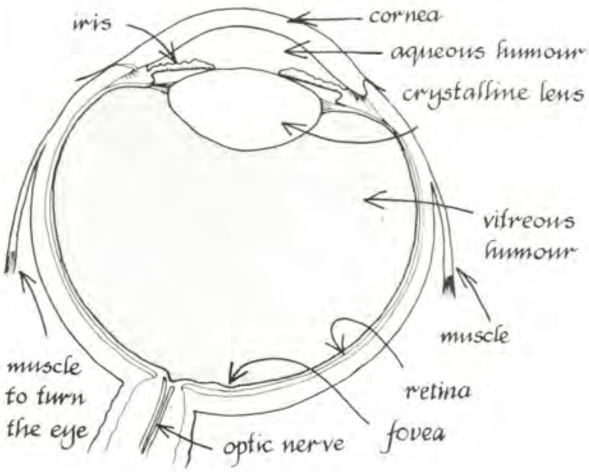
c. *(Optional)* Have you seen another form of telescope (Galilean or opera glass) which uses only two lenses and yet gives an upright final image? If so, what is the difference between that 'telescope' and the one that you have been using?

EYES

Your eye acts like a camera. Light from the things you look at enters through the clear front window, which acts as a strong lens.

The black centre of your eye is just a hole to let the light in. It is called your eye-pupil. The hole looks black because your eye is almost a closed ball and is black inside—like any good camera—to lessen stray reflections.

The coloured iris round the pupil can be pulled by muscles to make the pupil larger or smaller, to adjust to shade or sunshine. Look at a person's eyes in a poorly lit room; shine a bright light suddenly on his eye and watch what happens to the iris.



Behind that is a lens whose power can be changed. It is made of tough material like hard jelly. Muscles squeeze that lens and make it stronger when you wish to focus something nearer.

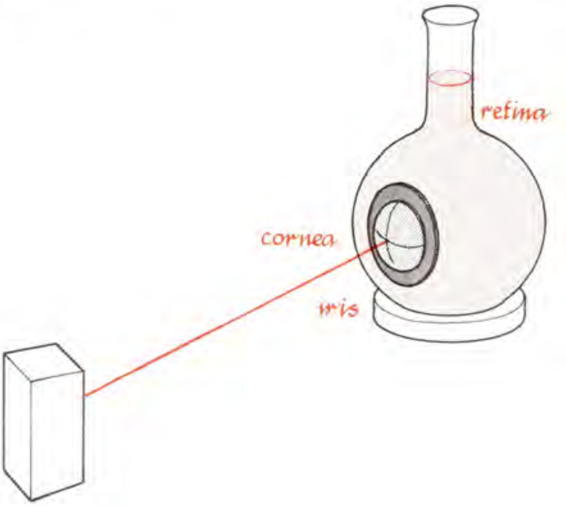
There is salt water between the front window and that lens.

Behind the focusing lens there is a large region of clear watery jelly.

The light finally arrives at an image on the sensitive film of nerves at the back of your eyeball.

Demonstration 24
Model Eye with Flask of Water

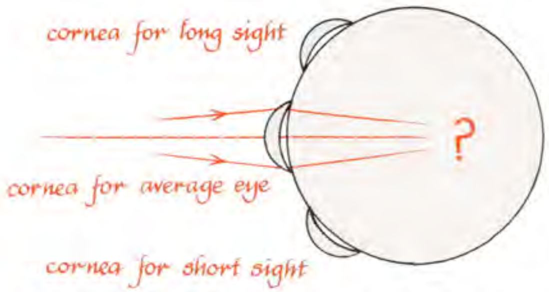
See this model. A little fluorescent dye in the water makes the path of rays visible. Lenses on the front of the flask enable you to see a normal eye focusing rays to an image on the 'retina' at the back; then a short-sighted eye, and then a long-sighted eye, failing to focus there until spectacles are added.



Details of the Eye

Here are some names and notes. If you see a bullock's eye being dissected you may find these useful—otherwise you should omit most of these notes. You need not learn the names, though they are useful labels. (Naming is not real science, but it helps scientists to organize their knowledge and talk about it.)

CORNEA is the transparent front window. It is tough, so you need not fear your cornea will be damaged easily. The main bending of rays occurs



here, where they pass from air to the denser material of the cornea. Rays are bent here, and bent some more inside, to form an image on the back of your eye.

AQUEOUS HUMOUR is salty water that carries chemicals to nourish the cornea. And it presses the cornea outward to keep it fully rounded.

CRYSTALLINE LENS is the adjustable lens, held by muscles that squeeze it to make it more bulgy—a stronger lens.

VITREOUS HUMOUR is clear watery jelly which helps to keep the eyeball fully rounded.

RETINA is a fine network of nerves which are sensitive to light. Those nerves all lead into the optic nerve, a fat 'telephone cable' which carries the messages of seeing to a main part of your brain.

The retina is fed by a network of tiny blood vessels which, curiously enough, are on the *front* surface of the retina—so the light forming the image goes through the network before it reaches the nerves.

Sensitivity. The iris can make the eye-pupil larger to let in more light. (In some animals, the change is great: a cat's eye-pupil changes from a narrow slit in daylight to a large hole at night.) But that is not the main adjustment your eye can make. The light-sensitive chemicals in your retina can be stored up till your eyes in a dark room are a million times more sensitive than in sunlight.

(Some animals gain a little more for seeing at night by having a reflecting layer between the retina and the black backing. That gives the light two chances to excite the retina. These eyes shine back at a car's headlights on a dark road.)

Power of the eye. The POWER of an eye differs from one person to another. In rough round numbers, the bending at the cornea contributes about +40 D; and the total POWER may be +60 D or greater.

The crystalline lens, embedded in less dense material, contributes about +20 D. But the most important thing about that lens is that it can be squeezed to change its power. In an 'average eye' the lens can increase by 4 D when it is pulled into greater power to focus something nearby. That change for focusing objects at different distances is called 'accommodation'.

YELLOW SPOT (FOVEA). The human eye has a small patch in the middle of the retina where there are no blood vessels in front. You use that patch for your most accurate seeing—as in reading.

To learn the size of your yellow spot, look at a page in a book and fix your eye on *one* word. (Hold your hand over the other eye.) Try to keep your eye still; don't let it run on to other words. Try that on several words in turn. What is the longest word you can see perfectly sharply? (You will see other words before and after it, but can you see them sharply?) You are finding the size of that yellow spot for sharp seeing.

If you try that, remember that your eye has a power of +60 D or more; so the real yellow spot is far smaller than that word. It is at least 20 times smaller and probably smaller still since you probably let your eye turn to-and-fro a little. Measurements show it is about $\frac{1}{4}$ millimetre wide.

BLIND SPOT. There is another interesting patch on your retina, where all the nerves of the retina are bundled together into the optic nerve, to go to the brain. There are no nerve endings there, so it is a blind spot. But the blind spot gives you no trouble in seeing because your eye is constantly shifting the image tiny distances to-and-fro on the retina. So you never notice your eye missing anything that falls on the blind spot for an instant.

You can learn that your blind spot is really there by the following experiment: Cover your left eye with your hand. With your right eye stare fixedly at the mark X below. Move the page a little closer, then farther—still staring at X. Do you see the • disappear? If so, its image has fallen on your blind spot.

X   •

Fortunately, as you can see, your blind spot is some way away from your yellow spot for best seeing!

Question

74. Suppose someone who has not got this page wants to look for his blind spot. He has hurt his right eye. You give him this page. What will you tell him to do? (Try your instructions yourself.)

Demonstration 25
Dissecting a Bullock's Eye

SCLERA is the strong white coat of the eyeball. If you see a bullock's eye dissected you may see the muscles (red meat) that are attached to the sclera and control the eye's movements. There are three pairs of muscles, one for up-and-down movements, one for sideways, and one slanting pair to keep the eyeball from twisting round and hurting the optic nerve.

If possible, see a real eye of a bullock or a sheep being dissected. You will not find that a messy business, and you will see the real structure.

Eye and Brain

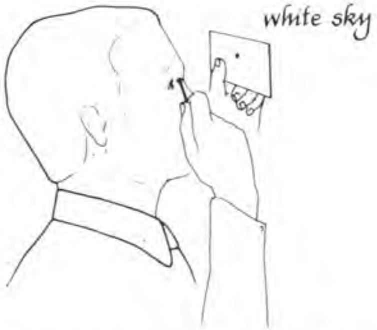
When a lens in a camera makes an image on the film at the back, the image is upside down. Your eye does the same: it makes an upside-down image of the thing you are looking at. *Then why don't you see everything upside down?* Because your brain never learnt that way. It has no other secret eye to peer into your own eye and see an upside-down image on the retina.

All your brain gets is a set of messages from your retina. It has learnt, from the time you were a baby, to accept the messages from the upside-down image as a picture of right-way-up objects that you can touch and feel with your fingers.

Experiment 26
Experiment with Your Own Eyes

Make a pinhole in a small card. Hold the card a few centimetres from one eye and look towards bright white sky.

The pinhole is far too close for your eye to form an image of it on your retina. Rays of light from different parts of the sky come straight through the pinhole and spread out as they go to your eye. And your eye lens only bends them enough to make a bright round patch on your retina.



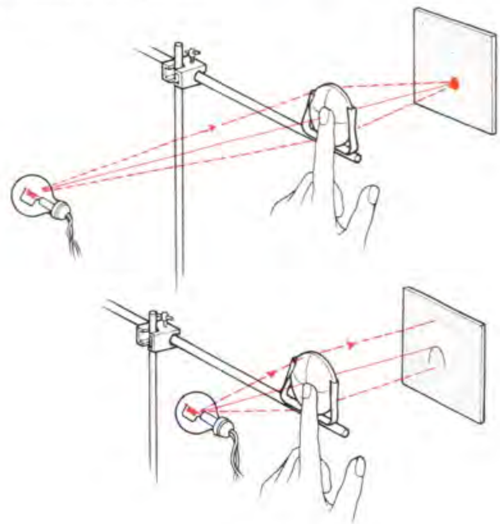
While you look towards the pinhole, hold a pin *very* close to your eye. Hold it by the point, with its head among your eyelashes. *What do you see?* Light from the hole in the card is casting a shadow of the pin on your retina.

Since the pin is very close, your eye cannot possibly form an upside-down image of it on the retina. All you get is a shadow of the pin, the same way up as the pin. *But what does your brain—which learnt its lesson long ago—do with that?*

If that seems puzzling, try the experiment sketched.

Experiment 27a
Model of Pin's Shadow

Instead of a bright pinhole, and a pin and your retina, use a bright ray-streaks lamp, and a finger, and a sheet of paper.



The lamp acts like the bright pinhole, but it has rather a long filament. It will be better to twist the lamp so that its filament is horizontal.

Let your partner hold an ordinary lens ($+7$ D) to represent an eye. Place the lamp about $\frac{1}{2}$ metre in front of the lens. Hold a sheet of paper behind the lens and move it away till you have caught the image of the lamp filament.

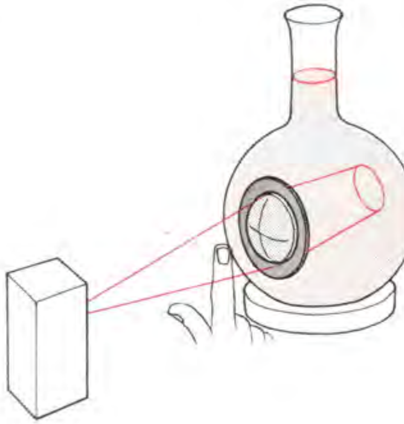
Hold the paper ('retina') at that place. Ask your partner to move the lamp up much closer to the lens—about $\frac{1}{4}$ metre. Then you will have a large round patch on your paper. Still keep it there.

Ask your partner to hold his finger, pointing upward, just in front of the lens. That represents the pin. *Which way up is the shadow of the finger on your paper 'retina'?*

What does your brain do when that happens in your eye?

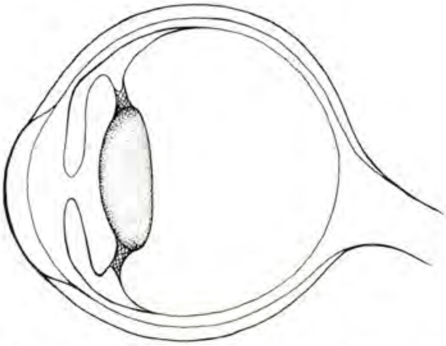
Demonstration 27b
Pin's Shadow with Model Eye

See this argument about the pin's shadow demonstrated with the model eye. Place the lamp very close to represent the pinhole. The eye cannot focus it to a point at the back of the flask. It only manages to bend the light to a round patch. Put a finger, *pointing upwards,* very close to the model eye. That represents the pin. *Which way up is the shadow of the finger on the back surface of the eye?*



Progress Questions

EYES AND SPECTACLES



75. This drawing shows a 'slice' through an eye. Copy the drawing and label:

L the eye lens which changes its power for focusing
O the white outside case
W the clear 'window' at the front *(cornea)*
I the coloured ring just inside the front *(iris)*
P the hole in the coloured ring *(eye-pupil)*
R the sheet of nerve endings *(retina)*

76a. *(i)* Which eye is looking at something bright?
(ii) How can you tell? (Answer in a few words.)

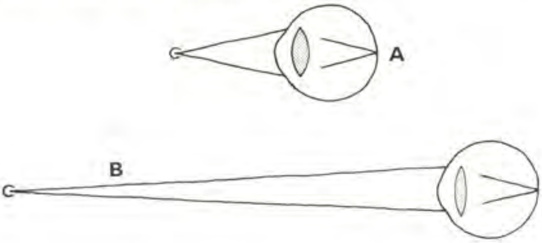
b. Copy the sketch of the eye which is looking at something in a dark room. Label *(i)* P the eye-pupil, *(ii)* I the iris, *(iii)* O the white outer case of the eyeball.

c. What is the eye-pupil really?

d. What job does the iris do?

77. Fig. A shows rays going into a normal eye looking at something quite close. Fig. B shows a normal eye looking at something a long way away.

a. How has the eye lens changed?



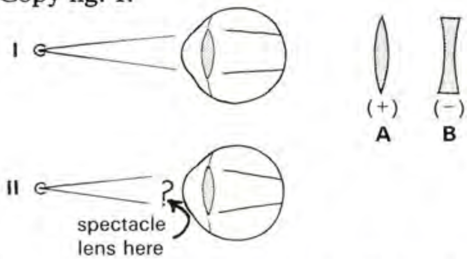
b. Copy the diagrams (about twice as big). Then copy and complete this remark:

When you look at something close the lens inside your eye has to be extra [/*bulgy*/*flat*/]. Then it is extra [/*strong*/*weak*/].

When you look at something a long way away, your eye lens has to be extra [/*bulgy*/*flat*/] so it is extra [/*strong*/*weak*/]. The muscles inside your eye have to pull hard to make the lens bulgy, so it is tiring to look at something [/*VERY close*/*a VERY long way away*/].

EYE

78a. Fig. I shows rays going into a long-sighted eye. Copy fig. I.

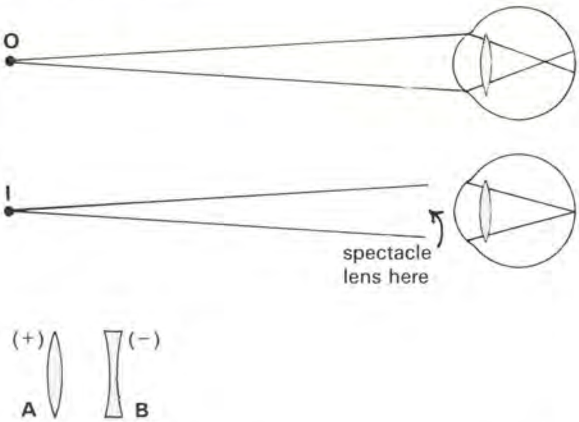


b. The eye is to see the object-point O clearly. Do the rays need to be pulled in more or spread out more?

c. Which sort of lens will help, A or B?

d. Copy fig. II for the *same* eye and add the right sort of spectacle lens.

79a. Fig. I shows rays going into a short-sighted eye. Copy fig I.



b. The eye is to focus the object-point O. Do the rays need to be pulled in, or spread out more?

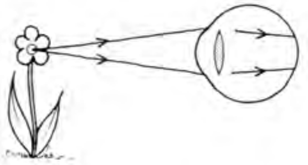
c. Which sort of lens will help, A or B?

d. Copy fig. II and draw in the right sort of spectacle lens.

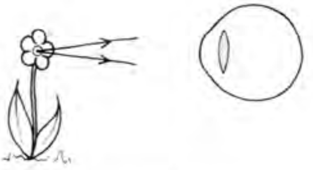
80. This long-sighted eye cannot focus the flower (fig. A).

a. What is the eye lens unable to do?

b. Copy fig. B and put a correcting spectacle lens in front of the eye. Now draw the rays through both lenses to the retina to show how it can now see the flower clearly.



A



B

Questions

THE EYE

81. Write out the following sentences, filling the gaps and making the correct choice where necessary.

The optical system of the human eye is similar of that of a . . ? . . . A positive lens system, consisting of the cornea and the interior parts of the eye acting together, forms a [/*real*/*virtual*/], [/*upright*/*inverted*/], [/*magnified*/*reduced*/] image on the . . ? . ., which is the light-senstitive surface of the eye.

The . . ? . . is the hole through which light enters, and corresponds to the . . ? . . of the camera.

But, there are important differences. In the camera focusing is performed by . . ? . . .

The length of the eye system remains the same, but the curved shape of the inner lens can be varied. This action, which enables us to focus objects at different distances, is called . . ? . . .

Another difference is that the inside of a camera is filled with . . ? . . but the eye contains . . ? . . .

82. The eye is able to adjust itself for different brightnesses of light falling on it, so that we are able to see comfortably in all lighting from bright sunlight to nearly complete darkness. There are two ways in which the eye does that. One is by changing the amount of sensitive chemical on the retina. What is the other?

83a. How do you account for the fact that although 'we see everything upside-down', this causes us no inconvenience?

b. Describe an experiment to show what happens when the image of an object formed on the retina is the same way up as the object.

EYES AND CINEMA

84a. A cinema film normally runs through the projector at the rate of '24 frames per second'. This means that 24 separate pictures are shown on the screen in one second: if, for example, the picture shows a man walking, then, on the screen, he 'walks' in jerks $\frac{1}{24}$ second apart. In between each picture the screen is dark. Yet we see no jerkiness and no darkness. How do you account for this?

b. Of course, to show things moving with their true speed on the screen, the pictures in the film camera were taken at the same rate at which they are projected on the screen, in this case, 24 per second. Describe the appearance you would expect on the screen if *both camera and projector* were run at:

(i) 10 frames per second;
(ii) 4 frames per second;
(iii) 48 frames per second?

AVERAGE EYE

85a. What do we mean by an 'average eye'.

b. Are your eyes (at your present age) average eyes? Explain.

(NOTE. This question does *not* ask whether you are short-sighted or long-sighted, etc. It is a more general question about eyes and age, the same for all people of your age.)

c. Does a man or woman of 60 have 'average eyes'?

RANGE OF ACCOMMODATION

86. The 'average' eye is said to have a range of accommodation from $\frac{1}{4}$ metre to infinity.

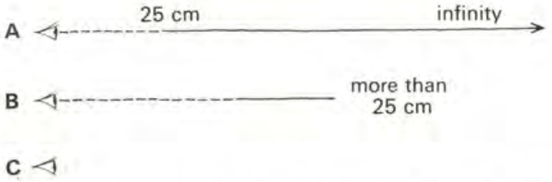
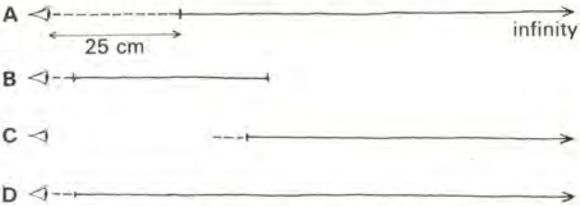


Fig. A represents 'normal range'. Fig. B is for a long-sighted person and C for a short-sighted person. Copy the three diagrams and complete B and C.

87. A man is 40 years old. He does not need spectacles. He has a range of clear seeing from $\frac{1}{4}$ metre away to a distant mountain or star (infinity). We say he has 'average eyes'.

a. When he was a boy 12 years old, his range did not begin at $\frac{1}{4}$ metre. Did it probably begin nearer his eyes or farther?

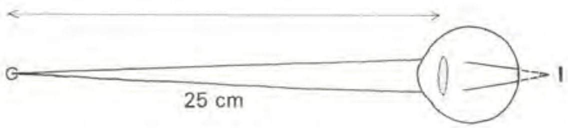
b. Fig. A shows the range for a man's 'average eye' at age 40. Figs. B and C show the ranges of two other people, also about 40 years old. One of them has short sight. The other has long sight. Which does the person fig. B have?



Make a guess about the person whose range is D.

88. A long-sighted person has to hold a book at arm's length to be able to read it without glasses; his 'near point' is at 60 cm instead of 25 cm.

a. Copy the diagram, and explain why he sees only a blurred picture of an object $\frac{1}{4}$ metre away. Also draw a similar diagram for a normal eye looking at an object $\frac{1}{4}$ metre away.



b. Assume that, with a near point of 60 cm, the long-sighted man has the same *range* of accommodation (in lens power) as a normal person. Would you expect him to see an object at a great distance clearly without glasses? Write a sentence in explanation.

SPECTACLES

89. Copy and complete this remark:

Long-sighted people can see things that are [/*close*/*a long way away*/] but they cannot see things that are [/*close*/*a long way away*/]. Their eye-lenses can't get [/*bulgy*/*flat*/] enough, so they need [/*positive*/*negative*/] spectacle lenses to help.

Short-sighted people can see things that are [/*close*/*a long way away*/] but they cannot see things that are [/*close*/*a long way away*/]. Their eye lenses cannot get [/*bulgy*/*flat*/] enough, so they need [/*positive*/*negative*/] spectacle lenses to help.

90. Write out the following sentences, filling in the gaps and making the correct choice where necessary:

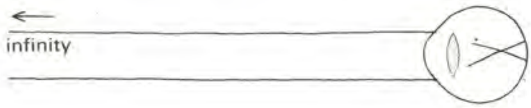
The right eye of a certain long-sighted person has a near point of 60 cm instead of 25 cm. To correct this defect he needs a spectacle lens which will form, at .. ?.. cm, the image of an object which is actually at .. ?.. cm. He will then be able to see the image clearly.

The spectacle lens must be [/*positive*/*negative*/] and it forms a [/*real*/*virtual*/] image which is [/*the right way up*/*upside down*/].

His trouble is that his eye lens is [/*not sufficiently*/ *too greatly*/] convex (bulgy), and therefore he has to have a [/*positive*/*negative*/] lens to correct the fault.

91. *(Advanced)* The diagram of Q. 88 shows a long-sighted eye looking at a point nearby. Copy the sketch but include a correcting spectacle lens.

92a. A certain short-sighted person cannot see objects clearly if they are far away. His 'far point' is at 1 metre instead of infinity.



Copy the diagram and explain why he sees only a blurred picture of an object at infinity.

Draw a second, similar, diagram for a normal eye looking at an object at infinity.

b. Assume that, with a far point at 1 metre, the short-sighted man has the same range of accommodation as a normal person. Would you expect him to be able to see an object at $\frac{1}{4}$ metre from his eye clearly without glasses? Write a sentence in explanation.

93. Write out the following sentences, filling the gaps and making the correct choice where necessary:

The right eye of a certain short-sighted person has a 'far point' at 1 metre instead of infinity. To correct this defect he needs a spectacle lens which will form, at . . ? . . the image of an object which is actually at . . ? . .. He will then be able to see the image clearly.

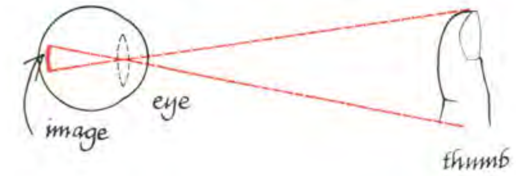
The spectacle lens must be [/*positive*/*negative*/] and it forms a [/*real*/*virtual*/] image which is the [/*right way up*/*upside down*/].

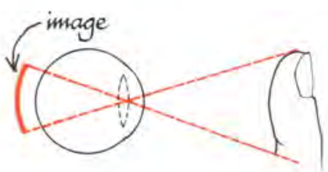
His trouble is that the eye lens is [/*not sufficiently*/*too*/] convex (bulgy) and therefore he has to have [/*positive*/*negative*/] lens to correct the fault.

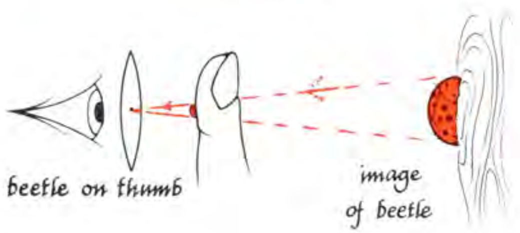
94. *(Advanced)* Draw another diagram like that in Q. 92, but this time include the correcting spectacle lens. Show what happens now when the eye looks through the lens at a very distant object.

Magnifying Glass

When you use a positive lens as a magnifying glass it forms a virtual image which is farther away than the object. If you look directly at some object, say your thumb, the image on your retina grows bigger and bigger as you bring the object closer. So the object *seems* to grow bigger and bigger. But you cannot bring the object very close and still focus it clearly. A magnifying glass lets you bring the object much closer still. It gives you a virtual image within your range of vision.







Suppose the image is three times as far away behind the lens as the object is; then the image will be three times as tall. If you hold your eye close to the lens, the image will *look* the same size as the object—since it is three times as high but also three times as far away.

However, that *image* will look clear and easy for your eyes to focus, while the object alone is too close. So you do gain, because the magnifying glass lets you bring the object closer. If you like, try an experiment to see how much you gain.

Then set up a model microscope to give greater magnification.

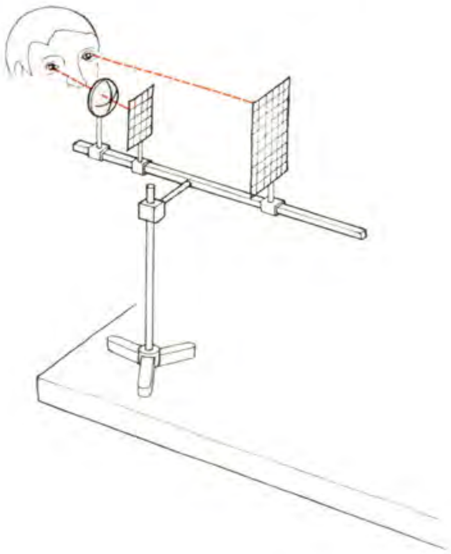
Experiment 28
Magnifying Glass: Magnification
(Advanced Experiment)

Set up the bar, as for a telescope, at head height for comfort. Place a single lens, +14 D, near your end as a magnifying glass. When you look through that lens, hold your eye quite close to it.

Arrange two pieces of graph paper in holders on the bar. Place one piece, O, just behind the magnifying glass, as the object to look at.

Use the other piece of graph paper, C, as an image-catcher. Put it where you would like the image to be and try to place the image there. It is better to decide like that where you would like the image and then move the object.

Keep both eyes open. With one eye look through the magnifying glass at the image of O. With the other, naked, eye stare at the catcher, C. *Concentrate your attention on C.* Move O forward and back a little until you see its magnified image sitting on the catcher.



When you are successful, ask your teacher to come and see your placing of object and catcher. Then move O and C away from their places and let your partner have a try from a fresh start.

If you like, estimate the magnification. Look at one magnified millimetre in the virtual image and see how many real millimetres that covers on the catcher.

Questions

MAGNIFYING GLASS

97. Copy out the following sentences, choosing the correct words where a choice is offered.

A [/*positive*/*negative*/] lens can be used as a single magnifying glass. Used in this way it forms a magnified [/*real*/*virtual*/] image [/*through from*/] which the light [/*actually passes*/*appears to come, but does not actually come*/].

The image is on the [/*same side as*/*opposite side from*/] the object. And the object is placed [/*closer to*/*farther from*/] the lens than the focal length.

98. A boy looks through a positive lens at a millimetre scale, S_1. He holds the lens close up to his right eye, E_R. At the same time he looks with his left eye, E_L, at a similar scale S_2, which is 25 cm away. With *both eyes open*, he sees a large scale with a small scale on top of it. He can see both scales in focus comfortably at the same time.

a. Which eye sees the large scale S_1?

b. Which eye sees the small one?

c. How far from his right eye is the image of S_1 situated? (Assume that both his eyes are normal and that S_1 is placed to give the best and largest-looking image that he can see comfortably.)

d. Describe how he can estimate the magnification the lens produces.

e. *(Advanced)* What would be the effect on what he sees if he moves his head and the lens:
(i) nearer to S_1; *(ii)* farther from S_1?

Progress Questions

MAGNIFYING GLASS

95. When you use a lens *as a magnifying glass:*

a. Where do you put the object—close to the lens, or a long way off?

b. Where do you put the lens—close to your eyes, or a long way off?

c. What is the image (the picture you see through the lens) like? Is it the same way up as the real thing, or upside down? Is it bigger, or smaller than the real thing?

d. Which makes the best magnifying glass—a fat bulgy lens, or a thin flat lens?

96. The diagram shows two lenses A and B, both made of the *same* kind of glass.

a. Which lens *magnifies more* when used as a magnifying glass?

b. Which lens would you call the *stronger* lens?

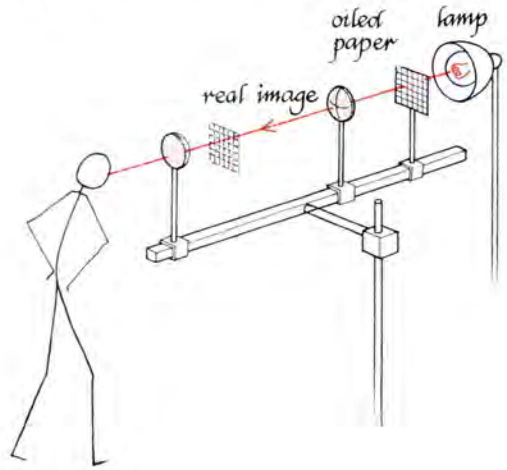
c. Which lens makes the smaller image of a distant window (or other object)?

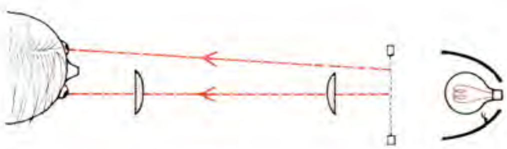
Microscope

Experiment 29
Large Model of a Microscope

In a *telescope*, the first lens (the objective) makes a small real image of the distant object; then you look at that image with a magnifying glass. In a *microscope*, the first lens makes a large real image of the object. Then you look at that image with a magnifying glass.

Find a picture in this book of an object walking towards a positive lens. As the object approaches, the real image grows bigger and bigger. When the object is close enough, the image is magnified many times.





Arrange a +14 D lens as the first lens of your microscope, to make a magnified image of the object. Look at that real image with a magnifying glass, +7 D.

First set up a bar to carry lenses at head height for comfort as in your telescope model.

To arrange the distances, you need to start with a very bright object, so that you can catch its real image on paper. Make a piece of graph paper translucent by smearing it with oil (or use a transparent millimetre scale). Place your +14 D objective about 15 cm from the far end of your bar. Place the graph paper object about 10 cm beyond the lens, on the far side from you. Put a bright lamp *behind* that object to begin with. Hunt for the real image with a sheet of paper. Hold the sheet about 30 cm from the lens on your side. Move the object slowly until you catch its image on your sheet of paper. Then fix the object at that place.

Move your +7 D eyepiece until it acts as a magnifying glass for the piece of paper you are still holding at the real image.

Take away the piece of paper. Move the eyepiece a little forward and back until you see the final image clearly in focus.

KEEP BOTH EYES OPEN. Look through the microscope lenses with one eye while you look directly at the original piece of graph paper with the other, naked, eye. CONCENTRATE ON THE NAKED EYE and move the eyepiece until you see the final image also clearly in focus.

You need not hold the lamp there all this time. Instead of that, shine the light on the graph paper from in front, instead of through it from behind.

If you like, make an estimate of the overall magnification made by your large model microscope. Keep both eyes open and decide how many millimetres of the original graph paper one magnified millimetre of the final virtual image just covers. A rough estimate will do.

Then let your partner have a try. He should start from the beginning and arrange the lenses himself. Let him make his estimate of magnification and compare it with yours.

Experiment 30
Using a Commercial Microscope

If professional microscopes are available, use one to look at some interesting object: a hair from your head, a piece of paper, a smear of blood. . . .

Light up the stage on which you place your slide.

To focus the microscope you must use a special method to keep the valuable lens from being hurt. If it touches the slide or some object on it, it might be scratched. Squat down till your eyes are level with the stage. Move the body of the microscope down until the bottom of the lens *almost* touches the slide. Then sit or stand and look through the microscope; and raise the body of the microscope until you see the object in focus.

Keep both eyes open and try to focus the microscope so that the final virtual image is down at the object itself (or even lower, on the table).

When you have focused the microscope comfortably, let your teacher have a look. Then raise the body of the microscope until everything is out of focus, and let your partner focus it.

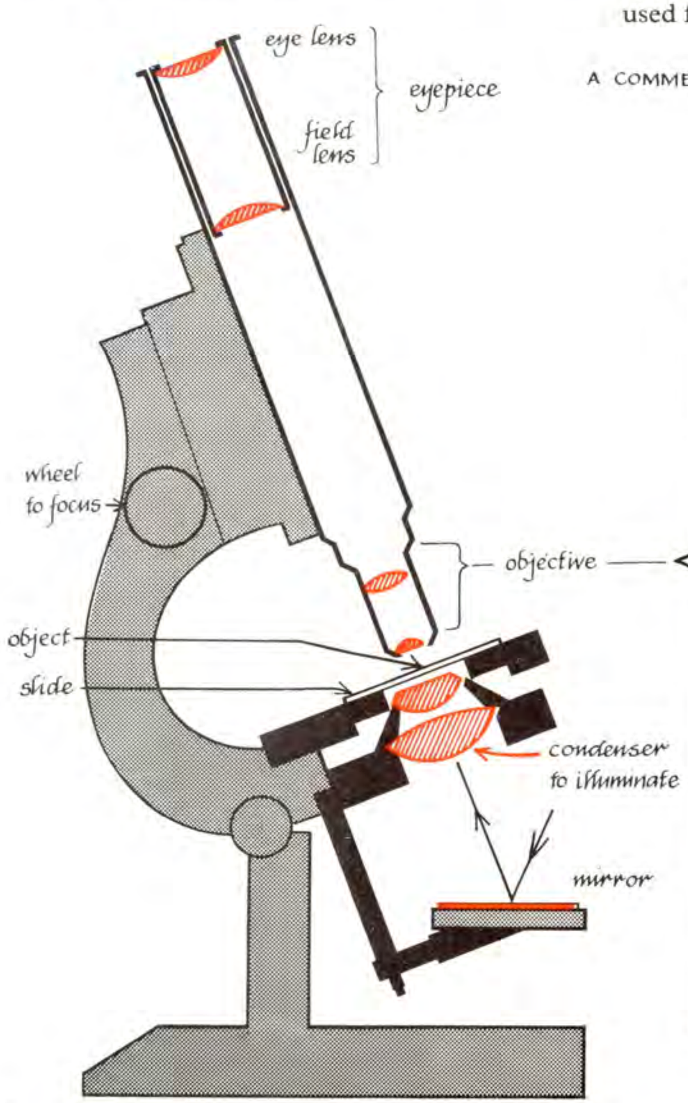
Microscope design In commercial microscopes both the objective and the eyepiece consist of more than one lens.

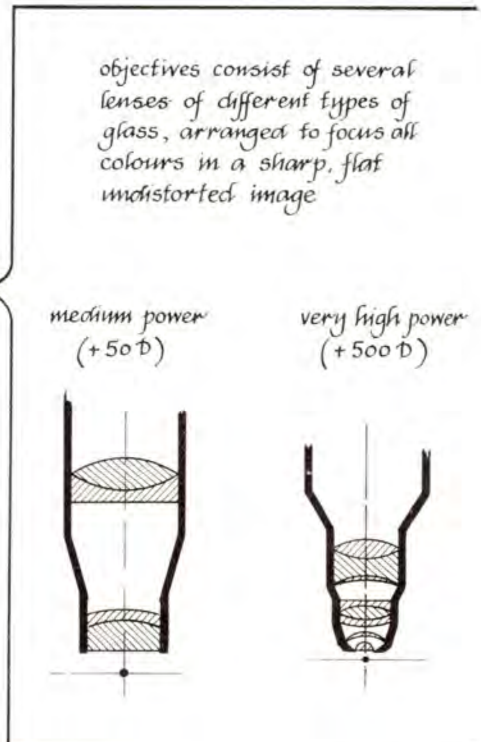
The objective lens. Lenses of different kinds of glass are combined to remove colour troubles; and their shapes are chosen to lessen spherical aberration—which you saw with ray streaks.

The eyepiece. The eyepiece consists of two (or more) lenses. The first lens is placed near the image to catch all cones of light passing through the image and bend them towards the middle of the second lens. The second lens then sends the cones to the eye, through an eye-ring close to it. This arrangement gives a large field of view with little distortion and hardly any trouble with colours.

The need for a large aperture. Light waves will deceive you and produce unreliable or fuzzy images of *very* small objects unless the objective lens has a large aperture, to take in very wide cones of light which bring large samples of wave-fronts. This requirement raises serious difficulties when high magnifying power is required. Compound lenses of special shape and arrangement have to be used for the objective lens.

A COMMERCIAL MICROSCOPE





Ray Streaks to show the working of Telescope and Microscope

Now that you have focused your own telescope and set up a microscope, you should make your own ray-streak models of those instruments to see how they treat rays and form images and images of images.

Experiment 31a
Ray-Streak Model of Telescope, with Two Lamps

One Lamp. Start with one lamp. Place it 1 metre or more away from the sheet of paper where you will set up your telescope.

Use your weakest cylindrical lens, +7 D, as your telescope objective to make an image of the lamp. *(Which way round should that lens be for less aberration, that is, for a better image? Flat face towards the lamp or bulgy face towards the lamp?)*

Place a comb a short distance before the objective lens.

Use your strongest lens, +17 D as eyepiece—as a magnifying glass to look at the real image and form a virtual image of it far away. The virtual image should be back where the lamp is. Ask for help if necessary.

When you have arranged the lenses well, ask your teacher to come and see the pattern of rays.

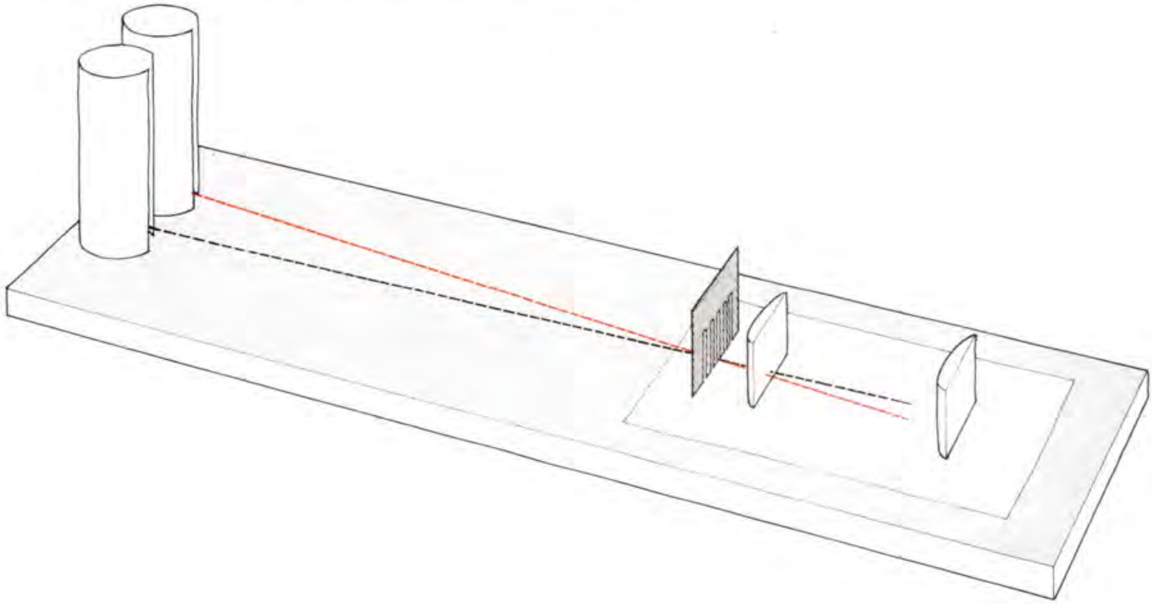
Two Lamps. Then obtain a spare lamp (or join up with another pair of pupils) so that you can have two lamps side by side as head and foot of an object. PLACE THE LAMPS AS CLOSE TOGETHER AS POSSIBLE.

Look at the two real images. Arrange your eyepiece to form virtual images of them far back.

(If a piece of coloured glass or plastic is available, place it in front of one lamp. That will make it easier to tell one lot of rays from the other.)

When you have arranged the lenses well, ask your teacher to come and see the pattern of rays.

(If you find this arranging the lamps and lenses too difficult, you might make it simpler by using only 3 rays. Ask your teacher about the 'three-ray trick'. It is rather dishonest optically, but a great help.)



Questions

MICROSCOPE

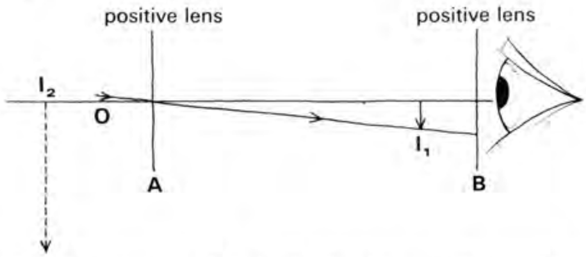
(If you set up a model microscope yourself in the lab and made it work, try any of the following questions. Otherwise leave them out.)

99a. Which part of a microscope is basically the same as in a telescope? What job does it do in both cases?

b. In the model microscope which you made, you almost certainly noticed faults (apart from low magnification) which you would not find in a good microscope in the biology lab. What were these faults?

c. The instructions for using a good microscope tell you to squat so that your eyes are level with the stage, bring the microscope body down, *and then watch for focusing while you raise the microscope body.* Why is that method the best way to treat a microscope?

100. The diagram shows the positions of the images in a compound microscope (distances drawn about half-scale). A is the objective lens and B the eyepiece.



O is the small object; I_1 is the image formed by the objective; and I_2 is the final image formed by the eyepiece. The distance from I_2 to the eyepiece is $\frac{1}{4}$ metre.

Copy the diagram and use it to explain (to a pupil who has missed the experiment) how a compound microscope works.

101. In the microscope of Q. 100:

a. Is image I_1 real or virtual?

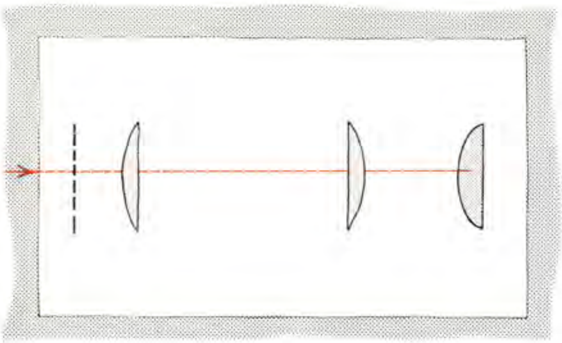
b. Is I_2 real or virtual?

c. One ray, through the centre of lens A, is drawn on the diagram. Draw this ray onwards, from B to the eye.

d. O is $1\frac{1}{2}$ millimetres high in the diagram. Find, by measuring the height of I_2, the magnification that the microscope produces.

Optional Experiment 31b
Ray-Streak Model of Telescope with Field Lens

Commercial telescopes usually have an extra lens a short distance before the eyepiece.



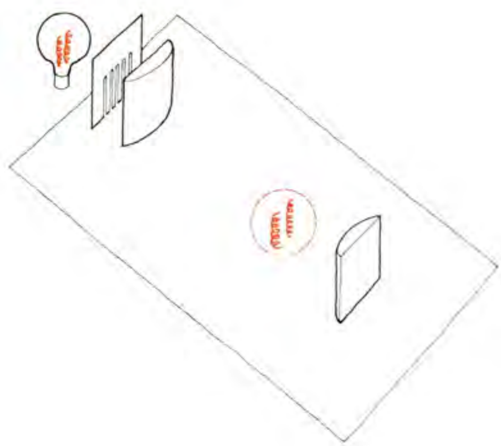
Set up a telescope model with two lamps as before.

Add an extra lens (+7 D or +10 D) at the place where the real images of the two lamps are.

What advantages can you see?

Experiment 31c
Ray-Streak Model of Microscope

For this it is best to use a special lamp with two vertical filaments close together, to represent the head and foot of an object.



Use your strongest cylindrical lens, +17 D, as objective. The flat face of the lens should be towards the lamp. Place it about 7 cm from the lamp filaments. It will make real images of them farther apart ('magnified').

Place a comb just before the objective lens. If you find the images are spoiled by aberrations, move in barriers to narrow the aperture.

Use a $+17$ D lens as eyepiece. It must be placed beyond the real images so that it forms virtual images of those images.

When you have arranged the lenses well, ask your teacher to come over and see the pattern of rays.

Experiments 31d
Further Experiments with Ray Streaks *(OPTIONAL)*

If you have time to spare and are interested you could make ray-streak models of other instruments such as:

Galilean Telescope ('opera glass').

Terrestrial Telescope (with two extra lenses to turn the final image the right way up).

Exhibits of 'curvature of field' and 'distortion' when a single lens makes a real image of a wide object.

Progress Questions

GENERAL OPTICS

102. Make a list of things that you know about which have lenses inside them. Draw sketches of some of them, and show where the lenses are. (You may get help from books in a library.)

103. Write a letter to a friend describing, as clearly as you can, the nicest part of the work you have done on light (Optics).

104. Write down three NEW things you have learned about light.

105. Look at a slide projector at school. Read the following description; then answer the questions.

Description. You have used a lens to make a picture on a screen. A projector for slides has a lens which does the same thing.

Usually the projector's lens isn't just one piece of glass like the lens you used. That is because a single lens would not give a clear picture all over a wide screen. The projector's lens has several inside it, put together like a sandwich. They are specially shaped, so that the picture is clear all over.

You know if you fix the distance between the lens and the slide, there is just *one* fixed place where you must put the screen to get a clear picture on it. If a projector had its lens fixed, you could only use it in one size of room; and that wouldn't be very good. So the projector's lens can slide in-and-out.

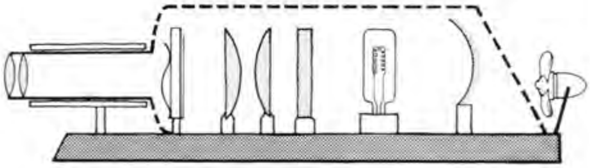
Suppose you have got a good lens which can make a clear picture on a screen. The next difficulty is to make the picture bright enough. Projector lamps are usually very strong (100 watts in a small projector, 250 watts in a big one).

A strong lamp gives a lot of radiation, only some of it visible light, so there is a fan to keep the projector cool. If the slide gets too hot it will bend and go out of focus or even melt! And the lamp itself needs some cooling. There is a special flat piece of glass in front of the lamp which stops most of the invisible 'infra-red' radiation going through and heating things, but it lets visible light through. It is called a 'heat filter'.

There is a curved mirror behind the lamp to send more light forward onto the slide. (Sometimes the mirror is the glass of the lamp itself coated with bright metal so it acts as the mirror.)

And there is a pair of extra lenses called 'condenser lenses'. These collect the light rays which spread out from the lamp, and bend them onto the slide.

QUESTIONS



a. This is a *simple* diagram of the main parts inside a projector.

Copy this diagram carefully, and put labels on your copy for:

P projector lens
S slide
L lamp
F fan
H heated filter
M curved mirror
C condenser lenses

b. *(i)* Why is it useful to be able to slide the projector lens forwards and backwards?
(ii) Suppose you take the projector into a bigger room, with the screen farther away. Which way must you move the lens? (In, nearer the slide; or out, away from the slide?)

c. Copy and complete:
The picture on the screen is [/*bigger*/*smaller*/] than the picture on the slide. The screen is [/*nearer to*/*farther from*/] the lens than the slide.

d. When you made a picture on a screen with a lens, the picture was upside down. How can you make the projector's picture on the screen come the right way up?

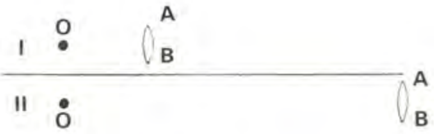
e. *(i)* What is special about the lamp?

(ii) Write down the wattage of some of the lamp bulbs at home. (Look at a bulb when it is not running. You will see the wattage printed on most bulbs with a W after it.)

f. What is the job of *(i)* the fan, *(ii)* the curved mirror, *(iii)* the heat filter, *(iv)* the condenser lenses?

g. If you have looked at a different type of projector, draw a simple diagram of it, and label the parts.

Questions for Ray Diagrams—see pages *a–h*



1. In figure I above, a lens AB (which may be the lens of an eye, or the objective lens of an optical instrument) is 11 cm away from an object O. In figure II the lens is 45 cm away. 4.5 cm here are equivalent to 45 cm; and the lens AB has been drawn 0.5 cm wide.)

a. Copy the diagrams and draw cones of rays from O to AB in each case.

b. Which diagram has the cone with the narrower angle?

c. In which diagram are those rays which enter the lens more nearly parallel?

d. Draw another diagram showing a 'cone' of rays from a VERY distant point ('at infinity') arriving at a lens.

e. One of the following statements X and Y is right and one is wrong. Write out the correct statement.

X 'Rays from a distant object arriving at a lens are nearly parallel because the farther two rays go, the more nearly parallel they become.'

Y 'Rays from a distant object arriving at a lens are nearly parallel because the cone of rays from the very distant point that the lens selects is a cone with such a very small angle.'

2. An object OP, as shown in the diagram, is 5 cm high and is placed 20 cm from a positive lens AB. The lens forms an image of O at I, 40 cm from the lens. Copy the diagram this size, which is one-tenth life size (that is, 2 cm here represents 20 cm).

a. Mark the point Q which is the image of P.

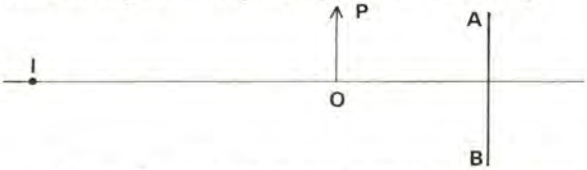
b. Draw a cone of rays from P to the lens, and then to Q and continue them beyond Q.

c. Copy the diagram again. Draw an eye looking at Q and the cone of rays entering the eye. (The eye is supposed to be an 'average' eye with a least distance of comfortable vision of 25 cm.)

d. How tall is IQ, the image of OP?

(Note. It does not matter how tall you draw the lens so long as it is not unnaturally large.)

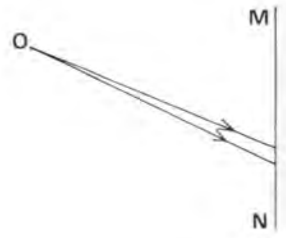
3. OP is an object 5 cm high placed 10 cm from a magnifying glass AB. The lens makes a virtual image of O at I, 30 cm from AB. Copy the diagram (scale one-fifth) and find the position of the point Q which is the image of P. Draw a cone of rays from P to the lens AB, and then draw it on through the lens. Draw an eye (least distance of comfortable vision = 25 cm) looking at Q, and with the cone of rays entering the eye. How tall is IQ?



(NOTE. Remember to use *dotted lines* for construction rays along which light does not actually pass. Virtual images, such as IQ in this question, should also be drawn with dotted lines. The lens AB should not be drawn very tall but should be taller than OP.)

4. The diagram shows an object O placed 50 cm from a plane mirror MN (5 cm on this one-tenth scale drawing). Two rays, the boundaries of a narrow cone from O to the mirror, are also shown.

a. Copy the diagram. Mark in I, the image of O. Draw an eye on your diagram where it can look at the image. That place should be about 40 cm from the mirror (4 cm on this scale).



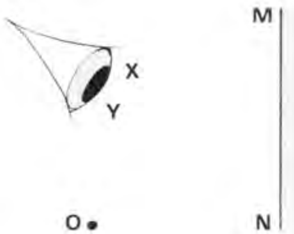
Then draw the paths of the rays straight from the image to the eye. Parts of those paths are 'real' rays along which light does travel after reflection. Other parts of those rays are not real and you should show them with broken or dotted lines.

b. Is the image of O real or virtual?

c. Is the image the same size as the object, magnified, or diminished?

d. Can the image be seen on a screen placed at I?

5. In the diagram you are shown the mirror MN, the object O, and the position of an eye viewing the object in the mirror. Two rays that leave the object are reflected by the mirror and then enter the eye, one at X the other at Y. Draw the paths of those two rays.



(HINT. First mark in I, then draw the rays *backwards* from X and Y. Remember to add arrows to the rays, pointing in the right direction.)

6. Copy the diagram which represents an astronomical telescope.

X is the position of the objective lens. The telescope is being used to look at an object far away. The real image formed by the objective is at I_1.

Y is the position of the eyepiece, which forms a magnified image at I_2 of the real image at I_1.

The dashed line is a construction line drawn from the tip of the image at I_1 through the optical centre of the eyepiece.

The distance XI_1 is 50 cm, represented by 10 cm on the diagram (scale one-fifth). I_1Y is 5 cm, represented by 1 cm. I_2, the position of the final image, is 25 cm from the eyepiece, represented by 5 cm.

Three parallel rays are shown arriving on the left. They come from the top of an object very far away. Only the centre ray is continued to the eyepiece. Suppose the foot of the object is on the axis of the telescope.

a. Draw the other two rays from the objective to the eyepiece.

b. Draw (dotted line) the final image at I_2.

c. Now draw the paths of the three rays from the eyepiece to the eye (draw construction lines dotted).

d. What is the focal length of the objective? *(YOU NEED NO FORMULA)*.

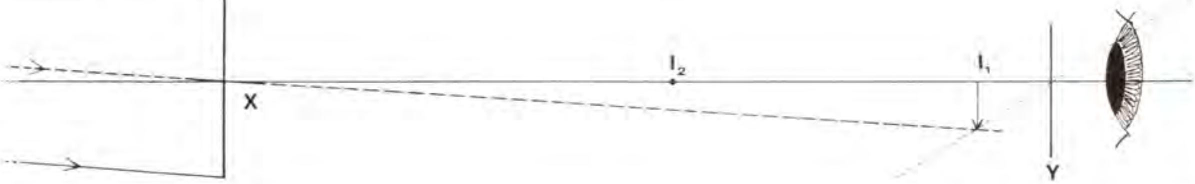
e. I_1Y is 5 cm, but the focal length of the eyepiece is not 5 cm, it is over 6 cm. Why is there this difference?

7. Copy the diagram of Q.6, but this time I_1Y is $6\frac{1}{4}$ cm, which on one-fifth scale will be $1\frac{1}{4}$ cm. The eyepiece is the same lens as before, and the final image I_2 is now at infinity.

a. Trace the three rays through to the eyepiece, as in Q.6. (The final image I_2 is at infinity and cannot be drawn.)

b. Continue the three rays on through the eyepiece to the eye.

c. Estimate the focal length of the objective.



HOW TO DRAW RAY DIAGRAMS

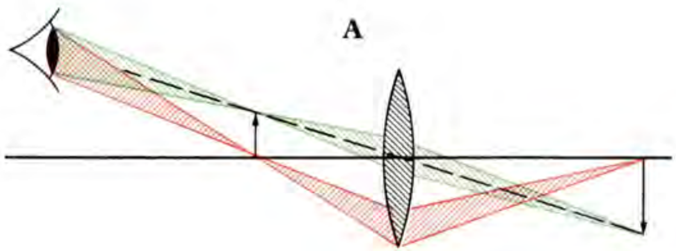
Some people like to draw diagrams to show how light goes through optical instruments. If you would like to do this, read this section carefully.

Viewing a Real Image

Small cones of rays to an eye Suppose you want to draw a diagram of an eye looking at a real image formed by *any* lens of *any* object. In such a diagram you should sketch an eye, at a suitable distance from the image it is viewing. Show it receiving cones of rays which start from *two* specimen object-points, one *on the axis* of the lens and one *off the axis*. You need not be fussy about the distances of the object and image from your lens. Choose any distances which you think from your experiments would look all right.

A specimen Sketch A shows how your completed diagram ought to appear:

A

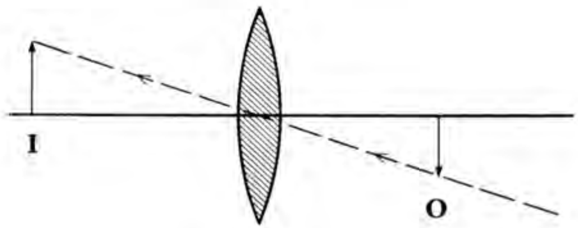


There the eye, the lens, and the object and image distances are all in fairly good proportion. This is easy enough to draw if you use the right method. Here are the stages of making that drawing.

Choose lens and object To get the object and image sizes in the correct proportions, first choose a suitable object height (NOT equal to the lens height).

Undeviated rays Draw the undeviated rays from the top and bottom of the object as in sketch B.

B

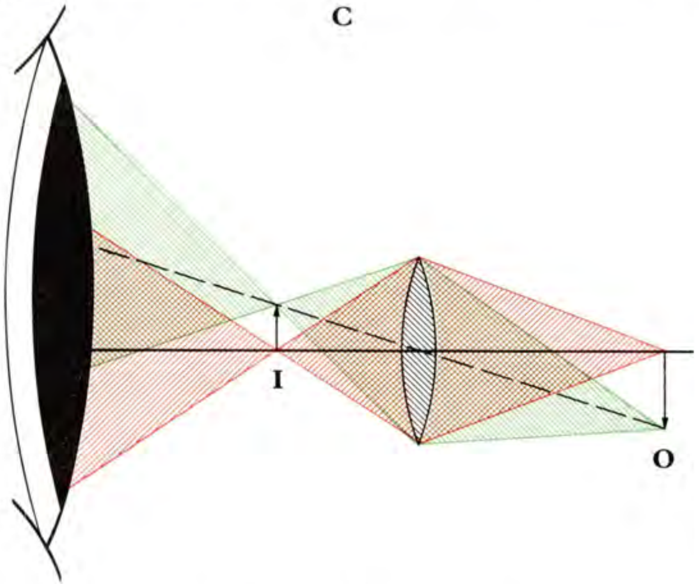


In drawing any of these diagrams, always draw in undeviated rays first of all. If there are several lenses, draw undeviated rays for each.

Choose the place for the image Before you can draw the rest of the diagram, you must know how far away the image is. In these diagrams you may just choose a place for the image that looks suitable. Suppose you have decided to place the image at 'I'. Then it is easy to put in the correct image height (from the two undeviated rays).

Plan cones of rays Now construct two cones of rays. If you start from the object and draw full cones from points on it you may end with a very ugly diagram requiring a huge eye to admit both cones that emerge. For, remember, the eye must be some way behind the image to be able to see it clearly. Sketch C would be too ugly.

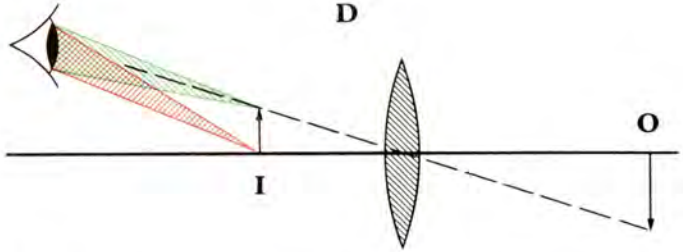
C



Place the eye first instead Place a *small eye* in a suitable position.

Draw cones from image to eye Show the eye looking at the image, by drawing the extreme rays of small cones *from head and foot of the image to the eye*. Fill each cone with shading to show all the rays along which light travels to the eye (Sketch D).

D

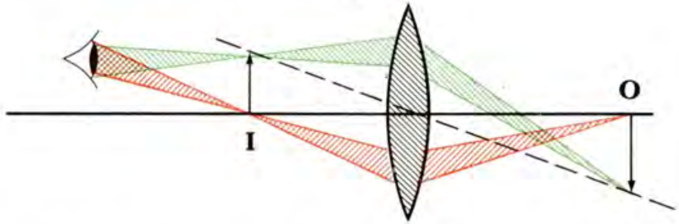


Continue the cones back to the lens Remember that although the rays entering the eye do come from the image they really start from the object and are bent by the lens. They pass through the image—*each of them straight through without bending there*.

Continue the rays that you drew from image to eye, back through the image (without bending them there) until they meet the lens. Then you know where those rays came out of the lens.

Draw cones from object to lens Complete the diagram by drawing rays from the proper object-points to these places on the lens (Sketch E)*.

E



Now you have a diagram which shows an eye looking at the real image. Notice that the eye in this case does not make use of the full aperture of the lens for any one object-point.

*You may feel doubtful what to do about the place where rays are hidden by the lens. If so here is a trick:
(i) Draw a middle-line down the lens. Continue the rays till they hit that; then start their new directions from there.
(ii) That is not true, but gives a fair picture if you now draw joining lines through the lens.

Viewing a Virtual Image

To show an eye looking at a virtual image, use much the same procedure.

Lens, object, and undeviated rays (Sketch F) First draw in an object and the undeviated rays from the top and bottom of the object.

F

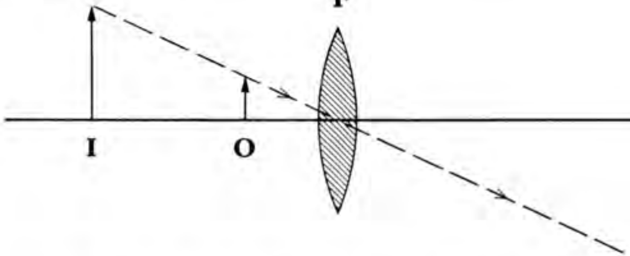
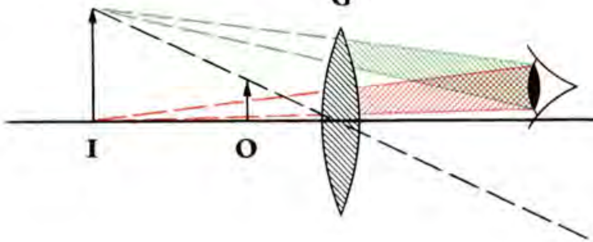


Image Place the image farther back on the same side of the lens as the object. Use the undeviated rays to mark its size.

Eye Place a small eye in a suitable position for looking at the image.

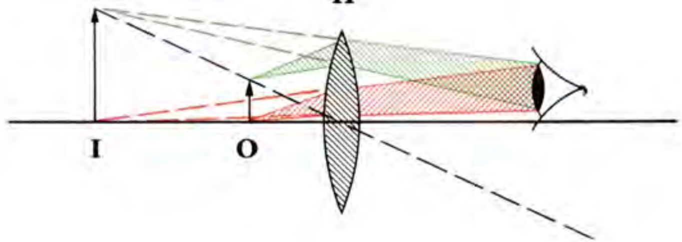
G



Small cones, image to eye (Sketch G) Show the eye looking at the image by drawing the extreme rays of a small cone from the head of the image to the eye. Do the same for a small cone from the foot of the image. Use broken lines (-→-) for virtual rays along which the light does not travel and *full lines* (→—) for real rays. Shade in the real *part* of the cone along which light actually travels to the eye. Those cones that extend back from the lens to the virtual image do not contain 'real' rays but only 'virtual' rays.

Draw cones, object to lens (Sketch H) Then, finally, you can complete the cones by extending them back from the lens** to the object, as shown.

H



**See footnote * on page above.

Ray Diagrams for Telescope

An astronomical telescope usually has stars at infinity as objects. But a diagram of a telescope viewing a nearby object gives an easier picture of the way a telescope works and shows its magnifying power.

Lens, object, undeviated ray (Sketch I) To draw such a diagram first draw an objective lens, but don't make this too tall. Remember how much taller a man or a tree or something else you are going to look at is than the telescope lens. Also don't make the objective lens very thick.

(Remember that the weaker this lens is, the farther behind it the real image will be, and therefore the larger that image will be. So you need a *weak* lens.)

Next, draw in an object some distance from the telescope with its foot on the axis and its head a *little* higher than the top of the lens.

Draw undeviated rays from the head and foot of the object to the lens, to locate the size of the real image.

Choose position of real image Since you are not told how strong a lens to use you should pretend you have chosen a suitable object-lens which will produce a real image at a suitable distance behind. Of course for a telescope the original object is *much* farther away from the lens than the real image is; so to make a sensible diagram that you can get on to the paper, you should make the image distance about a quarter of the object distance, or even less.

Decide where the image is in your diagram, and pretend that you have chosen an objective lens which will put it there. The undeviated rays will tell you the height of that image.

Choose a position of eyepiece Place the eyepiece lens a short distance beyond the real image. Suppose you want the telescope to 'magnify' about six times. Then the distance from eyepiece to real image should be about $\frac{1}{6}$ of the distance from the objective lens to real image. That means you have settled what lens you need for the eyepiece.

Pretend you have obtained a lens of that power and draw in the eyepiece.

Undeviated ray for eyepiece Draw a new undeviated ray from the real image through the eyepiece. Continue that undeviated ray **backwards** towards the object, to find the height of the virtual image formed by the eyepiece.

Place the virtual image Choose a suitable distance back for the virtual image. It might be as far away as the object or it might be nearer. It is probably clearer to draw it a little nearer than the object as in the sketch here.

When you have decided where the virtual image is, its size is settled by the undeviated rays—the one you have drawn for the head, and the axis for the feet.

Full cone (Sketch J) Draw a full cone of rays from the top of the object to the *full* aperture of the objective lens. Continue those rays from that lens to the real image and straight on through it to the eyepiece.

Cone for virtual image When those rays emerge from the eyepiece they must *seem to come from* the virtual image: therefore draw them as *broken lines* (not real rays) from the virtual image to the eyepiece; and then as *full lines* from the eyepiece out towards the eye.

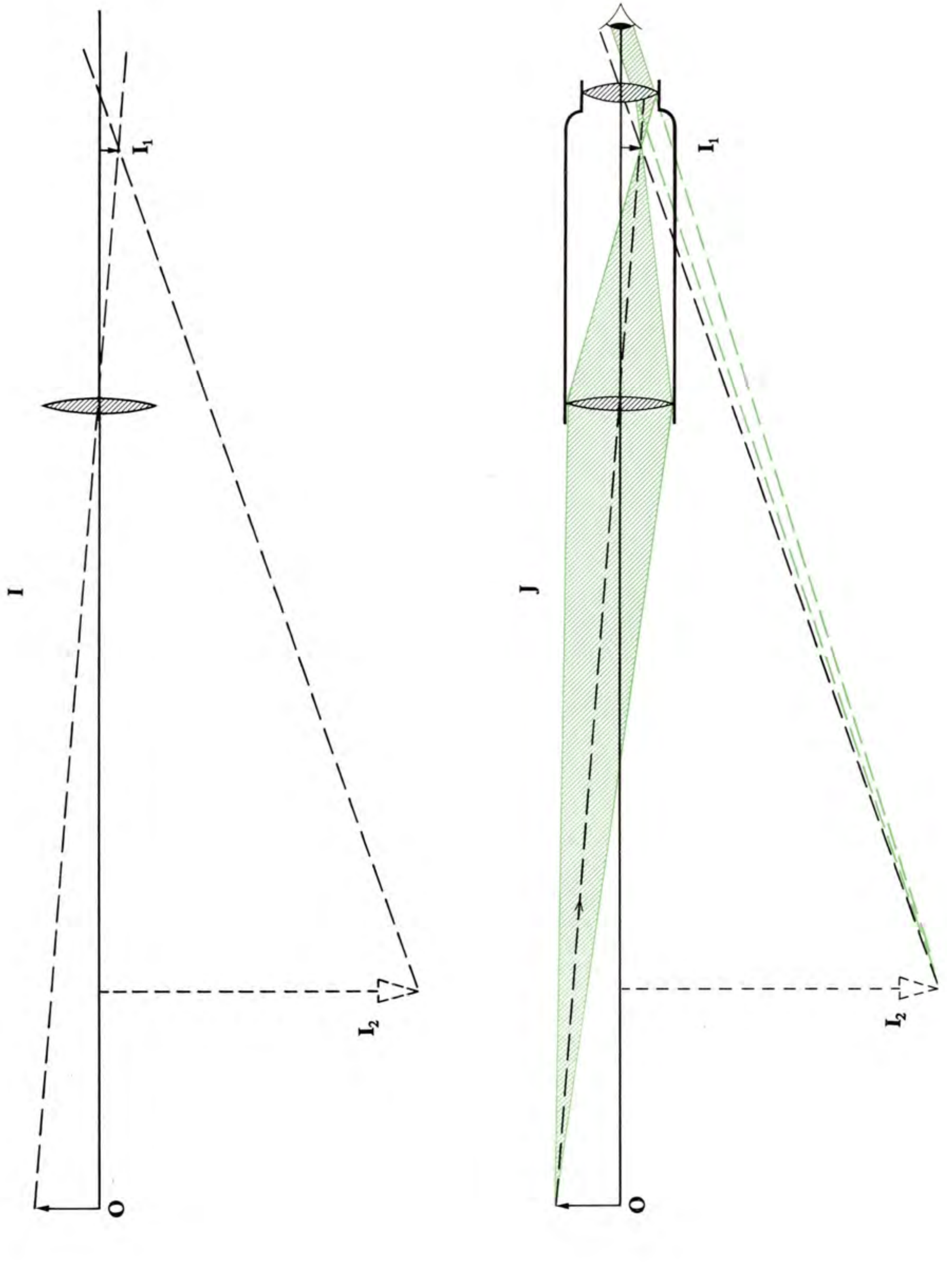
Eyepiece size You will have to choose the size of the eyepiece to catch all those rays—a matter of trial and error. You should make it a strongly curved lens, to show it needs to be a strong one to give some magnification.

General comments To make the diagram here simpler, we have drawn only one cone of rays. This will suffice, provided you understand what would happen to the cone of light from another object point.

When drawing a simplified diagram like this, always choose an object-point *off* the axis so that the diagram will show how the instrument magnifies.

The final virtual image may be any convenient distance from the eye, from $\frac{1}{4}$ metre to infinity. For most comfort in looking at distant things with the telescope, the final virtual image should be placed as far away as the object.

But if the observer wishes to make notes in a nearby book (or if he is short-sighted) he should place the final virtual image much closer. This makes very little change in the magnification


I
J
O
O
I_1
I_1
I_2
I_2

f

Diagram for Telescope directed at two Stars

Sketch K shows the passage of a beam of light from a distant star through the telescope to the eye of an observer. Note the very important undeviated rays.

The objective lens forms a real image of the object. Cones of rays continue *straight through* this real image to the eyepiece, which forms a virtual image of the real image.

Notice that the beam from the star is made up of parallel rays—because the star is very far away. In fact, it is so distant that we cannot draw beams from the top and bottom of the star. Its image is just a point of light.

In Sketch L beams from two stars are shown.

All the light that enters the object lens (from *any* direction) passes finally through the eye-ring. That is where the observer's eye should be placed for maximum field of view.

K

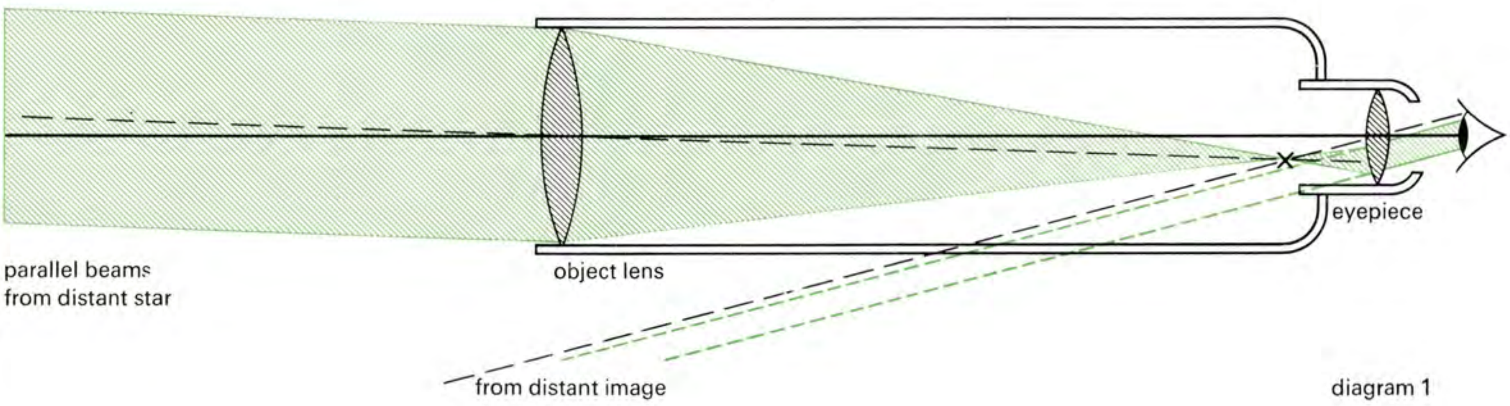


diagram 1

L

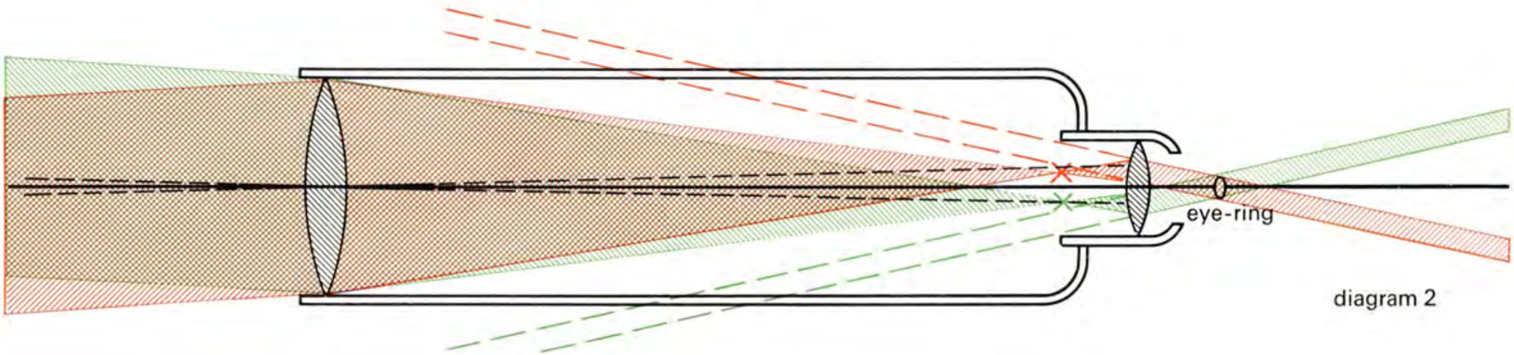


diagram 2

The terrestrial telescope The astronomical telescope gives a final image which is upside down. This is inconvenient for navigating, surveying, and other terrestrial purposes.

A telescope with Galileo's negative eyepiece gives a very poor field of view. So good terrestrial telescopes are astronomical telescopes with an arrangement to turn the final image the other way up. This arrangement is either a pair of prisms (in field glasses) or an extra pair of lenses.

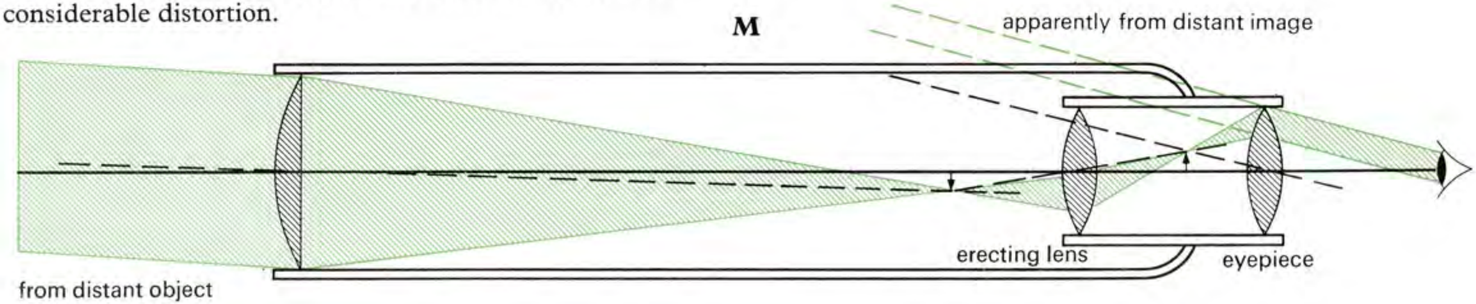
A single lens could be used to make a second real image. Although that would give a final image the right way up, it would give a distorted field of view. Sketch M shows that. Note the steep slant and severe bending of rays at the eyepiece. This is one of the reasons for the considerable distortion.

The distortion may be avoided by using two lenses, as in Sketch N. Here again note the important use of undeviated rays. An undeviated ray need not be continued beyond the place where it shows the height of the next image.

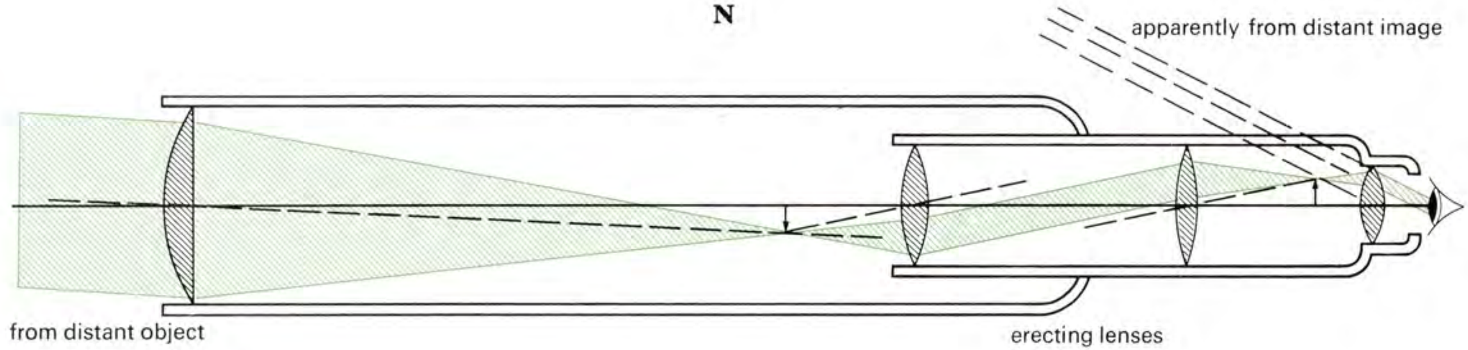
The pair of erecting lenses *can* be used to produce some additional magnification.

'Prism binoculars' (field glasses) consist of two astronomical telescopes, in which the light path has been 'folded', zig-zag-zig, by the use of prisms as reflectors. This makes a much shorter instrument. The reflections by the prisms also serve to make the final image the right way up.

M



N



Magnifying Glass

This is a single convex lens used to make a virtual image of an object held close to the lens. Sketch H is a ray diagram for that.

Compound Microscope

Sketch P shows a ray diagram for a compound microscope.

Draw the diagram in the same way as the diagram for the telescope.

Start by just choosing a very small object and strong objective lens. Draw the undeviated rays from head and foot of the object through the objective lens.

Select a suitable place for the magnified real image. Draw full cones from the head and foot of the object to the objective lens. Then continue those cones to the real image, and straight on through that image to the eyepiece.

In this case, the eyepiece may have a larger aperture than the objective lens.

When you have chosen the position of the eyepiece, draw undeviated rays through it, from the real image. (One of them is just the axis.)

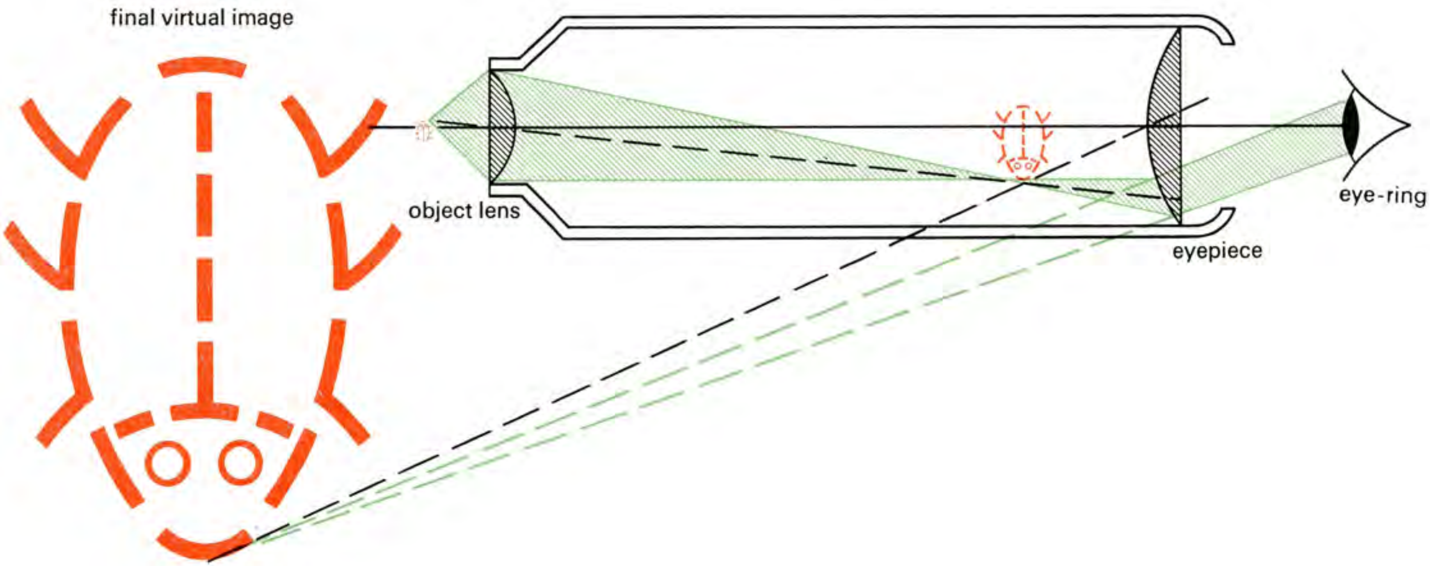
Carry those undeviated rays *backwards* to the virtual image of the real image.

It is best to place the final image back at the object, or a little farther, as if really $\frac{1}{4}$ metre from the eye.

Then draw virtual rays (broken lines) from the final image to the lens, and on beyond the lens as real rays.

Shade the full cone of rays from the head of the object.

P



CHAPTER 3

LIGHT AND COLOUR

Experiments and theories

This chapter has three parts. The first part has some advanced experiments on bending rays of light. You could postpone these.

The second part has some very interesting experiments with coloured lights.

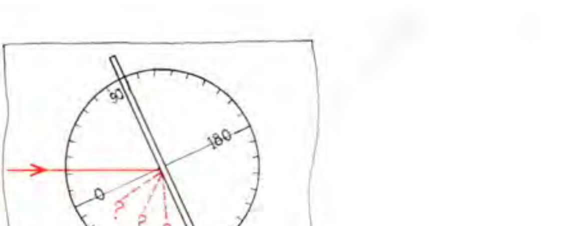
The third part has an advanced description of theories of light, which you could postpone.

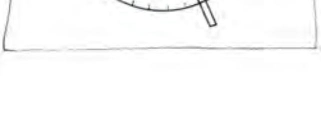
Bending Rays: Reflection and Refraction

You have seen lenses and mirrors form images by bending the paths of rays. There are questions about what happens to each ray in Experiments 32 and 33.

Advanced Optional Experiment 32 Law of Reflection

Can you describe what happens when a ray bounces off a mirror? Can you tell a simple story about angles, that holds true for all rays or mirrors?





You may not have found such a 'Law of Reflection' with ray streaks. But if you are not sure, or have only seen it in books, look now with a ray streak and a protractor.

The easiest way to make a protractor show the story is to use a paper protractor marked in degrees. Place the mirror along the 90° line, so that the 0° line is perpendicular to it. Shoot a ray in to the place on the mirror which sits on the centre of the protractor's circle.

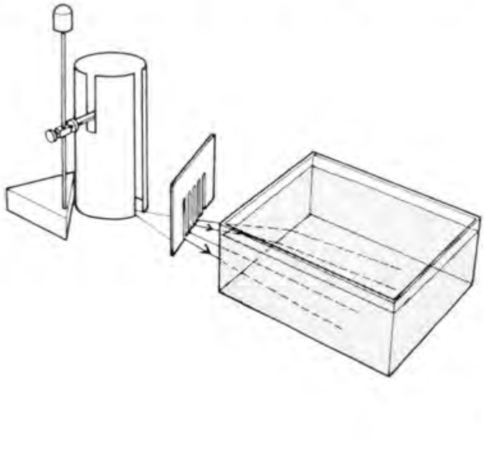
Now look at the angles. Try to write a general story, for all rays, in clear words.

Experiment 33 Refraction of Rays with a Box of Water

What happens to a ray when it meets the glass of a lens?

That is too difficult to see with thin lenses because rays are bent when they enter the glass and bent again when they come out. You should now see the two bendings separately by letting rays enter and leave a square tank of water.

Such bending of rays is called *'refraction'*. It is obviously important in the designing of lenses;



also in discussing the question 'Is light a *stream of bullets* or a *train of waves?*'

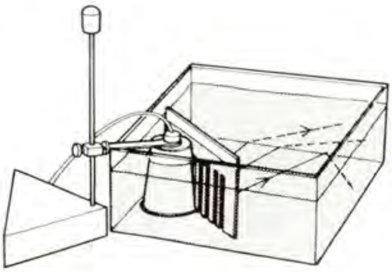
Set up a lamp and comb and make ray streaks.

(i) Air to water. Fire a fan of rays at the side of a plastic box with clean water in it. Looking down from above, see what happens to the path of each ray when it goes through the wall of the box, from air to water.

(To see the rays clearly *in the water* you need to paint the bottom of the box white on the inside, or else to submerge a piece of paper there.)

You need not make measurements: just watch the way the rays behave.*

(ii) Water to air. Place the lamp and comb carefully inside the box under water, near one corner. Look at the paths of rays as they cross the box and hit the wall. Again, watch the way they are bent as they pass from water to air. Look at the behaviour of rays that reach the side of the box at several different angles.



Do you see anything new, or do you see just what you would expect?

Experiment 34
Examples of Refraction

34a Coin in Water

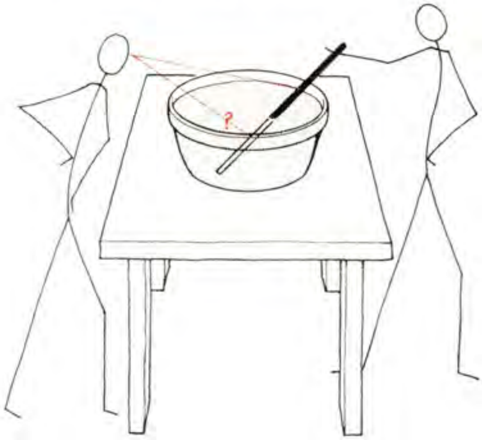
(This is an experiment to try at home.) Place a coin on the bottom of an empty jam jar or wide tumbler, near the far side. Stand away so that you cannot see the coin through the open top. (Cover the side of the jar with paper if you like; then you cannot see the coin at all.)

Ask someone to fill the jar with water. The coin will appear.

Can you explain that by a sketch showing rays of light from the coin being refracted as they go from water to air?

34b The Bent Stick

(Another experiment to try at home.) Dip a straight stick or pencil into a sink or large bowl full of water. Tilt the stick at about 45°. Stand and look down at the stick. *Does it look bent? If so, can you sketch rays being refracted to explain that?*



34c Is a Pond as shallow as it looks?

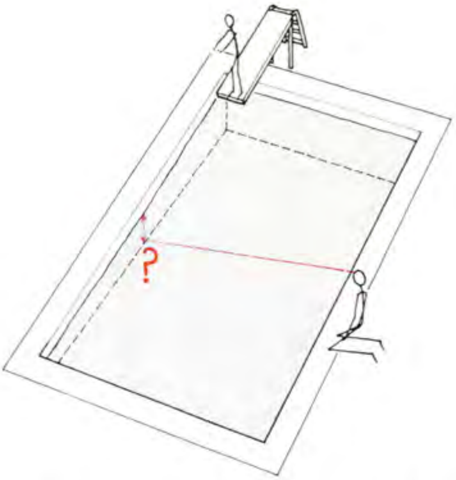
Look at objects at the bottom of a pond or a clear river. The water looks shallower than it really is. That is something fishermen have to learn.

Lie in a warm bath with the water just covering your feet. Look at one foot while you raise it out of the water.

Kneel at one *side* of a swimming bath and see how deep the water looks as you glance from your side across to the far side.

*There *is* a 'Law of Refraction' but it is not simple like the Law of Reflection; and you will not need to investigate it.

However, if you are keen to know more about it, you should ask your teacher for some apparatus (a semicircular box of water or block of glass) for a special optional experiment on the bending of a ray streak.

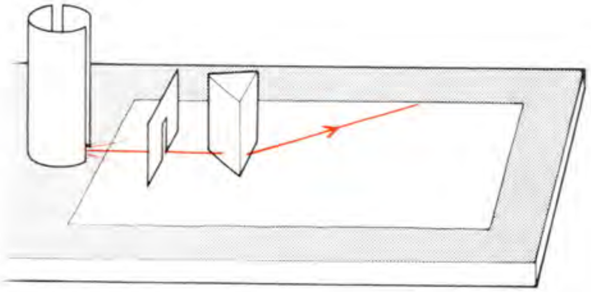


Does the bottom look flat and level? Or does it look curved? If it looks curved, how could you make sure it is not really curved (without having the water all emptied out, and without diving in)? Does it look shallower or deeper than it really is?

Can you sketch rays being refracted to explain the mistaken impression?

Experiment 35
Single Ray Passing through a Prism of Glass

Arrange a lamp and single slit to make a ray streak across a sheet of paper. Place a glass prism in the path of the streak and watch what happens to the ray.



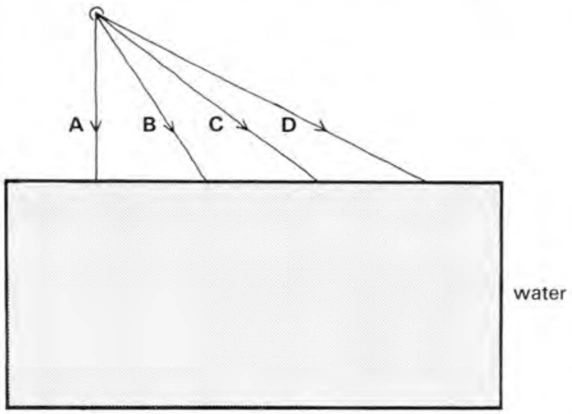
Try twisting the prism round, so that the streak hits it at different angles.

If you like, squat down and look back along the ray that comes out of the prism and see what seems to have happened to the ray.

Progress Questions

RAYS IN AIR AND WATER

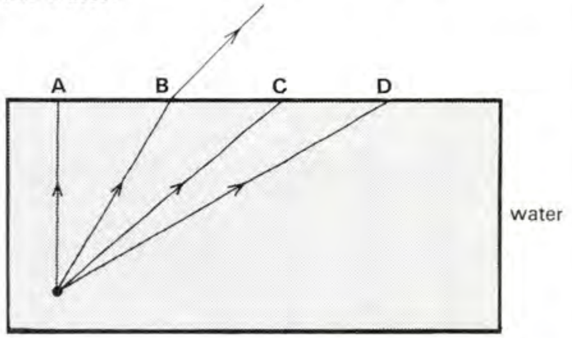
1. When the rays from the lamp go into a box full of water most of them bend at the surface.



a. Which ray goes straight on, without bending at all?

b. Which ray gets bent most?

c. Copy the diagram and draw in the rays inside the water.



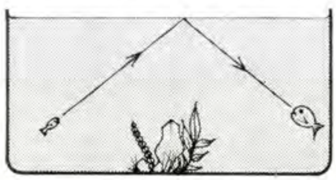
2. When the rays from the lamp go out of the water into the air, most of them bend at the surface.

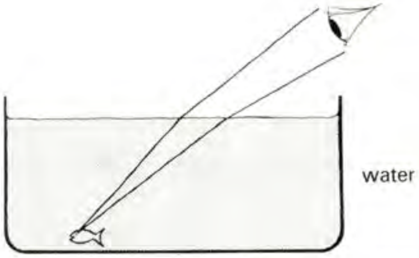
a. Which ray goes straight on, without bending at all?

b. Which ray bends most?

c. Copy the diagram and draw in the rays in the air, as for the ray b.

3. Where does the big fish see the little fish?





4. The rays of light leave a point on a fish in the water. The fisherman is deceived into thinking that the fish is somewhere else.

Copy the diagram and show where the fisherman 'thinks' the fish is.

5. Look for a description of a 'fish-eye camera' in books in a library. (It takes a picture of things straight ahead *and* all the way round to the left *and* all the way round to the right. You may see some of its distorted pictures in modern advertisements.)

Make a sketch and write a short description of that camera. Explain how it takes such very-wide-angle pictures.

Questions

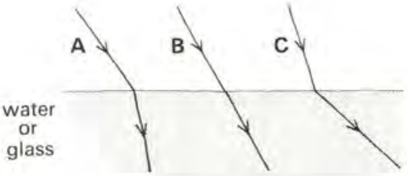
REFLECTION

6. 'This table doesn't bend when I sit on it,' says your partner in the lab. You say, 'Yes it does. The bending is too small to see, but it happens all the same.'

You have a small mirror and a lamp arranged to give a narrow light beam—also a white ceiling over the table. Explain how you would show your partner that the table bends when he sits on it. Draw a rough diagram showing where you would put the mirror, relative to the table leg and the position of your partner. (You need not draw him properly, a round lump will do!)

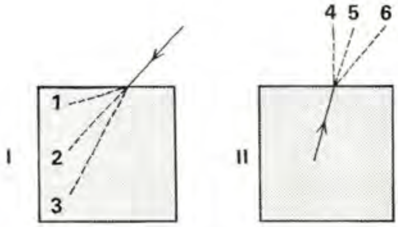
REFRACTION

7a. One ray in this diagram is shown bending in a correct way. Which one?



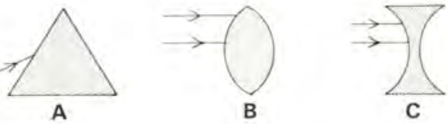
b. You could write down a 'rule' for a ray of light passing from air to water (or glass), to help you remember which way a ray bends. Invent a rule that says whether rays bend to become 'more slanting' or 'less slanting'.

8a. A horizontal ray of light falls on the side of a transparent box full of water as shown in fig. I. What is its path in water like? Two of the three choices (1, 2, and 3) shown in the diagram are incorrect. Copy the diagram but include only the correct path, as a full line. Omit the other two.



b. If you like, draw the correct ray onwards to show what happens to it when it comes out from the box. (Make the box longer if you wish.)

c. Copy fig. II showing, as a full line, the proper path (one of 4, 5, and 6, omitting the other two). Then draw the path of the ray as it entered the box.

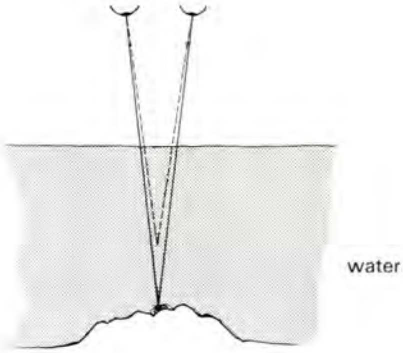


9a. Fig. A shows a ray of light falling on a glass prism. Copy the diagram and complete it by sketching in a possible path for the ray after entering the prism and after emerging from it.

b. Fig. B shows a 'thick' lens, not like the 'thin' ones you have used in lab experiments. Two parallel rays fall on it as shown: copy fig. B and show possible paths for the rays in the lens, and after emerging from it. (HINT. Use your answer to (a). The outer parts of the lens are like prisms!)

c. A 'thick' concave lens is shown in fig. C. Copy the diagram and again show possible paths for the rays into and out of the lens.

d. What happens to a ray along the axis (centre line) of B and C above?



10a. Copy the diagram and use it to explain why an object seen under water appears to be nearer the surface than it actually is.

b. Notice the meaning of 'explanation' in your answer to (a): you 'explain why' apparent depth is less than real depth by referring to another happening ('phenomenon') that you already know about. What phenomenon? Write a sentence or two in answer.

11a. Describe a simple experiment to show that real depth in water and apparent depth in water are not the same.

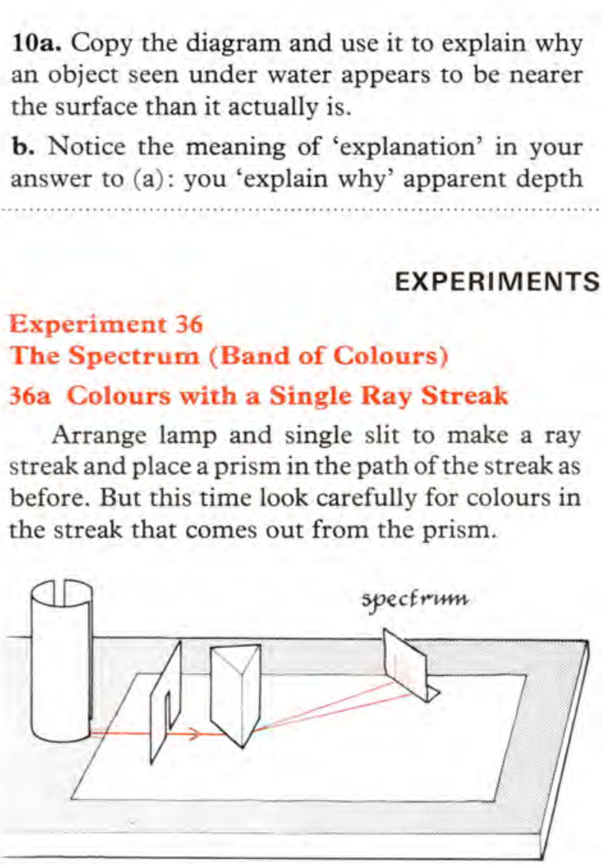
b. It is said that, during the siege of Paris in 1870, hungry soldiers tried to kill fish in ponds by shooting at them. Why is a soldier on the bank of a pond unlikely (if he knows no physics) to hit a fish a few yards out? (A sketch will help your answer.)

c. Your face is 1 metre away from a tank with a vertical side of plain glass. There is water in the tank and a fish in the water. The fish looks out and sees you. Would you appear to be a metre away from the glass? or more? or less? Explain.

EXPERIMENTS WITH COLOUR

Experiment 36
The Spectrum (Band of Colours)
36a Colours with a Single Ray Streak

Arrange lamp and single slit to make a ray streak and place a prism in the path of the streak as before. But this time look carefully for colours in the streak that comes out from the prism.



You will see those better if you let the streak run a long way from the prism and then catch it on an upright scrap of paper.

Twist the prism until the colours seem best.

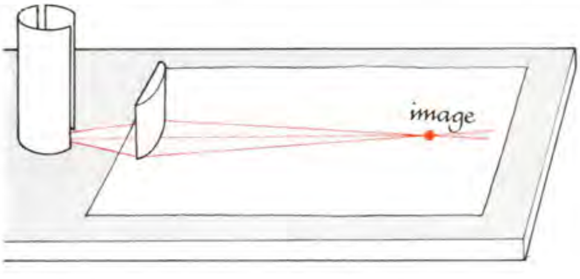
Turn the paper so that the band of colours spreads out wider. The band is called a spectrum —meaning something to look at.

36b Spectrum with a Fan of Rays

Direct a fan of rays at a +7 D lens so that the rays that come out from the lens go to an image 40 or 50 cm away. Use a comb to arrange your experiment; then do *without any comb* and *use all the rays of light from the lamp*.

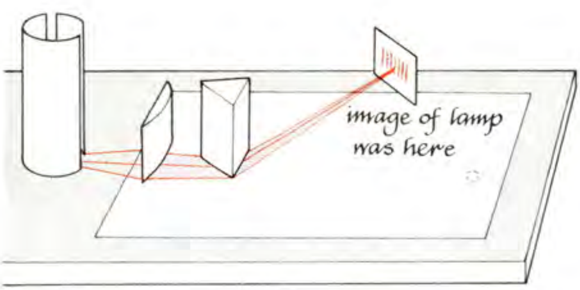
Then place a prism just beyond the lens. The prism swings all the rays round to a new direction. Find that direction and hold a piece of paper, upright, to catch the rays. Move the paper to about the same distance as the image was before, 40 or 50 cm from the prism in the new direction.

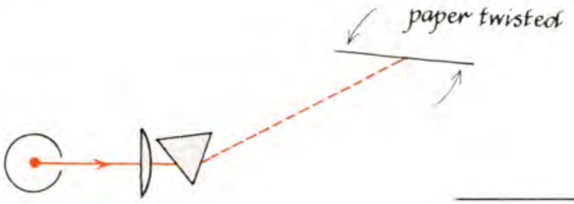
Before you put the prism in, the lens made a bright image of the lamp filament. But now it makes a whole set of images: a red image, an orange image, a yellow image, a green image, and so on in the broad coloured band of overlapping colours.



Try twisting the prism. Find the position in which it gives the clearest band of colours.

Then twist the upright sheet of paper so that the spectrum meets it in a slanting direction. That





will spread the spectrum out to a wider band so that you can look at it more carefully.

36c Effect of Coloured Plastic or Glass

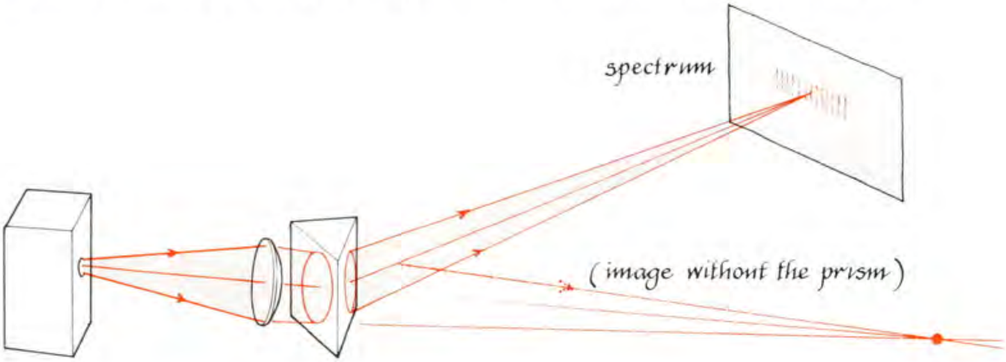
Hold a piece of transparent red plastic (or red glass) in the light on its way to the prism. See what it does to the spectrum. Also try a piece of green plastic or glass.

Some dye has been melted into the red plastic or glass to make it red. *Does that dye colour all the parts of the spectrum red, or does it absorb (cut out) some colours? Is the dye a colour-ADDER or a colour-SUBTRACTOR?*

Demonstration 37a Wide Spectrum

Look at a large spectrum made on a screen far away with white light from a very bright lamp.

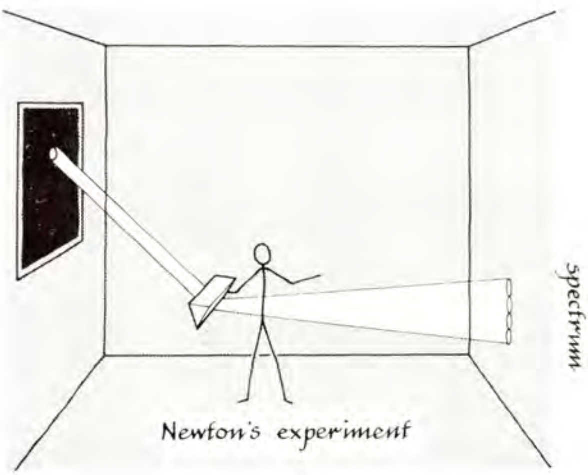
A lens makes an image of the lamp filament on a white screen far away. A prism catches the light just after the lens and swings it round to a new place where you see a spectrum.



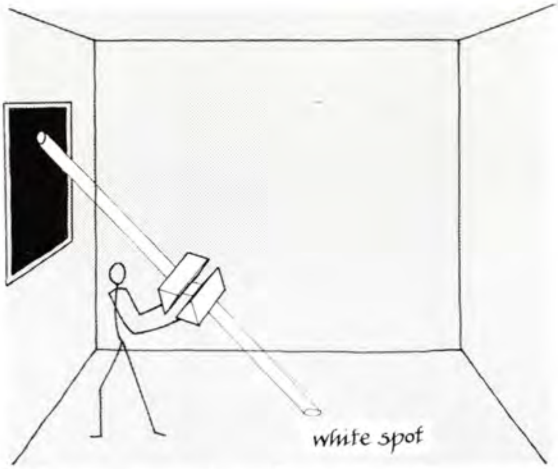
Were the colours there before the white light went through the prism? Three centuries ago Isaac Newton—who built the great theory of gravitation for astronomy (which you will meet later)—did careful scientific experiments with a spectrum.

He let a ray of sunshine into a dark room, through a hole in the blind. He held a glass prism (probably from a chandelier) and caught the ray on it. He saw it bend the ray and spread the white light into the many colours of the spectrum.

That must have often been seen before, but Newton *thought* about it. He decided that it showed white light to be a *mixture* of all those



Newton's experiment



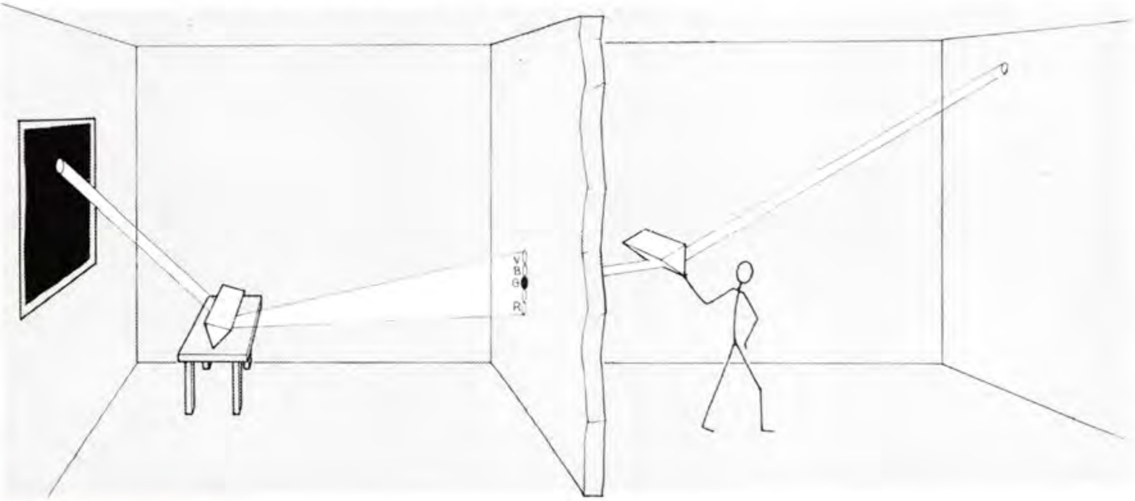
colours put together. He guessed that the prism sorted out the colours; it did not add dyes to *make* the colours.

He tested his idea in several ways. He placed another prism the opposite way just after the first and put the colours back into white light again.

He wanted to show that a prism is not a colour factory that manufactures lots of colours but only a colour-sorter—like the sorting office for letters in the post office.

You could paint the spectrum colours on a spinning top and hope to see white when the top is spinning fast. But paints are too dull and you would only see grey. It is better to add bright patches of coloured light together on a white wall; and you may see that soon: in Demonstration 37b.

Newton tried a very clever experiment. He made a spectrum on a white screen. Then he cut a hole in the screen just where one colour of the spectrum fell. He let the light that came through that hole hit a second prism. *Did that second prism make a new set of colours (as a colour factory) or did it just spread the same colour a little (as a colour sorter)?*



Demonstration 37b
Trial with Second Prism

If possible, see the wonderful test that Newton made.

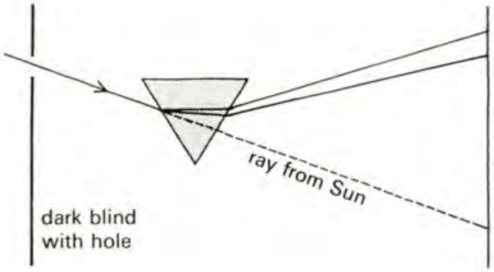
Progress Questions

SPECTRUM

12. Unless you are colour-blind (and there are always a few people who are) you can see a number of different colours. We call the light from the Sun or from a very bright lamp 'white light'. Suppose white light is bent by a prism, and goes on to a screen. What do you see?

Draw a sketch of the spectrum and label it with some names of colours.

13a. Copy the diagram and use it to explain Newton's original spectrum experiment, which showed 'colours of the rainbow'.



b. When did Newton do this experiment, 100 years ago? 200? 300? 400? or more?

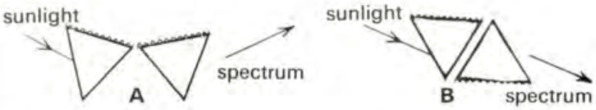
Questions

SPECTRUM

14a. You have a lamp with a narrow slit, a prism, and a screen. Draw a sketch to show how you can arrange them so that you get a spectrum on the screen. Mark the red and blue on the screen to show where they come.

b. If you had a convex lens as well, how would you make a spectrum which is much brighter and clearer?

15. *(Optional Now)* Newton performed other experiments following upon his first spectrum experiment, including (a) and (b) below.



a. He picked out one colour from the light emerging from the prism, and passed it through a second prism. Draw a simple sketch to show how this was done. Say, briefly, what result he observed.

b. He passed the *whole* spectrum of colours from a prism P through a second prism Q. What was the result,

(i) if the prisms were placed as in fig. A?
(ii) if the prisms were placed as in fig. B?

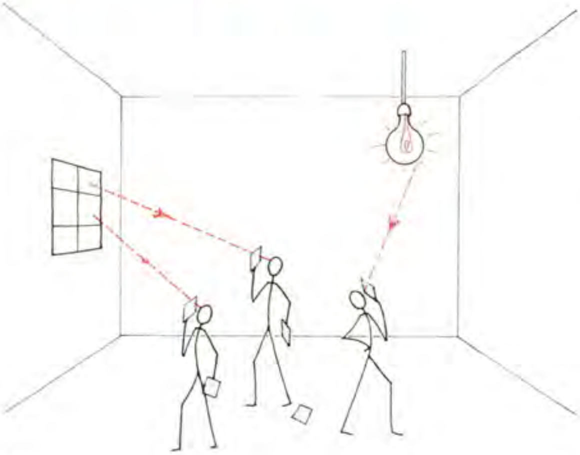
16. *(Optional Now. Postpone this question unless you have discussed it in class.)*

As a result of the experiments in the previous two questions, and other experiments, Newton decided he knew some things about white light and prisms.

a. What did he decide about white light?

b. And what action does a prism have on white light?

Experiment 38
Colours
38a Examining Colour Filters



You have used a piece of transparent red plastic (or glass) in your spectrum experiment. Now try five other coloured sheets as well as the red.

Hold each sheet up to your eyes and look through it at bright sky or a well-lit screen, so that you know what its colour looks like.

Here are names for the colours you will use:

RED is plain red.

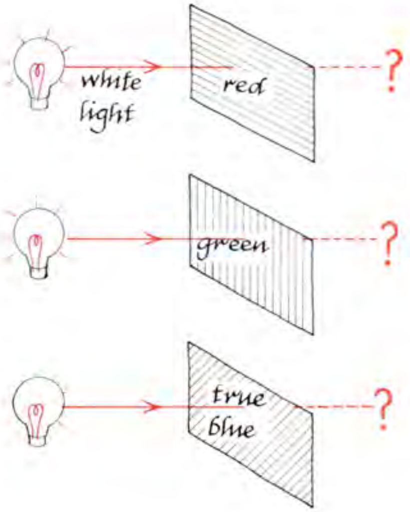
GREEN is plain green (it is the colour for which your eyes are most sensitive).

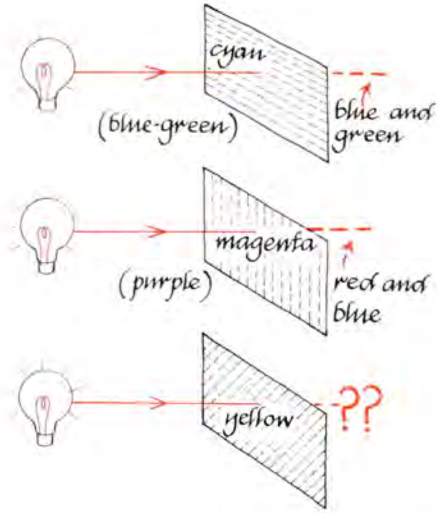
TRUE BLUE looks a very deep blue or even violet.

CYAN OR BLUE-GREEN is BLUE & GREEN together.

(The blue of a paint box or dress is really cyan.)

MAGENTA (named after a bloody battle) is RED & BLUE together.



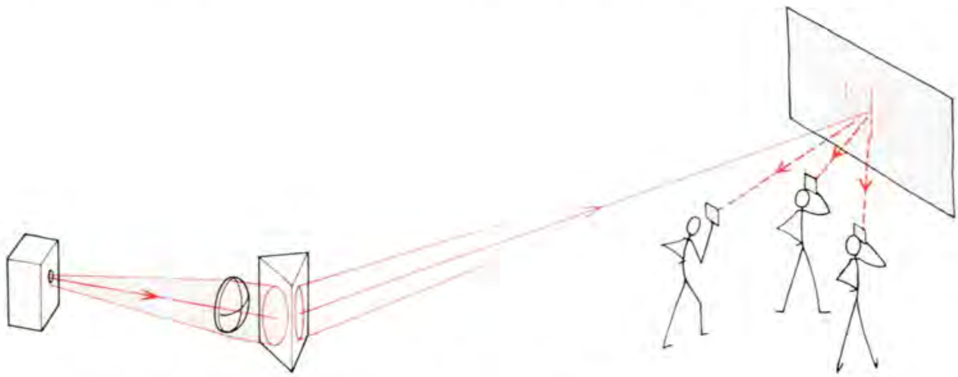


YELLOW is 'ordinary yellow', not the pure yellow that you see coming from a salted flame or from sodium street lamps. Soon you will see what this common yellow is made up of.

38b Primary Filters and Spectrum

You tried holding a piece of transparent red plastic in white light going to a spectrum. Now try the other coloured sheets.

Instead of placing each sheet in turn in your own spectrum experiment, you can just hold it close to your eyes and look through it at a large spectrum on the wall. Then each member of the class can have a coloured sheet and all can look at the spectrum at the same time.



That will tell you the same thing about the coloured sheet as if you held it in your own spectrum experiment. It will catch the light on the way to your eyes, instead of earlier on the way to the spectrum.

With the lab quite dark except for a wide spectrum on the wall, look through each coloured sheet at the spectrum. Start with the RED one; then the GREEN; then the TRUE BLUE.

What does a sheet which looks red against the sky do to the spectrum?

Some red dye has been melted into the plastic. *Does that dye paint all parts of the spectrum red or does it just cut out other colours and leave only the red that was always there in the white light? Is it a 'colour-ADDER' or a 'colour-SUBTRACTOR'?*

Why is your sheet of red plastic called a 'filter'? What do filters do in coffee machines, chemical experiments, or public water supplies? What does a scratchfilter do in a record player?

38c Secondary Filters and Spectrum

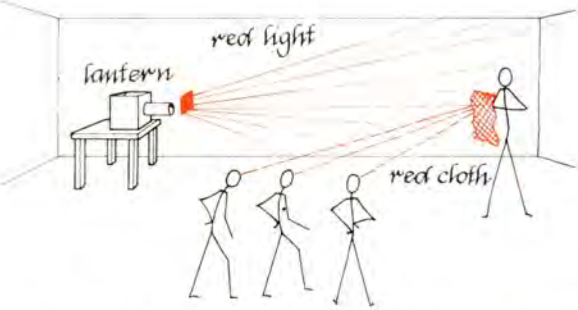
Then try the double-colour filters: CYAN, MAGENTA, YELLOW. Look at the demonstration spectrum through each of those in turn.

From what you actually see, you could then say 'Magenta is just a quick name for (red + blue)'.

In the same way, you could say 'Cyan is just . . ? . .' And 'Common yellow is just . . ? . .'

38d Seeing the Colours of Things

Why does a red scarf look red? Red cloth has been treated with dye like the red dye in your red filter. It can send red light to your eyes; BUT IT CAN ONLY DO THAT IF IT RECEIVES RED LIGHT TO SEND BACK.



Hold a piece of red cloth in a dark room and shine *red* light on it. *What do you see?*

Shine *white* light on it; shine *magenta* light on it. Each time you see it red, because red light, white light, and magenta light *all contain red*.

Shine green light on the red cloth. *What do you see? Why?*

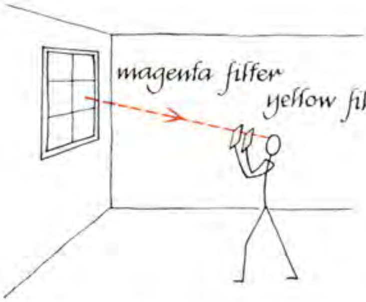
Anything coloured can only show its *full* colour if it is offered light with all the parts of that colour.

What would magenta cloth look like in red light? Why?

What colours can white paper send back, if it receives them? (What did Newton—and your own experiments—tell you white light is made up of?) What would white paper look like in red light? in magenta light? in green light?

38e Painting and Printing

Water-colour paintings, coloured pictures in books, and Technicolour films make their colours by using dyes like those in your colour filters.



They do not use red dye, green dye, blue dye, because then those would be the only colours that could be shown. It would be no good to mix two of those or put one on top of the other. (Try putting a red filter and a green one together and looking at the sky through them. What do you see?

For painting and printing the '*secondary*' colours are used, sometimes one of them alone, sometimes two mixed or sandwiched together.

Take your MAGENTA, CYAN and YELLOW filters and look through each *pair* of them at a bright sky.

When you hold MAGENTA and CYAN *together* you see a deep blue when you look through the sandwich. That is because magenta lets through red and blue, and cyan lets through green and blue; so the only colour that gets through both is blue. This is 'true blue', the blue and violet part of the spectrum, without any green.

The dyes in your filters can be used in water-colour paints, and even when the paints are mixed each dye just does its own filtering job. So mixed paints behave like your two-filter sandwich.

What colours does the yellow filter let through? Think about a sandwich made of a yellow filter and a magenta filter. Predict the colour that will get through. Then try it.

Then try a yellow filter and a cyan filter together. Now you know why children using a paint-box say 'blue and yellow make green when mixed'. (True of their paints but they are really mixing *cyan*—which they call '*blue*'—with *common* yellow.)

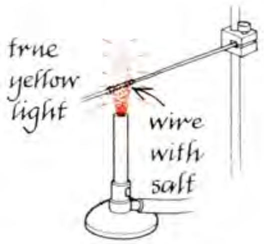
With water-colour or coloured ink paint a yellow patch on white paper. When that is dry, brush a bar of cyan across the yellow. You will see the colour filters at work.

Painting, Technicolour films, and colour printing in its simplest form use just three filters, magenta, cyan, and yellow. What colours can be made, using just those three and no others? Magenta can print plain magenta. Magenta and cyan mixed (or painted on top of each other) will print true blue. Continue this list. (There are seven things they can print, not six, because there is also plain white with no filter.)

Analysing the colours of materials. Look through a filter at coloured cloth or at coloured patterns on a dress. Which three filters should you use for the easiest, thorough, enquiry?

38f True Yellow

Pure yellow is only a narrow part of the spectrum but it is useful for some purposes—for one thing, in a flame test for sodium in chemistry.



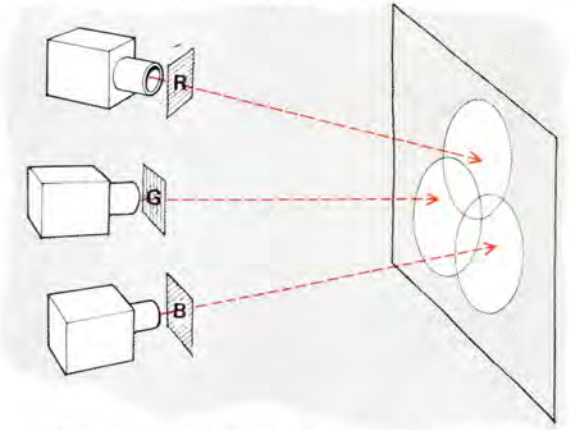
A salted Bunsen flame gives out pure yellow light and almost no other light. Arrange one or two such flames in a dark room and look at faces, brightly coloured dresses, or flashy ties.

Once again: coloured things can only return some colours that are offered them. Offered only pure yellow, any material has only a narrow choice; it must look yellow, or grey, or black.

Subtraction. All the things you have been doing or seeing with filters are examples of the filter *subtracting* some colours, while it lets other colours through. Now look at colours being *added.*

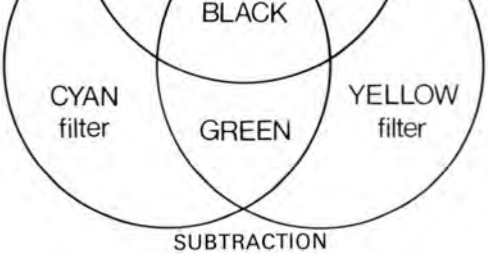
Demonstration 39
Additive Colour Mixing

Colours are added on a theatre stage when two coloured spotlights illuminate a white object, perhaps the heroine's white dress.

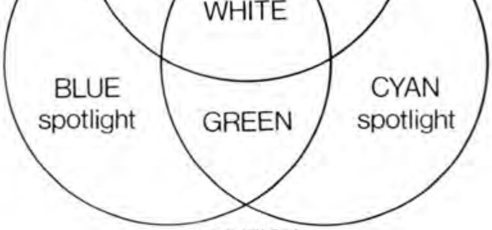


You have already seen a patch of red light projected on white paper in a dark room. And you can guess what you would see with a patch of green light instead. Predict what you would see where the two patches overlap: red light from one projector and green light from another projector both directed at white paper.

See that done with three projectors, each with a filter so that it provides one colour. For this you need the primary filters, red, green, blue. *What do you see where all three colours overlap?*



SUBTRACTION



ADDITION

The colour story in code *(OPTIONAL)* Make a simple code: R for red; G for green; B for blue. Then you don't need M for magenta because you can call magenta $R+B$ and thereby give more information than by calling it M.

Think about the spectrum of white light. The full list of colours runs:

RED ORANGE YELLOW GREEN BLUE VIOLET*

Now simplify that list. Orange can be imitated by a large dose of red with a small dose of green added; so we can leave orange out of the list of necessities. True yellow is so weak that we can usually forget about it and just use a mixture of red and green. Violet is very faint: there is not much of it in common white light and our eyes are not very sensitive to it. The list then runs:

RED ORANGE YELLOW GREEN BLUE VIOLET

and we leave out the less important ones and say:

WHITE light is chiefly:

RED + GREEN + BLUE.

That agrees with the demonstration of adding those three colours.

Then, in our code, $W = R+G+B$.

A red filter lets through red (does nothing to red) but subtracts (stops) green and blue so we may call it $-G-B$.

White light meeting a red filter is $W-G-B$,

that is, $(R+G+B)-G-B$

that is, just R.

Cyan lets through green and blue, and stops red, so another name for it is 'minus red' and that is what the colour-printers and film people call it.

In the same way common yellow is 'minus blue'. Then white light passing through cyan *and* yellow filters gives $W-R-B$

that is, $(R+G+B)-R-B$

and that is just G, plain green.

Each colour has a 'complementary' colour, the opposite colour, such that the two added together make white. It is easy to find complementary colours with our code. E.g., 'What is the complementary of RED?'

We say $R+$(complementary of R) $=$ white;

$W = R+G+B$

Therefore (complementary of R)

$= R+G+B-R$

$= G+B$; that is, cyan.

Try working out other complementaries for yourself.

*When Isaac Newton wrote his list, about 300 years ago, he included a special blue, 'indigo', which we do not bother to name nowadays;
RED ORANGE YELLOW GREEN BLUE (INDIGO) VIOLET
(Some people like to remember the list by a jingle:
Richard Of York Gained Battles in Vain
or, in reverse,
Very Inky Boys Go Yellow On Rubbing.)
However, learning names by heart is not serious science; and it is far better to remember what the colours of the white-light spectrum look like. Think of a rainbow's colours.

Progress Questions

COLOUR (OPTIONAL NOW)

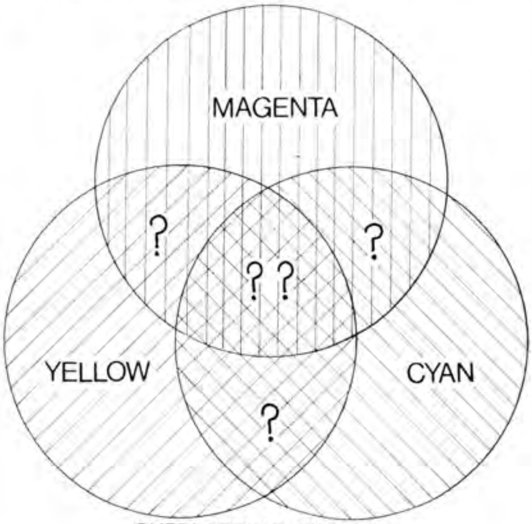
17. You make a clear big spectrum on somebody's green cardigan.

a. What colour does her cardigan appear to be:
(i) in green light in that spectrum?
(ii) in red light in that spectrum?
(iii) in white light when you look at it in daylight?

b. Which colours do you think the green cardigan *can* reflect?

c. What happens to the colours it doesn't reflect?

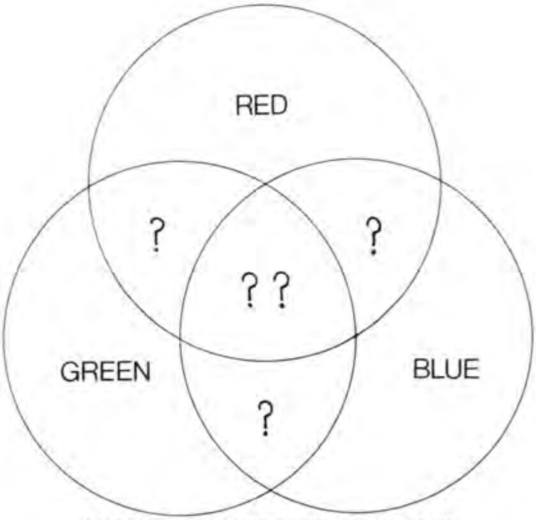
18. Write about some other things you have found out about colours.



OVERLAPPING FILTERS

19. The sketch shows three round patches of colour filter (magenta, cyan, and yellow) overlapping. Suppose you are looking through them at a white sky. What colours would you see in the places where there are question marks? Copy the sketch and write the names of the colours you would see in each case.

20. The sketch shows three round patches of light thrown on a white wall by three projectors each of which has a colour filter in front of the lens. The filters are red, green, and blue. What colours would you see in the places where the patches of light overlap? Copy the sketch and write the names of the colours in each place.



ADDING COLOURS BY SPOTLIGHT

Question

COLOUR (OPTIONAL NOW)

21a. Yellow light may be either of two kinds, a pure colour of the spectrum or a mixture which looks yellow to us.

(i) How can you obtain pure yellow?

(ii) What does the mixture (subjective or 'false' yellow) consist of?

b. Suppose you have four patches of coloured cloth;

patch R is pure red	patch G is pure green
patch M is magenta	patch W is white

Those are the colours the patches will show if you shine white light on them.

(i) If you hold the patches in a pitch dark room and shine pure red light on them, what colour will each patch show?

(ii) If you shine pure green light on them, what colour will each show?

(iii) If you shine pure yellow light on them, what will each show?

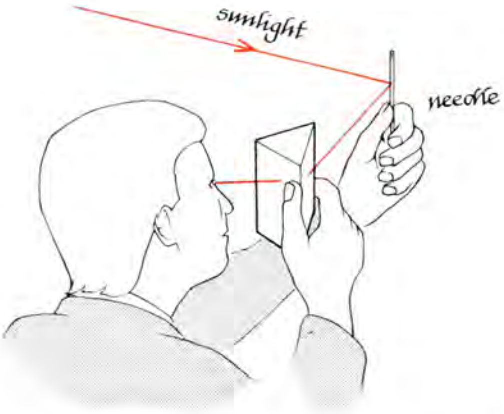
(iv) If you shine common mixed yellow light on them, what will each show?

Experiment 40
Poor Man's Spectrum with Sunlight

(OPTIONAL)

Stand indoors in bright sunlight with your back to the Sun. Hold a prism close to one eye.

With the other hand, hold a bright sewing needle upright at arm's length. The Sun reflected by the needle will look like a tall thin line. Twist the prism until you see that line, in a different direction, and spread out into a spectrum of colours.



THE REMAINING SECTIONS OF OPTICS ARE ALL 'OPTIONAL NOW'.

That means you can leave them out without hurting your knowledge much at present; but you will need them if you continue physics to the examination stage two years later. They can be postponed till then.

However some of these remaining things may look specially interesting to you. If so you should certainly read about them and try them. The more you try, the more you will know.

Theories of Light

Two thinking-models of light have been argued about for many years. Two hundred years ago Isaac Newton favoured the idea that light is a stream of small bullets. Some other scientists agreed with him but some put a different view: that light is a stream of waves, like ripples in a ripple tank (but the stuff that moves to-and-fro cannot be seen or touched like water).

Which view or model do you prefer?

Bullets? Light travels in *straight lines* and casts sharp shadows. Do very fast bullets travel (almost) straight?

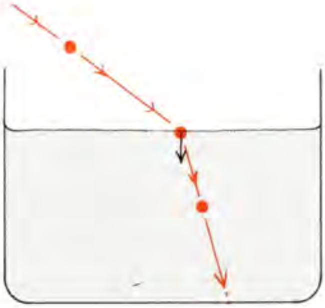
Bullets? Rays of light are *reflected*, with a simple rule of angles. Do bullets 'obey' that rule?

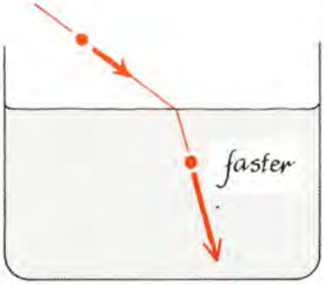
Experiment 41
'Reflection' of a Particle

Does a ball thrown at the wall bounce with angles that fit the reflection rule?

Bullets? Rays of light are *refracted* (bent) when they enter water or glass from air. If light is a stream of bullets, what must happen to a bullet of light when it enters water from air, and its path is bent?

In the diagram the ray is bent *downward* as it enters water. The light-bullet must be pulled downward by some force as it enters water—just a sudden tug made by the water. But what *must* happen to the bullet's speed if it is tugged like that? (A real bullet fired into water would go



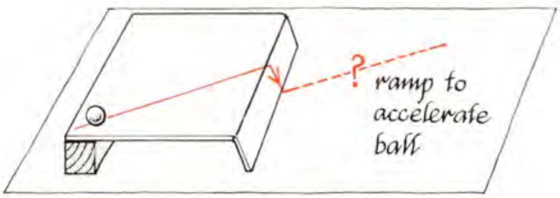


straight on. Also it would begin to slow down at once and finally come to a stop. A light-bullet would have to behave differently.)

Try a model with a rolling ball, with gravity allowed to give it a successful tug.

Experiment 42
Particle Model of Refraction *(OPTIONAL NOW)*

Set up a small level plate to represent 'air', with a short downhill slope to the table. Gravity will make its successful tug on that slope. Arrange a launching ramp for the ball on the upper plate. Let the ball roll along a slanting path. Watch what happens to its path, and its speed.



That model suggests that light bullets (*if* that is what light is) must move faster in water or in glass than in air.

Waves? Suppose, instead, light is a stream of waves. Did you see water ripples being 'refracted' when they travel from deep water to much shallower water, with a change of speed at the boundary? That was Experiment 4t in Chapter 1. If you postponed it, you should try it now.

Experiment 43
Refraction of Ripples

This *is* Experiment 4t in Chapter 1. Look at the description there and try the experiment.

Do the ripples change speed at the boundary between deep and shallow water?

If they strike the boundary at a slant, are their guiding 'rays' bent?

By watching real ripples, decide whether light, *if it is a stream of waves,* must travel faster in water (or glass) than in air, or slower.

Decision? *Can you think of a 'crucial experiment' which would help you to make a decision between these two 'thinking-models' for light?* Such an experiment has been done. Ask your teacher about it.

More Experiments and Arguments
(OPTIONAL NOW)

There will be experiments and discussion concerning the 'Bullets *vs* Waves' question for light in *Pupils' Text 5*; but if you are specially interested you may want to pursue the rival models now.

You may have decided already, by asking your teacher about the 'crucial experiment'; but that experiment might not be completely conclusive so you had better wait and see. Before you make up your mind, try some more experiments.

Suppose light *is not* a stream of bullets, but is a train of waves instead. What experiments could show its 'waviness', as the patterns did for water waves in the ripple tank? You could *see* the water there; but light passes freely through air and through open space between the Sun and us, and even between the stars and us. So, if there are light-waves, they cannot be waves in stuff like water or rope, stuff that you can see or feel.

Experiment 44
Special Ripple-Tank Experiments for Comparison with Light *(OPTIONAL NOW)*

44a Straight ripples pass through a gateway

Arrange a ripple tank with $\frac{1}{2}$ cm of water, with the motor and beam to make straight waves.

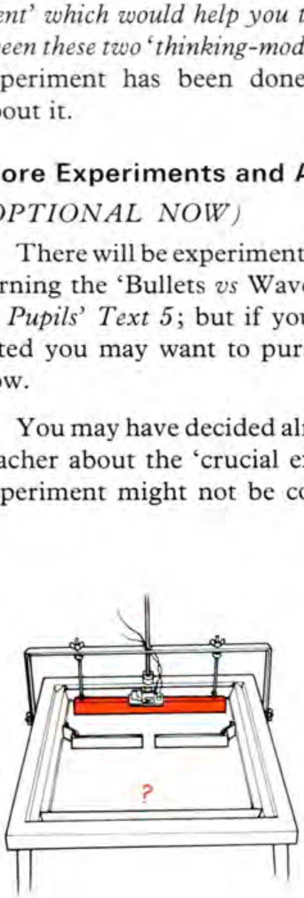
Let the waves meet a wall across the tank, with a narrow gap in the middle. Watch what the ripples do as they pass through the gap. Try making the gap *wider* and then *much narrower*.

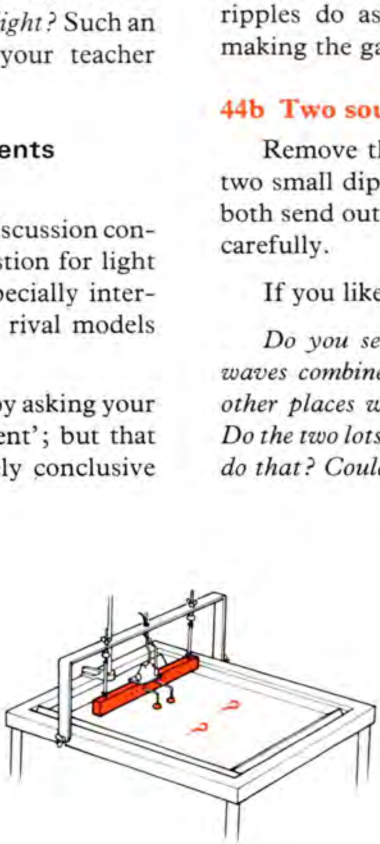
44b Two sources make Ripples

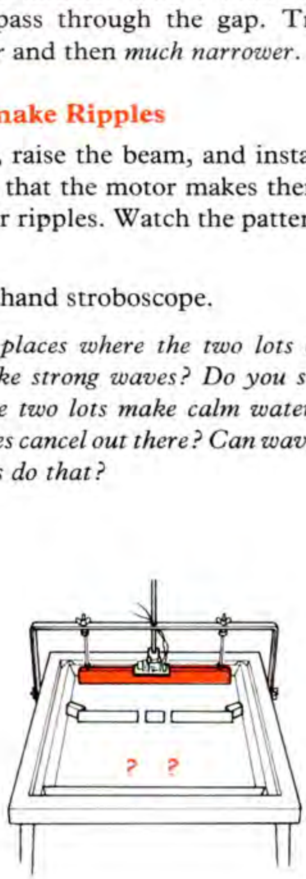
Remove the wall, raise the beam, and install two small dippers so that the motor makes them both send out circular ripples. Watch the pattern carefully.

If you like, use a hand stroboscope.

Do you see some places where the two lots of waves combine to make strong waves? Do you see other places where the two lots make calm water? Do the two lots of waves cancel out there? Can waves do that? Could bullets do that?







44c Double gateways *(DIFFICULT)*

Repeat (b), if you like, with straight waves meeting two very narrow gateways close together. For water ripples this is much the same as (b) but harder to arrange and see. But the experiment you will try with light is more like (c) than (b).

Experiment 45 Special Experiments with Light for Comparison with Water Waves *(OPTIONAL NOW)*

Demonstration 45a Sharp Shadows?

See the shadows of a plate with holes in it and of various other objects, cast by light from a very small bright source. If light is a stream of speedy bullets, the plate with holes should cast a dark shadow with round patches of light for the holes.

Look closely at the metal plate with holes and any other objects held beside it in the light. Hold a sheet of paper JUST BEYOND the objects and see sharp shadows.

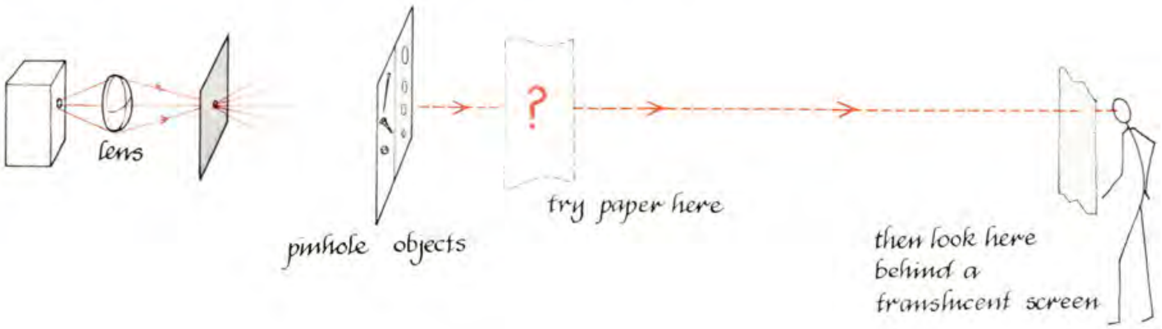
Then go *much* farther away and catch the shadow on paper.

The pattern is probably too faint to see clearly on a wall at that distance. Therefore, let it fall on a screen of TRANSLUCENT paper and LOOK AT THAT FROM BEHIND.

What has the light done that passed through small holes?

See the strangest sight of all: the shadow of a small ball or disk. *Could bullets pass by a ball, or bounce off it, and make what you see there?*

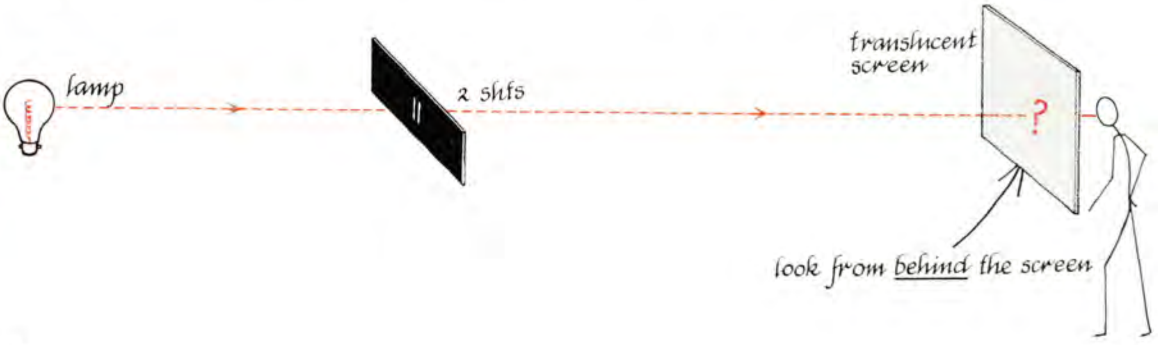
For comparison with the ripples passing through a gateway, see what the light does when it passes through a slit in a plate; first a narrow slit, then a very narrow slit, then an extremely narrow slit.



Experiment 45b Light from a Pair of Slits: 'Young's Fringes'

The shadows are strange; but the clearest witness to give evidence in the dispute about light is this experiment.

Let light pass through two narrow openings (double slits) and go on to a screen far away. (This is rather like the ripple-tank experiment with two gateways.) THIS EXPERIMENT IS TO FIND OUT WHAT YOU CAN SEE ON THE SCREEN.



Use a ray-streaks lamp as source of light, near one end of the room. Make sure its filament is STRAIGHT and VERTICAL.

Ask for a small sheet of glass coated with black paint. You can scratch two slits in the paint very close together. Then, if light shines on the black sheet, two lots of light will get through the slits and make two patches of illumination on a screen at the far end of the room. If the slits are thin and close together the light from each slit will spread and the two patches will overlap. *What will you see there?*

To make the slits, hold a ruler across the glass sheet and scratch the black paint away by dragging a blunt pen along the ruler. To make the second slit, hold the ruler there, but tilt the pen and drag it again. The slits need to be *very* close, about $\frac{1}{2}$ millimetre apart, or even less.

(You may be offered a special machine to hold the glass and guide for the making of slits, but simple ruling is quicker. An old ink drawing-pen is best of all. Its two blades rule the two slits in one go.)

Make several pairs of slits. Then ask your teacher to look at them and choose a pair that will behave well.

Place the slits in a clamp, one or two metres from your lamp. Make sure the slits are VERTICAL, parallel to the lamp filament.

When the room is dark, hold a piece of paper just beyond your pair of slits and see the light that comes streaming through and spreading out a little.

Then go as far away as possible—it must be several metres—and hold a *translucent* screen of greaseproof paper there. Place the paper to catch the light that has come through the pair of slits.

Go round BEHIND the SCREEN and look at the bright patch where the two lots of light overlap.

What do you see? What do you think that tells you about light?

A Discussion of Waves 'Interfering'*

Think about the waves from two sources in a ripple tank. They make a strange pattern, because their effects add together.

Interference Patterns in a ripple tank At some places in a ripple tank, wave trains from two sources arrive in step with each other. One wave arrives and makes the water bob:
UP-AND-DOWN, UP-AND-DOWN . . .

The other wave arrives and makes the water bob:
UP-AND-DOWN, UP-AND-DOWN . . .

There the two waves add together and make the water bob:
UP-AND-DOWN, UP-AND-DOWN . . .

But at some places one wave has to travel a little farther than the other and they arrive *out of step*. There, while one wave makes the water bob:
UP-AND-DOWN, UP-AND-DOWN . . .
the other wave makes the water bob:
DOWN-AND-UP, DOWN-AND-UP . . .

The two waves add together and there is . . ? . .

So there is a pattern of places where there is much motion UP-AND-DOWN, and places where there is no motion.

Can you imagine bullets doing that, adding up in some places (BULLETS + BULLETS making BULLETS) and cancelling in others (BULLETS + BULLETS MAKING . . . ?)

Now think about what you saw from light coming from two slits.

Demonstration 46
Plastic Wave Model to explain Interference

You may see the demonstration sketched, a teaching-model made of two strips of plastic or wood with a wavy pattern on each. These represent two streams of waves. When you have seen that, try making your own model with strips cut from corrugated cardboard.

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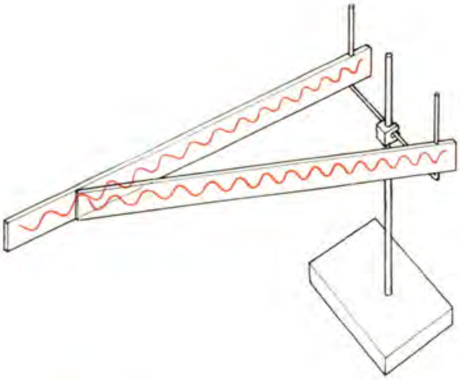
*Where the waves arrive 'out of step', the scientific name is a very misleading one: '*interference*'. Waves don't bother or upset each other; they simply add up.



Experiment 47
Model of Wave Interference, with Corrugated Cardboard

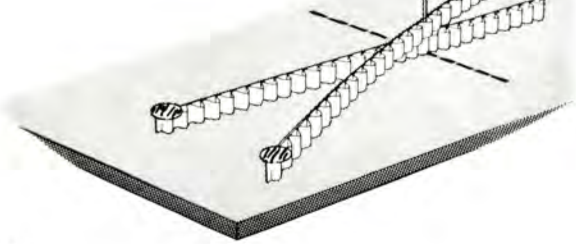
Cut two long narrow strips from the cardboard. Place them *on their sides* on a drawing board. Pin each strip to the board by a drawing pin through a wave-hump near one end.

Those anchored ends should be a few centimetres apart. They represent two sources of waves, like the two slits for Young's fringes.

Near the other end of the board mark a line to represent the screen where you expect to find a pattern of 'bright' and 'dark'.

Pull the two strips taut and stick a single pin through two wave-humps (one hump of each strip) to find a place on the 'screen' where the waves add up to 'bright'. Find several such places on the 'screen'.

This is an experiment you could show at home to explain Young's fringes if you show the real experiment with light there.



Interference Patterns made by Thin Films

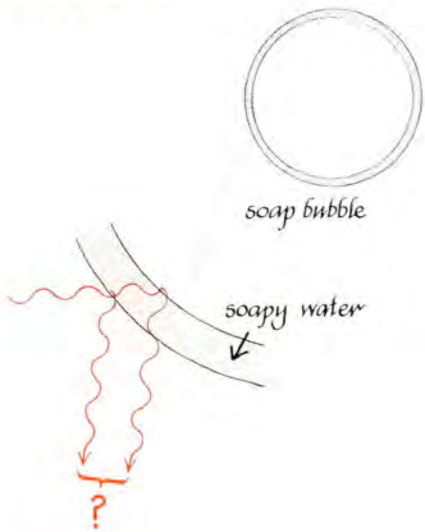
Instead of using streams of light from two slits, you can use streams of light reflected by two mirrors very close together, one behind the other.

The light comes from one original source. Reflection by a mirror makes the reflected light seem to come from the image of that source. The two mirrors make two images, close together, which serve as (virtual) sources.

The mirrors must not be silvered ones like an ordinary looking glass, because then no light would get through to the second one to be reflected. The mirrors are the front and back surfaces of a piece of soap bubble, or of a piece of very thin glass sheet.

With the help of the model, you saw how the bands of bright and dark (Young's fringes) are made by differences of *path-length* from the slits to the screen. In this case they are made by differences of *film-thickness*.

The light has to travel farther for the reflection at the back of the film. Since it travels through the film and back, its extra path is just twice the thickness of the film. So you see the bands of dark and light or bands of different colours according to the thickness of the film.

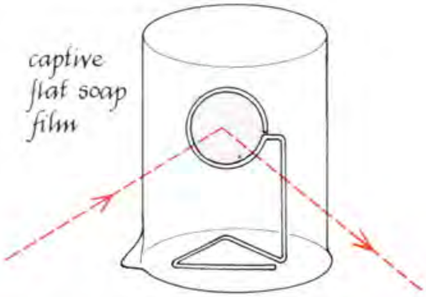


Demonstration 48
Soap Film

If you blow a soap bubble you see a fine display of colours as it drains to a thinner film of soapy water. It becomes thinner and thinner at the top and remains thick at the bottom.

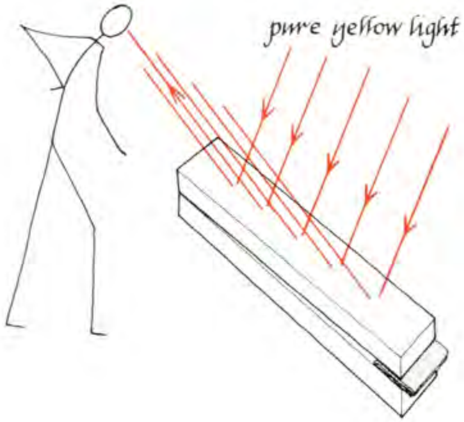
It is easier to see the bands of colours if you make a *flat* soap bubble by dipping a ring of wire in soapy water. A vertical flat film drains to a wedge shape in thickness.

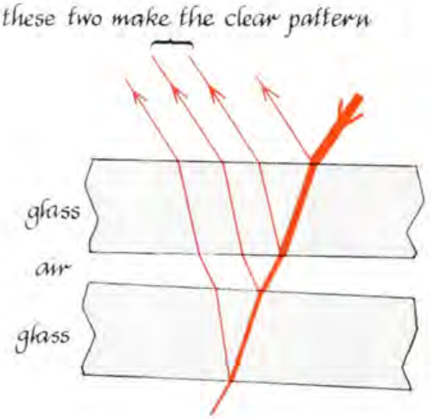
Preserving a bubble. Soap bubbles grow thinner as they drain but they soon grow too thin and break. That is because water evaporates from them too fast. But you can keep a bubble for a very long time if you shelter it with a wet jam jar or glass beaker. Rest the bubble on a small scrap of flannel or carpet; wet the jar inside, and invert it over the bubble.



The thinnest spot. Let a bubble or flat film drain. When the thinnest part at the top gets *very* thin you will see an unexpected sight. Watch for it.

Why are there colours? Look at a soap bubble (or flat film) through a red filter then a green one in quick succession. *What do you guess from that?*





Experiment 49
A Thin Film of Air

Make a sandwich of two plates of glass with a very thin layer of air between them. That layer of air can take the place of a soap film.

Make the layer of air wedge-shaped by propping the plates apart at one end with a scrap of thin tissue. Clamp the plates together with a bulldog clip at each end, so that the thickness of the air layer is zero at one end and one tissue-thickness at the other end.

Hold the sandwich in front of a wide source of pure yellow light; and look at the source's image reflected by the sandwich.

There are four streams of reflected light: two from the inner faces of the sandwich, where glass meets the thin wedge of air; and two from the outer surfaces of the glass plates. The two streams from the inner faces have a small path-difference (about twice the thickness of the air wedge at each place); and you will see interference bands of bright yellow and black. The air wedge is behaving like a drained wedge of soap film.

The streams reflected from the outer surfaces of the glass plates have too great a path-difference to show an interference pattern noticeably.

Newton tried this experiment using a very weak positive lens instead of one of the plates. He pressed the lens hard against a glass plate. Can you predict what he saw, even in white light? If you like, ask for a very weak positive lens and test your answer.

Other Examples

When you receive radio on VHF, the antenna may pick up two signals, one direct from the broadcasting station, the other a little late after reflection by some wall nearby. Those may combine to produce a loud sound ('bright fringe') or a soft sound ('dark fringe'). Move your radio to a different place in the room and you may move from 'dark' to 'bright' or vice versa.

If you are watching television on a receiver with an indoor aerial which stands on top of the set, you may find that the picture suffers from interference which can be caused by you moving about near the receiver. The effect is similar to the brightening and darkening seen in Young's fringes.

When an aircraft flies overhead, waves reflected from it may 'interfere' with direct waves from a broadcasting station and you may see this effect spoiling your TV 'picture'.

[*Radar*. A radar picture is different. A short pulse of radio waves, of very short wavelength, is sent out from the ground. An aircraft far away reflects a little of that pulse, but the reflected waves arrive back at the ground after the original pulse has ended so there is no interference pattern. But it makes a very useful signal, a blip on an oscilloscope screen.

Depth sounders on ships use sound waves in much the same way as radar uses electromagnetic pulses.]

Moving interference patterns In the examples mentioned so far, fringes are made by two streams of waves of the same frequency, the same wavelength—the same pitch if they are sound waves, the same colour if they are light.

If one stream has slightly different frequency and wavelength from the other, the fringe pattern will move; it will sweep across the observer. That is how you hear 'beats' when two musical instruments play notes that are almost, but not quite, the same.

Questions

THEORIES OF LIGHT (OPTIONAL NOW)

22. *(A question which will appear again in a later year.)*

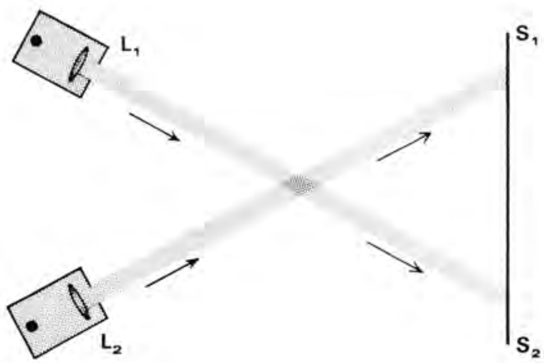
a. A friend says, 'I've never thought about it before, but I suppose the idea of light being particles, rather like bullets, does explain some things. It explains why light travels in straight lines so that an electric-light bulb *is* where I see it, and not somewhere round a corner. But what else does it explain?'

Write a few sentences telling your friend, in *your own words*, how the particle theory explains: (a) reflection, and (b) refraction, of light.

b. Your friend then says, 'We can have a very bright light or a very dim light, and anything in between. How do particles explain *that*?' What is your answer?

23. *(An optional question for thinking out and guessing.)*

Two boxes L_1 and L_2 contain lamps and lenses, and they produce beams of parallel light which shine on a screen and make spots of light S_1 and S_2. The beams are arranged to cross (pass through) each other. Absolutely no difference is noticed in spot S_2 when L_1 is switched off, or in S_1 when L_2 is switched off.



Suppose light does consist of particles, what conclusion do you draw from this experiment?

24. Suppose we assume a particle theory of light. The particles of light cannot be very *strongly* attracted by matter, otherwise we should find rays of light being bent when they pass near benches or tables, etc. However a more exact and delicate experiment done in the lab might detect something.

a. Imagine you have a 'massive object' in the form of a large ball of lead, say $\frac{1}{4}$ metre in diameter, also a lamp and lens to make a narrow parallel beam of light rays. You may have any other ordinary apparatus you want. How would you do your best to detect a bending of light by the lead ball?

b. Suppose your experiment in (a) gave no sign of bending. What could you in fact safely say about light particles? What conclusion could you draw from such an experiment?

25. A photographer's light-meter measures the 'strength' or 'intensity' of light falling on it.

A light-meter is placed first 1 metre from a small light source and then 2 metres. At the 2 metres distance the strength of the light is only one-quarter of what it is at 1 metre. Explain how this observation is explained by a 'bullet' theory of light.

YOUNG'S FRINGES (OPTIONAL NOW)

26. *(If you have not seen Young's fringes made by real light passing a pair of slits, omit this question.)*

Imagine you are asked to set up the apparatus to show the fringes to two or three members of your class who were absent before. You have an electric lamp with a straight filament, a 'double slit', and a sheet of oiled paper (with, of course, the means of supporting them).

a. Where would you place the lamp, the double slits, and the oiled paper? And where would you place the pupils to see the fringes? (This is best answered by a sketch with labels.)

b. Suggest suitable distances between those things, or mark them on your sketch.

c. Would you start by placing the double slits so that they are parallel to the filament? Or at right angles? Or at some other angle?

d. What would you suggest for the spacing between the slits? 0.15 cm? 0.5 mm? 0.05 mm? 0.005 mm?

e. If you drew the slits too far apart, making the spacing too great, how would that affect the appearance of the fringes?

f. Suppose you show the 'white light' fringes; then put green glass or green celluloid in front of the lamp. Someone then asks, 'Why is it I can now see *more* fringes than before?' What would you say to that? How would you use a red filter (red glass) to support your explanation?

You would point out to your 'pupils' that here we have 'light + light = no light'. You ask them what other experiment they have seen in which (something) + (something) could give nothing. What do you hope they will reply? Describe briefly the experiment you would then like them to repeat.

DIFFRACTION (OPTIONAL NOW)

27. *(Did you see a very small source of light casting shadows of various small objects on a screen far away? If so, you may like to try the following questions.)*

a. When the screen was far away, did the shadows have sharp edges?

b. What did the shadow of a needle's eye look like? If you remember it, sketch it.

c. A metal plate with holes cast a shadow. The light passing through the holes made round bright patches. Were those patches bright all over, or did you see something strange?

e. Did you put small obstacles in a ripple tank? If so did you see them casting 'sharp shadows'? Or did the ripples seem to bend round the edges?

SPEED OF LIGHT (OPTIONAL)

28. Many years ago, before people knew how fast light travels, two men tried to measure the speed of light by copying a method used for the speed of sound.

They stood several miles apart, each on a small hill. Each had a lantern fitted with a dark shutter that could be opened for a moment to let out a flash of light. So the men, X and Y, could signal to each other. One man, X, had a clock that could measure time in quarter seconds.

After some practice in sending signals to and fro, to show that all was ready, X sent a flash from his lantern to Y. At the same instant of time he sent the flash X noted the reading of his clock. As soon as Y saw the flash, he immediately sent a flash back to X. And X noted the time when he saw the return flash.

In the time-interval, t, measured by X on his clock, light had travelled $2d$, twice the distance between the hills. So they thought they could easily calculate the speed, namely $2d/t$.

They did observe a very small time-interval t, a fraction of a second. But the trouble was that changing the distance d seemed to make no difference to the time t. Whether they were close together or far apart, t remained about the same.

a. How do you account for the fact that there *was* a time-interval, but that it did not seem to depend on the distance?

b. Can you suggest an improvement? It might be better to replace the man Y by . . ? . .

c. *(Advanced Question)* The man X must also be replaced by something that can open and close a shutter much more quickly than he can. You have used something that might be suitable: a stroboscope disk with slits. Try to suggest a way of finding the speed of light. If you can guess one, sketch it and ask your teacher if this is one of the ways in which the speed of light has been measured successfully.

CHAPTER 4

MOTION AND FORCE

Informal preparation for Newtonian dynamics

Physics asks a lot of questions about *motion*: about the speed of things; about things moving faster and faster; about forces that make things move; . . . And physics answers some of those questions. Here are some questions that you may meet this year or later:

(1) How does an Earth satellite keep going without using up fuel?

(2) What does a space ship do, far out in space? Does it travel slower and slower or keep the same speed as time goes on? Does it travel in a circle or in a straight line or how?

(3) When a policeman starting out on a motor cycle speeds up to 30, 40, 50, . . . kilometres per hour, it takes him some time, and some petrol, to reach 70 kilometres per hour. What is it that prevents him reaching that speed *at once*? Is it air resistance, or road friction, or something else? (Try starting to run carrying your younger brother on your back; try again without him.)

(4) Suppose a rocket has a downward blast of hot gases that is just strong enough to keep it hovering a short distance about the ground (without rising or falling). What will that rocket do *with the same blast* if it is aimed horizontally? What will the force-measuring machine on a test bench show, if the same rocket is fired horizontally but is kept at rest, tied up to the machine?

(5) Can a rocket go faster and faster in a vacuum?

(6) Does a railway diesel engine need friction on the rails?

(7) If a diesel engine pulling *ten* carriages takes 30 seconds to speed up to 50 kilometres per hour, how long will the same engine take if it is pulling *twenty* carriages?

(8) Is there any force pulling or pushing the Moon as a whole?

(9) Some radio-active atoms shoot out a small particle—a chip of their central core, their nucleus. In some cases that is an 'alpha-particle', which turns out to be a helium nucleus itself. Then the remainder of the original atom is quite a different atom with different chemical properties. When an atom at rest shoots out a high-speed alpha-particle like that, does the rest of the atom recoil (bounce backwards) faster than the alpha-particle, or slower? Or does it not recoil at all?

To find out answers for such questions you need some knowledge about SPEED and CHANGES OF SPEED.

Class Demonstration 50
Motion of a Ball rolling Downhill
Acceleration

a. Let a large marble or a steel ball run down a channel on a sloping plank. Watch its motion.

Hang above the channel some scraps of metal as flags for the ball to hit as it runs. Then you can hear the progress of the ball by the 'clink' that it makes as it hits each metal flag.

Start by arranging the flags equally spaced all the way down the plank. If you have a strip of pegboard behind the plank, space the flags every 8 or 10 holes from the starting point. (If you have some other arrangement, space them every quarter metre: $\frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1, 1\frac{1}{4}, \ldots$ metres from the start.)

Listen to the clinks as the marble runs down the plank. *Is it moving with constant speed, or faster and faster, or slower and slower?*

We say the marble is accelerating. That means 'moving faster and faster'. Or we say it has an *acceleration.*

When we put the brakes on in a car and it moves slower and slower, we can say the car has a *deceleration.* But it is better science to say the car has a *negative acceleration.* (Better science because it is more economical: the same word, acceleration, fits into both stories.)

b. *Listening to accelerated motion.* Suppose you wish to hear the clinks *equally spaced in time*, so that they sound like a perfectly regular series of drum beats. You will have to move the metal flags. Try that.

Leave the first flag where it was and move the others till you hear the sounds, clink . . . clink . . . clink . . ., quite regularly.

If that is difficult, just leave it. You need not finish this part of the experiment.

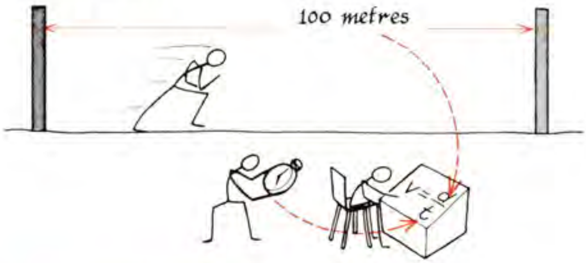
Home Experiment H50
Ball Rolling Downhill

That is also an experiment you could try at home. You could use any markers that will make a noise when the marble hits them, such as match-boxes, coins, or paper clips. Raise one end of a table to make a slope. Hang coins by tape from piles of books.

Measuring Speeds

Experiment 51
Measuring Your Own Speed

Time another pupil while he runs 100 metres, or several laps of the length of the classroom. Then let him time you.



51a Rough measurements

Use the clock on the classroom wall or your watch if it has a large hand that goes round once a minute. Or, if your own watch has a small 'seconds hand', use that with a magnifying glass.

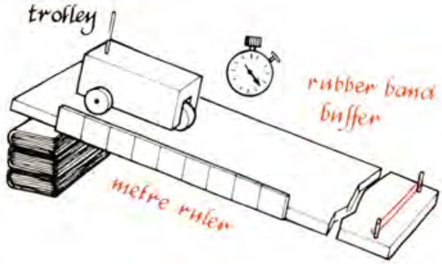
51b Precise measurements

Use a stop-watch or an electric stop-clock.

Record the measurements of distance and time. Work out your speed by dividing distance by time. That will tell you the speed in metres per second.

That gives you a measurement of a speed which stays much the same as you run. You will soon need to make measurements of moving things that accelerate, things which *change* their speed, like a car speeding up or slowing down. Then you need careful measurements of short times. Try using a stop-watch for a marble or a small cart running down a hill.

Experiment 52
Timing a Coasting Cart



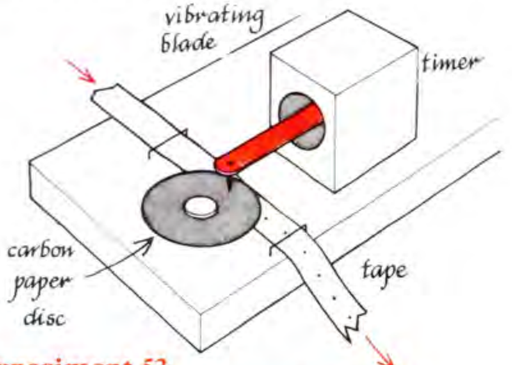
Let a trolley run down a sloping runway. Use a stop-watch to find out how much time it takes for the first $\frac{1}{2}$ metre from start. Then measure the time for the *next* $\frac{1}{2}$ metre after that, then the next $\frac{1}{2}$ metre, and so on.

What do your timings tell you about the motion of the trolley?

Even though you use a stop-watch, you will find your measurements are rough. The times for successive half metres are too short to tell a clear story. You need better measurements of time.

Ticker-timer

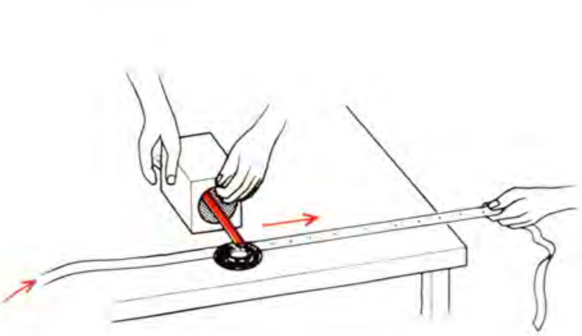
You need better measurements of time. So you should use a 'ticker-timer'. This has a vibrating blade, rather like the arm of an electric bell. It is driven electrically at a regular rate.



Experiment 53
Trying the Ticker-timer and Tape

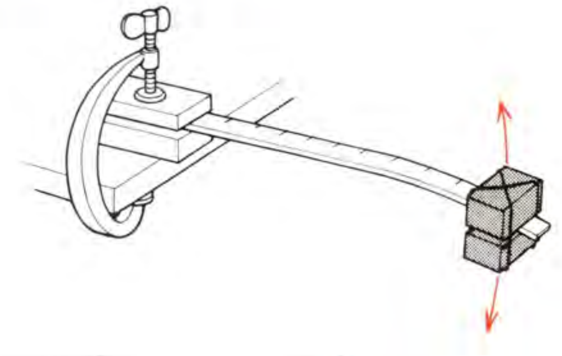
The end of the blade has a small knob that hits a piece of carbon paper and makes a dot on the paper tape underneath.

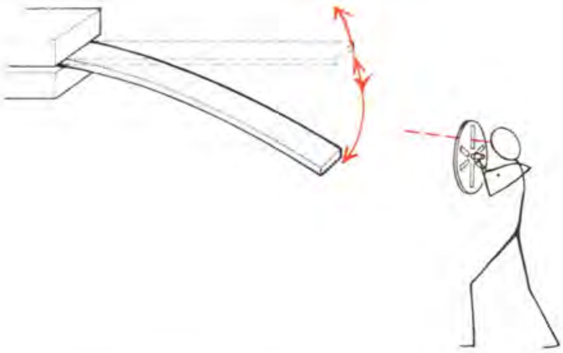
Put some tape under the carbon paper disk and drag the tape through, so that you can see all the dots made by the knob.



Experiment 54a
Giant Model of Ticker-timer

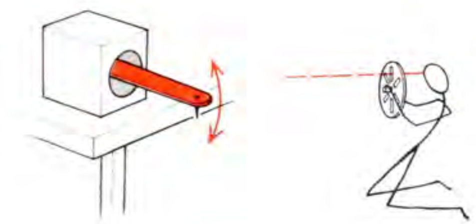
a. Watching a giant timer. Watch the slow vibrations of the loaded blade. Can you time them with a stop-watch? *When the load is removed can you time the rapid vibrations?*





b. Watching a giant timer with stroboscopes (OPTIONAL). How could you be sure the blade vibrates regularly and does not change its rate? Try using a hand stroboscope. (See the description of stroboscopes in the ripple-tank experiments.) *How would you know from that whether the blade vibrates regularly?*

Experiment 55
Watching a small Ticker-timer with Stroboscopes *(OPTIONAL)*



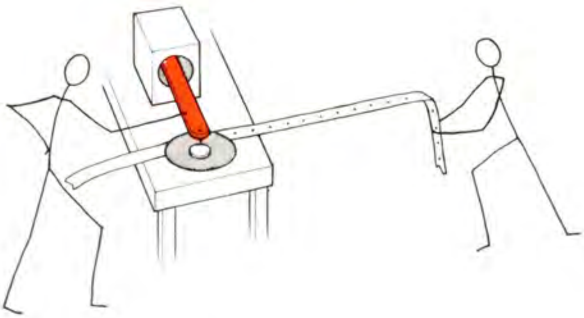
If you like, use a stroboscope to watch the vibrating blade of the ticker-timer you are going to use.

Experiment 56
Using the Timer as a Clock

If your timer vibrates quite regularly you can use it as a clock. You do not know the actual time, in seconds or fractions of a second, that it takes from one hit on the carbon paper to the next. So we shall call that amount of time 'one tick'.

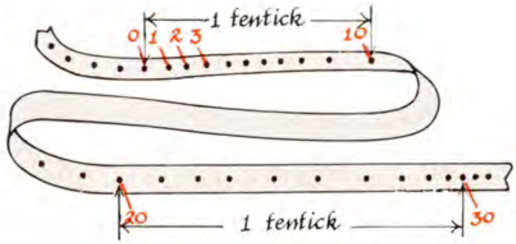
Ask your teacher to give you two signals, by clapping his hands. Measure the time between those two signals in ticks. Pull the tape through; then count the number of spaces between dots. Your partner needs to switch the electric timer on at the first signal and off at the second, while you pull the tape through.

Experiment 57
How long IS one tick? How many Ticks in 3 seconds?



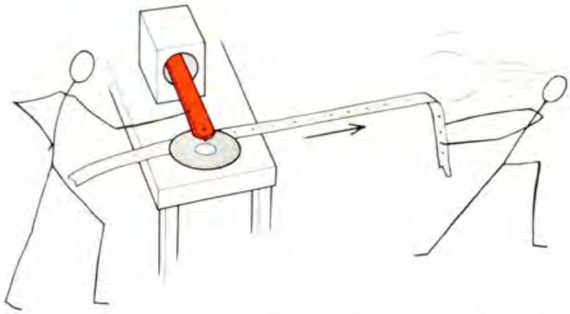
This is like the last experiment, but you should have the two signals just 3 seconds apart. Make the two signals, by watching a stop-watch or a big clock.* Then you can find the rate of your timer; that is, the number of ticks it makes in each second. And you will know how much time it takes for one tick, or for ten ticks.

A 'tentick' You will find ten ticks make a useful length of time, so we shall call that one '*tentick*'. That is the time from dot No. 0 to dot No. 10 on the tape. (Also from dot No. 10 to dot No. 20.)

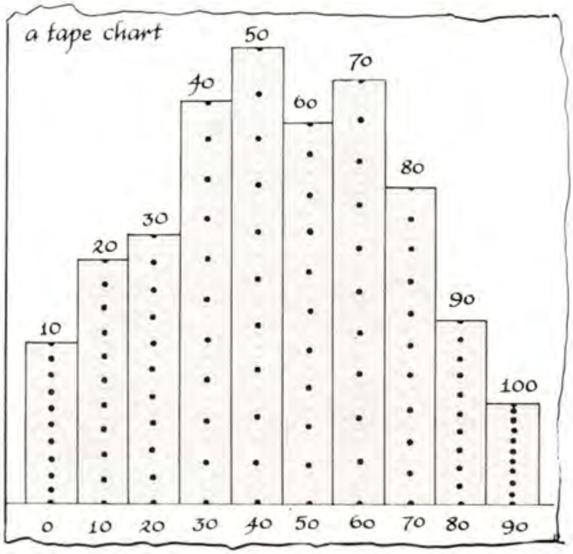


Experiment 58
Analysing your own Motion

Let your partner operate the timer while you walk away from it, pulling the tape. Also try running.



The dots are made by the vibrating blade at regularly spaced *times*. But they will not be equal *distances apart* along the tape, because you do not walk at absolutely constant speed.



*If you are in a large group, of 4 or more pupils all using one timer, make the signals 10 seconds apart. Then share out the counting of the dots among the group.

Find out how far you walked in the first 10 'ticks' from dot No. 0 to dot No. 10. That is how far you walked in one 'tentick'.

Cut off the strip of tape for the first tentick period of your walk and paste that on a sheet of paper. Cut off the next tentick strip and paste that strip beside the first one, and then the next, and so on for all your tape. Each strip shows how far you walked in one tentick of time.

If you put all the strips on your chart with their feet on the same line at the bottom, their *heads* will show you how your speed changed as you walked.

Here are some questions to think about, which will help you to understand what your tape-charts mean.

A. If a pupil ran along without changing his speed at all (that is at *constant* speed), what would the line of tops of the tape chart look like?

B. Can you describe the way a pupil was running if the tops of the strips on the chart make a *horizontal straight line*, all the same height?

C. Suppose the runner is speeding up, going faster and faster and faster. What will the line-of-tops look like?

Progress Questions

TIMING

1a. I have got a watch which ticks 4 times a second. How do you think I found out this was its ticking rate? If you have got a watch, see if you can find out how many times a second yours ticks. (HINT. There are 60 seconds in a minute.)

b. Listening to my watch, I timed two people running the length of the laboratory. A took 18 ticks, and B took 15 ticks. Which was running faster?

SPEEDS

2. Copy and complete:

If you travel 10 kilometres in 2 hours, your speed is . . . km per hour.

If you travel 15 kilometres in $\frac{1}{2}$ hour, you would travel . . . km in 1 hour, and your speed is . . . km per hour.

If you run fast at 20 kilometres per hour for 2 hours, you will cover . . . km.

3. In one second, sound travels 340 metres, so we say the speed of sound is . . ? . . metres per sec.

If a small plastic ball falling through water goes 20 cm in 10 sec, we say its speed is . . ? . . cm per sec.

4. When I went on my holidays, the journey was in lots of parts:

a. 1 km at 5 km per hour, walking.

b. 5 km at 30 km per hour, in a bus.

c. 160 km at 80 km per hour, in a train.

d. 800 km at 800 km per hour, in a plane.

e. 20 km at 60 km per hour, in a coach.

f. $\frac{1}{2}$ km at 4 km per hour, in a gondola.

(i) How long did the journey take?

(ii) And where did I go to?

5. People usually walk at about 5 km per hour (≈ 3 miles per hour). Think about some places you walk, and write out a sentence like this for each one.

When I walk from . . . to . . . it takes me about . . . hours/minutes, so the distance must be about . . . kilometres.

6. Think about a journey from London to Edinburgh, by car.

a. Suggest a sensible speed for the car.

b. The journey is about 800 km. How long will the *driving* take?

c. How many stops (for rest, food, petrol) do you think you would need?

d. How long will the whole journey take?

7. Copy the chart and fill in the blanks. Be careful to say whether your number is a number of seconds, or kilometres, or kilometres per hour, or whatever.

	Distance covered	Time taken	Speed
a	10 kilometre	2 hours	
b	15 km	$\frac{1}{2}$ hour	
c	10 km	$\frac{1}{4}$ hour	
d	180 km	3 hours	
e	20 km		10 km per hour
f	5 km		10 km per hour
g		2 hours	50 km per hour
h		2 hours	3 km per hour
i	6 km		3 km per hour
j		4 hours	3 km per hour
k	25 cm	5 sec	
l	100 cm	2 sec	
m	1 km	$\frac{1}{2}$ sec	
n	50 cm		10 cm per sec
o	5 cm		10 cm per sec
p		10 sec	100 cm per sec
q		$\frac{1}{2}$ sec	100 cm per sec

(OPTIONAL) Try the following (**r, s, t, u, v, w**) if you travel in a car that has the speedometer marked in *miles*, not kilometres; or if you think of a smart walking pace as 4 miles per hour; or if you know the record of a 'four-minute mile'.

	Distance covered	Time taken	Speed
r	10 miles	2 hours	
s	180 miles	3 hours	
t	20 miles		10 miles per hour
u		2 hours	50 miles per hour
v	8 miles		4 miles per hour
w	1 mile	4 min	? ft per sec

8. A bus takes 30 minutes to do a journey of 8 km

a. What is the *average* speed of the bus? (Give your answer in kilometres per hour.)

b. Suppose the bus stood still at stops or traffic jams for a total of ten minutes during the journey. What is then its average speed while moving?

WHAT DO TAPE + TIMER TELL US?

9a. *(i)* Suppose you have a long strip of paper and wish to make marks on it spaced at equal distances apart, say every 5 cm. The spacing need not be accurately 5 cm as long as the distance from one mark to the next is the same all the way along. How would you do that, given any apparatus you wanted?

(ii) How would you make the marks on the tape at equal distances as in *(i)* if you had no equipment except a pencil and another *short* piece of tape?

b. (This is a question about equal spacing of times, *not* of distances.)

Suppose you move your finger along the paper tape from one end to the other. Ask a neighbour to take a pencil and mark the paper to show where your finger is after one second, after two seconds, three seconds, from the start. Then those marks are separated in TIME by one second between each mark and the next.

c. What would the DISTANCE between one mark and the next on the marked tape of (b) tell you?

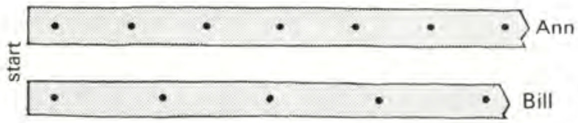
TAPES

10a. How many spaces are there between dot 0 and dot 10?

b. We call the time between dot 0 and dot 10 a 'tentick'. Why?

c. Measure how far the tape moved between dot 0 and dot 10, i.e. in 1 tentick.

VIBRATOR AND TAPE



11. Here are tables of two children who ran.

a. Who was going faster?

b. How can you tell?

12. Here are tapes for three pupils.

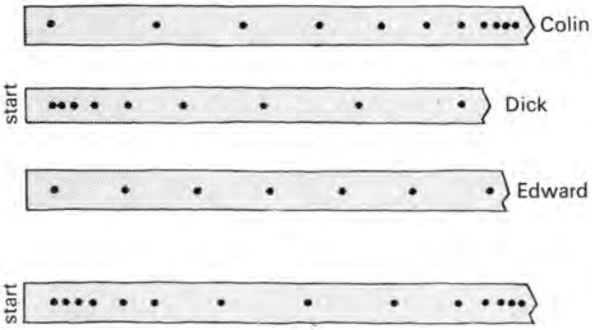
a. Who started off slowly, then got faster?

b. Who started off fast, then got slower?

c. Who went at a steady speed? How can you tell?

13a. What was happening?

b. Draw the sort of pattern of dots you would get for a tape that is pulled through fast, then slow, then fast again. Label the fast parts and the slow part.



Questions

TIMING

14. Find out how good you are at estimating a time interval of half a minute. Check your time-sense by trying the following experiment on yourself. You will need a watch or clock with a seconds hand.

Look at the seconds hand while 30 seconds go by, so that you get a good *preliminary* idea to start with, or what 30 seconds 'feels like'.

Now shut your eyes and keep them shut until you think that 30 seconds have passed. Notice the time on the seconds hand just before you close your eyes and again when you open them. How many seconds were you wrong by?

Repeat this six times more, and make a list of the errors you made in all seven estimates.

a. Does your list show that you were getting better, or getting worse, at estimating 30 seconds?

b. What was your *average* error in the *last five* estimates you made?

15. Seconds of time may be counted by saying '*Mississippi one, Mississippi two . . .*' (or else '*one little second, two little seconds . . .*') saying each syllable clearly at normal speed. Use this method to estimate 30 seconds with your eyes shut. Do it five times and compare.

a. Find the average error in these five counts with the average error you found in Q.14b.

b. Is the new average error greater than in Q.14b, or the same, or less? Is this method an improvement?

16. A simple pendulum consists of a small bob hung on a light thread about a metre long. The other end of the thread is held tightly between two slabs of wood.

Suppose a pendulum makes 100 complete swings in 184 seconds. (NOTE. A complete swing means a complete cycle, one 'swing-swang'.)

a. What is the time it takes for 1 complete swing? For $\frac{1}{2}$ a swing? For $\frac{1}{4}$ of a swing?

(Advanced question)

b. Why would you *not* expect the time for $\frac{1}{8}$ of a swing to be half that for $\frac{1}{4}$ of a swing?

17. A stick of wood, about a metre long, has a hole near one end. The stick is hung on a nail through the hole as in the sketch and allowed to swing like a pendulum. Describe how you would find by experiment the length of the simple pendulum which has the same time-of-swing as the stick. Sketch the apparatus you suggest.

Try this if you like; and look for an interesting result.

18. Here is a way of making a simple water-clock for measuring short intervals of time. Find a tin can (such as a fruit tin). Remove the top of the can completely with a tin-opener. Punch a small hole in the bottom of the can with a nail and hammer. Make a mark near the top—a dent will do, or a mark with a greasy pencil.

Hang the can over a sink so that the water in the can can be kept up to a dent (or a fixed mark scratched inside the can) near the top. Pour in water from a jug (or use a tap over the sink). Make sure there is room under the can for a measuring cylinder to be held there.

a. How could this arrangement be used to measure time intervals of a few seconds?

b. Keeping the water-level up to the mark is a nuisance. Can you invent a different design which would avoid this trouble? If so, describe it or sketch it.

VIBRATOR AND TAPE

19a. Two pupils have a stop-watch as well as a vibrator and tape. Their vibrator runs at an unknown rate. They want to find 'How many ticks in 5 seconds?' Tell them how to do this.

b. They make four 'runs' and count the number of dots in each 5-second run.

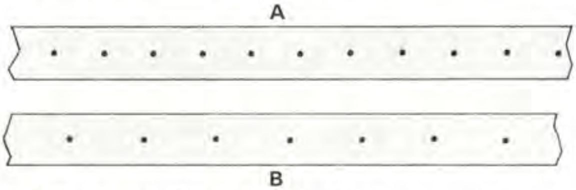
The four counts are: 285, 332, 306, 298.

How should they calculate their best estimate of the number of ticks (spaces between dots) in 5 seconds; and what result should they get?

c. Suggest three important reasons why the counts are not all the same.

d. You are told that their vibrator is supposed to be making 60 dots in a second. Do you find the pupils' results agree with this? Write a sentence or two of explanation.

20. A and B are diagrams of torn-off strips of tapes. Both of these represent the same type of motion, though with differing speeds. The vibrator makes 50 dots per second.



a. What type of motion do they represent?

b. What SPEED does strip A show in centimetres per tick? (Use a ruler.)

c. What SPEED does strip B show?

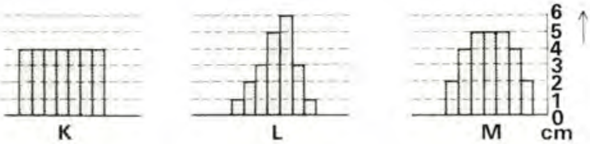
21. Which of the tapes X, Y, Z in the diagram shows motion that:

a. Slowed down then speeded up again?

b. Reached the greatest speed?

Give a reason for each answer.

22. K, L, M show pieces of ticker-tape cut off every ten ticks and pasted side by side. In each diagram there are seven pieces, and the heights are shown in cm. The first few dots at the start and some of the end of each run were too close to count properly, so only the middle sets of tentick strips (70 ticks in all) are shown.



a. Describe briefly the kind of motion followed by the person or object pulling the tape through, if the result is *(i)* like K; *(ii)* like L; *(iii)* like M.

b. *(i)* So far as you can tell from the diagrams, which tape showed the greatest speed?

(ii) What was that GREATEST SPEED in cm per ten-tick? (Remember that each strip of tape corresponds to a time of ten ticks.)

(iii) What was that GREATEST SPEED in cm per second? (Assume the vibrator tapped out 50 dots in one second.)

c. *(Advanced)* Actually it seems likely that the greatest speed reached was more than that calculated in (b), though for a shorter time than ten ticks. Why is this?

23. Look again at the tape-charts K, L, M of Q.22.

a. How far did the object pulling the tape move in 70 ticks ($= \frac{7}{5}$ seconds) for the motion shown in K?

b. How far for the motion shown in L?

c. How far for the motion shown in M?

AVERAGE SPEED

24. *(Advanced)*

a. Calculate the AVERAGE SPEED for the 70-tick period shown in fig. K of Q.22. To do this, use your answer for Q.23a and remember that the time is 70 ticks $= \frac{7}{5}$ seconds. Calculate by using:

$$[\text{AVERAGE SPEED}] = \frac{[\text{TOTAL DISTANCE MOVED}]}{[\text{TOTAL TIME TAKEN}]}$$

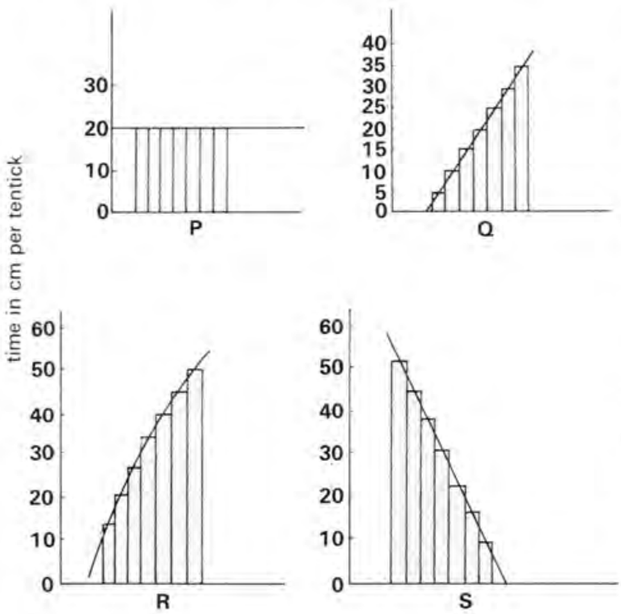
b. In the same way, calculate the AVERAGE SPEED for the 70-tick period shown in fig. L.

c. Then do the same for fig. M.

d. The AVERAGE SPEED you found in (a) is, of course, the ACTUAL SPEED of tape K throughout the time of 70 ticks. This is *not* true for tape L. Did tape L *ever* have the actual speed you found in (b)? If so, how many times did it have that speed?

(NOTE. The same question could be asked about tape M, and the answer would be the same.)

VARIOUS TYPES OF MOTION



25. P, Q, R, S in the diagram are tape charts showing four different motions. The length of each piece of tape corresponds to 10 ticks.

a. Two of these charts show an *increase* of SPEED. Which two?

b. Which one of these shows a *steady rate of increase* of SPEED? (That is called a 'CONSTANT ACCELERATION'.)

c. Which one of these shows a *steady rate of decrease* of SPEED? (That is called a constant 'DECELERATION' or 'NEGATIVE ACCELERATION'.)

d. *(i)* Which one of these shows zero acceleration (that is, neither acceleration nor deceleration)? *(ii)* In this case, what can you say about the SPEED?

26a. What is the value of the CONSTANT SPEED represented by tape chart in Q.25? Give the answer in *cm in each tentick*.

b. *(Advanced)* Imagine a new chart P′ made with strips for 50 ticks instead of 10 ticks. How tall would they have been for the same speed?

c. Suppose 50 ticks take one second, what is the value of the CONSTANT speed represented by chart P? Give it in *cm per second*; also in metres per second.

27a. Chart Q (Q.25): by how much does the speed *increase* in every tentick of time? Give the answer in *cm per tentick*.

b. How much is this INCREASE OF SPEED in *cm per second* and in *metres per second*? (50 ticks = 1 second.)

c. Answer (b) is the ACCELERATION in cm per second in every tentick. What is the ACCELERATION in cm per second in every second? Also in metres per second in every second?

18. *(Advanced)* Look at chart S (in Q.25) and find the (negative) ACCELERATION shown by S.

Use the same method as you used for Q.27. (Don't forget the minus sign.)

DISTANCE COVERED

29. Look back to charts P, Q, R of Q.25. Remember that each piece of tape represents the distances moved in a time of 10 ticks.

a. In P, how far did the object attached to the tape move in the whole time of 70 ticks?

b. In Q, how far did it move in 70 ticks?

c. In R, how far did it move in 70 ticks?

AREA UNDER GRAPH

20. *(Advanced)* Look again at charts P, Q, R, S of Q.25. Remember that each piece of tape represents the DISTANCE moved in a time of 10 ticks.

a. Why does the AREA of the whole patch of pasted tapes tell you something about TOTAL DISTANCE TRAVELLED?

b. In which does the area look largest, P, Q, R, or S?

c. *From your answers to (a) and (b)*, say in which case the object travelled farthest in the 70 ticks.

SPEED

31a. You are in a car approaching a town and you see a sign like A(i) or A(ii) in the diagram. Later you see a sign like B. What do these signs mean?

b. Suppose that between sign A and sign B, you travel at a steady speed of 50 kilometres an hour

A(i) A(ii) B

(or 30 miles an hour). How far do you go in one minute?

c. Beyond sign B you speed up and travel at 100 kph (or at 60 mph). How far do you go in one minute now?

(NOTE. The proper abbreviation for kilometres is km, not just k; but Continental speedometers are usually marked in kph when they mean km p h or kilometres per hour.)

32a. Suppose you are driving in a car whose speedometer is marked in mph (miles per hour) and you see a sign saying 'SPEED LIMIT 40 km p h'. What is that speed limit on your speedometer?

b. Suppose you are driving in a car whose speedometer is marked in kph (see the note at the end of Q.31). You see a sign marked 'SPEED LIMIT 35 mph'. What is that speed limit on your speedometer?

(NOTE. 1 kilometre is almost exactly $\frac{5}{8}$ mile. 1 mile is 1.6 km.)

33a. A large stone which has fallen freely for 2 seconds has a SPEED about 10 metres per second. How much is that in km per hour?

b. Suppose you find a question in an old exam paper with miles per hour and feet per second in it. In these units,

1 mile $=$ 1760 yards $= 3 \times 1760$ feet.

How much is 60 miles per hour in feet per second?

34a. The 'reaction time' of a certain very alert driver is $\frac{1}{5}$ of a second. That is the time he takes to see-recognize-think-decide-and-act (all almost automatically). It is the shortest time interval between the instant he notices something and the instant he makes his muscles do something.

When he is driving at 25 metres per second the man sees the road blocked ahead and 'instantly' (so he says) puts on the brakes. How far does he travel between seeing the danger and putting on the brakes? (25m/sec $\approx$ 56 miles/hour).

b. Actually, the car travels much farther than your answer to (a) before it comes to a stop. Why?

35a. A good sprinter can run 100 metres ($\approx$ 110 yards) in 11 seconds. What is his speed in kilometres per hour? (Nearest whole number will do.)

b. If 11 seconds for the 100 metres is a good time, what is a good time for the old-fashioned distance, 100-*yard* dash? (You need to know how many yards in a metre. *You* should find that out by yourself somehow.)

36. In (a) and (b) below you are asked to calculate two speeds, one small, one large. For each calculation you need to know that the circumference of a circle is 2π times the radius, where $\pi = 3.14\ldots$ However, for these calculations it will be accurate enough to use 3 for π and 6 for 2π and so avoid awkward arithmetic.

a. A wrist-watch has an hour hand of radius 1 cm. What is the speed of the tip of the hand in metres per second?

b. The radius of the Earth is 6400 kilometres. What is the speed of a point on the equator in metres per second? (This asks for the speed due to its daily spin—not the speed along its yearly orbit.)

37a. Think about answering question 36b for places *not* on the equator—the British Isles for example. Are we moving faster or slower? Explain your answer with the help of a sketch.

b. What about a man at the North Pole? How fast is he moving?

38a. *(i) (A metric record)* How fast is a '$2\frac{1}{2}$-minute kilometre' in kilometres per hour?
(ii) (In old-fashioned units) How fast is a '4-minute mile' in miles per hour?

(NOTE. In such records, the time is the time to run 1 kilometre in *(i)* or 1 mile in *(ii)*.)

Parts (b), (c), (d), (e) below refer to a*(i)* or a*(ii)*, whichever you choose.

b. Would you expect the runner to run *all* the time with *exactly* the speed you calculate?

c. Could he have done that?

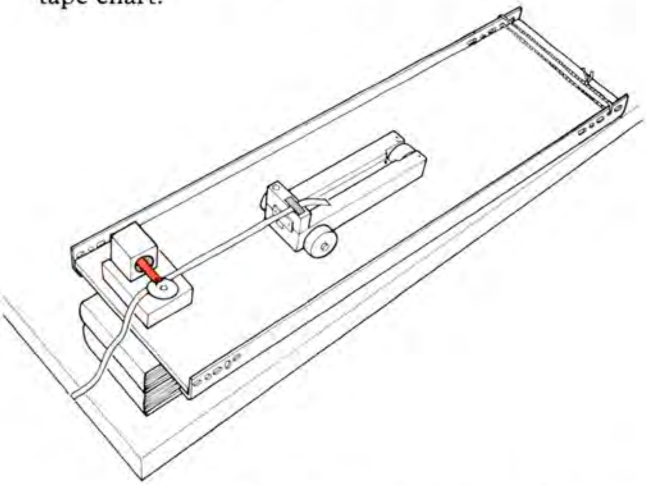
d. Why must he at some time have been running faster than the result you give?

e. Would you call your result the runner's greatest speed, or maximum speed, or slowest speed, or steady speed, or average speed—or what?

39. Describe something you have noticed (*not* something you have read about or been told) which leads you to think that light travels faster than sound.

Experiment 59
Motion of a Cart coasting Downhill

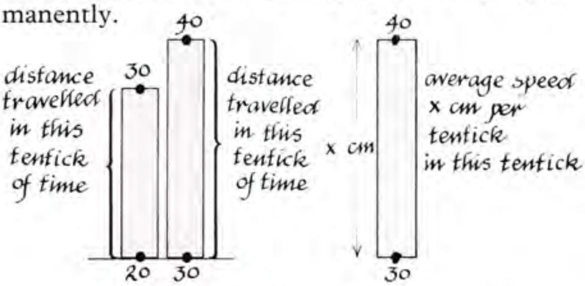
Investigate the motion of a trolley with good wheels coasting down a smooth slanting runway. This is like the motion of a cyclist coasting without brakes, or a person on skis or a sled on a snowy slope. Use a ticker-timer and make your own tape chart.



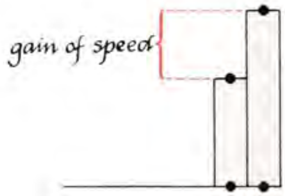
Share a trolley and runway with two or three other pupils. Make the runway a sloping hill, by propping up one end with books or blocks of wood, 10 to 15 centimetres for a 2-metre runway. Place the ticker-timer on the runway, at the upper end.

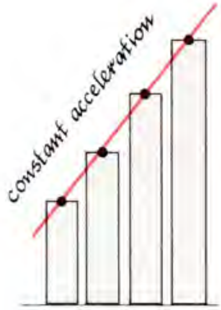
Cut off about 2 metres of tape. Pass the end of the tape through the timer and connect it to the trolley. Hold the trolley ready to start just below the timer, so that it will drag the tape through the timer as it coasts.

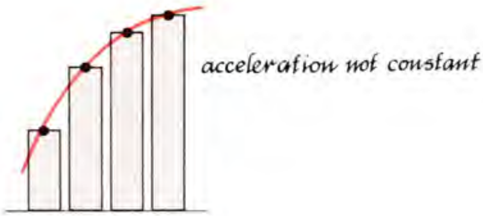
Start the timer. Release the trolley. Be careful to catch the trolley at the end of the runway; a traffic accident can damage the wheels permanently.



NOTE. If you have never noticed anything of the kind, then invent a suggestion. Think of something you might observe which would enable you to decide which travels more quickly, light or sound.







Each pupil in your group should repeat that run; so that each of you has his own tape.

Cut up your own tape into tentick strips. (Choose a clear dot that was made soon after the start and label that dot No. 0. Mark dot No. 10, dots 20, 30, . . . Then cut up the tape.)

Paste your tape strips side by side to make a tape-chart.

Discussion This time you may be able to see the story of the motion more clearly. If the length of tentick strip increases from one to the next, that tells you the speed is increasing.

Suppose a trolley's speed increases from each tentick to the next. We say the trolley is ACCELERATING. Or, it has ACCELERATION.

A moving object has constant acceleration if it gains the same amount of speed from one tentick to the next, to the next, . . . *What would that look like on a tape chart?*

What kind of motion did your trolley have?

ACCELERATION

40. A car has already a speed of 32 kilometres per hour when the stop-watch is started. Two seconds later its speed is 36 kph. Two seconds after that, 40 kph. We can tabulate this:

time, seconds	0	2	4
speed in kph	32	36	40

a. If it continues to accelerate like this, what will its speed be at time 6 seconds?

b. What would you think its speed was at time -2 seconds, that is, 2 seconds *before* the stop-watch was started?

c. How much increase of speed is there in two seconds?

d. How much increase of speed is there in one second?

e. Which of the above answers is the car's ACCELERATION?

41. Readings of the speedometers of three cars, A, B, and C, are taken every five seconds:

time, seconds	0	5	10	15	20
A's speed, kph	40	40	40	40	40
B's speed, kph	40	44	48	52	56
C's speed, kph	40	30	20	10	0

a. How much does A increase in SPEED every 5 seconds? What is A's ACCELERATION?

b. How much does B increase in SPEED every 5 seconds? What is B's ACCELERATION?

c. How much does C increase in SPEED every 5 seconds? What is C's ACCELERATION? (Remember to get your + and − signs correct.)

d. What does '0' mean, for C's speed at time 20 seconds?

e. It is unlikely that car C would continue after 20 seconds with the same acceleration, but if it did, what would its speed be at time 25 seconds? Explain what your answer means.

42a. A train increases its speed from 12 metres per second to 22 metres per second in 5 seconds. What is its ACCELERATION? (Be careful to give your answer in proper units.)

b. Another train increases its speed steadily from 40 km per hour to 50 km per hour in 5 seconds. What ACCELERATION does it have? (Keep the speeds in km per hour, and the change of speed in km per hour. Be careful, therefore, about the units for your answer.)

43. A friend of yours sees your answer to Q.42a, and says, 'What a silly thing to write, "metres/second per second"; either it means "no units" or it means the same as "metres per second".' Write a few sentences explaining to him:

a. What is meant by a statement (for example) '2 metres/second per second'.

b. What kind of thing is measured in these units.

c. What '2 metres/second' means, and what it is that is measured in such units.

44a. Suppose you are riding a bicycle at a steady speed of 6 metres per second. How far do you go in 1 minute?

b. Suppose you are riding a bicycle at 6 metres per second and you suddenly stop pedalling. The bicycle takes one minute to slow down to a stop. Suppose it has a *steady* deceleration (negative acceleration) all the time. How far does it go before stopping?

c. The answer to part (b) is half as big as the answer to part (a). Why?

45. *(Not difficult. Easy,* if you can answer Q.44c. This is a TRICK QUESTION: it requires thinking but *almost no arithmetic.)*

A train is $1\frac{3}{4}$ kilometres from a station when the guard operates a lever which disconnects the last coach from the rest of the train. The train continues with the same *constant speed* (100 kilometres per hour if you like). But the coach has its brakes on so that it has a *constant deceleration* and comes to a stop at the station.

a. How far away is the train when the coach stops?

b. Yes, easy! But now, explain in two or three sentences why your answer is correct.

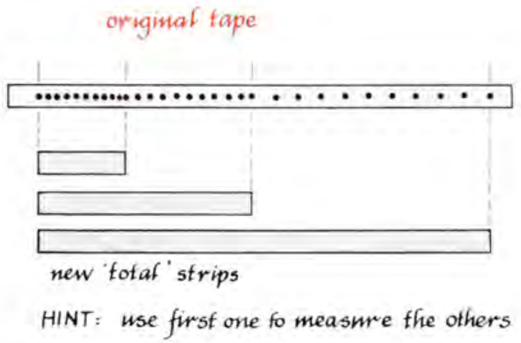
What do tape-charts tell? When you paste strips of tape side by side, each strip is one tape-width from the next. So you are really making a simple graph of SPEED (= distance travelled in one tentick), plotted upward and TIME (in tenticks), plotted along. (You are plotting TIME along because each strip of tape happened one tentick later than the strip just before it. And you are making each strip-width represent one tentick.)

Optional Extra Experiment 60
Trolley running Uphill

What happens when you set a trolley at the bottom of a hill and give it a push to start it running uphill? Once you have left it to run uphill on its own, what kind of motion does it have? Investigate with ticker-timer and tape. Make a tape chart.

Experiment 61
A Different Exhibit of Tapes *(OPTIONAL NOW)*

Make a careful tape record of a trolley running down a sloping runway. This time, stop the ticker-timer until you are ready to start. Then start the timer at exactly the instant you release the trolley. Then you can be sure that the recording on the tape starts just when the trolley starts.



It would be difficult to switch the timer on at the right moment. Keep it switched on and let your partner keep his finger on the blade until the start.

After the run, mark your tape at the dot for the starting instant. Call that dot zero. Mark your tape after 10 ticks, and after another 10 ticks, and so on. (Call these dot No. 10, dot No. 20, etc.) DO NOT CUT UP THAT TAPE.

Take some more tape without any dots on it. Cut off a piece of the new tape just equal to the distance the trolley travelled in the first 10 ticks from rest, from dot 0 to dot 10.

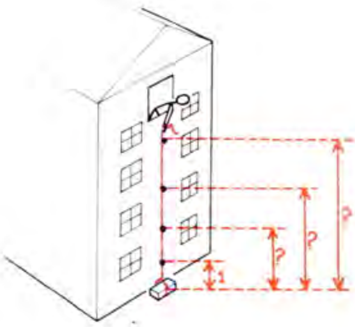
Then cut off another piece of the new tape equal to the distance your trolley travelled in the first 20 ticks from rest, from dot 0 to dot 20. Then another piece of new tape for the trolley's travel in the first 30 ticks from rest: and so on.

Put all those new pieces of tape side by side on the table and see if you can find anything interesting about their lengths. HINT for finding one of the number-secrets: take the *shortest* of the new tape strips and use that as a measuring stick to measure the length of each of the others.

Discuss this with your teacher.

Home Experiment H.62
Testing Free Fall by Ear *(OPTIONAL)*

If you found a number-secret with the help of the hint above, you could make a simple experiment to test whether something falling freely has the same type of motion as your trolley coasting down a hill.



Get half a dozen small stones and a long piece of string. Attach one stone to the end of the string. Tie another stone to the string 10 centimetres from that end. Then tie the other stones at distances from the end which you decide from your number-secret. (*Better still:* start with 25 cm and make all the distances correspondingly larger.)

Hold the other end of the string so that it hangs down in a tall stair well with the bottom stone just touching the floor. (Or lean out of an upstairs window and hold the string with the bottom stone touching the ground.)

Let go and listen.

Progress Questions

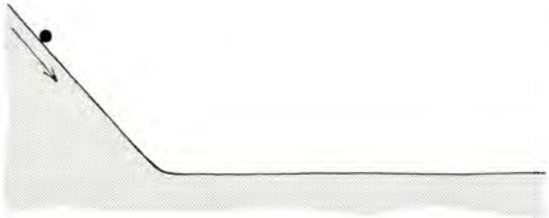
MOTION ON HILLS

46a. A piece of curtain rail has the shape shown in this diagram. A ball is put on it at P, and is left to roll.

b. How far up the opposite slope will the ball go before it stops for a moment (after that, it rolls back again)? Give the reason for your answer.

c. If the surface of the ball and the rail were perfectly smooth, with no friction, how far would it go up the slope now?

47. This time the ball runs down a slope and then along a horizontal surface.



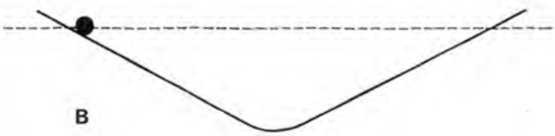
a. Describe how it goes *(i)* down the slope, *(ii)* along a flat surface.

b. Did you answer (a) for a perfectly smooth surface or for a rough one?

Questions

48a. Fig. A shows a curved glass surface—a large 'watch-glass' from the chemistry lab. It is placed on the bench and supported. A small steel ball is released near the edge. What does the steel ball do?

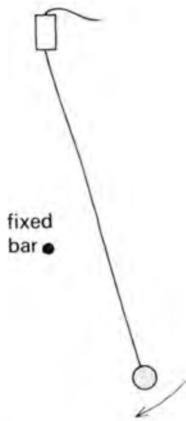
A



b. Fig. B shows a length of curtain rail, bent as shown. A ball is placed at position x and is let go. How far does it go up the other side? What happens then?

49. The diagram shows a small hill A followed by a higher hill B. A ball is given a push so that it rolls up and over the first hill. Describe what happens:

(i) if the ball is given only *just* enough speed to get over the small hill;
(ii) if it is given enough speed to shoot over the small hill with plenty to spare.



50a. The pendulum bob is released from the position shown. Copy the sketch and show on your sketch the position that the bob has swung to when it is next motionless.

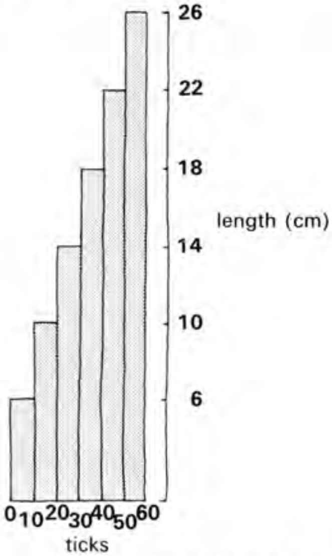
b. Draw a curved 'hill' down (and up) such that a ball could roll on it and follow a path just like the path of the bob.

NOTE. You should use a pair of compasses.

51. A ball rolls down a hill on to a flat horizontal surface.

a. What happens to a real ball on a real surface?

b. What would happen if there were no friction or air resistance at all?



52. A trolley runs down a sloping plank. As it goes, it drags paper tape through a vibrator. Two pupils then cut up the tape into six lengths, the first from 'dot No. 0' to 'dot No. 10', the next from 'dot 10' to 'dot 20' and so on.

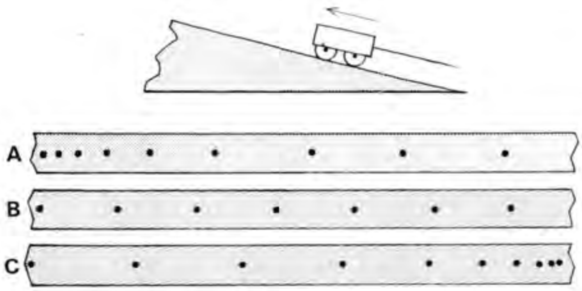
(For 'dot 0' they choose the first of the clearly marked dots—not the actual beginning of the trolley's movement because the dots are too close together to see clearly.)

They then stick the six lengths of tape beside each other, as in the diagram, which is drawn one quarter of actual size.

a. What does this tape-chart tell you about the motion of the trolley?

b. Give the reason for your answer to (a).

c. If you can, calculate the acceleration of the trolley:
(i) in cm/tentick in every tentick.
(ii) in cm/second in every second. (Remember 50 ticks make one second.)



53. A trolley is given a push *up* a hill from right to left so that it travels some way up before stopping. It drags tape through a vibrator.

a. Which looks like the tape record you would expect, A, B, or C? If none of them look right, draw a fourth tape, D, which *does* look right.

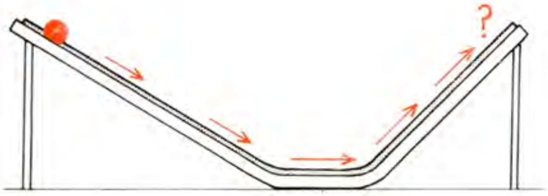
b. Give the reason for your choice (or for your new tape D) in answer (a).

54. You pick up a piece of paper tape which looks like E. Draw a sketch (like the sketch above the tapes in Q.53) showing the sort of runway the trolley that made this has been travelling on.

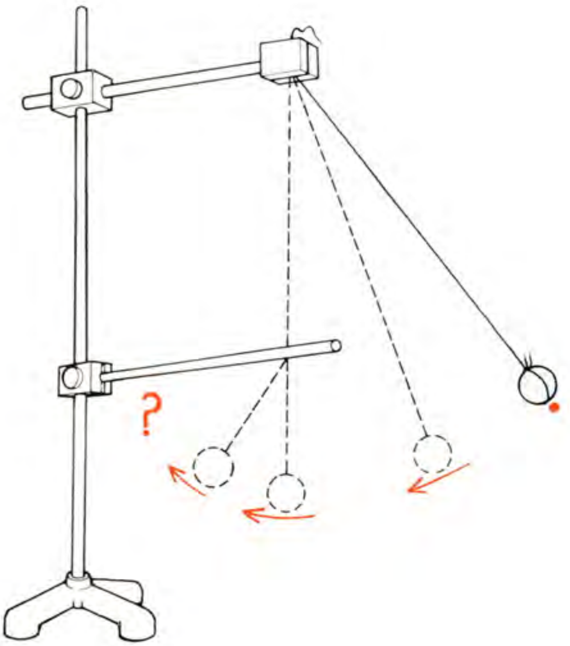
55. A trolley pulling tape through a vibrator runs down a sloping plank and on to a flat horizontal plank. Make a rough sketch of a piece of the tape with dots showing what happens when the trolley passes from somewhere near point A to somewhere near point B.

Demonstration 63
Downhill-and-Uphill Motion

What would happen to a trolley which runs downhill and then runs along the level and then meets an uphill slope? See the demonstration sketched with a rolling ball instead of a trolley.



How would you explain this experiment's failure to give the simple result you might hope for?

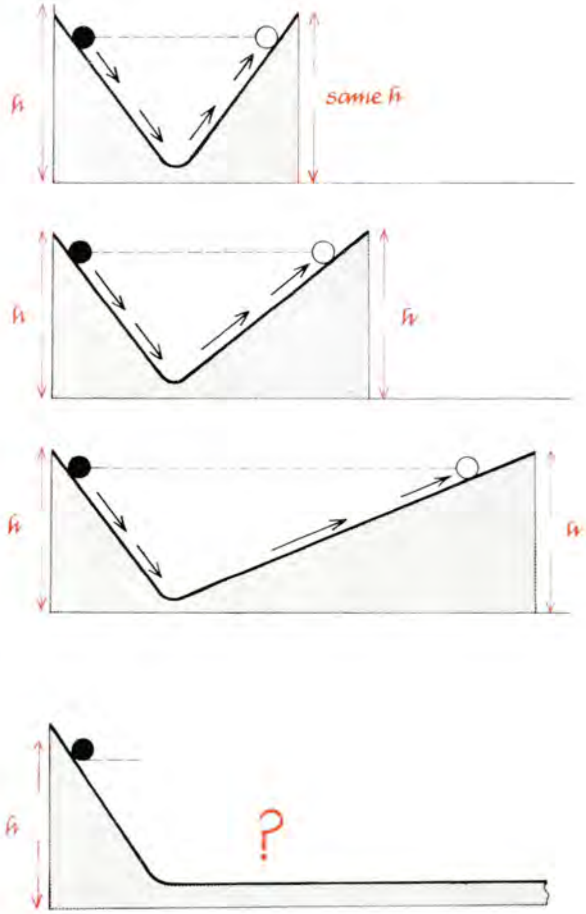


Demonstration 64
Galileo's Pin-and-Pendulum Experiment

Three and a half centuries ago Galileo argued about that downhill-and-uphill experiment. He wanted to do it without any trouble from friction; and he succeeded. See Galileo's (almost) frictionless experiment.

Motion with No Force

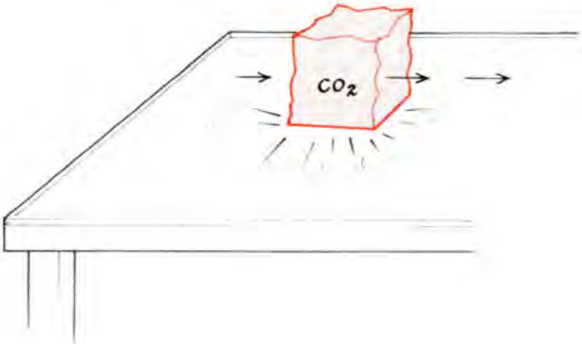
A thought experiment Feeling quite sure that the simple result is the true one, except for friction, Galileo carried out a 'thought experiment' in his head. You may call that just an argument; but in a way he was doing a proper scientific experiment because he was using information from other things he had seen.



He imagined the ball running down one hill and up another steep hill; then he made the second hill less steep; then still less steep until finally the second hill—in his imagination—did not slope at all. See the sketches. *What do you think the ball would do in that last case, if it did not suffer any friction?*

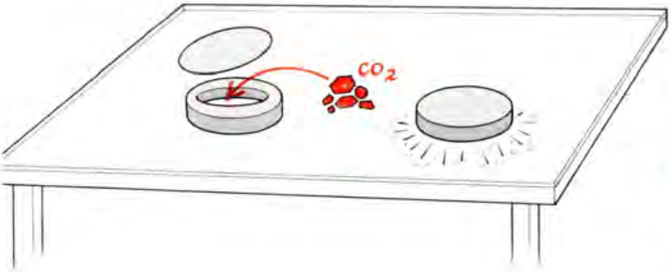
Demonstration 65
Frictionless Motion: Hovercraft

See one or more of the demonstrations sketched. They show an object moving with practically no friction on a level table.



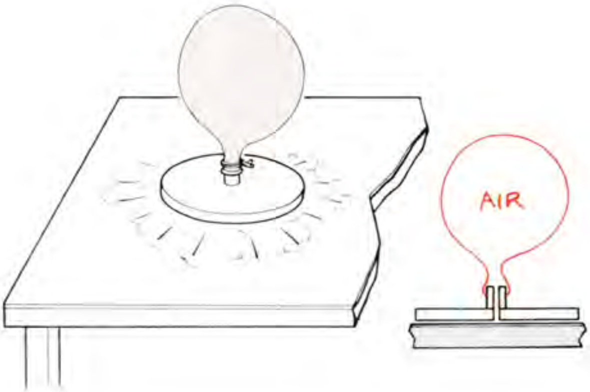
65a The Coasting Iceberg

Solid carbon dioxide ('dry ice') is very cold. It turns into gas when it touches the warm glass, and the gas can support an object, as air supports a hovercraft.



65b Ring Hovercraft

A little solid carbon dioxide turns to gas and that supports the ring. (Or a tiny air pump driven by batteries can maintain a hovercraft 'puck' for a longer time.)



Experiment 66
Home-made Hovercraft

A balloon squirts air out through a hole in a small wooden disk, and that makes a hovercraft.

Questions

MOTION WITH NO FORCE

56. You may have seen an experiment in which a special puck is placed on a level sheet of glass and is given a gentle push. IF you have seen that:

a. Describe what happens, and explain what happens.

b. Say what you think 'friction' is. (Do not look in books—make up an answer of your own.)

c. Explain how the puck is prevented from feeling any friction.

57a. A space ship is moving far out in space, far away from any large bodies like the Earth or the Sun or the planets. Its jets are shut off. Describe its motion after that.

b. What similarity is there between the motion of the space ship, and the motion of the puck in Q.56a? Also, what differences are there?

58a. Suppose you have, on a glass surface, a special puck which slides perfectly, so that there is no friction at all. There are still *two* forces acting on the puck. What are they? Which is the larger? Or, are they equal?

b. Suppose a locomotive pulls a train along a flat horizontal track with a forward pull (force) which exactly equals in size the backward drag of friction, air resistance, etc., on the train. What can you say about the motion of the train?

59. You can now draw a general conclusion from the experiments and observations you have seen, and heard about.

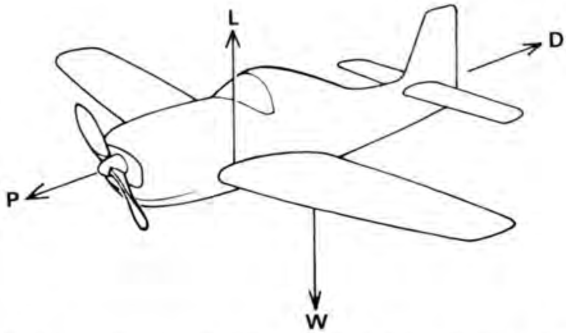
a. If all the forces acting on a moving body exactly balance each other (OR if there are no forces at all acting on the body), what do you expect to find about the motion of the body?

b. What difference does it make if the body we were talking about in (a), is at rest?

60a. Give one different example (not in these questions) of a moving body for which all the forces acting on it are exactly balanced. Say what happens to it.

b. Give one example of a body which is and stays at rest but has forces acting on it. The forces are exactly balanced. Say what happens as times goes on.

61. Lastly—and this is important—if you happened to see a body *either* at rest *or* moving at a steady speed in a straight line (e.g. a car moving at a steady 50 kph), what could you say about the forces acting on it?



62. A small aircraft is flying 'straight and level' and at a constant speed. The propeller pushes air backward as it spins. That air, therefore, pushes the propeller forward. The forces acting on it can be represented by four vectors (lines drawn to scale in the proper directions). These are:
P, the forward push of air on the propeller;
W, the weight of the aircraft (downward pull of the Earth on it);
D, the 'drag', or friction resistance due to the air;
L, the 'lift' provided by air pressures on the wings.

a. The aircraft is flying horizontally with constant speed. You can make *two* separate statements, each using two of those four forces. Write those two statements (or write two equations if you prefer).

b. *(Advanced. Do not answer unless you wish.)* As the forces are drawn in the diagram, which two seem to be trying to turn the aircraft's nose downwards? And which two are trying to turn its nose upwards? If the aircraft continues to fly straight and level, what can you say about the turning-effects of these pairs of forces?

Inertia

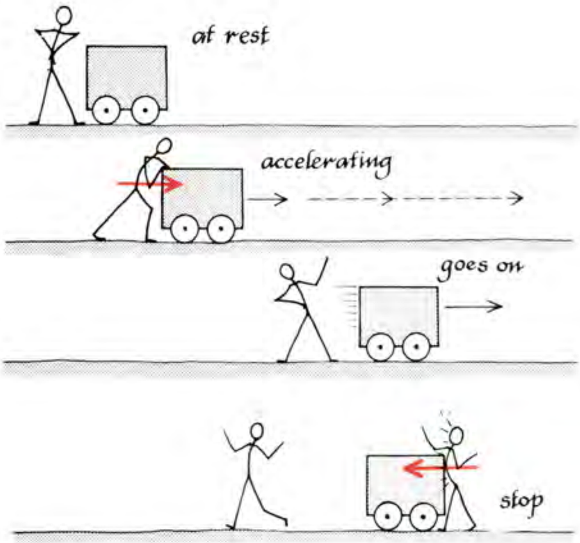
When is a force needed? You have now seen how things go on moving along when they are left alone and are not dragged to a stop by friction.

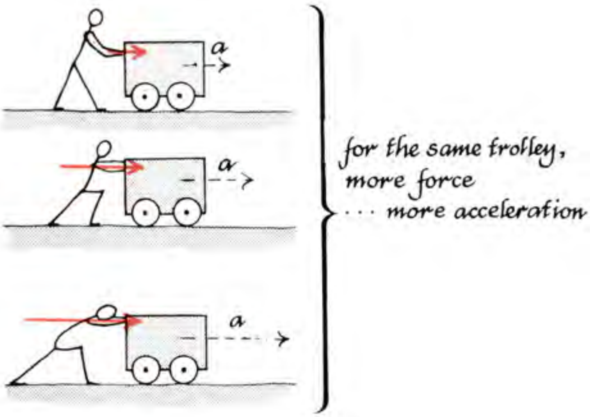
If you start an object moving you have to give it a push: you apply a force. To stop an object moving you must apply a force. And to make a thing move faster or slower you must apply a force. *Whenever motion is changing*, a force must be acting.

If you pile one trolley on top of another, you will find that the double trolley is harder to start or to stop or to make faster or slower. You need a larger force to change its motion, compared with changing the motion of a single trolley. The more stuff there is—the more trolleys piled up—the bigger the force you need for some standard acceleration.

A thought experiment *Can you stop a moving goods waggon that is running along a smooth railway line after being shunted? You can stop it; but can you do that easily, or at once?* Now you are doing a 'thought experiment'. As you imagine pushing the waggon for a long time you can feel how difficult that huge waggon is to stop.

Inertia We say that every object possesses some 'INERTIA', some quality which makes it difficult to start or stop or accelerate. We believe that an object's inertia would be just the same on the Moon although gravity would pull it much less there. Even far out in space or in an orbiting spaceship, where things seem 'weightless', their inertia would still be the same; they would need just as big a push to get them going or just as big a push to stop their motion.





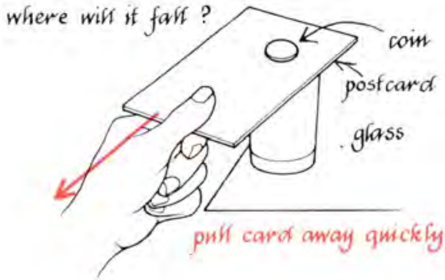
Experiment 67
Feeling Inertia

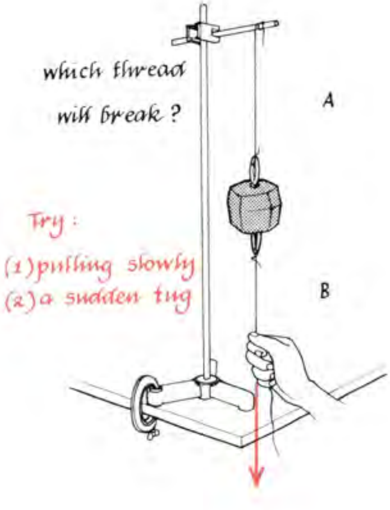
Try the experiment sketched. One tin can is full of sand, the other empty. Try pushing each to start it moving. Try stopping each when it is moving.

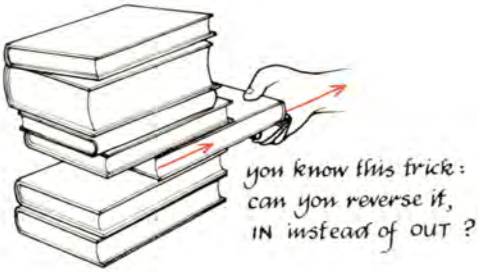
Why are safety belts worn in cars? What happens to passengers on the back seat with no safety belt, when the car suddenly stops? What happens when it suddenly starts? When it goes round a sharp corner?

Optional Experiment 68
Tricks that Illustrate Inertia

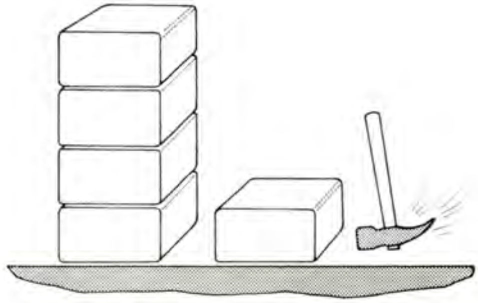
You may see or try some of the experiments sketched. (They are amusing, but it will not matter if you miss them.)







A shorter name for inertia We often say MASS instead of INERTIA. However, we still use the word 'inertia' because it reminds us of laziness. INERTIA *is* the 'laziness' of matter, and MASS is the measured amount of inertia, measured in kilograms.



MASS is quite different from weight. WEIGHT is a FORCE, the pull of the Earth on an object. MASS is the amount of stuff in the object; it tells us how difficult the object is to start moving or stop. And we believe the MASS of an object is the same wherever it is: on the Earth, on the Moon, out in space . . .

Progress Questions

INERTIA

63. Here is a set of speeds:
4 kph (kph = kilometres per hour)
64 kph
1200 kph

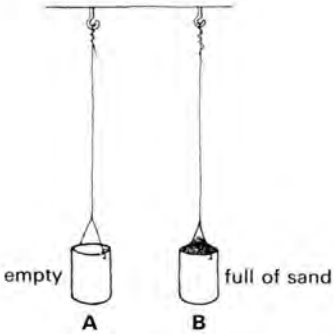
Copy out these speeds, and next to each one write the most likely of the following cases. (Look up some of these in library books.)
A fast race-horse
A fairly slow walking pace
The speed of sound in air

64. Two coffee tins are hung by strings so that they can swing freely. One (A) is empty, the other (B) is full of sand.

a. You flick both tins with your finger. Which is more easily set moving?

b. You start the tins moving so that they have equal swings. Which needs more force to stop it?

c. You cut both strings at the same time. Do the two cans hit the ground at the same time? If not, which hits first?



Questions

INERTIA

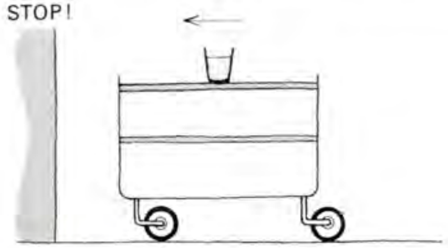
65. A fat boy is sitting on a toboggan (a small sled) on smooth icy ground which slopes *slightly* downhill. The slope is just sufficient for him to slide at a steady slow speed (that is, just sufficient to compensate for friction). Suppose another boy comes up behind and pushes steadily for a few seconds.

(i) His uncle says, 'The slope already "overcomes friction", so the slightest extra force will immediately produce a *very large increase of speed.*'

(ii) The boy agrees that the slope has already compensated for friction; 'but', he says, 'that only means that any extra force will make no difference'.

Is either comment *(i)* or *(ii)* right? If not, what do *you* say would happen?

66. The diagram shows a tea-trolley or dinner-wagon with a tumbler of water (shown here out of scale) standing on it. The trolley is moving to the left when it suddenly hits a wall and stops.



a. If the tumbler slides, which way does it slide, to the left or right?

b. If the tumbler topples over, which way does it topple over? (Answer by a sketch.)

c. If the water slops out, without the tumbler falling, which way does it slop out? (Answer by a sketch.)

d. Now suppose the tea-trolley is at rest and you want to make the water slop out of the tumbler towards X (without tilting the trolley). What should you do to the trolley?

67. A man's hat blew on to a path. A boy who was passing gave it a good kick, and ran away.

The man knew the boy would come back soon, and decided to 'get his own back'. He put the hat on the path with a large brick underneath. The boy came back and kicked the hat. He squealed because he hurt his foot.

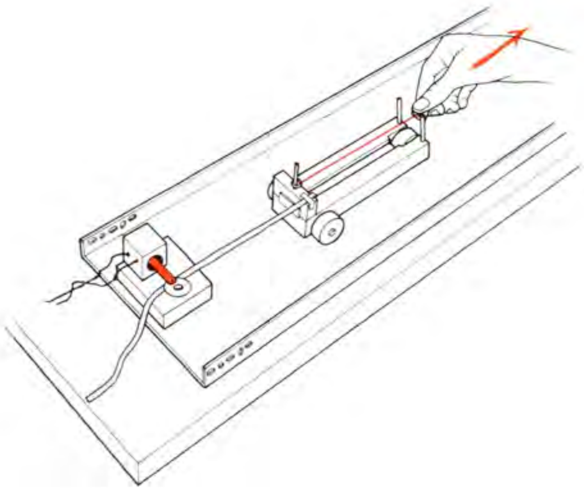
The boy's brother said it served the boy right. His brother tried pushing the hat and brick with his foot; it moved quite easily along the smooth ground. Why was it that the boy hurt his foot and his brother did not?

Force and Motion

Experiment 69a
Pulling a Cart with a Steady Force

Instead of gravity, use a rubber band or an elastic thread to pull a trolley along a level table with a steady, unchanging force. Find out all you can about the trolley's motion by making measurements of speed with a ticker-timer and tape. You should have a special smooth straight board as a runway instead of the table top.

Let your partner take charge of the timer and tape, while you pull the trolley. Keep the elastic thread stretched by the same amount all the time, as you walk along beside the moving trolley. With



practice you will find you can do that if you stretch the thread to just the same length as the trolley itself.

Choose a dot on your tape soon after the trolley's start, and mark that dot 0. Mark dot No. 10; and dots 20, 30, 40, ... Cut your tape into ten-tick lengths. Make a tape-chart.

What type of motion have you got, with your steady pull acting alone? Does your record show constant speed, increasing speed, decreasing speed, unevenly changing speed, constant acceleration, increasing acceleration, decreasing acceleration, or just confused motion?

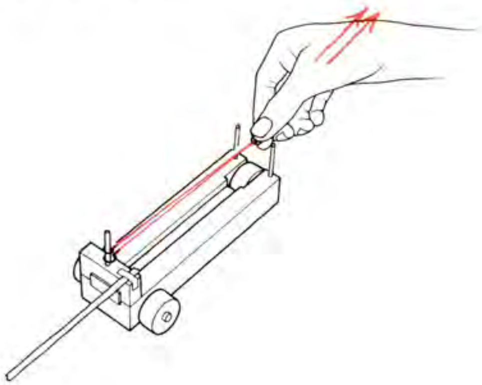
Consult your teacher. Then go straight on with double and triple pulls (Experiment 69b).

Calculating the acceleration Acceleration is rate of gain of speed or

$$\frac{\text{(gain of speed)}}{\text{(time taken to make that gain)}}$$

which you may write $\frac{\Delta v}{\Delta t}$ if you like.*

You will not need to calculate accelerations until a later year: but you could, if you wished, calculate your trolley's acceleration from your chart. (See the note at the end of this chapter for extra help with that.)



* *Useful Mathematical Shorthand.* When you want to say 'change of' or 'gain of' or 'increase of' something measured such as speed, you may use instead the shorthand sign Δ (which is the Greek capital D, used to mean 'Difference').

Here, using v for speed or velocity, and t for time-of-day, you can write Δv for the gain of speed and Δt for the increase of time-of-day, the time taken to make that gain. Then for acceleration you can write: $a = \Delta v / \Delta t$.

Experiment 69b
Pulling with Different Forces

Now that you are not using gravity to pull the trolley, you can easily try different amounts of force by pulling with several equal elastics side by side. You already have a tape-chart for one stretched thread pulling the trolley. Now try *two* threads, then *three*.

Experiment 69c
The Careful Experiment

Your experiments on FORCE and MOTION are very important but now that you are a good experimenter with trolley and timer and tape we must ask an awkward question: '*Was the force which accelerated the trolley really one elastic-pull, then twice that, then three times that?*'

Is the pull of the elastic the only force that affects the trolley's motion? The wheels suffer from some friction, and the timer drags the tape backward with some small force. It would make a simpler experiment if you could do without friction, or at least forget about it. Discuss this 'friction problem' with your teacher and decide how to arrange your runway to compensate for friction.

Then compensate your runway for friction *WITH THE TROLLEY PULLING TAPE THROUGH.*

Try again, very carefully this time, pulling steadily with *one* elastic, then with *two* elastics, then (if you have time) with *three*. Each partner should take his own tapes. Make your own tape charts for the three motions.

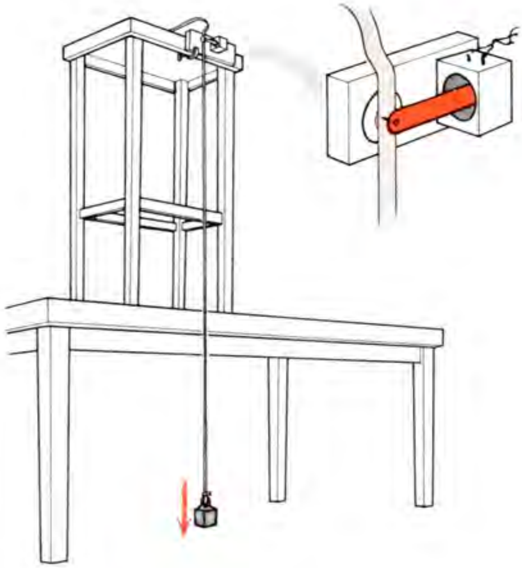
DISCUSS THE RESULTS WITH YOUR TEACHER.

Free Fall

Experiment 70
Investigate the Motion of a Falling Object

First watch the fall of a stone (or a small brick or lump of metal) when you drop it. Then investigate the motion using a ticker-timer and tape.

Hang the heavy object on 2 metres of tape and let it drag the tape through the timer as it falls. If you work with partners, each should make his own tape.



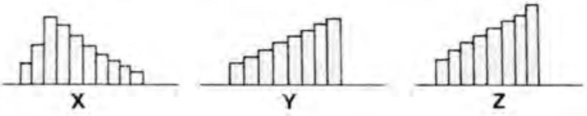
Make a tape-chart of all the motion, by cutting the tape into tentick strips. Each of those strips show how far the object fell in a tentick of time. *What does your tape-chart tell you about the motion?*

(You could estimate the large acceleration, in centimetres/tentick per tentick; but that is better postponed to a later year when you will have a quicker method. Here the important thing is to describe the type of motion.)

Progress Questions

TAPE-CHARTS

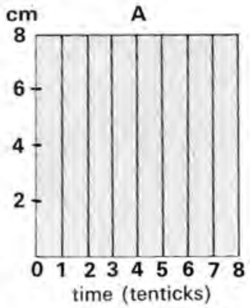
68. These charts X, Y, Z, were made from the tapes of a trolley moving on a runway.

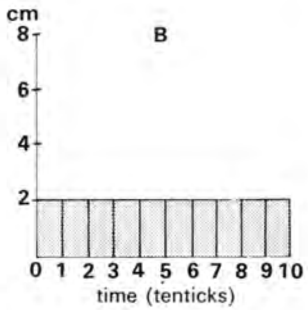


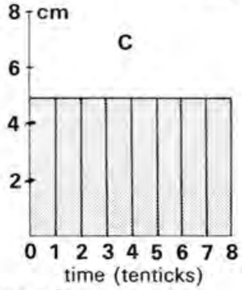
a. In one experiment, the trolley board was raised at the starting end. Which of the charts might have come from that experiment?

b. Then the slope was made steeper. Which chart came from that experiment?

c. Then the board was lifted at the finishing end, so it sloped up. The trolley had to be given a push to start it. Which chart did this give? Describe in words the way the trolley moved.







69a. In each experiment, A, B, C, the trolley was going at a steady speed. How can you tell.

b. Which trolley was going fastest?

c. How far did trolley A go, every tentick?

d. Write down the speed of trolley A in cm per tentick.

e. Write down the speeds of trolleys B and C, in cm per tentick.

f. Which trolley kept on moving for the longest *time*?

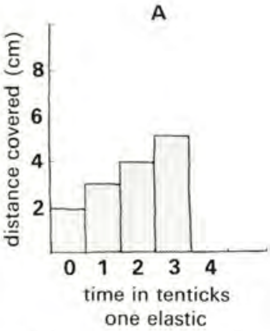
g. Copy and complete:

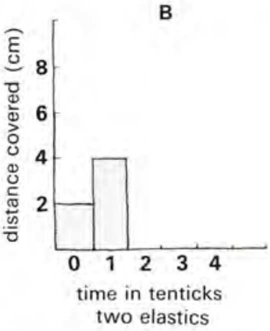
In the first tentick trolley B went . . . cm; and in the second tentick it went another . . . cm, so after two tenticks it had gone . . . cm.
After 3 tenticks it had gone . . . cm.
All together it ran for . . . tenticks, and went . . . cm.

h. How far did trolleys A and C go, all together?

70a. Copy the chart for a trolley pulled by *one* elastic and draw in the next two strips.

b. Copy chart B, for a trolley pulled by *two* elastics, and draw in the next four strips.





c. Draw a sensible chart for a trolley pulled by *three* elastics. Show 6 strips.

d. Explain in your own words:
(i) the patterns of the charts,
(ii) the difference the extra elastics make.

FRICTIONLESS MOTION?

71. Even a very good trolley is slowed down a little by friction—but there are ways of holding things up (without wheels) so they can move with hardly any friction.

a. Describe one way of doing this (use a diagram to help).

b. Describe the sort of motion you get on a level surface.

72. Rockets and meteorites travel far out in space without any motors driving them.

a. Is there anything to make them slow down?

b. How do you think they move when very far from any planet or the Sun: faster and faster, or slower and slower, or at a steady speed?

Questions

FORCE AND MOTION

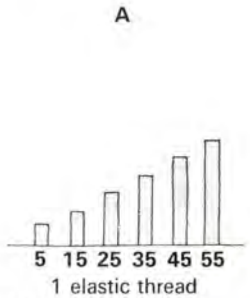
73. You have done acceleration experiments with small trolleys pulled by elastic. First you had to pull a trolley along with a steady force F, unchanging over most of the trolley's run from start to stop. You used a piece of elastic.

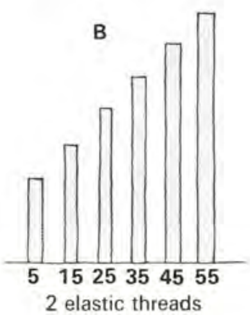
a. How did you make sure that the force you used was a steady one which did not change its size? (Give details of exactly how you did this.)

b. Then you pulled it with a force of $2F$, then perhaps, $3F$. How did you get forces of $2F$ and $3F$?

c. You also tilted the runway slightly to compensate for friction—how did you find the correct tilt to use?

74. Two pupils did a trolley and tape experiment in which they pulled the trolley with one elastic thread. Then they pulled with two threads, each stretched to the same extent as before.





They took the first tape and cut the middle part of it into six lengths, one tentick each, dot 0 to dot 10, dots 10 to 20, 20 to 30, 30 to 40, 40 to 50, and 50 to 60. They pasted these on a sheet of paper to make a tape-chart, A. They did the same thing with the second tape, and made chart B.

Both charts A and B are one-quarter of real size.

a. Do these charts agree with the statement 'If twice the pull, then twice the acceleration'?

b. What method do you use to answer (a) using the charts given?

c. The first strip in chart B is more than twice the length of the first strip in chart A. Similarly for the last strips. How do you explain this?

75. One boy sits on a tricycle and a second boy Y pulls with a steady force P. The tricycle has a speedometer on it. The passenger reads the speedometer every few seconds. They plot a graph which looks like fig. II (line OA).

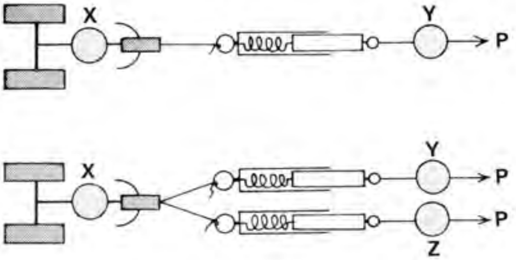
The same boy X remains on the tricycle during a second 'run', pulled this time by *two* boys Y and Z *each* exerting a force P.

a. Make a rough copy of the graph and add to it a second line OB which, you think, might represent the speed-against-time graph for the trolley pulled by two boys with a force of $2P$.

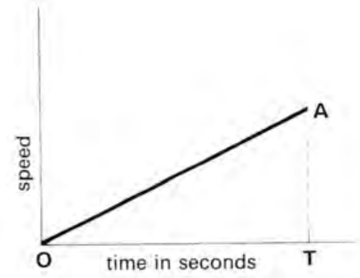
b. Draw in the vertical line (shown dotted) AT, and produce it upwards to cut your new graph at B. Did you make BT equal to twice AT? If so, why? If not, why not?

Don't just say 'Because $2P$ is twice one P.' Give a more convincing reason—a brief account of what *you* found when *you* did an experiment if you like.

I



II



Experiment 71
Falling Objects

Suppose you hold a small stone and a big one high above the ground and release them, together. *What will happen?* Think of the big stone, which is so heavy, being pulled down hard, while there is only a small pull of gravity on the small stone. *How much earlier do you expect the big stone to reach the ground?*

Try that experiment yourself. You do NOT need a special gadget to release the two stones. Just hold one in each hand and let go of both at the same instant.

Galileo and Free Fall

The Leaning Tower There is a story, unfortunately untrue, that Galileo, the great Italian scientist and teacher who wrote about force and motion three and a half centuries ago, gave a wonderful public demonstration which surprised and shocked those who saw it. The story says he

which wins ?

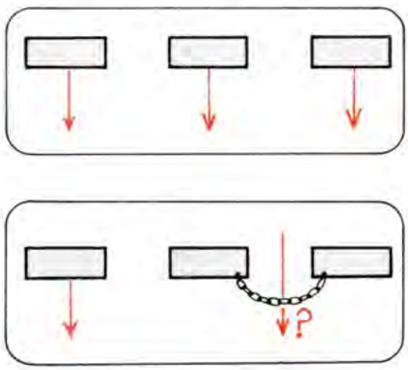
climbed to the top of the Leaning Tower of Pisa and dropped a little iron ball and a big cannon ball side by side. Everyone was astonished at the result; and some people were even angry. They expected the big ball, which weighed 10 times as much, to fall 10 times as fast.

Long before that, the Greek scientist Aristotle had said that a heavy object would fall much faster than a lighter one. Actually, he was thinking about things falling against strong air resistance and his idea was probably quite sensible. But later people copied what he wrote without understanding it; so they would be shocked by a Leaning Tower experiment—the experiment which you have just tried.

We know that Galileo did not make that public demonstration; but he lived near that Tower and he certainly knew the remarkable property of falling objects that you have just seen.

Another thought-experiment Galileo also invented a thought-experiment to upset people who were teaching Aristotle's statement blindly. Here is the kind of story he told:

'Suppose I let three equal bricks fall to the ground, starting together. They are all alike. They will all fall neck and neck with the same accelerated motion and all arrive at the ground at the same time.' His opponents agreed.



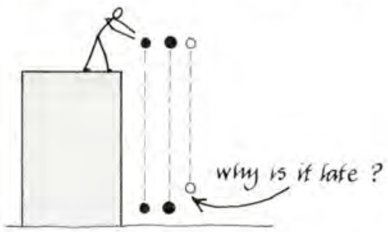
'Now suppose I repeat the experiment, but first I chain two of the bricks together with a light invisible chain, so light that it isn't really there. Then I suppose I have a double brick and a single brick. According to Aristotle, the double brick will fall twice as fast. Do you think that is likely, just because that little chain is there?'

'Ah yes,' one of his opponents might say, 'one of that pair of bricks gets a little *ahead* and drags the other down faster than the single one.'

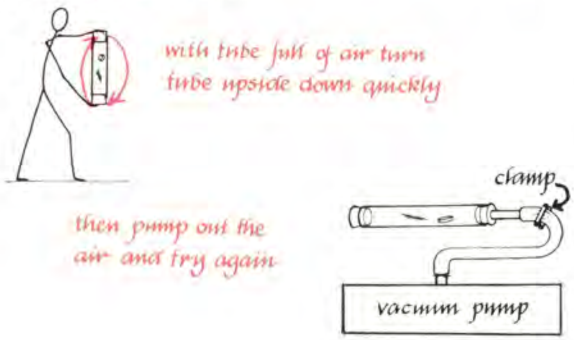
'Oh, I see,' Galileo would reply, 'the other brick of the pair gets a little *behind* and drags its companion upward, so that both fall slower!'

Galileo made his opponents furious by making their arguments look foolish like that.

Galileo suggested a reason why a wooden ball is left a little behind an iron ball, and a scrap of paper flutters down much more slowly. He said that the less dense things are simply delayed more by air resistance. He had no vacuum to show what would happen without any air; but he felt so sure that he predicted that, in a vacuum, a scrap of lead and a scrap of wool would both fall equally fast.



Not long after Galileo's life, Newton tried the actual experiment, with a golden coin (a guinea, £1.05) and a feather.



Experiment 72
The Guinea-and-Feather Experiment

Try Newton's experiment yourself. Ask for a glass tube and let your teacher pump the air out of it for you. Turn the tube upside down quickly—see the sketch.

Thinking about falling objects A large piece of rock is heavier than a small piece; its WEIGHT is greater, the Earth pulls it more. So, many people expect the heavy object to fall much faster. *Does that happen when air resistance is not important?*

If that does not happen, the heavier object must be richer in something else as well as WEIGHT (the Earth's pull on it). There *is* something else: 'INERTIA'. *To agree with experimental fact for free fall, must the heavier object have more inertia, or less, than the light one?* We say it has more MASS. *How much more?*

Progress Questions

FREE FALL

76. Describe the story of Galileo and the Leaning Tower of Pisa (even though he probably never gave a public demonstration).

77. Ann is upstairs, leaning out of the window. Bill is on the path outside.

Ann drops, all at the same time: a marble, a small lead ball, and a crumpled-up piece of paper.

What does Bill hear and see?

Questions

FREE FALL

78. A man leans out of an attic window, high up. He holds two things and lets go of both at the same time. You stand on the ground below and watch how the two things arrive. Say in each case whether you expect to see them arrive together, or one much later.

a. An apple and a grapefruit.

b. An apple and a walnut.

c. An apple and a stone of the same size as the apple but much heavier.

d. An apple and a skein of wool.

79. Find a small stone or other small dense object. Stand on a stool or chair or bench and drop the stone from a height of about $1\frac{1}{4}$ metres ($\approx$ 4 feet).

a. Make a guess at how much time (in seconds) it took to fall to the ground.

b. You cannot tell just by watching the stone, exactly what its motion is like—it could be a steadily increasing speed, or perhaps it falls faster and faster at first and then it reaches a steady speed' But it *cannot* have a motion with constant speed (steady unchanging speed) *all* the time from when you release it until it reaches the ground. Why not?

80a. You can count quarter-seconds by saying 'nought, one, two, three, four' (0, 1, 2, 3, 4) *quickly and distinctly*. Practice this while looking at the seconds hand of a watch or clock. Then, when you have the timing about right, repeat the stone-dropping described in Q.79, still from a height of $1\frac{1}{4}$ metres. Find the time taken—is it nearest to $\frac{1}{4}$ second, or $\frac{1}{2}$ second, or $\frac{3}{4}$ second, or 1 second?

b. Describe briefly how you did this.

c. Calculate the *average* speed of the stone during its fall in metres per second.

d. *(Advanced. No need to finish this unless you like.)* Assume (you don't yet know) that the stone increased its speed steadily (that is, had a constant acceleration). Write down:

(i) The average speed (your answer (c) above).

(ii) The final speed. (Remember that the speed at the start, when you released the stone, was zero.)

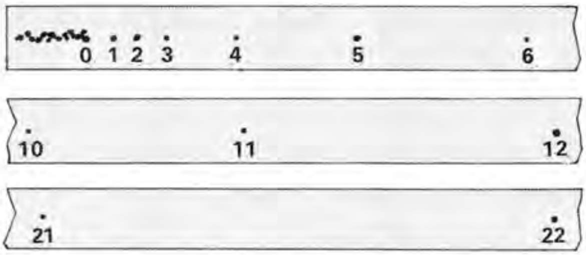
(iii) Your answer *(ii)* is also the increase of speed, because the starting speed was zero. This increase took place in the time you estimated by counting.

Now calculate the increase of speed *in one second.* That *is* the acceleration.

NOTE. This experiment is, of course, very inaccurate, but it does give you some idea of how big the acceleration is. (It gives what we call an 'order of magnitude estimate'—like being told which county a town is in.)

d. Why is (b) a highly inaccurate experiment?

81. Two boys set out to find whether a stone falling a distance of about 2 metres is accelerating all the time. They chose a heavy stone and attached it to paper tape which could be run through a vibrator. After a few attempts they obtained a clearly marked piece of tape about $1\frac{1}{2}$ metres long. The tape showed some confusion at the beginning, and the first clearly marked dot was about 3 cm from the start. They labelled this dot '0'. Then they numbered all the rest of the dots, about 23 in all. Three pieces of the tape are shown half actual size.



a. Describe how you would do this experiment; that is, say how you would place the vibrator and what measurements you would make. What is the chief source of possible error you have to guard against?

b. Do the marks on the tapes agree with the idea that the stone reaches a constant speed? OR, do they show that the stone was accelerating all the time?

c. Give the reason for your answer to (b).

d. *(Advanced. Omit if you like.)* The boys measured the distance along the tape from dot No. 0 to dot No. 10, and then from dot 10 to dot 20:

distance from dot 0 to dot 10 = 36 cm (in one tentick)

distance from dot 10 to dot 20 = 74 cm (in one tentick)

Notice that the middle dot at 'half-time' between dot 0 and dot 10 is dot 5; and the dot at 'half-time' between dot 10 and dot 20 is dot 15. Now write each of the following:

(i) The speed at a stage before-and-after dot 5 in cm per tentick.

(ii) The speed at a stage before-and-after dot 15 in cm per tentick.

(iii) The increase of speed between dot 5 and dot 15.

(The time from 'half-time' at dot 5 to 'half-time' at dot 15 is also one tentick.)

(iv) The answer to *(iii)* is the *acceleration* in 'cm/tentick in every tentick'.

(v) If 50 ticks take 1 second, how long do ten ticks take?

(vi) Now write down the acceleration in 'cm/second in every second'.

(NOTE. In answering (c) you assume that the stone is accelerating all the time. You know that from result (b). You also assumed that it has a *steady* (constant) acceleration. This also could be shown from the paper tape, though we did not ask you to do so in this question.)

82. A boy stands at the top of a flight of stairs and holds a string which is fastened to the floor below, or to a heavy object A on the floor. Small weights B, C, D, are attached to the string at points $\frac{1}{4}$ metre, $\frac{4}{4}$ metre, $\frac{9}{4}$ metre above the floor. The boy lets go of the string and listens to the timing of the 'clonks' as the weights hit the floor.

a. What would he notice about the timing of the noises he hears?

b. If he were able to have a string going up *two* flights of stairs, where should he tie a *fourth* weight E on the string.

c. Suppose, instead, he tied the weights at heights of 1, 2, 3, 4 metres above the floor, what would he now notice about the timing of the noises made as the string arrives?

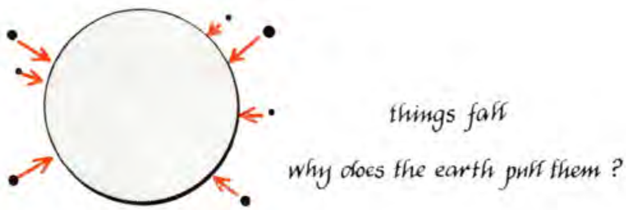
d. Suppose he did the experiment as in (a) and his partner recorded the noises on a tape recorder. Then his partner played the tape back, at $\frac{1}{4}$ of the original speed. What would he hear?

An Optional Advanced Discussion

Why do things fall? The usual scientific answer is, 'Because the Earth pulls them.' Until recently, that was not a very safe answer. If someone then asked, 'How do you *know* the Earth pulls things downward?', there were two reasons in reply:

(i) 'I can hold things in my hand and feel that they are heavy. The Earth pulls them and makes them feel heavy.' ('Yes, but how do you *know* that it is the Earth that does that?')

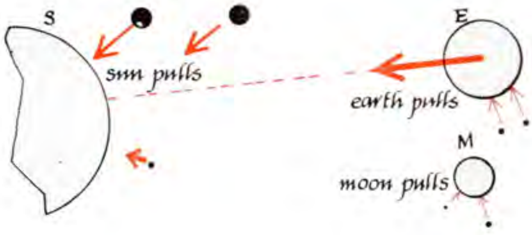
(ii) 'I see things falling faster and faster towards the Earth. That tells me the Earth pulls them.' (That amounts to: 'Why do things fall?' 'Because the Earth pulls them.' 'How do you know the Earth pulls them?' 'Because they fall!')



Long ago, Greek scientists had a safe answer to 'Why do things fall?' It was 'Because they *do*.' That was good science in a way. It just stated *what does happen*. But it was not fruitful; it made no predictions.

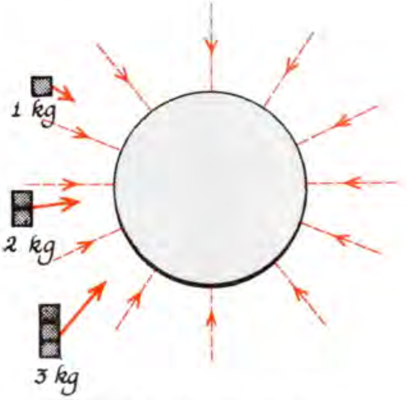
Then when explorers travelled round the globe of the Earth they could report that things always fall straight down; that is, straight towards the Earth's centre.

Then, when Newton described the Earth's pull more clearly and linked it with gravitation of the Sun and Moon, it seemed certain that it *is* the Earth that pulls things and makes them fall. Yet Newton himself said he did not know the *cause* of gravitation: he only knew *what it does*—rather like the attitude of the early Greek scientists.



Now that astronauts have travelled to the Moon and felt the Moon's weaker attraction, there can be no doubt. The Earth does pull things. So does the Moon; so does the Sun—all things attract each other. We call that *Universal Gravitation*; and in *Pupils' Text 5* you will find how Newton used that idea to explain many things in astronomy.

We think of the Earth as ready to pull, even when there is nothing there to pull on. We say the Earth has a GRAVITATIONAL FIELD, like invisible tentacles spreading straight out from the Earth waiting to clutch things. The field is not a force; it is a 'readiness-to-pull'. (When you go to a comic film, you are ready-to-laugh if there's a joke to laugh at.)



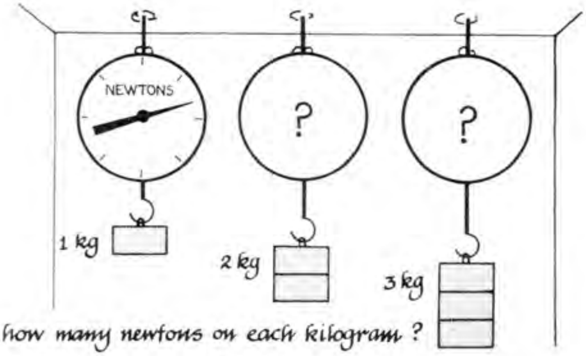
earth's gravitational field

We measure the Earth's FIELD STRENGTH by the force of its pull on each kilogram of stuff. Here is a simple experiment to illustrate that.

Demonstration 73
Strength of the Earth's Gravitational Field
(OPTIONAL)

Hang one kilogram on a newton balance to measure the force.

If the balance were to read 12 newtons, we should say the field strength is 12 newtons per kilogram. (But that is NOT its value—see the experiment for the true value.)



how many newtons on each kilogram?

Then hang 2 kg on the balance. Read the force and calculate the force ON EACH KILOGRAM. That is the field strength again.

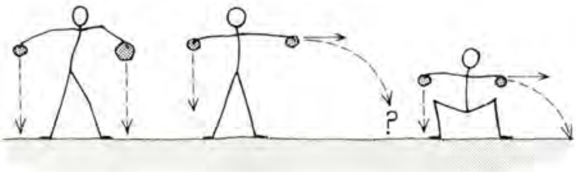
Try 3 or 5 kilograms. *Do you get the same* FIELD STRENGTH *every time?* If so you have a useful measurement that you will need in later years of physics. If you get different answers when you use 1, 2, 3, or 5 kg, what do you suspect? The spring balance's accuracy? Your arithmetic? Or the behaviour of the Earth's attraction?

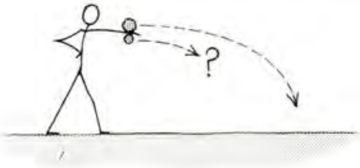
PROJECTILES

Experiment 74
Two Motions

What happens when you throw an object horizontally? As soon as you let go, it starts to fall faster and faster downward. *But what happens to its HORIZONTAL motion (its motion along)? Does that horizontal motion upset the vertical* *motion, or do they both happen without disturbing each other?*

Try the experiments sketched.





a. As in Experiment 71, release a large stone and a small one together.

b. Release one stone to fall vertically and at the same instant throw another stone out horizontally. (Use your two hands. You do NOT need a special gadget to do that. You will have a good clear test if you trust your own hands and your brain which controls them.)

c. Repeat the last experiment nearer the ground.

d. Throw a heavy stone and a light stone out both horizontally together.

What does the result of this tell you about satellites and their orbits?

Questions

GRAVITATIONAL FIELD

83. An 80-kilogram man goes from England where he was in a gravitational field of strength 9.81 newtons per kilogram, to the equator. At the equator he is in a gravitational field of strength 9.78 newtons per kilogram.

a. State the change of his weight (the pull of the Earth on him) in newtons.

b. *(Advanced question for thinking.)* Suppose he takes with him a bathroom weighing scale (which works by a spring inside). At home in England the scale reads 80 kg when he stands on it. At the equator, will it read more or less or the same?

c. What is it that is measured in kilograms? (For example the 80 for an 80-kilogram man.) (*Note:* The answer is *not* his WEIGHT. WEIGHT is a FORCE, measured in newtons.)

84. A space traveller, complete in his space suit, stands on a spring weighing scale on Earth. His WEIGHT is 980 newtons.

In the same suit on the spring balance on a smaller planet his WEIGHT is 245 newtons.

On a larger planet his WEIGHT is 1960 newtons.

The gravitational field strength at the surface of the Earth is 9.8 newtons per kilogram. What is the gravitational field strength on:
(i) the smaller planet;
(ii) the larger planet?

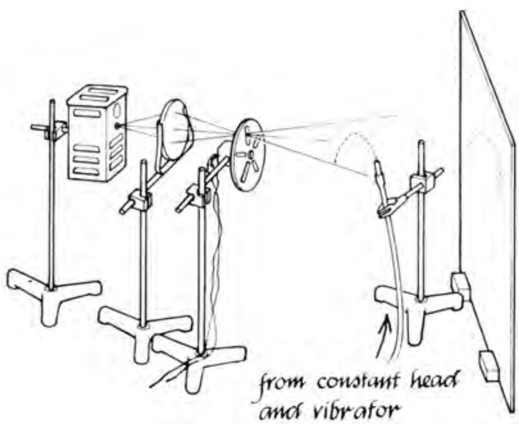
Independent Motions

Experiments 74b and c suggest that the vertical fall happens quite independently of horizontal motion—ONE MOTION DOES NOT DISTURB THE OTHER.

What happens to the horizontal motion (apart from the effect of air friction)? You will find you already know the answer if you think about the horizontal motion of something sliding with little friction on a level glass table. Demonstration 75 illustrates that.

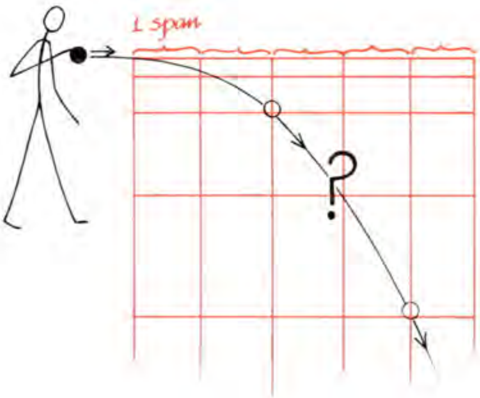
Demonstration 75
The 'Frozen Pearls'

A stream of water is squirted out of a tube. A ticker-timer jolts the rubber tube which carries



the water; and that makes the drops come out regularly exactly once every $\frac{1}{50}$ second. The drops are illuminated by flashes of light made by a bright lamp shining through a spinning strobe disk. At the right frequency of flashes, the drops seem to be 'frozen', fixed in mid-air.

Look at the distances ACROSS, horizontally, from each drop to the next. That will tell you about the horizontal motion.



Optional Extra Demonstration 76 'The Clever Parabola'

If you know the number-secret for the distances a freely falling object falls in 1 second, 2 seconds, 3 seconds . . . from rest, you can arrange an interesting demonstration.

Draw a horizontal line high up on the wall, as a starting line for a projectile thrown out horizontally. Draw lines below that, spaced according to the number-secret.

Draw vertical lines spaced at equal distances across the board, to represent moves with constant velocity horizontally. With the help of those lines, mark the positions of a projectile in the sketch.

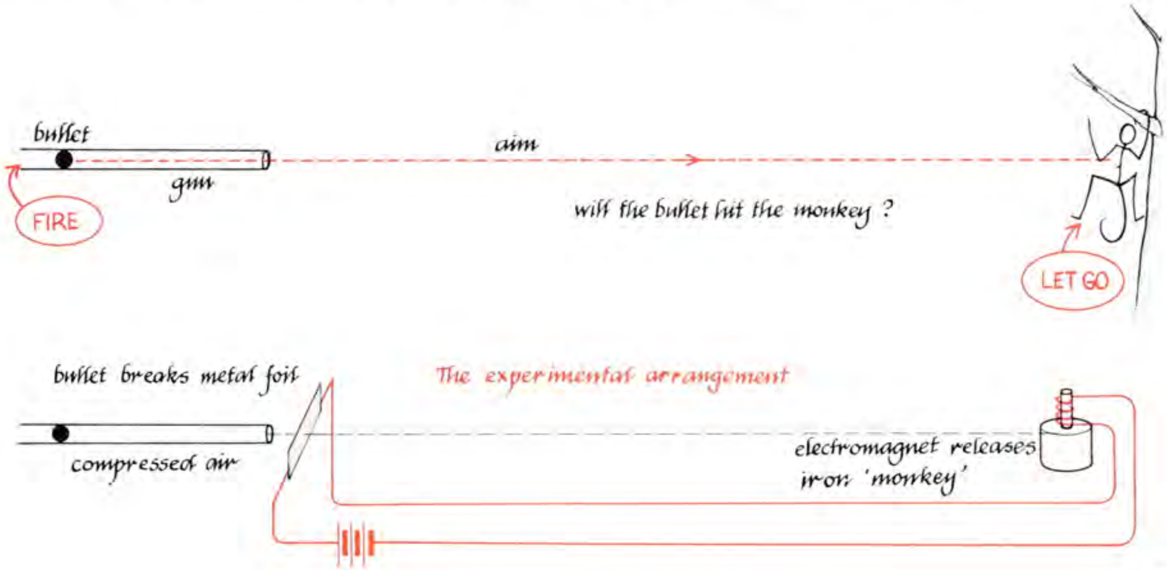
Then stand beside the wall and throw a small piece of chalk as a projectile. *Can you make it match the predicted path?*

Demonstration 77 The Monkey and Hunter

See the experiment sketched.

We pretend that a stupid hunter fires his gun at a monkey. The hunter does not know that a rifle bullet always falls with gravity motion however fast it comes out of the barrel. So he aims straight at the monkey who is hanging by one hand from a high branch of a tree. (The hunter takes his aim by removing the cartridge and looking at the monkey through the barrel of his rifle.)

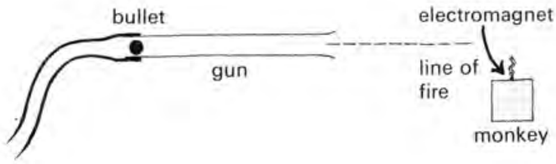
The hunter fires; but the monkey, thinking he understands the danger, lets go at the instant the gun is fired. *What happens?*



Progress Questions

MONKEY AND HUNTER

(Try one of these questions when you have actually seen the demonstration. You should not try either question if you have only heard about the experiment, or just read about it.)



85a. The sketch shows one way of arranging the experiment. There is something *wrong* in the sketch. Copy the sketch but change the wrong thing and make it right.

b. Say what made the bullet come out of the gun.

c. When did the electromagnet let go of the 'monkey'?

d. What did the monkey do when it was let go?

e. Did the monkey fall?

f. Did the bullet fall?

g. Describe all the things the bullet did.

h. This experiment showed you something important about falling objects. (It did not prove the important thing; but it did show you one example.) Say in a few words what it showed you.

i. There is a small electric 'switch' that is moved by the bullet.
(i) Where is the switch?
(ii) Does the bullet turn it ON or OFF?
(iii) Draw the electric circuit with that switch and a battery and the electromagnet.

86. *(If you have seen the 'monkey and hunter' experiment.)*

a. Draw a labelled diagram to show the important parts and use it to explain how the bullet makes the 'monkey' drop.

b. On your sketch, draw the path of the monkey and the path of the bullet.

c. The bullet sets off straight *along* and the monkey sets off straight *down*. How is it that the bullet hits the monkey?

Questions

MONKEY AND HUNTER

87. If you have seen it done, describe the 'monkey and hunter' experiment. Do all the following:

a. Give a sketch.

b. Say what was done.

c. Say what happened.

d. Say what conclusion about falling bodies you can draw from this experiment.

e. *(An advanced question for thinking.)* Sound travels at 350 metres per second. Suppose the bullet also travels at 350 metres per second, and the monkey *waits till he hears the gun fire* before he lets go. Will the bullet hit him?

88. *(Just a hard puzzle—not important.)* In actual fact, the sights on a real hunter's gun are arranged *so as to allow* for the falling of the bullet under gravity, during its travel. This means that the monkey gets hit if he stays on the branch because the gun sights make the hunter aim above the branch.

Sound travels at 350 metres per second. Suppose the monkey *waits till he hears* the gun fired before letting go. The bullet is fired from the properly sighted gun which allows for the bullet falling. Will the bullet hit him:

a. if it travels at 350 metres per second?

b. if it travels at 700 metres per second? ('Mach 2')

c. if it travels at 200 metres per second?

Optional Advanced Extensions: Calculating Accelerations

You do not need to do these this year. But you may try either or both now if you like.

(1) Acceleration of a trolley in centimetres/tentick in a tentick

If the feet of all your tentick strips stand on a base line, the slope of the slanting line through their heads tells you how fast the speed increased. If you measure the jump in height from one strip to the next, in centimetres, that tells you the *gain* in speed in centimetres/tentick, from one strip to the next.

And since the strips are samples of the motion one tentick apart from strip to strip, that gain of speed is itself made in one tentick. So each jump in strip height tells you the acceleration in centimetres/tentick in a tentick.

Units for acceleration

If those units seem puzzling, think of a lift, which must accelerate when it starts to haul people up from the ground to the top of a building. You might measure the lift's speed in metres/minute. An express lift in a skyscraper might make *most* of its trip at a steady speed of 120 metres/minute. But in starting it would have to accelerate, and its speed might be:

0 at start
60 metres/minute, 1 second from start
120 metres/minute, 2 seconds from start
(120 metres/minute steady speed after that)

Then, during the first two seconds the lift would have acceleration 60 metres/minute per second, meaning it would gain 60 metres/minute of speed *in each second.* That is its acceleration.

What is its acceleration in metres/*second* in each second?

(2) Acceleration of free fall, *g*

Suppose you recorded the free fall of a stone, with timer and tape. If you analysed your tape and obtained an acceleration 40 *centimetres/tentick per tentick*, what is that acceleration in *metres/second per second?*

How well does that result agree with the 'official' value 9.8 metres/sec^2?

Here is the argument to help you through the calculation:

The timer is fed by alternating current which makes 50 cycles per second. Therefore the timer's tentick is 10 lots of $\frac{1}{50}$ second.

1 tentick $= 10 \times \frac{1}{50}$ sec or $\frac{1}{5}$ sec.

The falling stone gained 40 cm/tentick in each tentick.

That is a gain of SPEED.

What is that *gain of speed,* 40 *cm/tentick,* in *metres/second?*

40 cm/tentick means 40 cm in 1 tentick.

That is the same as 40 cm in $\frac{1}{5}$ sec.

That is the same speed as . . ? . . cm in 1 sec
or . . ? . . metres in 1 sec.

So the falling stone was gaining . . ? . . metres/sec in each tentick. (That is, in each $\frac{1}{5}$ sec.)

Changing to scientific units

Therefore it was gaining . . ? . . metres/sec in each second.

The stone had acceleration . . ? . . metres/sec per sec
or metres/sec^2.