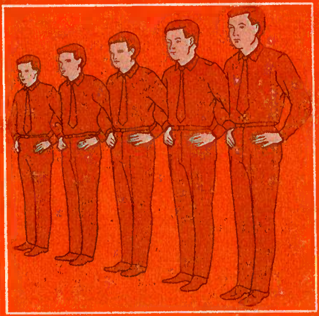
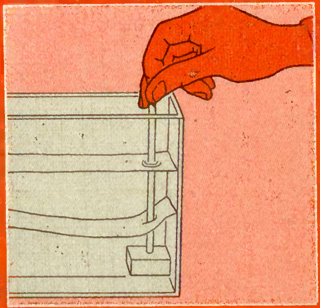
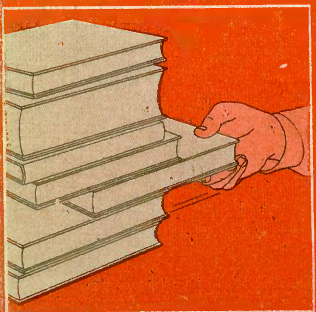
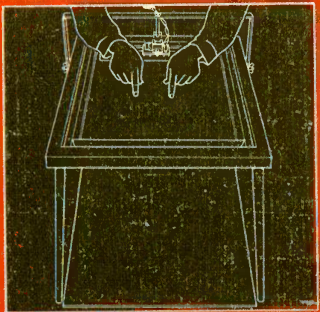
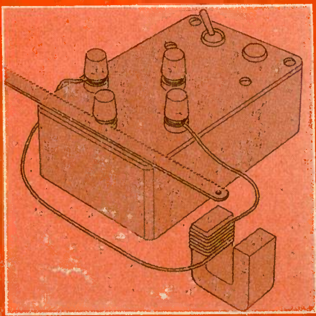
PHYSICS

Guide to experiments III

Nuffield Physics Guide to Experiments 3

PGE 04208

First published 1967
Reprinted with corrections 1967

Longmans, Green and Co. Ltd,
48 Grosvenor Street, London, W.1
Penguin Books Ltd,
Harmondsworth, Middlesex

Made and printed in Great Britain by
Cox & Wyman Ltd,
London, Fakenham and Reading

Set in Monotype Plantin

Designed by Ivan and Robin Dodd

Foreword

This volume is one of the first to be produced by the Nuffield Science Teaching Project, whose work began early in 1962. At that time many individual schoolteachers and a number of organizations in Britain (among which the Scottish Education Department and the Association for Science Education, as it now is, were conspicuous) had drawn attention to the need for a renewal of the science curriculum and for a wider study of imaginative ways of teaching scientific subjects. The trustees of the Nuffield Foundation considered that there were great opportunities here. They therefore set up a science teaching project and allocated large resources to its work.

The first problems to be tackled were concerned with the teaching of O-Level physics, chemistry, and biology in secondary schools. The programme has since been extended to the teaching of science in sixth forms, in primary schools, and in secondary school classes which are not studying for O-Level examinations. In all these programmes the principal aim is to develop materials that will help teachers to present science in a lively, exciting, and intelligible way. Since the work has been done by teachers, this volume and its companions belong to the teaching profession as a whole.

The production of the materials would not have been possible without the wholehearted and unstinting collaboration of the team members (mostly teachers on secondment from schools); the consultative committees which helped to give the work direction and purpose; the teachers in the 170 schools who participated in the trials of these and other materials; the headmasters, local authorities, and boards of governors who agreed that their schools should accept extra burdens in order to further the work of the project; and the many other people and organizations that have contributed good advice, practical assistance, or generous gifts of material and money.

To the extent that this initiative in curriculum development is already the common property of the science teaching profession, it is important that the current volumes should be thought of as contributions to a continuing process. The revision and renewal that will be necessary in the future, will be greatly helped by the interest and the comments of those who use the full Nuffield programme and of those who follow only some of its suggestions. By their interest in the project, the trustees of the Nuffield Foundation have sought to demonstrate that the continuing renewal of the curriculum – in all subjects – should be a major educational objective.

Brian Young
Director of the Nuffield Foundation

Introduction

This guide is a supplement to the *Teachers' Guide*, giving details of the class experiments and demonstrations to be done during the third year of Nuffield O-level physics programme. It is of course written for the assistance of teachers and is not intended for pupil use. It should be read in conjunction with the *Teachers' Guide*.

Reference is made in each experiment to the apparatus required. The item numbers refer to the numbers given to each piece of equipment needed for the programme, full details of which are given in the *Guide to Nuffield Physics Apparatus*.

Experiments in Year 3

Waves

1a	*Class Experiment*	– Transverse waves along a rope.
1b	*Demonstration*	– Examples of wave motion: pulses and continuous waves.
1c	*Optional Demonstration*	– Wave model.
2	*Demonstration*	– Waves along a line of pupils.
3	*Demonstration*	– Water waves seen in section.
4a	*Class Experiment*	– First acquaintance with a ripple tank.
4b	*Class Experiment*	– Simple circular pulses in ripple tanks.
4c	*Class Experiment*	– Simple straight pulses.
4d	*Class Experiment*	– Reflection of pulses by a straight barrier.
4e	*Class Experiment*	– Reflection at a curved barrier.
4f	*Class Experiment*	– Vibrator to generate continuous waves.
5	*Class Experiment*	– Introduction to a stroboscope.
4g	*Class Experiment*	– Using a stroboscope to 'freeze' continuous ripples.
4h	*Class Experiment*	– Using a stroboscope to estimate wavelengths of ripples.
4i	*Class Experiment*	– Reflection of a pulse by a barrier.

4j	*Class Experiment*	– Reflection of a straight wave by a barrier.
4k	*Class Experiment*	– Reflection at a parabolic barrier.
4l	*Class Experiment*	– Reflection of ripples at a circular barrier.
4m	*Optional Demonstration*	– Elliptical reflector.
4n	*Class Experiment*	– Watching what happens when one ripple crosses another.
4o	*Class Experiment*	– Interference with two sources, using two fingers.
4p	*Class Experiment*	– Interference with two sources, using vibrators.
4q	*Class Experiment*	– Interference using two slits.
4r	*Class Experiment*	– Diffraction at wide openings in barriers.
4s	*Class Experiment*	– Diffraction at narrow openings in barriers, and diffraction at obstacles.
4t	*Class Experiment*	– Refraction of ripples entering shallow water.
4u	*Class Experiment*	– Estimating wavelength, frequency, and velocity of ripples.

Optics

6a	*Demonstration*	– Shadows on a wall.
6b	*Demonstration*	– Ray of light on a wall.

6c	*Demonstration*	– Ray of light in water.
6d	*Optional Demonstration*	– Curved ray of light.
6e	*Demonstration*	– Ray of light being reflected.
6f	*Demonstration*	– Rubber ball 'reflected'.
7	*Class Experiment*	– Pinhole camera and lens camera.
8	*Demonstration*	– Smoke box showing image formation with a large lens.
9	*Demonstration*	– Image formation: moving paper in the path of rays of light.
10	*Class Experiments*	– Image formation with a lens.
11	*Class Experiment*	– Eye: range of accommodation.
12	*Class Experiment*	– First look at a telescope.
13	*Optional Class Experiment*	– Telescope with a close image.
14a–o	*Class Experiments*	– Rays of light and cylindrical lenses.
15	*Class Experiment*	– Plane mirror forming an image of a candle: empirical location of the image.
14p	*Class Experiment*	– Reflection of rays by a cylindrical mirror: aberration and the caustic curve.
16	*Demonstration*	– Image of a marble in a large spherical mirror.
14q–s	*Class Experiments*	– Rays of light and cylindrical lenses.

Nature of light

29	*Class Experiments and Demonstrations*	– The spectrum.
30	*Class Experiment*	– Particle model of reflection.
31	*Class Experiment*	– Particle model of refraction.
32	*Optional Class Experiment*	– Marching model of refraction.
33a	*Demonstration*	– Single slit and double slit demonstrations.
33b	*Demonstration*	– Diffraction shadows.
34	*Class Experiment*	– Young's slits with a ripple tank.
35a	*Demonstration*	– Interference with plastic wave model.
35b	*Optional Class Experiment or Home Experiment*	– Interference with corrugated cardboard wave model.
36	*Class Experiment*	– Young's slits.
37	*Films*	– Ripple tank films of refraction and interference.
38	*Demonstration*	– Interference patterns in a soap film.
39a	*Class Experiment*	– Interference in a thin air wedge.
39b	*Optional Demonstration*	– Interference using centimetre waves.
39c	*Optional Demonstration*	– Interference using sound waves.

Time, velocity, and acceleration

40	*Class Demonstration*	– Acceleration of ball rolling down a plank.
41	*Class Experiment*	– Measuring time intervals.
42	*Class Experiment*	– Rough timing of a trolley running down a slope.
43	*Class Experiment*	– Introduction to vibrators.
44	*Class Experiment*	– Time intervals with the vibrator.
45	*Class Experiment*	– Number of 'ticks' in 3 seconds.
46	*Demonstration*	– Introduction to measuring motion.
47	*Class Experiment*	– Measuring the pupil's own motion.
48	*Class Experiment*	– Investigation of free fall.
49	*Demonstration and Class Experiment*	– Diluted gravity experiment (acceleration down an inclined plane).
50	*Buffer Class Experiment*	– Diluted gravity experiment.
51	*Optional Experiments*	– Further experiments on diluted gravity or free fall.
52	*Buffer Class Experiment*	– Trolley running *up* the hill.
53a	*Demonstration*	– Galileo's experiment with a rolling ball.
53b	*Demonstration or Class Experiment*	– Galileo's pin and pendulum experiment.

54	*Demonstration*	– Frictionless motion.
55	*Optional Demonstration*	– Large pucks.

Inertia, force, and motion

56	*Class Demonstration*	– Inertia: two tin-can pendulums
57	*Optional Demonstrations*	– Inertia: further demonstration experiments.
58	*Class Experiment*	– Investigating acceleration with trolleys.
59	*Buffer Class Experiment*	– Effect on acceleration of changing the mass of a trolley.
60a	*Optional Class-Demonstration Experiment*	– Large trolley experiments on acceleration.
60b	*Extra Optional Class-Demonstration Experiments*	– Large trolleys and friction.
61	*Demonstration*	– Action and reaction with a metre rule.
62	*Optional Demonstration*	– Action and reaction: trolleys.
63	*Optional Demonstration*	– Multiflash photographs of free fall.
64	*Class Experiment*	– Falling objects.
65	*Class Experiment*	– 'Guinea and feather' experiment.
66a	*Class Experiment*	– Independence of vertical and horizontal motions.

66b	*Optional Demonstration*	– Multiflash photographs of projectiles.
67	*Demonstration*	– Pulsed water drop experiment.
68a	*Optional Buffer Demonstration*	– Testing projectile motion with a parabola drawn on the blackboard.
68b	*Optional Demonstration*	– Water jet following a parabola drawn on the blackboard.
69a	*Demonstration*	– The 'monkey and hunter' experiment.
69b	*Demonstration*	– Water jet through rings.
70	*Class Experiment*	– Gravitational field strength.

Kinetic theory of gases

71a	*Demonstration*	– Model for kinetic theory of a gas.
71b	*Class Experiment*	– Tray of marbles in constant agitation as a two-dimensional kinetic model.
72	*Class Experiment*	– Brownian motion.
73	*Optional Demonstration*	– Diffusion of hydrogen in air.
74	*Demonstration*	– Diffusion of bromine into air.
75	*Demonstration*	– Increase of pressure of a gas with temperature.
76	*Optional Demonstration*	– Increase of pressure of a gas with temperature.

77	*Class Experiment*	– Variation of pressure with temperature leading to the concept of absolute zero.
78	*Class Experiment*	– Expansion of air at constant pressure.
79	*Demonstration*	– Boyle's Law.

Electromagnetism

80a	*Class Experiment*	– Magnetic field due to an electric current in a wire.
80b	*Class Experiment*	– Oersted's experiment.
80c	*Class Experiment*	– Magnetic field due to a coil carrying a current.
81	*Optional Buffer Experiment*	– Simple galvanometer.
80d	*Class Experiment*	– Magnetic field due to a long close-wound coil.
80e	*Exhibition of Photographs*	– Magnetic fields.
80f	*Class Experiment*	– Magnetic field inside an open coil.
80g	*Class Experiment*	– Field of a bar magnet.
80h–k	*Class Experiments*	– Play with magnets.
80l	*Class Experiment*	– Magnetic fields due to arrangements of magnets.
80m	*Class Experiment*	– Electromagnets: field pattern.
80n	*Class Experiment*	– Electromagnets: forces.

80o	*Optional Class Experiment*	– Electromagnets: application to buzzer and the electric bell.
82	*Class Experiment*	– Force on a wire, carrying a current across a magnetic field.
83	*Demonstration and Class Experiment*	– The 'catapult' field.
84	*Class Experiment*	– Moving coil meter.
85	*Class Experiment*	– The electric motor.
86	*Demonstration*	– Fractional horse-power motor.
87a	*Class Experiment*	– Electromagnetic induction: the motor as a dynamo.
87b	*Optional Class Experiment*	– Electromagnetic induction: motor as a dynamo (a.c. form).
88a	*Class Experiment*	– Electromagnetic induction: magnet and coil.
88b	*Class Experiment*	– Electromagnetic induction: wire moving across magnetic gap.
88c	*Class Experiment*	– Electromagnetic induction: magnet and coil on iron core.
88d	*Class Experiment*	– Electromagnetic induction using an electromagnet.
88e	*Class Experiment*	– Electromagnetic induction: switching an electromagnet.
88f	*Demonstration*	– Electromagnetic induction: FHP motor connected to galvanometer.
88g	*Demonstration/Class Experiment*	– Bicycle dynamo.

89a	*Demonstration*	– Bicycle dynamo and oscilloscope.
89b	*Demonstration*	– Oscilloscope and a.c. voltage from transformer.
89c	*Class Experiment*	– Class oscilloscope.
90a	*Class Experiment*	– Transformer: d.c. supply and switch.
90b	*Class Experiment*	– Transformer: a.c. supply.
90c	*Demonstration*	– Transformer: dependence on number of turns.
91	*Class Experiment*	– Introduction to a voltmeter as a cell counter.
92a	*Demonstration*	– Water circuit board.
92b	*Demonstration*	– The voltmeter as a cell counter.
93	*Optional Buffer Experiment*	– Using a voltmeter to measure power transferred.
94a	*Class Experiment*	– d.c. model power line.
94b	*Demonstration*	– d.c. model power line at high voltage.
95a	*Demonstration*	– Electric fields.
95b	*Demonstration*	– Electric fields shown with paper indicator.
96	*Demonstration*	– Forces in an electrostatic field.
97	*Demonstration*	– Macro-Millikan apparatus.
98	*Optional Demonstration*	– Forces on charged polystyrene spheres: models of ions in motion.

99a	*Class Experiment*	– Electrostatic forces.
99b	*Demonstration*	– Demonstration electroscope.
99c	*Class Experiment*	– Gold leaf electroscope.
99d	*Class Experiment*	– Electrostatic induction.
100	*Demonstration*	– Deflection of electron beam in an electrostatic field.
101	*Class Experiment*	– Breaking bar magnets.
102a	*Demonstration*	– Model of a magnet.
102b	*Optional Film*	– Domain film.
103	*Optional Demonstration*	– Magnetization saturation.
104	*Class Experiment*	– Breaking ring magnets.

Appendices

I Operating instructions for the demonstration oscilloscope.

II Operating instructions for the class oscilloscope.

1a *Class experiment*

Transverse waves along a rope

Apparatus

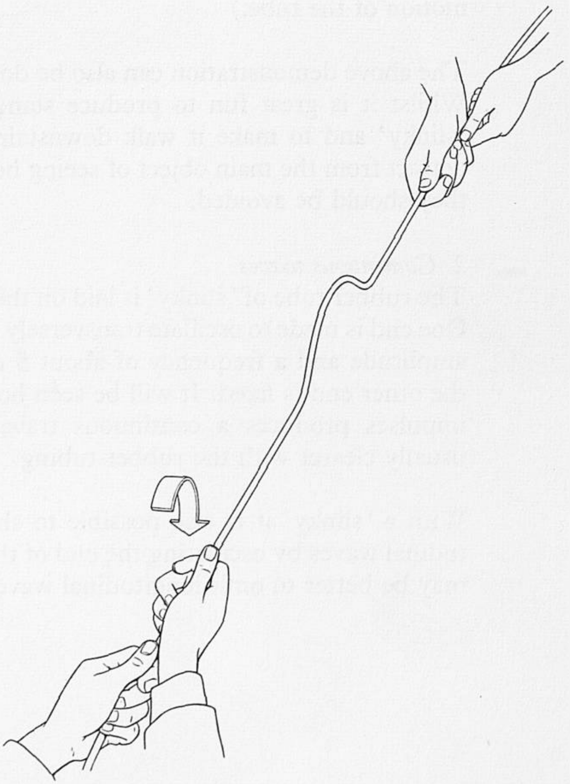
16 lengths of flexible rope

The longer the rope the better, depending on the space available, minimum length 3 metres.

Procedure

Pupils should work in pairs and each hold one end of the rope. A flick at one end of this rope sends a pulse down and back. (This is easily done by jerking the end of the rope up and quickly down to stop on the wrist of the other hand.)

The pulses can be reflected back and forth several times if the rope is held in mid-air, but it may be better to have it on the bench or on the floor.



1b *Demonstration*

Examples of wave motion: pulses and continuous waves

Apparatus

1 'slinky' – item 101
1 length of rubber tubing

The minimum length of the rubber tubing is 5 metres. It should be 8 mm or more in diameter.
The slinky should be at least 10 cm long when closed up.

Procedure

1. *Pulses*
The tube is held on the floor under slight tension and one end is given a sharp flick horizontally. This is most easily done by holding one's hand against one's ankle and then jerking it sideways and back to the foot again. Different tensions and slower pulses can be tried. (Pulses of a different shape can be produced by having a stop such as a chair leg to limit the motion of the tube.)

The above demonstration can also be done with a 'slinky'. Whilst it is great fun to produce standing waves with the 'slinky' and to make it walk downstairs, such experiments detract from the main object of seeing how a pulse travels, so they should be avoided.

2. *Continuous waves*
The rubber tube of 'slinky' is laid on the floor or on a bench. One end is made to oscillate transversely by hand with a small amplitude and a frequency of about 5 cycles per sec, while the other end is fixed. It will be seen how a regular chain of impulses produces a continuous travelling wave. This is usually clearer with the rubber tubing.

With a 'slinky' it is also possible to show travelling longitudinal waves by oscillating the end of the 'slinky', though it may be better to omit longitudinal waves at this early stage.

1c *Optional demonstration*

Wave model

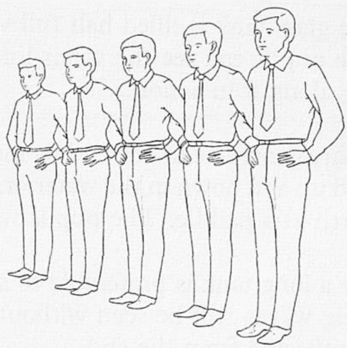
Where the laboratory already owns a wave model of any form that is ready for use, it may profitably be shown as a quick demonstration, *in addition* to the experiments in 1a and 1b.

2 Demonstration

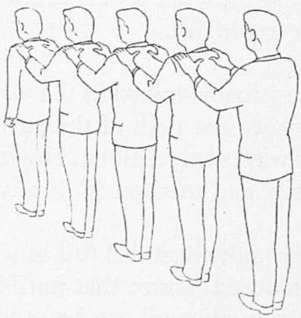
Waves along a line of pupils

Procedure

If pupils link arms in a line it is possible to send transverse waves and pulses down the line.



For longitudinal waves and pulses, the hands should be put on the shoulders of the neighbouring pupil, with elbows kept bent.



It is more vivid if the pupils face away from the teacher in a line, each with his hands on the shoulders of the one in front. A good shove from the teacher on the back of the end pupil can send a strong pulse down the line. When the pupils have picked themselves up, it is worth discussing the difference between this pulse and all the others so far: that the particles did not, in this case, return to their original places. (This occurs with waves in any medium when the medium is strained beyond its elastic limit.) It is also worth while to repeat the experiment with a gentle push while the pupils cooperate to carry a wave without disaster.

3 *Demonstration*

Water waves seen in section

Apparatus

1 large rectangular transparent tank – item 100/2

Procedure

(*a*) The glass tank is filled half full with water and placed so that the pupils can see the water line face on and any waves passing along it in action.

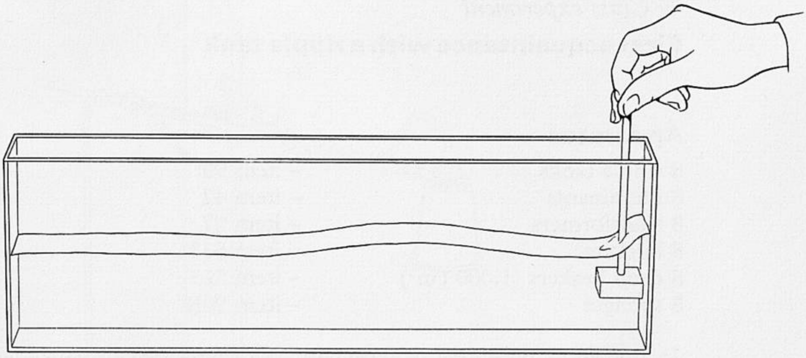
Waves are generated at one end by moving the hand or a block of wood up and down in the water or, better, sweeping it back and forth as a paddle. The pupils watch the motion.

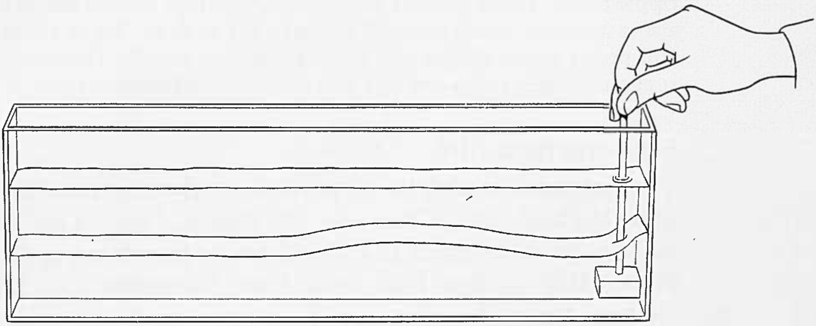
Clearly a long tank is preferable to a short one for the initial outgoing waves will be seen without the complication of the waves reflected from the end.

The tank need not be wide from front to back – 3 in would suffice. The height should be at least 6 in and the length as great as possible – one foot is probably too short, 3 ft would be good, but expensive.

If some sawdust is mixed in the water those watching at close range may see the path of the particles of the medium when the water waves travel along. However, that motion is too fast to see easily and method (*b*) is advocated.

(*b*) Fill the tank one-third full of water and add paraffin (preferably coloured) above that until the tank is two-thirds full. (Alternatively olive oil can be used, but it gives more damping and is unnecessarily expensive.) Generate transverse waves at the interface, keeping the paddle immersed.





4a *Class experiment*

First acquaintance with a ripple tank

Apparatus

8 ripple tanks	– item 90
8 illuminants	– item 47
8 transformers	– item 27
8 buckets	– item 533
8 deep beakers (1,000 cm^3)	– item 513
8 sponges	– item 90R

In this and subsequent experiments, the ripple tanks require legs, gauzes (or another arrangement to provide 'beaches'), and supports for the illuminants.

Some manufacturers supply special power units for use with the ripple tanks. These provide the necessary voltage for the lamps and also a variable voltage output to drive the motors. Some teachers will prefer these, others will use the transformers for the lamp, as suggested here, and a dry cell and rheostat for the motor.

Esso-Nuffield film

The experiments with the ripple tank are demonstrated in the Esso-Nuffield film *Waves and the Ripple Tank.* This film is intended for teachers and should not be shown to pupils. It is available on free loan from Esso Petroleum Co. Ltd., Victoria Street, London, S.W.1.

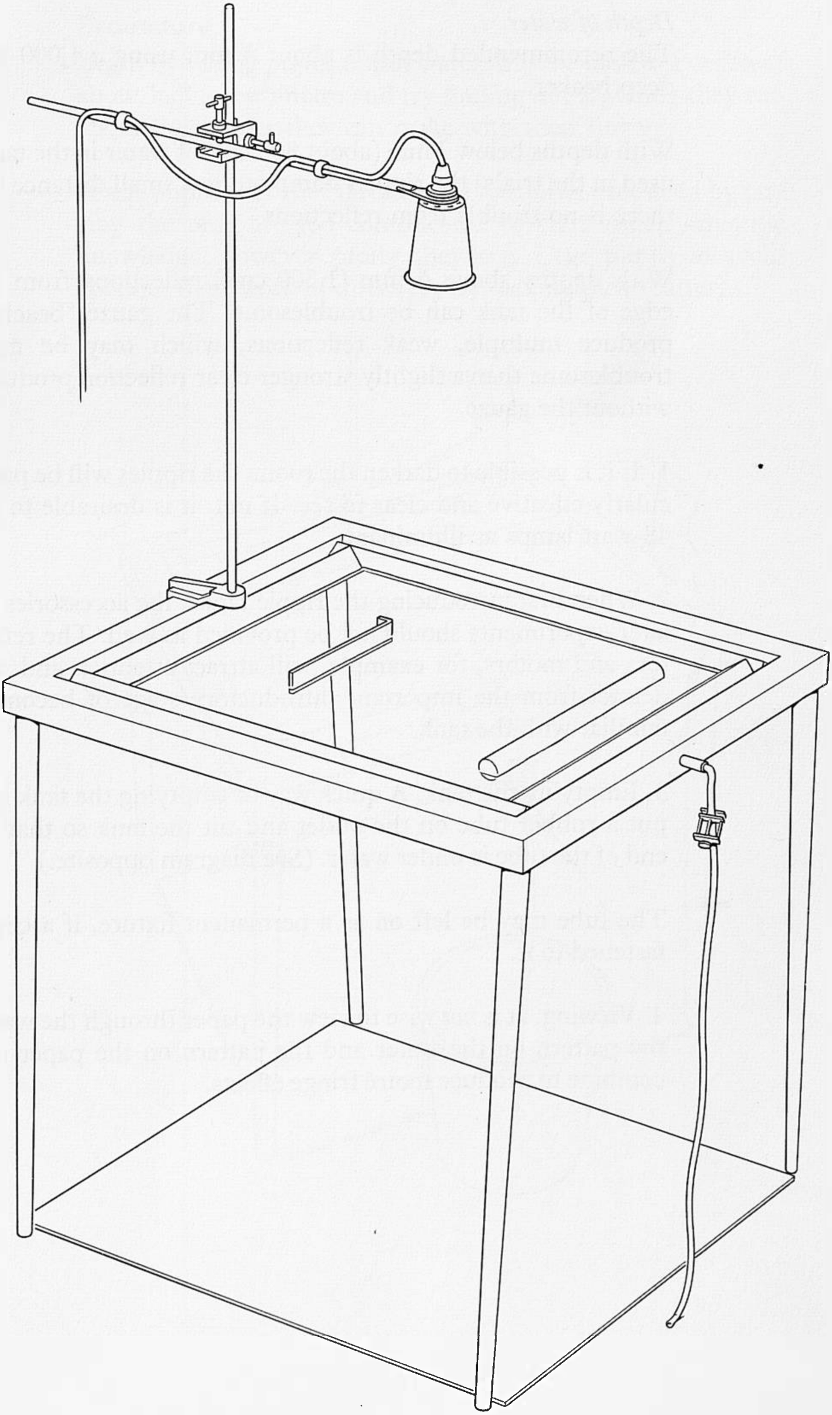
General notes on setting up the ripple tanks

To avoid unwanted vibrations, the tanks should be set up on the floor. Each tank should be filled to a depth of about 5 mm using about 1,000 cm^3 of water – for further comments on depth, see below. The tanks can be levelled quickly and easily by matching the two reflections of the lamp, one from the glass and one from the water surface.

A large piece of white paper underneath the tank will show the ripples. So will a piece of hardboard painted white.

The lamp should be adjusted in height to give the best picture. It should be about 50 cm above the tank.

The pieces of gauze in the water around the edges of the tank will cut down reflection of ripples by the edges.



Depth of water

The recommended depth is about 5 mm using a 1,000 cm^3 deep beaker.

With depths below 3 mm (about 800 cm^3 of water in the tanks used in the trials) the ripples damp out in a small distance but there is no trouble from reflections.

With depths above 6 mm (1,300 cm^3) reflections from the edge of the tank can be troublesome. The gauze 'beaches' produce multiple, weak reflections, which may be more troublesome than a slightly stronger clear reflection produced without the gauze.

1. If it is possible to darken the room, the ripples will be particularly effective and clear to see. If not, it is desirable to use 48-watt lamps as illuminants.

2. When first introducing the ripple tanks, the accessories for later experiments should *not* be provided as well. The reflectors and motors, for example, will attract attention and may detract from the important introductory stage of becoming familiar with the tank.

3. Emptying the tank. A quick way of emptying the tank is to put a rubber tube on the outlet and tilt the tank so that the end of the tube is under water. (See diagram opposite.)

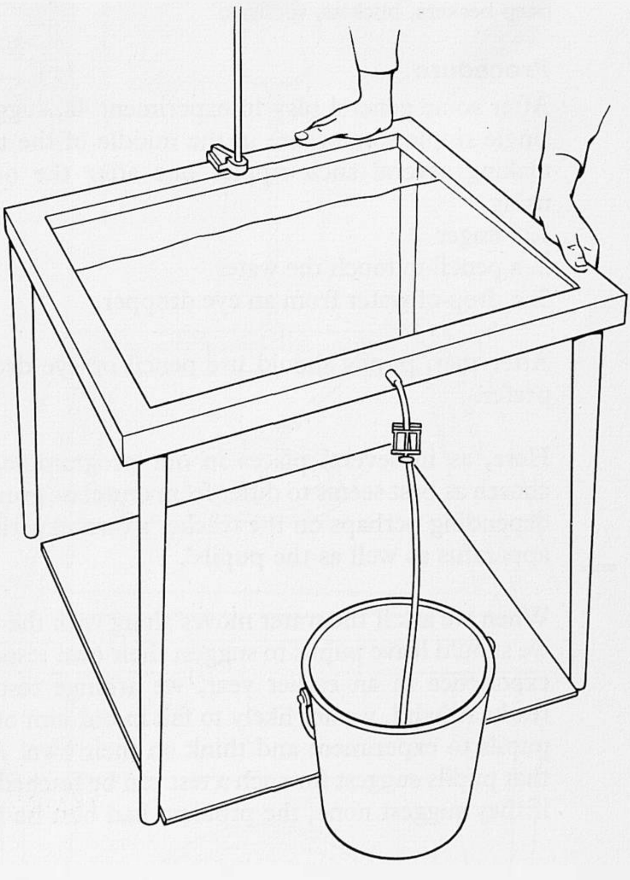
The tube may be left on as a permanent fixture, if a clip is fastened to it.

4. Viewing. It is *not* wise to view the paper through the water; the pattern on the water and the pattern on the paper may combine to produce moiré fringe effects.

Procedure

Begin by telling pupils to put water into the tank to a depth of about half a centimetre and try finding out anything they can about the ripples they can make with their fingers.

Warn pupils that the 'tartan plaid' patterns produced by jarring the tank are too complicated to yield much scientific knowledge, however pretty they are. Urge pupils to avoid spoiling their work of discovery by making those patterns.



4b *Class experiment*

Simple circular pulses in ripple tanks

Apparatus

8 ripple tanks	– item 90
8 water droppers	– item 90H
8 pencils	

The usual accessories will be required with the ripple tanks: legs, gauzes, illuminants, supports for the illuminants, transformers, deep beakers, buckets, sponges.

Procedure

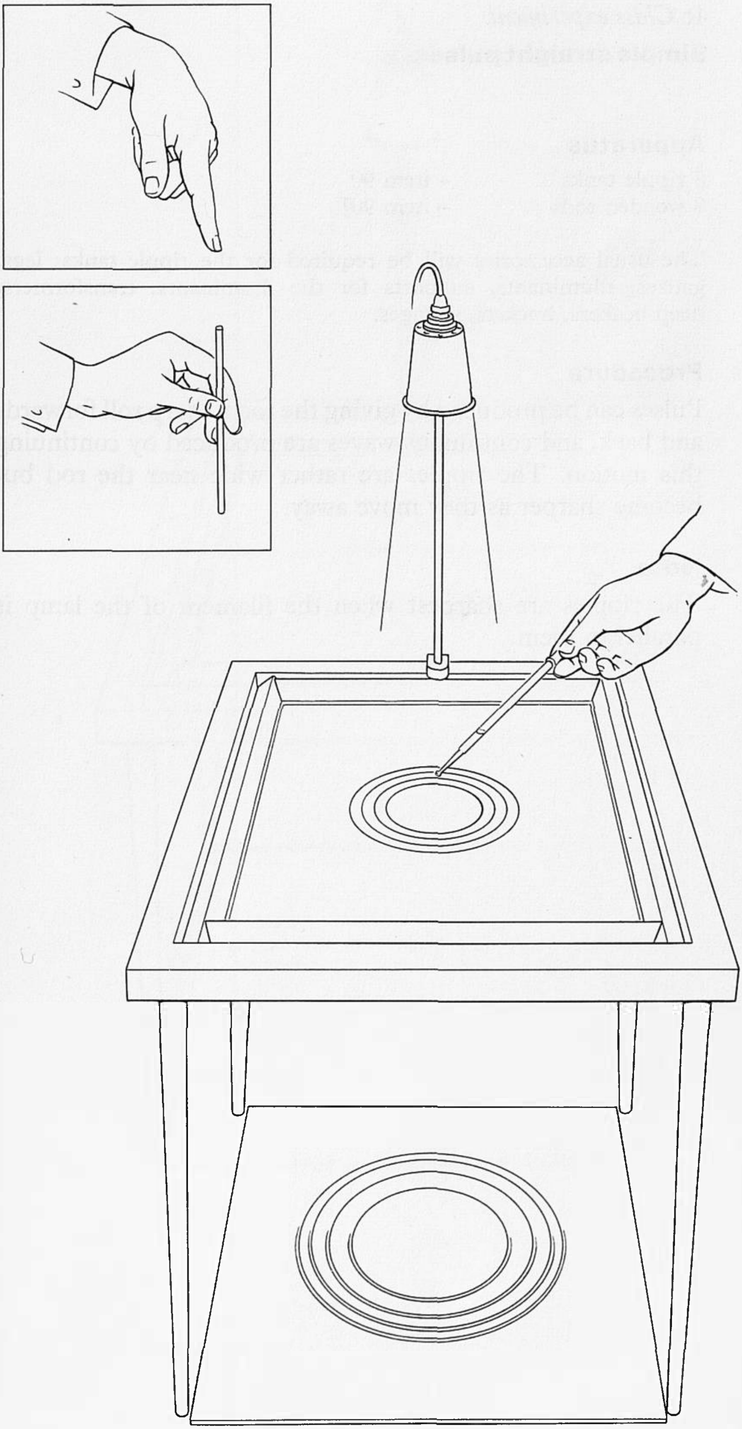
After some general play in experiment 4a, suggest starting a single ripple somewhere in the middle of the tank and then making several such ripples one after the other. Suggest using:

1. a finger
2. a pencil to touch the water
3. a drop of water from an eye dropper.

After that, pupils should use pencil or eye dropper as they prefer.

Here, as in several places in our programme, the method chosen as best seems to differ from one class group to another, depending perhaps on the teacher's own experience with the apparatus as well as the pupils'.

When we ask if the water moves along with the wave pattern, we should leave pupils to suggest their own tests. If, from our experience in an earlier year, we arrange testing materials ready at hand, we are likely to fail in our aim of encouraging pupils to experiment and think on their own. Any materials that pupils suggest for such a test can be fetched quickly; and if they suggest none, the problem had best be left unsettled.



4c *Class experiment*

Simple straight pulses

Apparatus

8 ripple tanks	– item 90
8 wooden rods	– item 90J

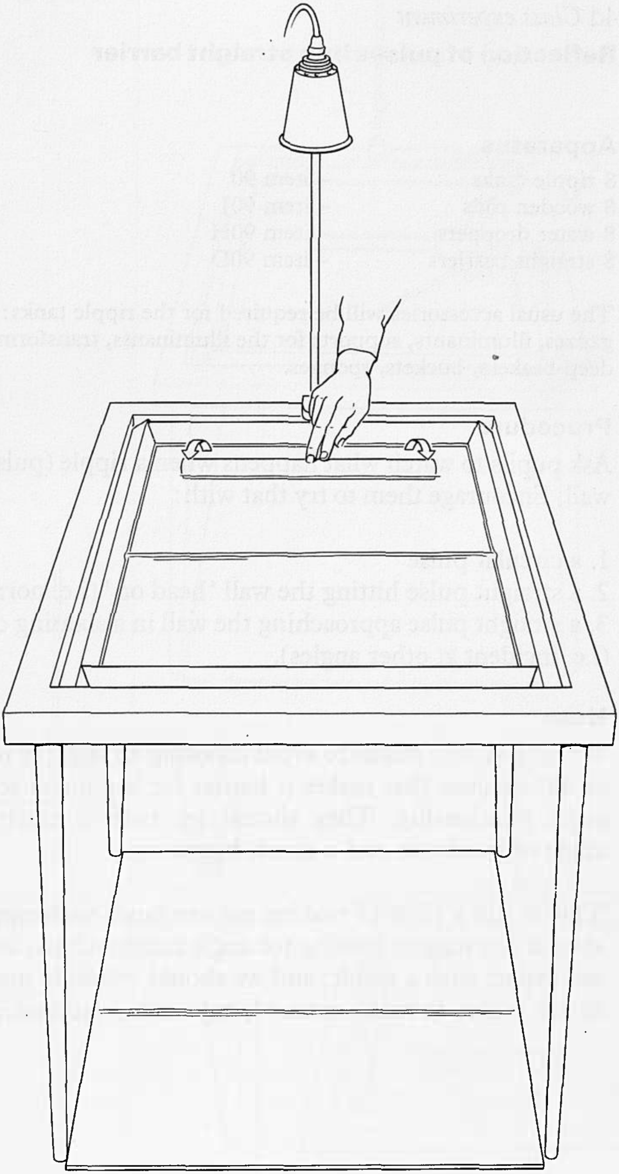
The usual accessories will be required for the ripple tanks: legs, gauzes, illuminants, supports for the illuminants, transformers, deep beakers, buckets, sponges.

Procedure

Pulses can be produced by giving the rod a sharp roll forwards and back, and continuous waves are produced by continuing this motion. The ripples are rather wide near the rod but become sharper as they move away.

Note

The ripples are sharpest when the filament of the lamp is parallel to them.



4d *Class experiment*

Reflection of pulses by a straight barrier

Apparatus

8 ripple tanks	– item 90
8 wooden rods	– item 90J
8 water droppers	– item 90H
8 straight barriers	– item 90D

The usual accessories will be required for the ripple tanks: legs, gauzes, illuminants, supports for the illuminants, transformers, deep beakers, buckets, sponges.

Procedure

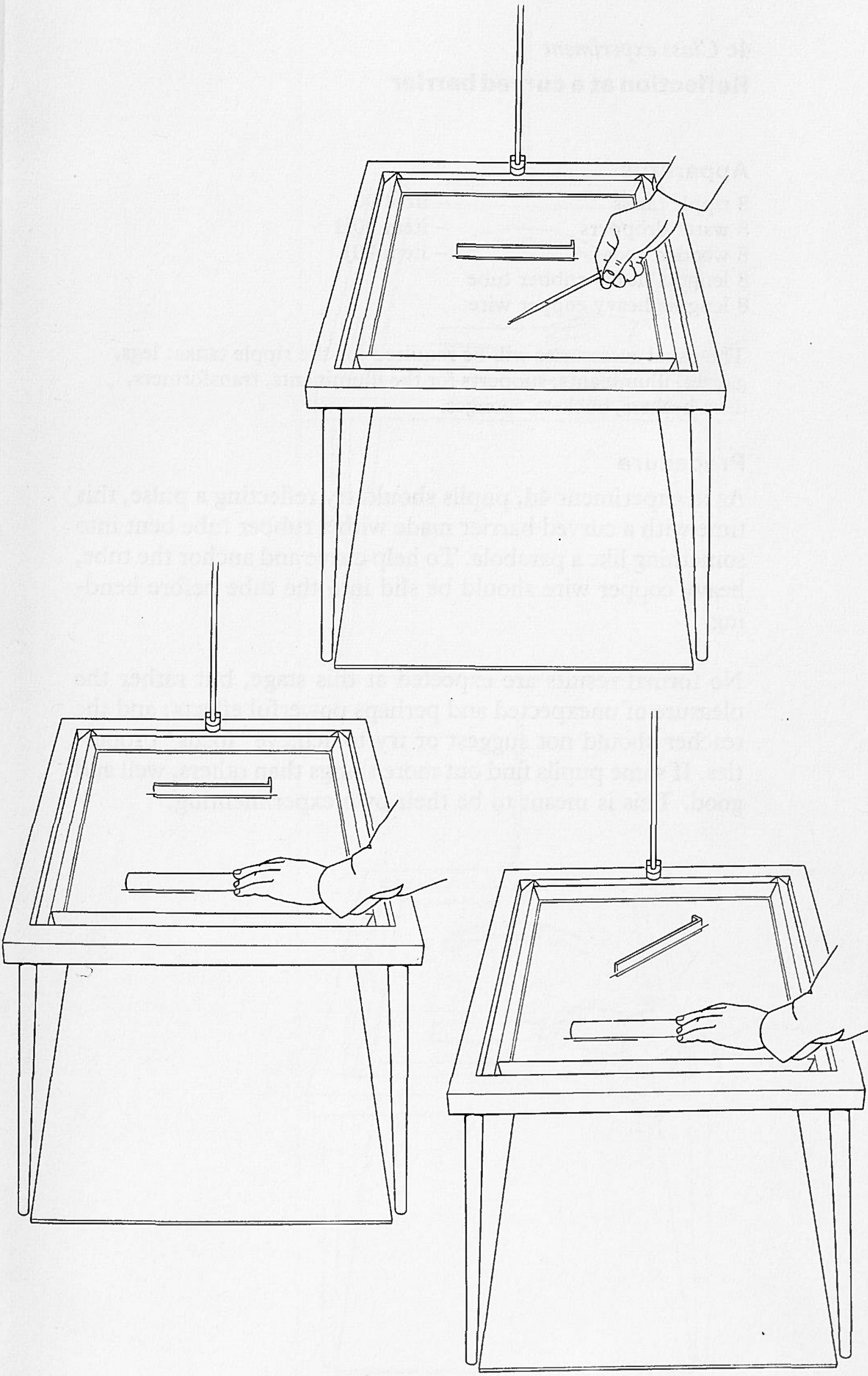
Ask pupils to watch what happens when a ripple (pulse) hits a wall. Encourage them to try that with:

1. a circular pulse
2. a straight pulse hitting the wall 'head on' (i.e. normally)
3. a straight pulse approaching the wall in a slanting direction (i.e. incident at other angles).

Note

We should help pupils to avoid choosing an angle of incidence of 45° because that makes it harder for beginners to see the angle relationship. They should try both a much smaller angle of incidence and a much bigger one.

This is still a stage of making acquaintance with ripples. We should not suggest looking for angle relationships; we should not expect such a result; and we should certainly not dictate, or ask pupils to make notes of, any such relationship.



4e *Class experiment*

Reflection at a curved barrier

Apparatus

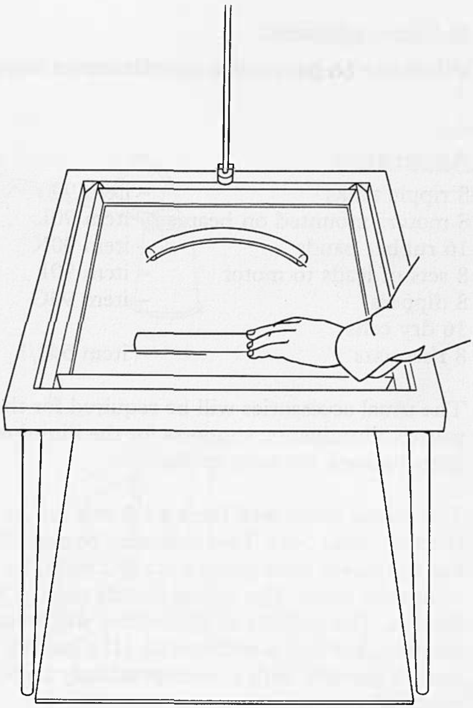
8 ripple tanks	– item 90
8 water droppers	– item 90H
8 wooden rods	– item 90J
8 lengths heavy rubber tube	
8 lengths heavy copper wire	

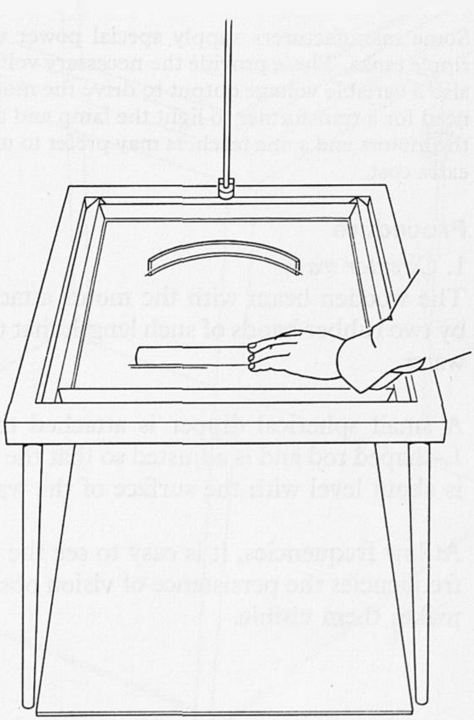
The usual accessories will be required for the ripple tanks: legs, gauzes, illuminants, supports for the illuminants, transformers, deep beakers, buckets, sponges.

Procedure

As in experiment 4d, pupils should try reflecting a pulse, this time with a curved barrier made with a rubber tube bent into something like a parabola. To help curve and anchor the tube, heavy copper wire should be slid into the tube before bending.

No formal results are expected at this stage, but rather the pleasure of unexpected and perhaps powerful effects; and the teacher should not suggest or try to achieve 'focus' properties. If some pupils find out more things than others, well and good. This is meant to be their own experimenting.





4f *Class experiment*

Vibrator to generate continuous waves

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
16 rubber bands	– item 90K
8 sets of leads to motor	– item 90I
8 dippers	– item 90G
16 dry cells	
8 rheostats	– item 541/1

The usual accessories will be required for the ripple tanks: legs, gauzes, illuminants, supports for the illuminants, transformers, deep beakers, buckets, sponges.

The motor works well from a 1·5 volt cell in series with a 12-ohm rheostat (item 541). Two cells may be needed for the higher speeds but the motor then goes rather fast with the rheostat set at its minimum value. The circuit boards used in Year II could be used for this. The polarity of the battery determines the direction of rotation, but that is immaterial. (If a battery with a higher e.m.f. is used, a rheostat with a correspondingly high resistance would be required.)

Some manufacturers supply special power units for use with the ripple tanks. These provide the necessary voltage for the lamps and also a variable voltage output to drive the motors. They avoid the need for a transformer to light the lamp and a separate supply for the motors and some teachers may prefer to use them despite the extra cost.

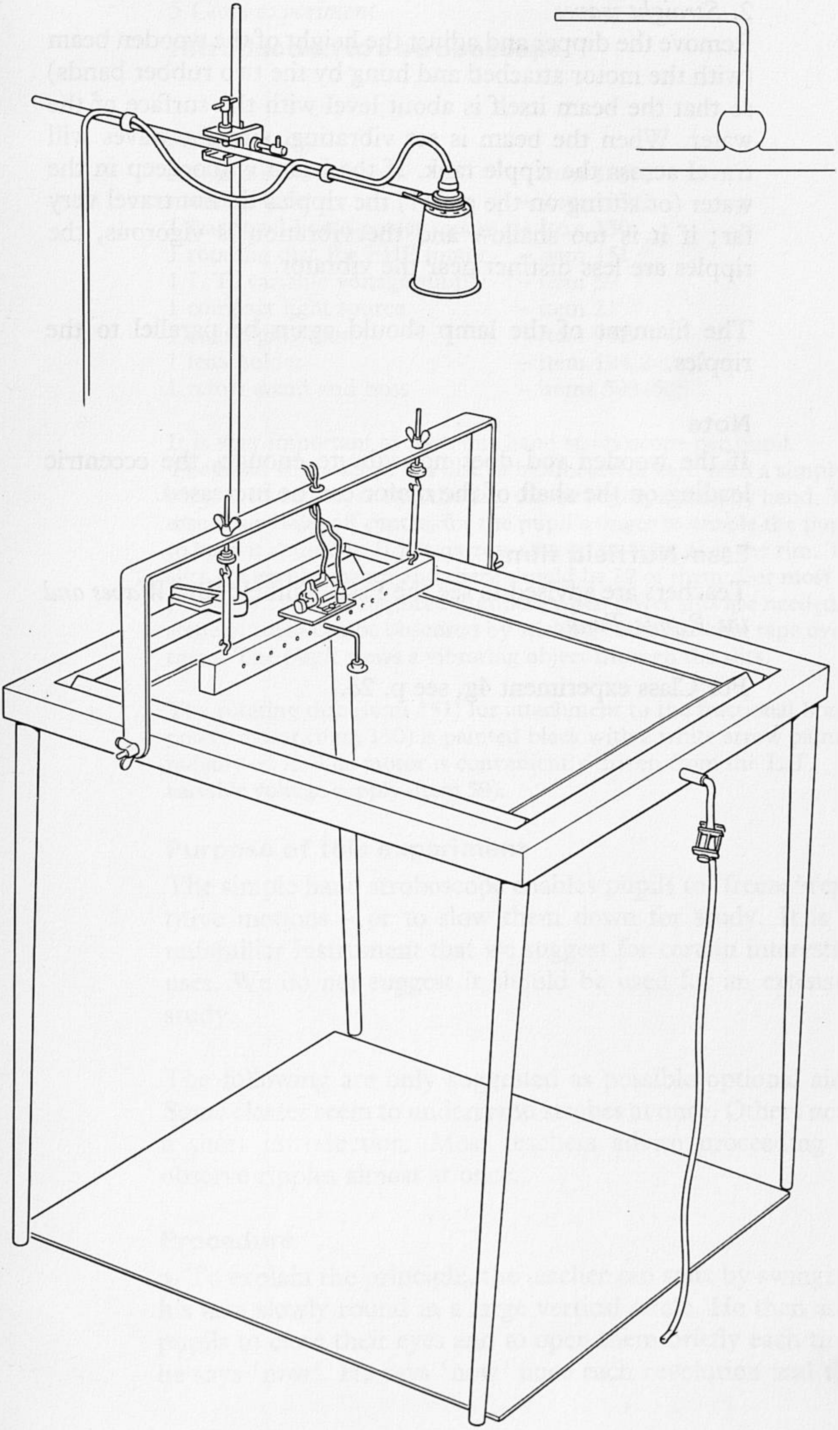
Procedure

1. *Circular waves*

The wooden beam with the motor attached should be hung by two rubber bands of such length that the wood is above the water.

A small spherical dipper is attached to the vibrator by its L-shaped rod and is adjusted so that the bottom of the sphere is about level with the surface of the water.

At low frequencies, it is easy to see the waves; but at higher frequencies the persistence of vision obscures them. Blinking makes them visible.



2. *Straight waves*

Remove the dipper and adjust the height of the wooden beam (with the motor attached and hung by the two rubber bands) so that the beam itself is about level with the surface of the water. When the beam is set vibrating, straight waves will travel across the ripple tank. If the beam is too deep in the water (or sitting on the glass!) the ripples do not travel very far; if it is too shallow and the vibration is vigorous, the ripples are less distinct near the vibrator.

The filament of the lamp should again be parallel to the ripples.

Note

If the wooden rod does not vibrate enough, the eccentric loading on the shaft of the motor can be increased.

Esso-Nuffield film

Teachers are advised to see the Esso-Nuffield film *Waves and the Ripple Tank.*

For Class experiment 4g, see p. 28.

5 Class experiment

Introduction to a stroboscope

Apparatus

32 hand stroboscopes	– item 105/1
masking tape	– item 105/2
1 fractional horse-power motor	– item 150
1 rotating disc for FHP motor	– item 151
1 L.T. variable voltage supply	– item 59
1 compact light source	– item 21
1 converging lens	– item 93B
1 lens holder	– item 124/2
1 retort stand and boss	– items 503–505

It is very important to have one hand stroboscope per pupil. The hand stroboscope is a disc of hardboard or card with a simple pivot at its centre, so that the disc can be kept spinning by hand. The disc has a hole, off centre, for the pupil's finger to enable the pupil to keep it spinning. It has narrow slits on its face, near the rim. The slits are evenly spaced and there should be 12 of them. For most purposes 12 is the required number; when fewer slits are needed, some of them can be obscured by sticking black masking tape over them. The pupil views a vibrating object through the slits.

The rotating disc (item 151) for attachment to the fractional horse-power motor (item 150) is painted black with a white arrow painted radially on it. The motor is conveniently driven from the L.T. variable voltage supply (item 59).

Purpose of this experiment

The simple hand stroboscope enables pupils to 'freeze' repetitive motions – or to slow them down for study. It is an unfamiliar instrument that we suggest for certain interesting uses. We do not suggest it should be used for an extensive study.

The following are only suggested as possible optional aids. Some classes seem to understand strobes at once. Others need a short introduction. Most teachers advise proceeding to observe ripples almost at once.

Procedure

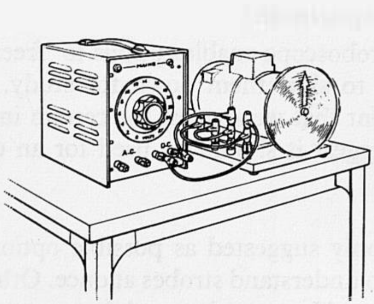
a. To explain the principle, the teacher can start by swinging his arm slowly round in a large vertical circle. He then asks pupils to close their eyes and to open them briefly each time he says 'now'. He says 'now' once each revolution and the pupils see his arm each time in the same position. He then says 'now' once every two revolutions and they see the same thing but less often. If he says 'now' once every half-revolution, they see his arm in two positions.

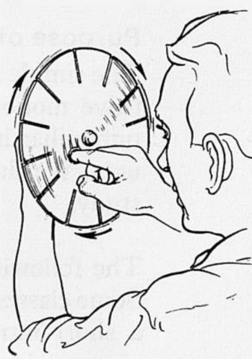
If this does not work well, it is *not* worth practising the pupils in opening their eyes. The main point is to show the principle of the stroboscope and this should soon be clear.

b. *Rotating Disc*
A black disc painted with a white arrow is driven by a motor. The hand stroboscopes give 12 glimpses per revolution. Black tape may be used to cut this down to 6, 4, 3, 2, or 1, but with this experiment it is simplest to use all 12 slits and to adjust the speed of the motor.

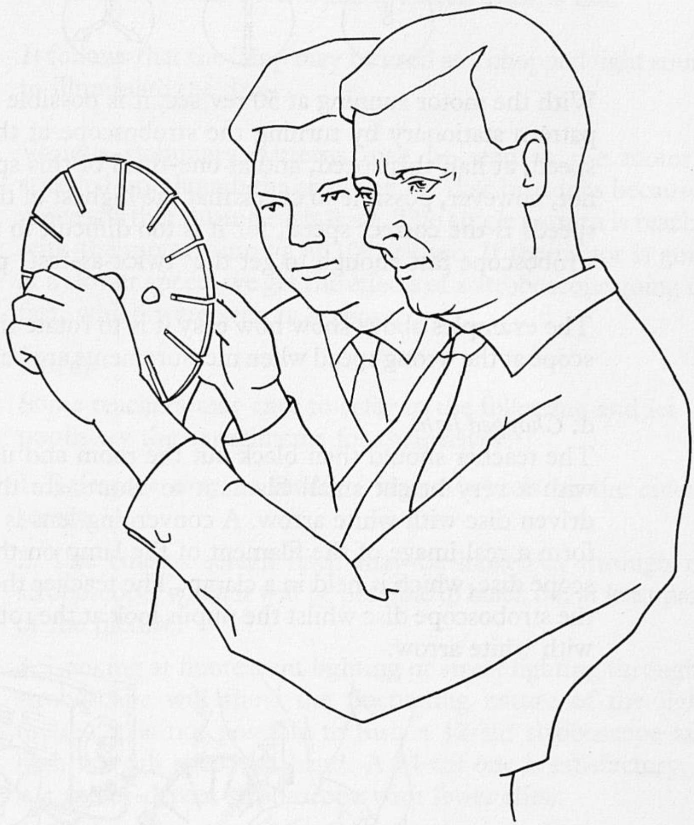
With the motor driving the disc at 25–30 rev/sec it is easy to stop the motion and see a single white arrow, though this does wander about. The stroboscopes are less likely to judder if the screw is not too tight and the handle is held loosely.

Pupils should be able, without much difficulty, to rotate their stroboscopes at the correct speed. By 'correct' is meant the speed when the number of slits passing the eye per second is equal to the number of revolutions per second of the motor.





Pupils who cannot see the stopped motion can be helped if the teacher works the stroboscope and looks through one side of it, while the pupil looks through the other side.

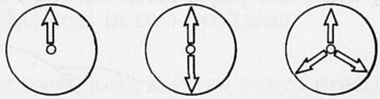


c. *Other speeds*

The following effects are described as diagnostic aids for teachers. We should *not* labour the introduction by telling pupils about these.

To show the effect of turning the stroboscope at half speed, and twice and three times the correct speed, it is necessary to have the motor running at different speeds, as the stroboscopes are difficult to turn at high and low speeds. Furthermore, at low speeds the white arrow becomes very spread out and indistinct, particularly at the edge of the disc where it is travelling fast.

With the motor running at 15 rev/sec it is difficult to turn the 12-slit stroboscope slowly enough to see a single stationary bar. But if the stroboscope is speeded up until it is twice as fast, three times as fast, and even four times as fast, a stationary pattern is seen, as shown below.

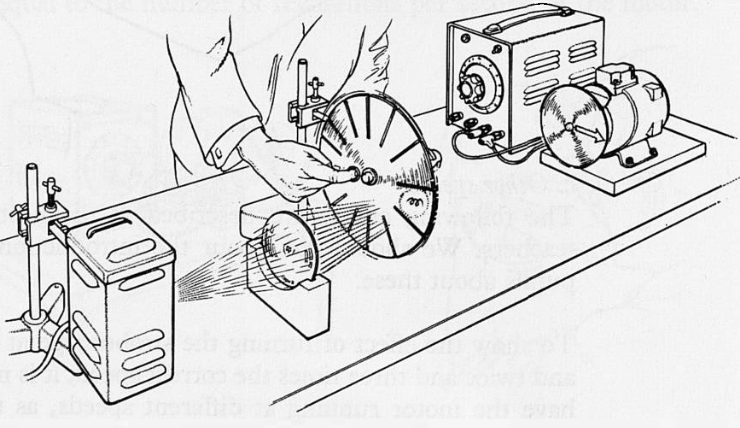


With the motor running at 50 rev/sec, it is possible to see the pattern stationary by turning the stroboscope at the correct speed, at half this speed, and at one-third of this speed. It is not, however, possible to check that the highest of these three speeds *is* the correct speed, for it is too difficult to rotate the stroboscope fast enough to get the 'twice-as-fast' pattern.

The examples above show how easy it is to rotate the stroboscope at the wrong speed when measurements are being taken.

d. *Chopped light*

The teacher should then black out the room and use a lamp with a very bright small filament to illuminate the motor-driven disc with white arrow. A converging lens is placed to form a real image of the filament of the lamp on the stroboscope disc, which is held in a clamp. The teacher then rotates the stroboscope disc whilst the pupils look at the rotating disc with white arrow.



This shows that roughly the same effect is obtained as before when the stroboscope is in front of the eye.

This method will be useful later, where several pupils need to see the same arrested motion. Then a motor-driven strobe disc will be used.

e. *Neon lamp on a.c. mains*
This can be looked at through the stroboscope. A large neon lamp is best for this and it is well to do it in daylight so that the bulb is visible even when the neon glow is not.

It follows that the lamp may be used as a chopped light source to illuminate the disc.

Various stationary patterns may be seen as the motor is speeded up, though the arrow on the disc broadens because it moves farther during each flash. The single pattern is reached with the motor running at 100 rev/sec. If the motor is going at a slower speed, we get the effects of a stroboscope going too fast, which were seen in c above.

Notes

Some teachers may care to refer to the following and let the pupils try the experiments for themselves:

1. Reference may be made to wagon wheels on the cinema screen.

2. The cinema screen itself may be looked at through the stroboscope, when it will be possible to black out at least parts of the picture.

3. Looking at fluorescent lighting or street lighting through a stroboscope will show the fluctuating nature of the light, though it is not possible to turn a 12-slit stroboscope at a high enough speed by hand. A 24-slit one is satisfactory, as is a motor-driven stroboscope with fewer slits.

4. Stroboscope discs for testing the speeds of gramophone turntables go very slowly and therefore have a large number of radial white bars. Each bar moves on one place for each flash of the mains lighting (100 flashes/sec).

5. A fan with several blades can be ‘stopped’ with various speeds of the stroboscope. If one blade is painted white it will be seen that many of these speeds do not give the actual speed of the fan.

6. The back wheel of an inverted bicycle may be looked at through the stroboscope. Many speeds of the stroboscope will appear to stop the wheel if the spokes look alike.

4g *Class experiment*

Using a stroboscope to 'freeze' continuous ripples

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
32 hand stroboscopes	– item 105/1

Procedure

After pupils have practised for a short time with stroboscopes (experiment 5, p. 23) they should try looking at ripples with them.

It is wise to proceed to ripples as quickly as possible, so that pupils do not lose their interest. Some pupils will understand stroboscopes much more easily when they find their relevance to the work on ripples, upon which they have embarked, than in training sessions with them.

Pupils should try viewing continuous circular ripples and continuous straight-line ripples. They will take some time to explore possibilities and to develop skill in 'freezing' the motion.

4h *Class experiment*

Using a stroboscope to estimate wavelengths of ripples

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
32 hand stroboscopes	– item 105/1
8 metre rules	– item 501
white paper	

Procedure

At a later class, after pupils have learnt to 'freeze' ripples with a stroboscope and after we have given them time to think about the question 'What measurement could you make?', we suggest measuring wavelengths (if that has not been proposed by the pupils). We ask them to estimate wavelengths by freezing the pattern and measuring a batch of wavelengths (say ten) on the paper on the floor.

We should make it clear that the idea is to get a rough estimate rather quickly, and not to try to achieve great precision with a technique which cannot really support it.

Pupils should try this for circular ripples and for straight-line ripples. Then they should change to a different frequency and see whether the wavelength is the same. (Since the speed of water ripples is a function of their wavelength, we must not expect the simple relationship between frequency and wavelength that we find for sound waves or waves on a rope or light waves in vacuum.)

If some groups of pupils work fast and get ahead of the rest, they might be asked to try this measurement again with much shallower water. For that they should be given a sheet of glass to be placed in the tank so that the water above the glass is very shallow indeed. That will anticipate experiment 4t on refraction, but here the waves should meet shallow water head-on (normally). The change of direction will not appear, but pupils may notice changes of wavelength and speed without any change of frequency.

4i *Class experiment*

Reflection of a pulse by a barrier

Note

This ripple tank investigation should be a test carried out by the pupils themselves in response to a specific question by the teacher.

Apparatus

8 ripple tanks	– item 90
8 water droppers	– item 90H
8 straight barriers	– item 90D

Some teachers will prefer to use pencils dipping in the surface instead of the water droppers.

Procedure

We ask the pupils: 'When a circular ripple (pulse) is bounced back by a straight wall, where does the wave seem to come from after that?' We do *not* give the answer to that, and we do not, at this stage, give any discussion of images. Instead, we ask pupils to look at the actual event in their ripple tanks.

The barrier should be placed somewhere near the middle of the tank so that the image from which the reflected ripple seems to come is well inside the tank.

When pupils have seen this for themselves, the teacher should suggest a further experiment:

'Now that you know where the ripple that bounces back seems to come from, try starting a ripple just there. Use the finger of your left hand. Let the ripple spread and hit the wall and bounce back. Mark the place where the bounced-back ripple seems to come from, with a finger of your right hand. Then start a ripple from that place with that finger.

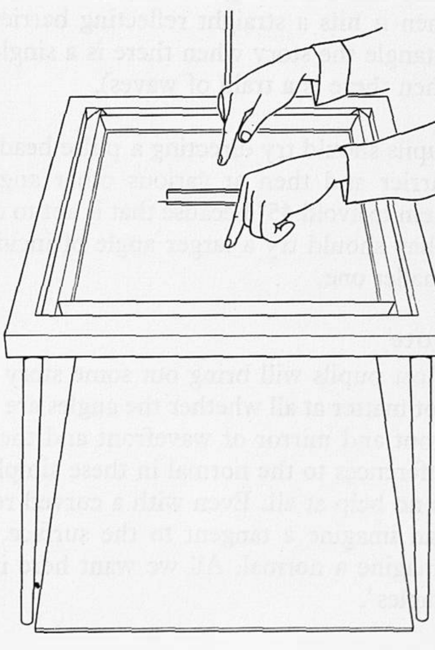
'Now start ripples with both those fingers at the same moment. Your left hand will start the main ripple and your right hand will start a ripple like the one that bounces back. Watch what happens.'

When that succeeds, it is amusing and almost uncanny. We should not spoil the fun by doing it for pupils even though a teacher can probably make the simultaneous ripples (the incident ripple and the image ripple) much more easily since he knows what he is trying to do. We should, however, help pupils who are unsuccessful by encouraging them to put the second finger at the right place – without our using the word image or giving the geometry. We should just judge the right distance with our own eyes and point to the right place. Then the pupil can try again, see success and enjoy it. He may notice the geometry, but it will not matter if he fails to notice it: the main aim here is to emphasize the idea of a 'place from which the reflected wave seems to come'.

If a pupil finds it difficult to remember the position of 'the place the reflected ripple comes from' (the image) let him put a small coin in the tank at that spot.

Note

It is best to use one finger on each of two hands for this for the sake of good teaching rather than for the sake of precision. An ingenious teacher may be tempted to devise a gadget that will start two ripples simultaneously from exactly the right positions, but that is *not* what we should offer here. This is the stage for simple direct experimenting.



4j *Class experiment*

Reflection of a straight wave by a barrier

Note

This ripple tank investigation should be a test carried out by the pupils themselves in response to a specific question by the teacher.

Apparatus

8 ripple tanks	– item 90
8 wooden rods	– item 90J
8 straight barriers	– item 90D

Procedure

We ask the pupils: 'Can you see any simple story about the direction of straight waves before and after meeting a flat wall? How are the angles related?'

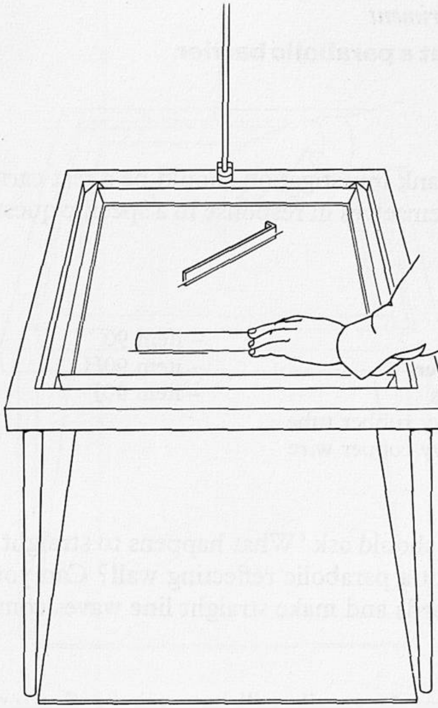
At this stage, we do not talk about laws of reflection or ask for measurements of angles or urge pupils to remember what they saw before. We ask them to try this in their ripple tank.

They make a straight-line pulse and watch what happens when it hits a straight reflecting barrier (it is easier to disentangle the story when there is a single pulse like this than when there is a train of waves).

Pupils should try directing a pulse head-on (normally) to the barrier and then at various other angles. We should help them to avoid 45° because that is apt to confuse the geometry. They should try a larger angle of incidence than that and a smaller one.

Note

Most pupils will bring out some story about angles. It does not matter at all whether the angles are angles between wavefront and mirror or wavefront and the normal. Dragging in references to the normal in these simple studies of reflection is no help at all. Even with a curved reflector, young people can imagine a tangent to the surface just as easily as they imagine a normal. All we want here is some idea of 'equal angles'.



4k *Class experiment*

Reflection at a parabolic barrier

Note

This ripple tank investigation should be a test carried out by the pupils themselves in response to a specific question by the teacher.

Apparatus

8 ripple tanks	– item 90
8 water droppers	– item 90H
8 wooden rods	– item 90J
8 lengths heavy rubber tube	
8 lengths heavy copper wire	

Procedure

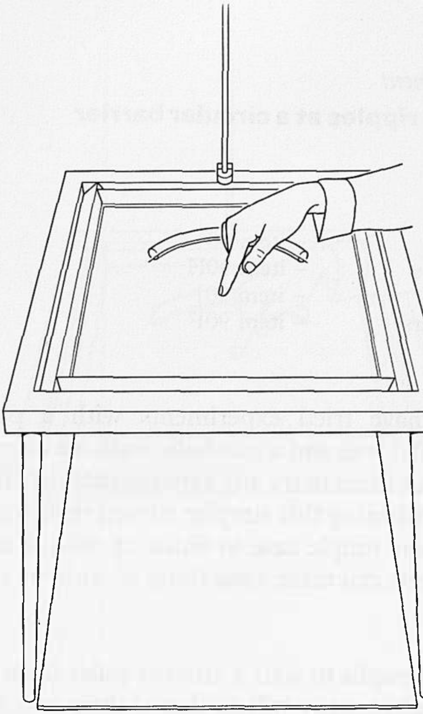
The teacher should ask 'What happens to straight line waves when they hit a parabolic reflecting wall? Can you turn that story backwards and make straight line waves come out from the wall?'

In experiment 4e, pupils will have tried reflecting a straight line pulse with a (roughly) parabolic reflector. They probably found the wave concentrated after reflection into a circular ripple which closed down to a small size and then spread out again. Whether they did or not, they can try that again now.

The parabolic reflector can be made with the rubber tubing. To help curve and anchor the tube, heavy copper wire (or solder) should be put into the tube before bending.

Then the problem is to guess what would happen in reverse, and to try that experimentally. This is an exercise in thinking as a physicist, so we should be very careful not to reduce it to an exercise in carrying out instructions. All we should do is ask the question about the reverse effect.

After pupils have seen the straight line ripple reflected into a circular ripple that moves to a point, they know where to put their finger to start the reverse experiment. (That is why experiment 4e was done with straight line ripples and this question is now framed this way round.)



41 *Class experiment*

Reflection of ripples at a circular barrier

Apparatus

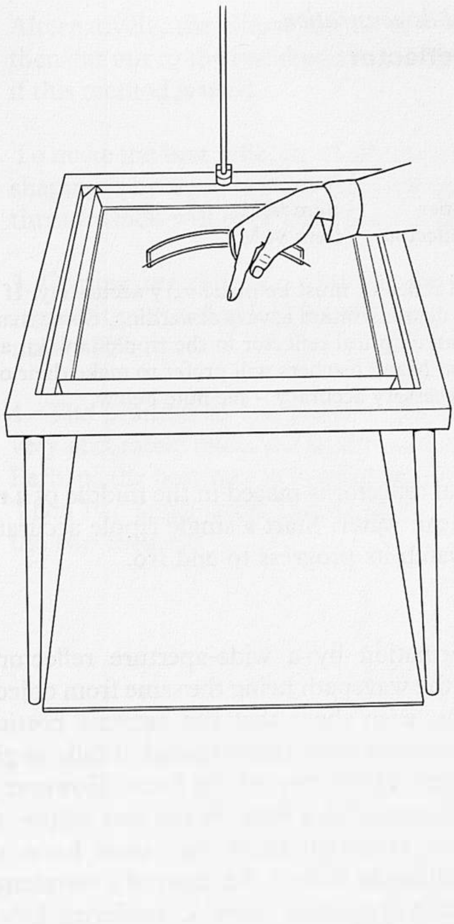
8 ripple tanks	– item 90
8 water droppers	– item 90H
8 wooden rods	– item 90J
8 circular barriers	– item 90F

Procedure

After pupils have tried experiments with a pulse being reflected by a flat wall and a parabolic wall, we offer a circular reflector and ask them to try any experiments they like with it. The point of deferring this simpler curved reflector until now is to offer a clear simple case to finish up with, a consolation prize, that pupils can make something of without any leading instructions.

We do *not* tell pupils to start a circular pulse from the centre of the reflector but many will do that of their own accord. We do *not* tell them to find the place where straight line ripples are brought to a point after reflection; and we certainly do *not* ask them to measure that distance and see whether it is half the radius of the mirror – that would be racing ahead into optics and spoiling the present flavour of leaving people to their own experimenting.

Teachers who have tried this series of experiments with ripple tanks as class experiments find that they take much longer than expected. We believe they yield a very valuable sense of experimenting when given plenty of time; but we do not believe that much benefit will emerge if the experimenting is interrupted by theoretical discussion or detailed measurements. So we do *not* recommend – except for extremely fast pupils – giving any discussion of the geometry or asking pupils to locate a 'focus', or asking them to turn the reflector round and use it as a convex reflector, and look for virtual image effects.



4m *Optional demonstration*

Elliptical reflector

Apparatus

1 ripple tank	– item 90
1 water dropper	– item 90H
1 elliptical reflector	– item 90M

The elliptical reflector must be made very accurately. If great care is taken, this demonstration is very rewarding. Some manufacturers supply such an elliptical reflector in the ripple tank kit as an optional extra. Many teachers will prefer to make their own to be sure of the necessary accuracy – see note below.

Procedure

The elliptical reflector is placed in the middle of a ripple tank with very clean water. Start a single ripple accurately at one focus and watch its progress to and fro.

Notes

1. Image formation by a wide-aperture reflector like this depends on the wavepath being the same from object to image by *all* routes, even those that use extreme portions of the aperture. An ellipse does this – though it fails to give a good image of points a little way off the focus. However, if part of the reflecting surface is a little off the true ellipse, the condition fails and reflection there may even harm the image instead of helping to form it. An error of $\frac{1}{4}$ wavelength in part of the surface will do great harm. Considering how small the actual wavelength of the equivalent ripples in a pulse must be, this error is very small. Furthermore, an error in angle inclination can shift a portion of focused wave to an undesirable place near by, but not at, the focus. In practice the beauty of the demonstration is even more sensitive to accuracy of the ellipse than those considerations would suggest.

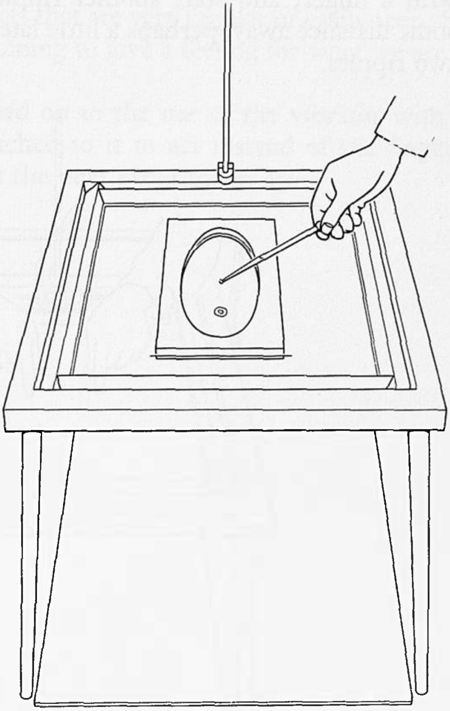
2. To make the reflector, an ellipse should first be drawn very carefully on paper and an expert mechanic can bend a springy brass strip to fit the ellipse, joining the ends with a butt joint and a strap outside. (This type needs very careful storage unless one adds straps across it.)

Alternatively, the ellipse can be drawn on plywood which is then cut out to the required shape. Great care must be taken if this method is used.

To make the best reflector of all, use a wall of plaster of Paris, shaping it by a peg moving with a loop of wire, instead of the thread which will have been used in drawing the ellipse.

3. Coating the reflector with paraffin wax may improve the regularity of reflection by making an angle of contact of nearly 90°.

4. The position of one focus of the ellipse must be located very accurately and used as the starting point of the ripples. Perhaps the best way of finding the focus is 'trial by ripples'. Then two small coins should be placed in the tank to mark the two focuses.



4n *Class experiment*

Watching what happens when one ripple crosses another

Note

This investigation should be carried out by the pupils themselves in response to a specific question by the teacher.

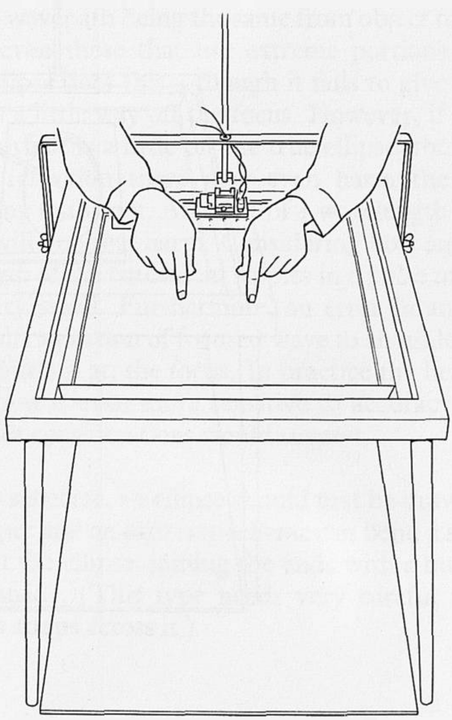
Apparatus

8 ripple tanks – item 90

Procedure

We ask 'What happens when one ripple crosses another? Do they upset each other? Do they each come out from the encounter the worse for wear?'

We suggest to pupils that they should make one ripple (pulse) with a finger, and start another ripple from another place some distance away, perhaps a little later, and then watch the two ripples.



4o *Class experiment*

Interference with two sources, using two fingers

Apparatus

8 ripple tanks – item 90
32 hand stroboscopes – item 105/1

Procedure

The teacher should ask the pupils to use two fingers of one hand as sources of ripples which will, therefore, start out 'in tune with each other'. They should try making a pair of single pulses in that way.

We hope they will then, of their own accord, move their hands up and down to make two streams of continuous ripples. Even with this informal source, pupils should try observing with a hand stroboscope. This method will not produce interference effects that are very regular or easily seen; but it is the proper beginning to give a feeling for what we are aiming at.

This will lead on to the use of the vibrator with two point dippers attached to it to act instead of the fingers. This is discussed in the next experiment, 4p.

4p *Class experiment*

Interference with two sources, using vibrators

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
16 dippers	– item 90G
32 hand stroboscopes	– item 105/1

Procedure

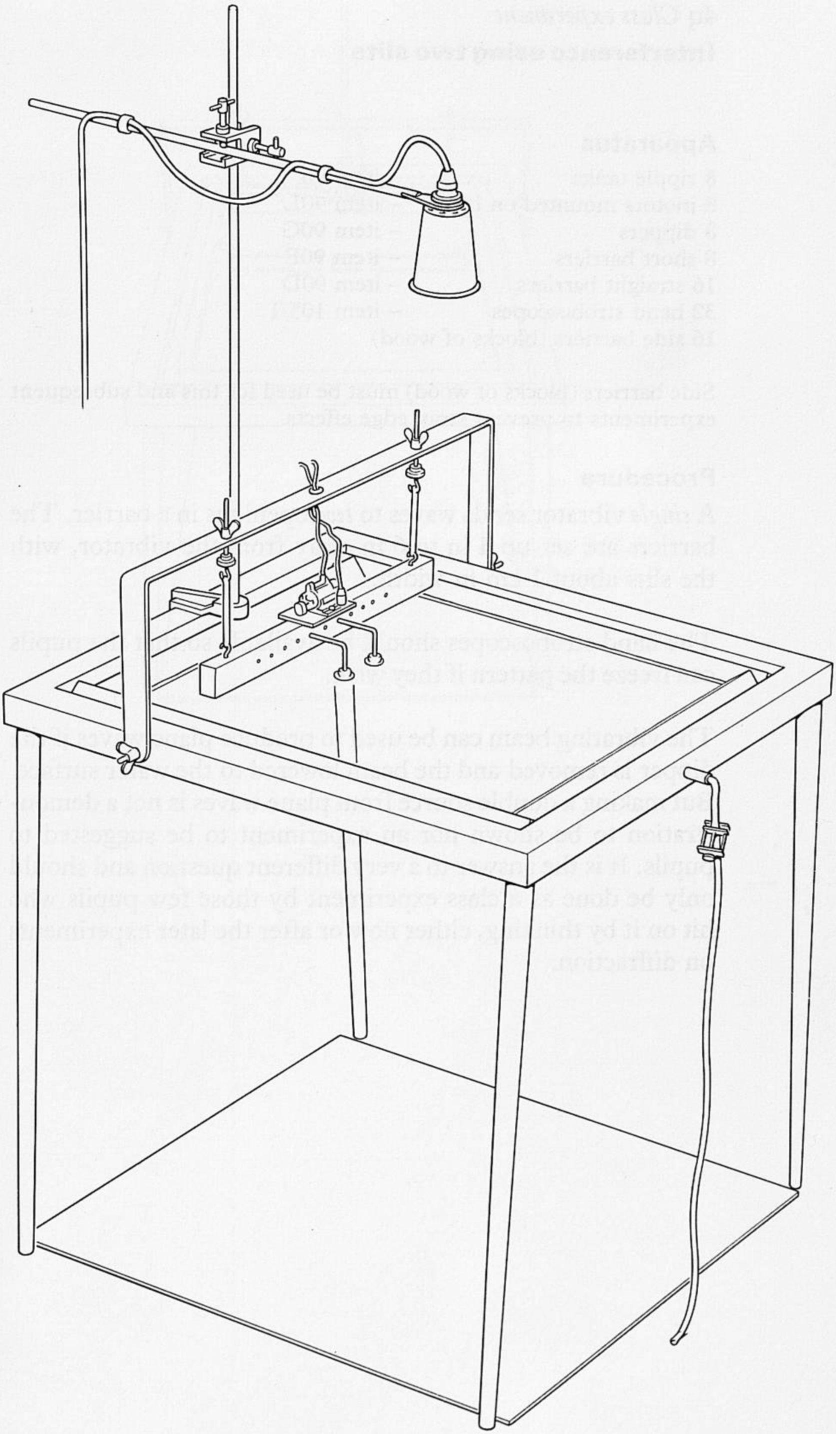
With two point dippers on the vibrator set up as in experiment 4f, interference effects are seen. The waves may be visible farther from the sources if the water is made deeper (for example, 1 cm or 2 litres), provided the reflections from the sides are not too troublesome.

When the dippers are 3 cm apart and the vibrator running as slowly as possible (about 10 rev/sec) about 2 minima are seen with the naked eye. As the vibrator is speeded up, more minima are seen, but at high speeds the stroboscope is needed to see the pattern, except near the dippers.

This is the time for a first glimpse at interference patterns. It is not the time to give elaborate explanations with demonstrations of wave motions adding together. Interference is studied again later in the year. In fact, some teachers with slower groups will wish to omit interference now and move on to new things, returning to interference later on. There is no serious harm in that, though they may regret missing an early qualitative glimpse.

Note

The spacing of the dippers can be increased to increase the number of minima and make them closer. This shows best with the vibrator running slowly; at high speeds the pattern is very beautiful, but the lines of minimum displacement (lines of nodes) are very close together.



4q *Class experiment*

Interference using two slits

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beam	– item 90L
8 dippers	– item 90G
8 short barriers	– item 90E
16 straight barriers	– item 90D
32 hand stroboscopes	– item 105/1
16 side barriers (blocks of wood)	

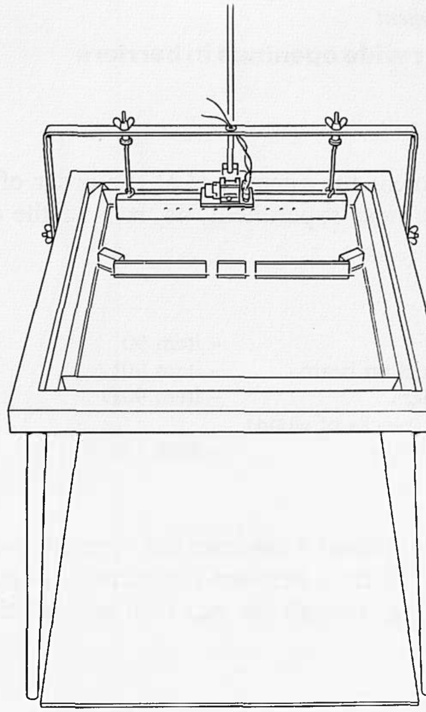
Side barriers (blocks of wood) must be used for this and subsequent experiments to prevent stray edge effects.

Procedure

A *single* vibrator sends waves to *two* openings in a barrier. The barriers are set up 4 in to 6 in away from the vibrator, with the slits about 1 cm in width.

The hand stroboscopes should be available so that the pupils can freeze the pattern if they wish.

The vibrating beam can be used to produce plane waves if the dipper is removed and the beam lowered to the water surface. But making a double source from plane waves is not a demonstration to be shown nor an experiment to be suggested to pupils. It is the answer to a very different question and should only be done as a class experiment by those few pupils who hit on it by thinking, either now or after the later experiments on diffraction.



4r *Class experiment*

Diffraction at wide openings in barriers

Note

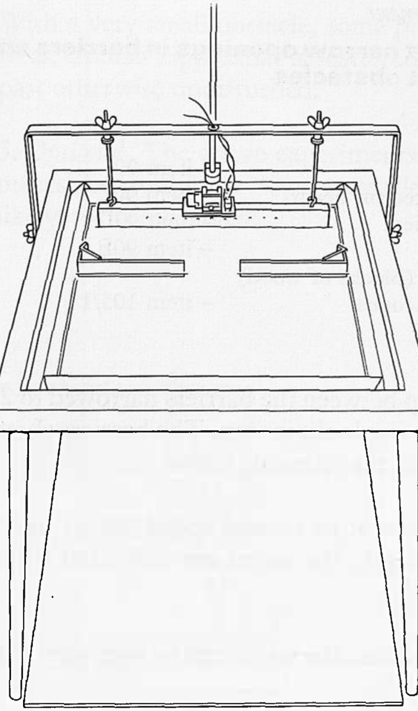
In this experiment the opening is of the order of 10 wavelengths. In the next experiment, 4s, it is of the order of $\frac{1}{2}$ wavelength.

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beam	– item 90L
16 straight barriers	– item 90D
16 side barriers (blocks of wood)	
32 hand stroboscopes	– item 105/1

Procedure

With the barriers about 5 cm from the vibrating beam, and a wide gap – say 10 cm – between the barriers, pupils will see waves proceeding through the gap with only a little diffraction-spreading.



4s *Class experiment*

Diffraction at narrow openings in barriers and diffraction at obstacles

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
16 straight barriers	– item 90D
8 short barriers	– item 90E
16 side barriers (blocks of wood)	
32 hand stroboscopes	– item 105/1

Procedure

1. With the gap between the barriers narrowed to 2 cm or less, diffraction at a single slit is seen. The barriers should again be about 5 cm from the vibrating beam.

With the vibrator at its slowest speed (10 rev/sec), giving the longest wavelength, the waves are diffracted through almost 90° on each side.

At high frequencies, the waves can be seen only with a stroboscope.

It will be found that waves coming round the end of the barriers are troublesome and they must be blocked off with side barriers. At high frequencies, the barriers themselves may start to vibrate, giving misleading effects, and this should be avoided.

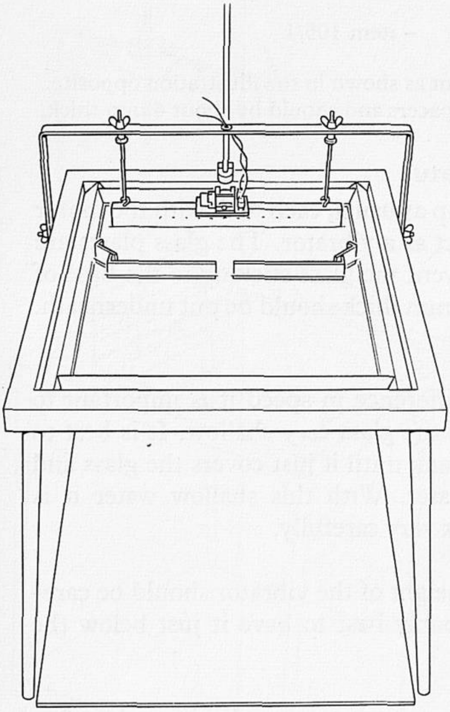
2. Some pupils will alter the gap width to show less diffraction with wider apertures.

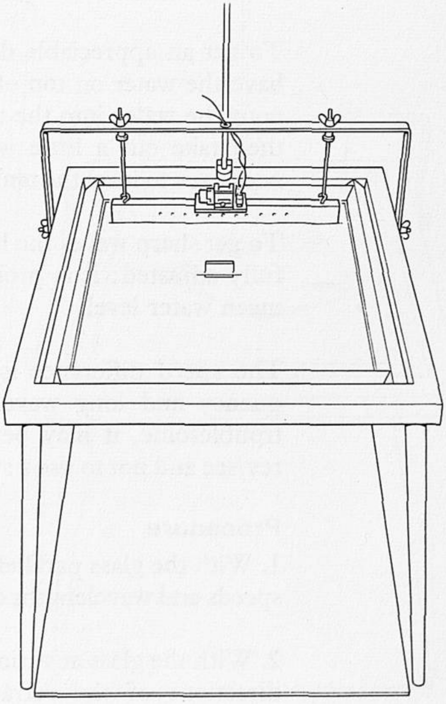
3. *Optional.* A source of circular ripples may also be tried.

4. *Optional.* Obstacles about 2 to 5 cm wide (e.g. the short barriers) are put near the vibrator. Long waves are scarcely affected but the 'shadow' of the obstacle becomes sharper as the wavelength is reduced or as the size of the obstacle is increased. The stroboscope is needed for high frequencies though once again at very high frequencies vibration of the barrier itself can give misleading effects.

With a very small obstacle, some pupils may notice the very weak circular ripple that is scattered as the main wave moves past otherwise undisturbed.

5. *Optional.* The above experiments may also be done with pulses but only the long-wave, low-frequency effects are likely to be observed.





4t *Class experiment*

Refraction of ripples entering shallow water

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
8 plates of glass	– item 90P
32 nuts or washers	
32 hand stroboscopes	– item 105/1

The glass plates should be cut as shown in the illustration opposite. The nuts or washers act as spacers and should be about 4 mm thick.

Setting up the Apparatus

The ripple tanks are set up as usual, each tank with the motor mounted on a beam to act as a vibrator. The glass plates are put in the tanks. To prevent the glass sticking to the base of the tank, spacers about 4 mm thick should be put underneath. Nuts or washers do well.

To get an appreciable difference in speed it is important to have the water on top of the glass *very* shallow. It is best to pour the water into the tank until it just covers the glass and then take out a little water. With this shallow water it is necessary to level the tank very carefully.

To get sharp waves the height of the vibrator should be carefully adjusted: it is probably best to have it just below the mean water level.

The speed difference is most pronounced with a low frequency and long wave. If diffraction effects are not too troublesome, it may be best in (1) below to use about 10 rev/sec and not to use a stroboscope.

Procedure

1. With the glass parallel to the vibrator, the difference in the speeds and wavelengths of the waves may be noticed.

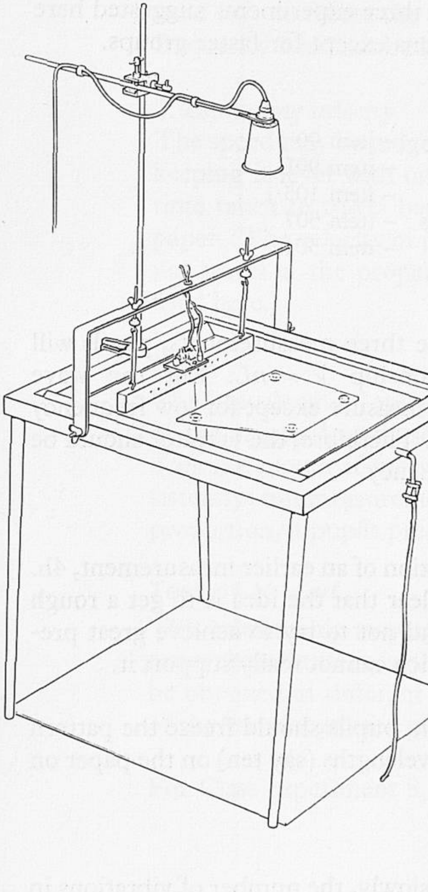
2. With the glass at various angles to the incoming waves, the directions of the refracted waves may be noticed. (See opposite.)

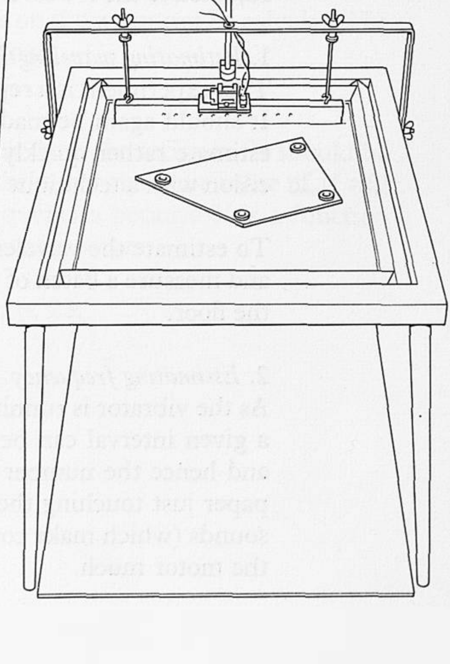
Very fast pupils might be encouraged to sketch a line normal to the waves in each case.

3. 1 and 2 might be repeated at a higher speed to show that refractive index may depend on frequency (wavelength).

Note

Oil or dirt on the water increases the friction and makes the refracted waves even harder to see.





4u *Class experiment*

Estimating wavelengths, frequency, and velocity of ripples

Pupils find *measurement* with ripple tanks difficult and they do not see the need, at this age, for measuring wavelength, frequency, and velocity, or the need for looking for a relationship between them. So the three experiments suggested here should be optional extensions except for faster groups.

Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
32 hand stroboscopes	– item 105/1
16 stop watches or stop clocks	– item 507
8 metre rules	– item 501

Procedure

It is hoped that with these three measurements, pupils will discuss briefly the relationship $V = nL$. But the wave velocity is very difficult to measure except for low frequency ripples of long wavelength. Therefore, the vibrator should be adjusted to the lowest frequency.

1. *Estimating wavelength*

This experiment is a repetition of an earlier measurement, 4h. It should again be made clear that the idea is to get a rough estimate rather quickly, and not to try to achieve great precision with a technique which cannot really support it.

To estimate the wavelength, pupils should freeze the pattern and measure a batch of wavelengths (say ten) on the paper on the floor.

2. *Estimating frequency*

As the vibrator is running slowly, the number of vibrations in a given interval can be counted (perhaps in groups of four) and hence the number per second deduced. A thin piece of paper just touching the spindle of the vibrator gives audible sounds (which make counting far easier) and should not slow the motor much.

It is difficult to measure frequency accurately, but rough measurements are possible. (The vibrator can be driven either slowly or fast and a different technique is necessary in each case. For high speeds, the hand stroboscopes can be used as discussed in experiment 5.)

Note that in estimating wavelength the stroboscopes were used *only* to freeze the pattern for easy measurement. Their frequency need not be known for that.

3. *Estimating velocity*

The speed may be judged by running a pencil along the paper keeping it level with one wave. Another pupil measures the time taken to travel between the two points marked on the paper. (The velocity of pulses is easier to measure but they do not travel at the proper wave speed, so they should not be used here.)

Note

The 'wavelengths' and speeds that are measured are not those of the ripples but those of their shadows on the floor. This does not matter if measurements on the floor are used consistently; but measurements on the water can be calculated by proportion, if pupils prefer that.

Test of $V = nL$

This relationship may appear from the estimate. It should be remembered that it is not likely that the same value of V will be obtained at different frequencies because V is a function of the wavelength for such water waves.

For Class experiment 5, see p. 23.

6a *Demonstration*

Shadows on a wall

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 white screen	– item 102
1 retort stand and boss	– items 503–505

The compact light source (item 21) requires 12 volts a.c. or d.c. at 8 amp. The L.T. variable voltage supply (item 59) provides this conveniently.

Procedure

The compact light source is set up in front on the screen, preferably with the room darkened.

Various obstacles are put between the source and the screen so that shadows are seen. A card with a slot will give straight shadows on the wall. The shadows will be sharpest when the edges of the card and the slot are parallel to the lamp filament.

6b *Demonstration*

Ray of light on a wall

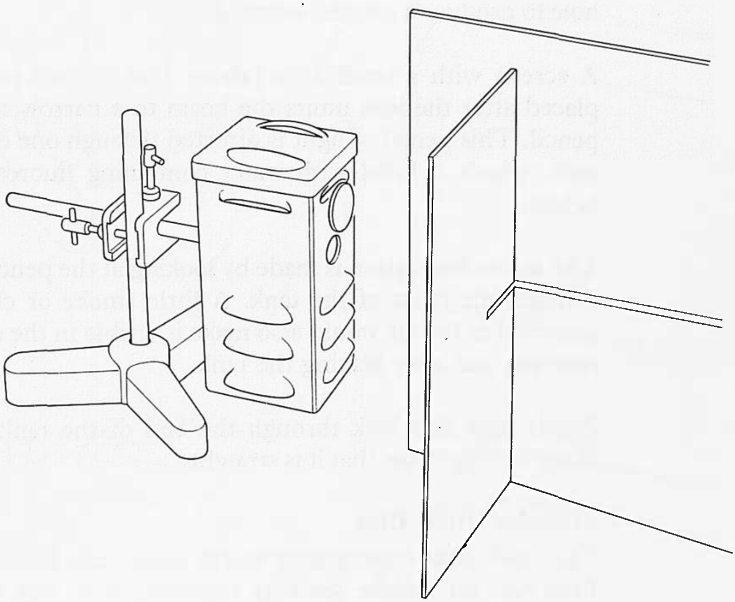
Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 white screen	– item 102
1 retort stand and boss	– items 503–505

Procedure

As a continuation of the previous experiment, 6a, the light source is moved close to the screen so that a wide beam of illumination falls across it.

A card with a slit in it is brought up as illustrated to show how a 'ray' of light can be made.



6c *Demonstration*

Ray of light in water

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 retort stand and boss	– items 503–505
1 large rectangular transparent tank	– item 100/2
1 converging lens	– item 112
1 lens holder	– item 124/1
fluorescein solution	

Procedure

A ray of light should be shown passing through a tank of water. The best source is the compact light source (item 21), which consists of a tungsten iodine lamp in suitable housing. A converging lens is placed a suitable distance in front of the hole to produce a parallel beam of light.

A screen with a small hole (about 1 or 2 cm in diameter) placed after the lens limits the beam to a narrow horizontal pencil. This pencil of light is directed through one end of the tank, which is filled with water containing fluorescein (see below).

The main observation is made by looking at the pencil of light through the front of the tank. A little smoke or chalk dust scattered in the air would also make it visible in the air before entering and after leaving the tank.

Pupils may also look through the end of the tank, looking along the ray to see that it is straight.

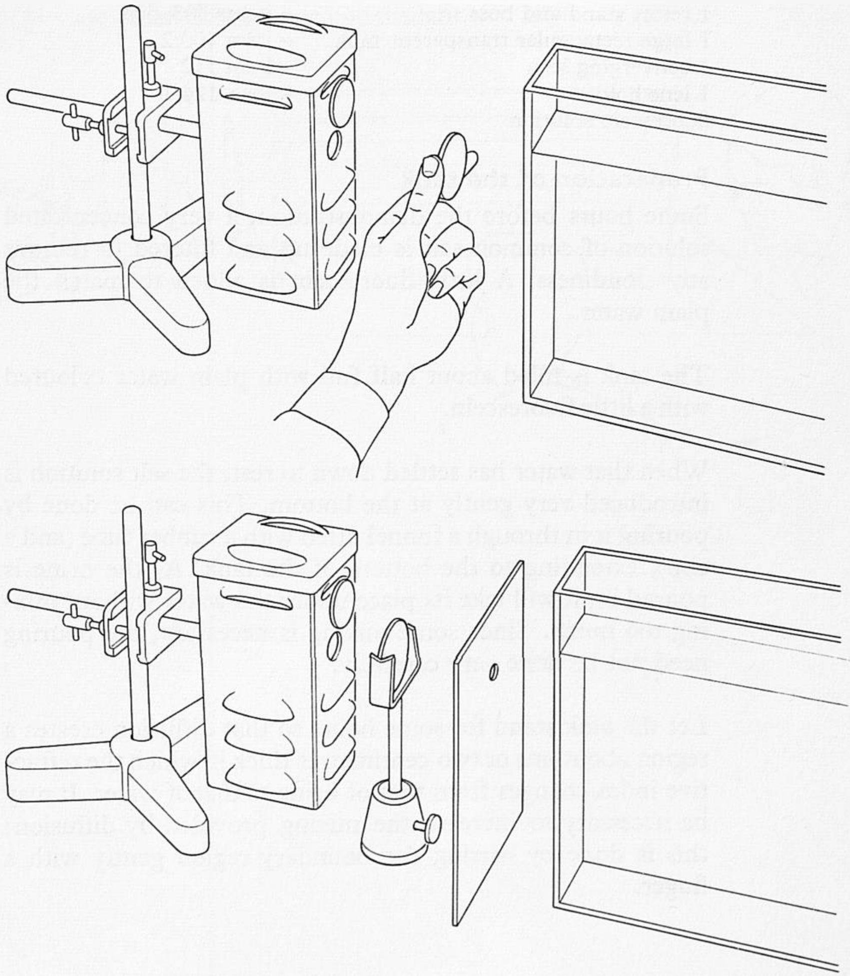
Esso-Nuffield film

This and other experiments in ray optics can be seen in the Esso film for science teachers *Experiments in Ray Optics*. It can be borrowed on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

Concentration of fluorescein

Fluorescein is best used in concentrations between 5×10^{-4} gm/litre and 5×10^{-3} gm/litre. These are most easily obtained by dissolving 1 gm of fluorescein in 1 litre of water to make a stock solution. Between 0·5 ml and 5 ml of this stock solution are then used to each litre of water. The lower concentration gives very good contrast between the light and dark parts of the water but the higher concentration gives brighter rays and is probably better for long-distance viewing.

If the fluorescein will not dissolve easily, it may be dissolved first in a little alcohol which is then diluted with water.



6d *Optional demonstration*

Curved ray of light

Note

This is an optional experiment repeating experiment 6c with layers of water and salt water in the tank so that the 'ray' passes through a region of changing refractive index and is bent. If shown, it should be on a later occasion than the previous experiment.

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 retort stand and boss	– items 503–505
1 large rectangular transparent tank	– item 100/2
1 converging lens	– item 112
1 lens holder	– item 124/1
fluorescein solution	

Preparation of the tank

Some hours before the demonstration, a very concentrated solution of common salt is made up and filtered to remove any cloudiness. A little fluorescein is added to match the plain water.

The tank is filled about half full with plain water coloured with a little fluorescein.

When that water has settled down to rest, the salt solution is introduced very gently at the bottom. This can be done by pouring it in through a funnel fitted with a rubber tube (and a clip), extending to the bottom of the tank. As the brine is poured in, it will take its place under the water without mixing too much. Since some mixing is necessary, the pouring need not be done very carefully.

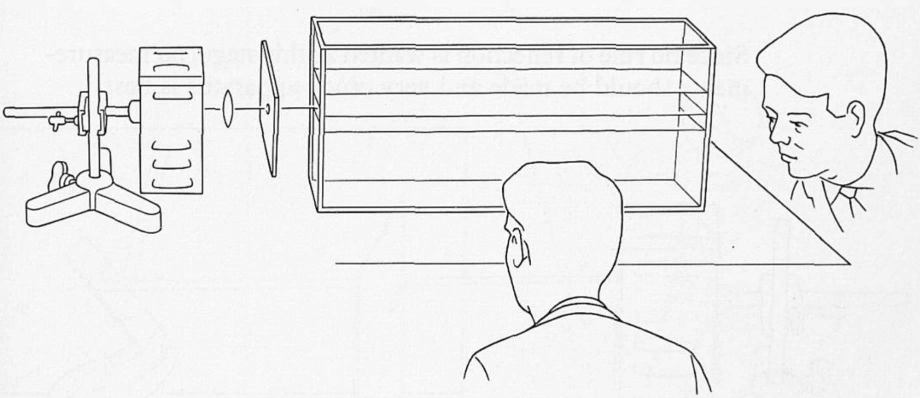
Let the tank stand for some hours so that diffusion creates a region about one or two centimetres thick in which the refractive index changes from that of brine to that of water. It may be necessary to increase the mixing provided by diffusion: this is done by stirring the boundary region gently with a finger.

Procedure

The 'ray' of light is directed in horizontally through the mixing layer. The ray must be tilted a little from the horizontal and moved up and down until the best effect is observed.

Pupils looking from the front of the tank will see that the ray is bent. But if they look along the ray, through the end of the tank, they will see something quite different – their line of vision follows the same path as the ray in the water and they think the ray is straight.

Alternatively, when the pupils have seen the bent ray, the water and brine should be stirred together so that they mix – then the rays become straight.



6e *Demonstration*

Ray of light being reflected

Apparatus

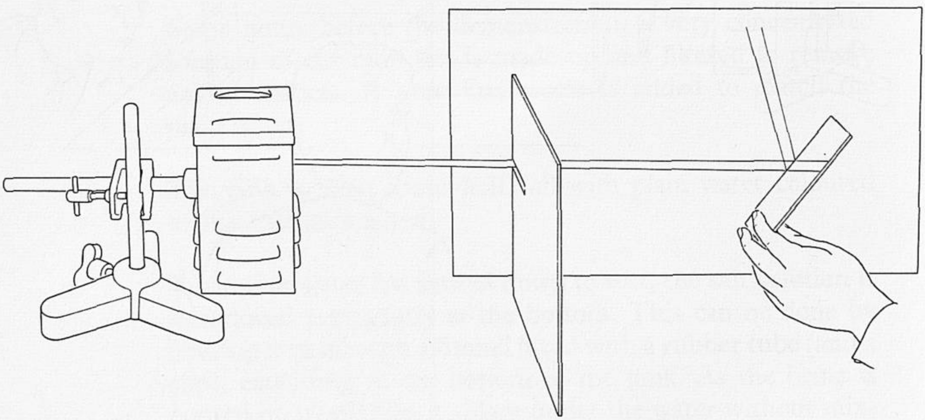
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 white screen	– item 102
1 retort stand and boss	– items 503–505
1 plane mirror	– item 116

Procedure

Set up the compact light source with a card and slit in front of it so that a thick 'ray' of light splashes across a vertical white screen.

Catch the ray with a piece of plane mirror held in the hand.

Since no rule of reflection is wanted at this stage, no measurements should be made and very crude apparatus is best.



6f *Demonstration*

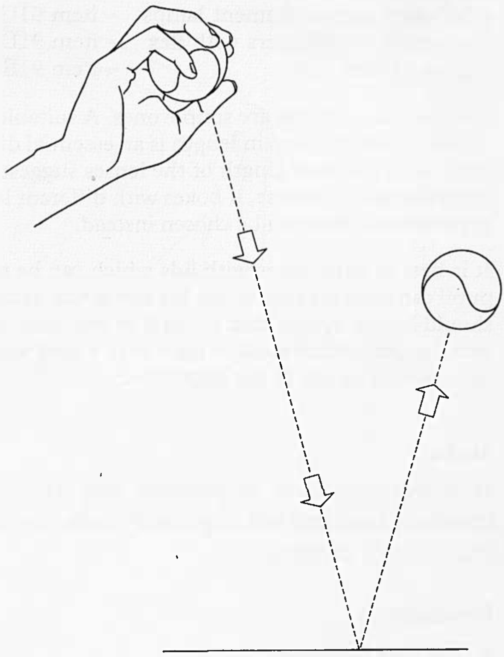
Rubber ball 'reflected'

Apparatus

1 rubber ball

Procedure

A rubber ball should be bounced against a hard wall or floor to show its reflection.



7 Class experiment

Pinhole camera and lens camera

Apparatus

1 pinhole camera kit	– item 91
32 lenses (+7D)	– item 112

The pinhole camera kit includes the following:

32 cardboard boxes	– item 91A
200 sheets of black paper	– item 91B
4 200-watt carbon filament lamps	– item 91C
4 mounted lampholders with flex	– item 91D
1 gross of pins	– item 91E

The cardboard boxes are simple ones. A suitable size is 6 in × 4 in × 4 in, of which the 6 in length is an essential dimension, chosen to agree with the focal length of the lenses suggested for this and other experiments. Of course, if boxes with different lengths are used, appropriate lenses can be chosen instead.

It is best to have boxes with lids which can be removed so that a pupil can hold his lens inside his box when necessary. Each box should have a square hole cut in it at one end, covered with grease-proof paper, which scatters light over a very small angle. A round hole should be cut at the opposite end.

Note

It is our aim here to provide very simple equipment of a common kind and not a specially made device to 'demonstrate the pinhole camera'.

Procedure

a. *Various pinholes*

The four lamps and lampholders are distributed about the laboratory so that eight children may work at a distance of about 4 ft from each lamp.

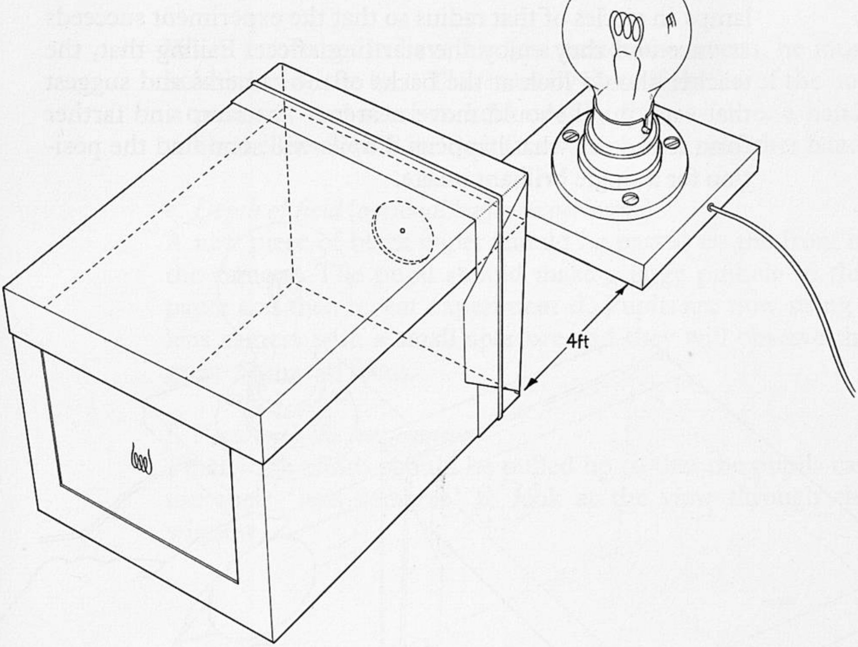
A piece of black paper is cut to size and fastened over the open hole at the end of each box. Paste is suitable for this. Some may prefer to use Sellotape, others may prefer to wrap paper round the end and secure it with an elastic band.

Each child is asked:

1. to make a small pinhole in the black paper, to look at the

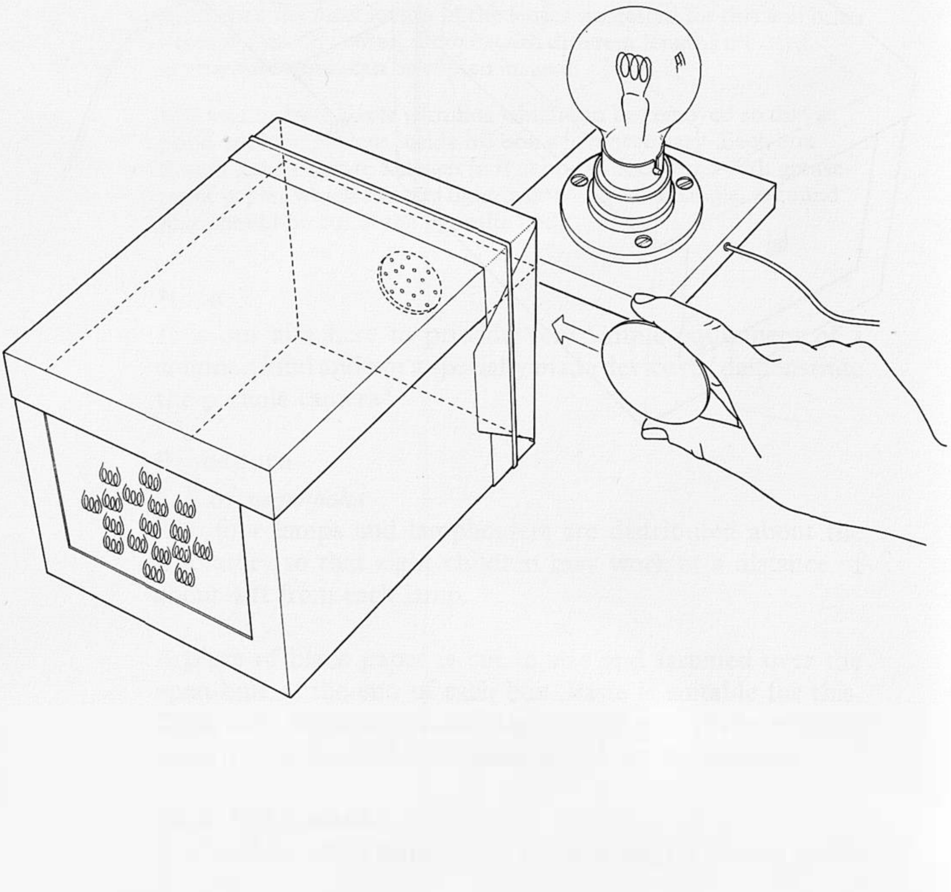
screen when the box is directed towards the lamp and to see what happens if the box is moved closer to or farther from the lamp;

2. to enlarge the pinhole and repeat;
3. to add several more small pinholes;
4. to pepper the whole sheet with pinholes.



b. *Adding a lens to a pepper of pinholes*
With the 'pepper' of pinholes still fitted to his camera, the pupil is given a lens to slide in front of the pinholes whilst he directs the box at the lamp.

If possible, the teacher should find out beforehand the distance from the lamp to the camera which will make the lens bring all the pinhole pictures together into one bright, sharp image. Then he should arrange the pupils round the lamps in circles of that radius so that the experiment succeeds at once and they enjoy the startling effect. Failing that, the teacher should look at the backs of the cameras and suggest that each pupil should move nearer to the lamp and farther from it and see what happens. Pupils will soon find the position for a single brilliant image.



c. *Enlarged hole with a lens*
Then the pupil should push a pencil, then a finger, through the pepper of pinholes. At each stage he should try to experiment with the lens again.

d. *Focusing the lens camera*
The pupil should then try the effect of moving the lens a little way away from the camera. He should also examine the effect when farther away from, and when nearer to, the light source.

When he wishes to have his lens nearer the screen, he must hold it inside the box. This is easily done if the lid of the box is removed and the box held upside down with one hand, while the lens is held inside it from below with the other hand.

e. *Depth of field (optional buffer experiment)*
A new piece of black paper should be pasted on the front of the camera. The pupil should make a large pinhole in this paper and then repeat experiment d. Pupils are now using a lens camera with a small aperture and they will observe the greater range of focus.

f. *View with the lens camera*
Finally the blinds should be pulled up so that the pupils can use their 'lens cameras' to look at the view through the window.

8 *Demonstration*

Smoke box showing image formation with a large lens

Apparatus

1 smoke box	– item 93A
1 smoke generator	– item 93G
1 large plano-convex lens	– item 93B
1 lens holder	– item 93C
1 aluminium sheet with holes	– item 93D
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 retort stand and boss	– items 503–505

The plano-convex lens is of condenser quality, say 10 cm in diameter, 15 cm focal length.

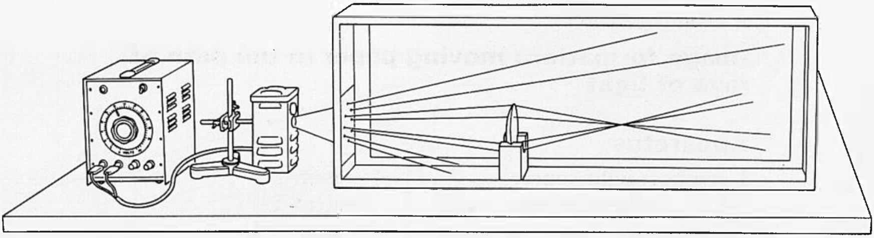
Procedure

1. The lens is put inside the box, about 10 cm from the end of the box with its convex side towards the lamp to reduce aberration. The plate with holes is put at the end of the box. A piece of sacking (about 20 sq cm) is lit with a match and when it is burning, it is inserted in the smoke generator. The generator is inserted through the small hole in the back of the smoke box and several strokes should fill the box.

The compact light source is arranged about $\frac{1}{2}$ m from the lens outside the smoke box. Rays are best seen by observers looking 'upstream' towards the source.

As the lamp is brought nearer, the image can be seen to move away. To get virtual images the lens may have to be moved right up to the end of the box.

2. The plate with holes may now be taken away to show the effect of the lens on the beam of light and, less vividly, the dark shadow produced by the lens.



9 *Demonstration*

Image formation: moving paper in the path of rays of light

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 aluminium sheet with holes	– item 93D
1 large plano-convex lens	– item 93B
3 retort stands, bosses and clamps	– items 503–506
pieces of plain white paper	

Procedure

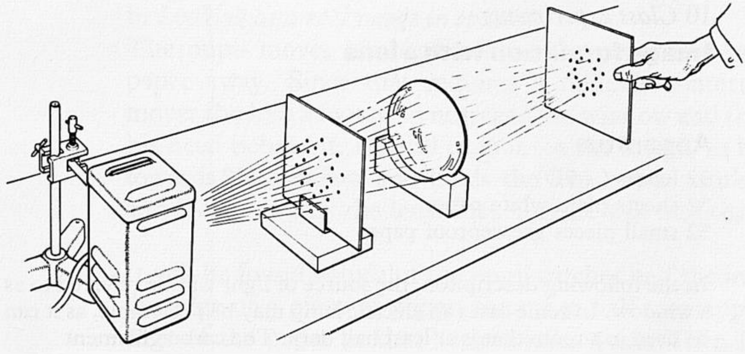
The same arrangement is set up as with the smoke box for forming a real image, but without the box or smoke.

Light from the compact light source falls on the aluminium sheet with holes. Pencils of light continue through the screen and hit the lens. The position of lamp, aluminium sheet, and lens are adjusted so that the lens forms a real image several feet beyond the lens, and the pencils from the outer holes in the sheet meet the lens at places near its edge. Although the lens bends these pencils to pass through the image point, neither rays nor image are visible to an audience in a dark room without smoke to scatter light.

Then the teacher shows that there are rays proceeding from the aluminium sheet to the lens by moving a piece of paper to catch those rays in the space between the sheet and the lens.

He asks what happens to the rays beyond the lens.

Then each pupil comes to the lecture bench in turn to see what does happen, by waving a sheet of paper in the space between the lens, and the image, and on beyond.



10 *Class experiments*

Image formation with a lens

Apparatus

32 lenses (+7D) – item 112
32 sheets plain white paper
32 small pieces greaseproof paper

In the following description, the source of light will be referred to as a window. In some cases an electric lamp may be preferable, as it can be used in a room that is at least half dark. The carbon filament lamp (item 91C) and mounted lampholder (item 91D) are suitable.

Notes

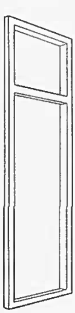
1. See the *Teachers' Guide* for details of the teaching procedure and for an account of what we hope the experiment will give to pupils.

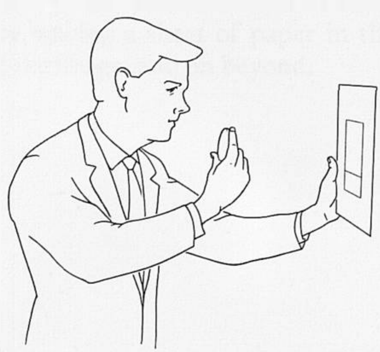
2. Pupils may sit at desks or tables for these experiments, but they should be far enough away from each other to avoid spoiling each other's field of view. Each pupil should be able to look towards a bright open window, in a room that is otherwise mainly dark.

Procedure

a. *Lenses forming real images*

The pupil faces away from the window, holds a sheet of paper at arm's length. He holds the lens in front of the paper and moves it to and from the paper (towards him and back towards the paper) until he sees an image of the window on the paper.





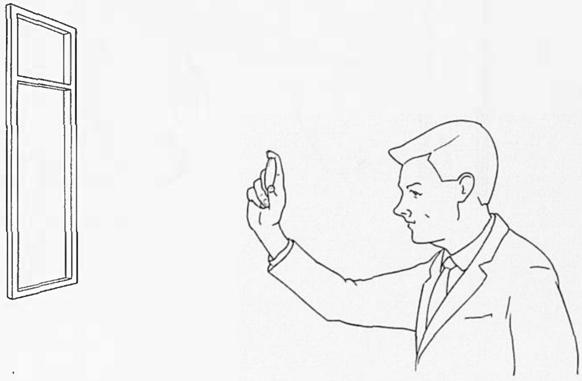
b. *Looking at a real image in space*

The pupil moves his head behind the paper and takes the paper away. Since that requires a difficult contortion, he moves the lens a foot or so nearer to the window and then puts his head behind it. He still cannot see the image, so he turns towards the window and holds the lens out at arm's length and looks towards the lens. Presently he will find the image.

It will be found helpful if the pupil catches half the image on the edge of a piece of paper, the other half overlapping the edge of the paper so that he sees it in space. Then he concentrates his attention and focuses his eye on the part of the image he sees on the paper, and then quickly takes the paper away.

Many pupils will need help, but there need not be much hurry for that, because this is a very important stage and pupils should find an image for themselves. The teacher reminds pupils that they cannot see a thing clearly when it is very close to the face: they must be a considerable distance from it.

This may lead to discussion of 'range of comfortable vision' and Experiment 11 should now be interposed.

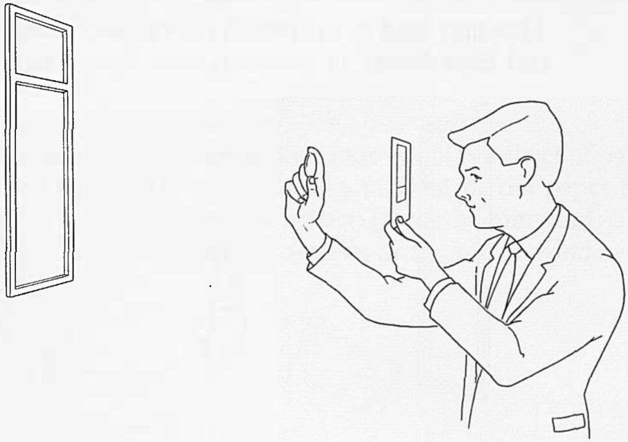


c. *Real image with and without screen*
This is a revision of (b) once experiment 11 has been done.

Each pupil holds a lens at arm's length towards the window. He holds a piece of greaseproof paper in his other hand and finds the place between the lens and his head where there is a clear image of the window on the paper. The pupil is looking at that image through the paper. His eyes should be focused on the paper itself.

The teacher should, if possible, visit each pupil at this stage and see that he has the image on the paper and help him to place his head suitably behind the paper so that he will be able to see the image when he takes the paper away.

The pupil removes the paper and looks at the image in space. If he cannot find the image he puts the paper back and repeats the process. The teacher gives help as far as he can by visiting pupils and suggesting strongly to them that the image is located in space just where the paper was, and to see it the pupil's eye must therefore be focused at that place.

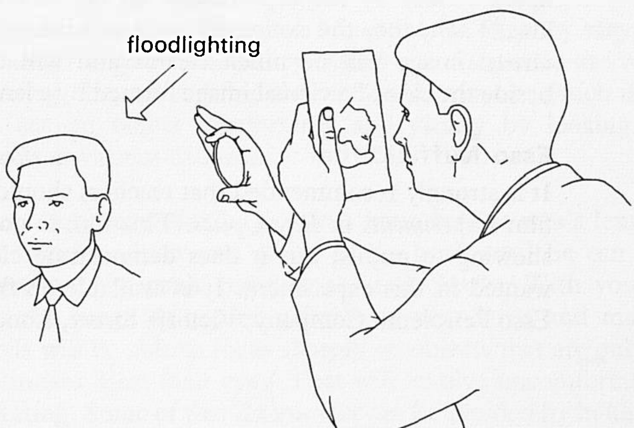


d. *Looking at the real image of a brightly illuminated face*
Darken the room and illuminate the face of a boy or girl brilliantly with floodlights.

Let each pupil form an image of the model's face and notice how the picture moves farther from the lens and grows in size as they move the lens nearer to the model.

Pupils should try this both with a piece of thin paper to catch the image and without the paper.

e. *Quick rough estimate of focal length*
Each pupil holds his lens so that it forms an image of a distant window or lamp on a sheet of paper or a wall and he measures (*roughly*) the distance from lens to image.



f. *Virtual image*
Each pupil holds his lens close to his eye and uses it as a magnifying glass to look at his own thumb (see *Teachers' Guide* for full discussion).

All beginners find the idea of a virtual image more difficult and strange than that of a real image. When they meet this difficulty, some pupils are helped by being shown a plane mirror forming a virtual image. This is not always as helpful as teachers hope since, to a beginner, the plane mirror acts in quite a different way from a transparent lens. So we suggest offering a plane mirror demonstration only as a tentative help to those pupils who have great difficulty.

The behaviour of a converging lens in forming a virtual image in some cases, and a real image in others, will be made much clearer by the experiments on ray streaks which follow. Then, too, the action of a plane mirror in forming a virtual image will be much clearer and will take its place beside the case of a virtual image formed by a lens.

Esso-Nuffield film

It is strongly recommended that teachers should see the Esso film *Experiments in Ray Optics*. This film is not suitable for showing to pupils, but it does demonstrate clearly what is wanted in this experiment. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

11 *Class experiment*

Eye: range of accommodation

Note

This experiment should be interpolated between 10b and 10c. It is something to do light-heartedly. It will involve a certain amount of discussion with pupils who have spectacles, but, provided this discussion is not worrying, it will be helpful.

Procedure

The teacher should ask pupils to look out through an open window (preferably not through a pane of glass) and decide whether they can see things that are far away very sharply. If they can, they can say that their eyes see things as far as 'infinity'.

If pupils with spectacles wish to take them off, they may do so; and if they then find they cannot see things that are very far away, they should find the farthest distance at which they can see an object comfortably and clearly by looking at objects at various distances.

Then each pupil should look at a book held at arm's length and bring it closer and closer to his head until he can no longer see the print comfortably and clearly. With young eyes the range of accommodation is very large and many pupils will be able to focus sharply on objects that are only a few inches from their eyes. That will involve uncomfortable squinting. Some of that discomfort can be avoided by holding a hand over one eye.

We should not labour this. All that is needed is for pupils to try looking at things far away, medium distance, fairly close and very close so that they know roughly the range of distances of objects that they can see clearly.

12 *Class experiment*

First look at a telescope

Apparatus

16 telescope mounts	– item 115
16 retort stands and bosses	– items 503–505
16 plano-convex lenses (+14D)	– item 113/1
16 plano-convex lenses (+2·5D)	– item 113/3
2 200-watt carbon filament lamps	– item 91C
2 mounted lampholders	– item 91D

The lamp as an object

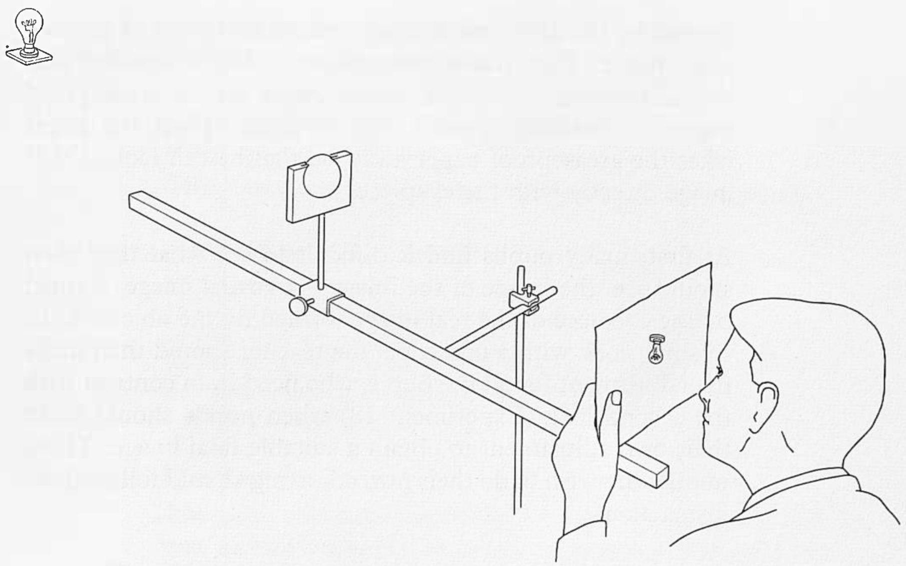
Most teachers find that a large carbon-filament lamp serves very well, run at normal voltage, in a room that is half dark or three-quarters dark. Pupils hunting for an image – which is an unfamiliar thing – find it more easily when the object is very bright. However, some teachers prefer to make the filament less bright. In such a case, a variac should be inserted in the lamp circuit.

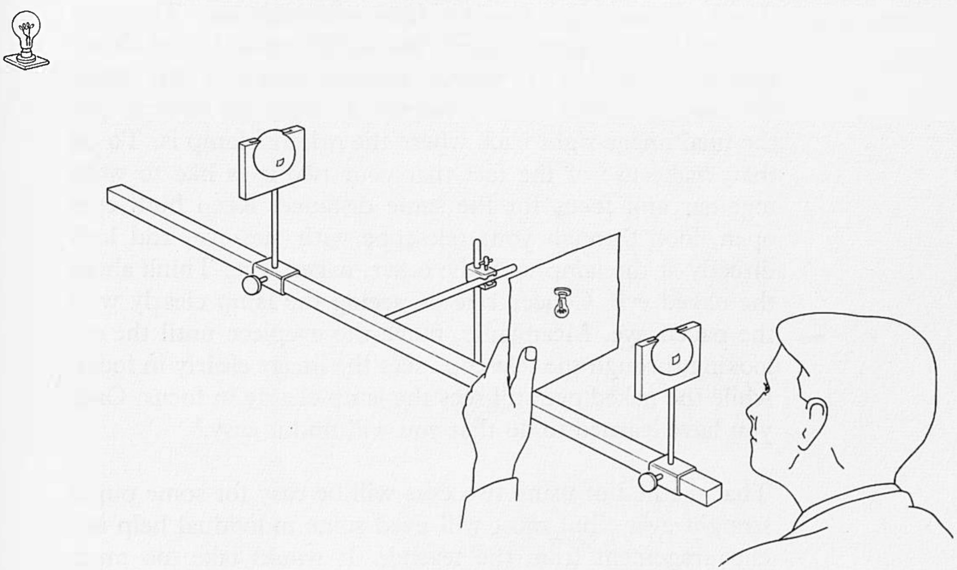
With a small class group, all the pupils can set up their telescopes at one end of the room and view the lamp placed at head-height at the other end. With a large class group, half the class should be at one end of the room and half at the other end. Then two lamps are needed, one at each end of the room. These lamps should be placed high up, well above head-height, so that pupils at one end of the room can view the lamp over the heads of the pupils at the other end.

The telescope mounts

The lens holders and mounts can be of any simple design that enables pupils to set up the telescope easily and use it comfortably up at eye level. (It must not have scales on it for measurement as these are a distraction.) Squatting or bending over to look through a telescope at bench level puts the observer at a considerable disadvantage. Therefore the rod or other mount used to carry the telescope lenses should be held at head level by a tall retort stand.

The lens holders should slide easily along the rod or mount so that the pupil can adjust lens positions easily in a half-dark room. The lens holders themselves should accept lenses easily and hold them firmly with their axes parallel to the slide. The holders and mounts recommended for use enable this to be done conveniently and they are strongly preferable to graduated optical benches.





Procedure

The $+2{\cdot}5$ D lens is put in place in a holder at one end of the mount. If it is plano-convex as recommended, the curved surface should be towards the object.

The telescope is pointed at the distant lamp and the image formed by the objective is caught on a small piece of greaseproof paper. Then the eyepiece lens (+14D) is installed and moved until the pupil can see the image on the greaseproof paper comfortably through the eyepiece. Then the pupil takes the greaseproof paper away, so that he can look at that image directly with the eyepiece.

At first, many pupils find it difficult to see what they then should see, the image of the image – a virtual image, formed by the eyepiece of the real image formed by the objective. In this first look with a telescope, the teacher should then make the adjustment for all the pupils who need it, in contrast with the second look (Experiment 18) when pupils should make their own adjustment to obtain a suitable final image. Those pupils who wish to do their own adjusting should follow these instructions:

'Look through the eyepiece lens with one eye. That eye should see the image of the distant lamp formed by the objective. You want the eyepiece to form an image of that image far away at a comfortable distance. In fact, you want to put the final image right back where the original lamp is. To do that, make use of the fact that your two eyes like to work together and focus for the same distance. Keep both eyes open, look through your telescope with one eye, and look directly at the lamp with the other, naked, eye. Think about the naked eye. Concentrate on seeing the lamp clearly with the naked eye. Meanwhile, move the eyepiece until the eye looking through the telescope sees the image clearly in focus, while the naked eye still sees the lamp clearly in focus. Once you have learned to do that you will find it easy.'

That method of using two eyes will be easy for some pupils straight away, but most will need some individual help and encouragement from the teacher. It would take too much time in this preliminary look at telescopes if the teacher tried to give such help to all members of the class. Instead, it is better, at this preliminary stage, for the teacher to make the adjustment for most pupils so that they use the telescope successfully at once.

Esso-Nuffield Film

For this experiment too, it is recommended only teachers see the film *Experiments in Ray Optics*.

13 *Optional class experiment*

Telescope with a close image

Note

This experiment is only for very fast and skilful pupils.

Apparatus

16 telescope mounts	– item 115
16 retort stands and bosses	– items 503–505
16 plano-convex lenses (+14D)	– item 113/1
16 plano-convex lenses (+2·5D)	– item 113/3
2 200-watt carbon filament lamps	– item 91C
2 mounted lampholders	– item 91D

Procedure

The same telescope experiment as in experiment 12 but the final virtual image is placed only 10 in away (as it would be by an astronomer who wished to move quickly from his telescope to a notebook to make sketches).

14 *Class experiments*

Rays of light and cylindrical lenses

General description of this group of experiments

In these experiments, pupils working in pairs look at the behaviour of rays of light. These 'rays' are not ideal rays but narrow pencils or blades of light that emerge from the slits of a comb illuminated by a small lamp. The lamp has a vertical line filament and the comb has evenly spaced vertical slits. The light emerging from these slits makes 'rays' on a horizontal piece of paper which is placed under the comb and continues beyond it.

Lenses with cylindrical faces (axes vertical) bend the paths of these 'rays' to form images. The image-forming behaviour of lenses can be seen and studied by pupils when they look at these 'ray streaks' on paper on their table in a fairly dark room.

By using two or more lenses, pupils can see the way in which an optical instrument such as a telescope treats rays of light and forms images.

It is necessary to use cylindrical lenses so that the full paths of rays through images can be seen. With a spherical lens, rays are bent down into the paper as well as laterally, so when they converge to an image they disappear into the paper and cannot be seen thereafter.

Special plano-cylindrical lenses are provided, with suitable powers to make models of optical instruments. These lenses have wide apertures to enable pupils to see how real lenses treat rays. The comb used is a 'painter's graining comb' which has uniform slits. For some experiments a screen with a single slit is used instead, and for some experiments a screen with three slits is used. Pupils are provided with small 'barriers' to enable them to narrow the aperture used; and they are encouraged thus to exclude rays which show too much aberration.

The white paper on the table-top (or on a drawing-board on the table) is intended to make these streaks visible. It is not supposed to have rays marked on it with pencil lines, because that would delay the progress of the experiments and would not produce reliable drawings – it is better for pupils to keep their eyes on real 'rays'.

Object of these experiments

These experiments are intended for two purposes:

1. To enable pupils to find out or see for themselves some simple important properties of lenses, rays, and images.

2. To enable pupils to illustrate with real rays the behaviour of some optical instruments.

All the experiments in this series are intended to be class experiments in which pupils gain personal experience by working with rays on their laboratory table. Thus, the apparatus differs strongly in its use from the usual 'ray box demonstration'. Ray boxes are too expensive and not flexible enough for pupils in these class experiments. Therefore, we hope that teachers will not substitute ray boxes for our simple equipment, and we hope very strongly that ray box demonstrations will not take the place of these class experiments.

This set of experiments is intended to provide a continuous programme of work in the laboratory, to make acquaintance with lenses and images. We do not recommend interrupting it by any note-taking or measurements. Optical knowledge can be revised and consolidated later.

Esso-Nuffield film

Most of the experiments described here are illustrated in *Experiments in Ray Optics*, which teachers are recommended to see. It is available on free loan from Esso Petroleum Company, Victoria Street, London, S.W.1. The film should not be shown to pupils; it would ruin both the fun and the value of their own investigation.

Apparatus

1 kit for ray optics	– item 94
3 transformers	– item 27
16 plane mirrors	– item 116
16 holders for mirrors	– item 117

The ray optics kit contains sufficient for a class of 32 with pupils working in pairs. It includes:

16 lamps, holders and stands	– item 94A
8 pairs housing shields	– item 94B
16 metal plates with single slits	– item 94C
16 metal plates with three parallel slits	– item 94D
16 metal combs	– item 94E
16 holders (for combs and plates)	– item 94F
32 barriers	– item 94G
32 plano-cylindrical lenses $+7D$ ($f = 14{\cdot}3$ cm)	– item 94H
16 plano-cylindrical lenses $+10D$ ($f = 10$ cm)	– item 94I
16 plano-cylindrical lenses $+17D$ ($f = +6$ cm)	– item 94J
16 plano-cylindrical lenses $-17D$ ($f = -6$ cm)	– item 94K

The lamps should be 12 volt 24 watt and of the type that will give a vertical filament in the lampholders.

The lenses suggested for this have been chosen carefully after extended trials. Their sizes and powers are chosen to provide for good illustrations of instruments, as well as of simple lens behaviour, in the space available on ordinary laboratory tables.

The lenses should be at least 2 in wide; narrower lenses will not give the extensive fans or rays that pupils should see. Some of the lenses need to be 2 in high so that blades of rays through them extend far enough along the paper. Other lenses, used only as eyepieces, need not be more than 1 in high.

The powers suggested provide for the various instrument models that pupils should try. Changing to other powers, particularly to weaker lenses, is likely to restrict the value and range of the experiments greatly.

Lenses of plastic instead of glass would have to have steeper curves for the same powers, and the aberrations would therefore be much greater; and that would not be at all desirable.

Notes

1. It is unwise to give pupils all the lenses, slits, etc., straight away. Pupils should have lamp, comb, barriers, and white paper. At the beginning they should be given one lens, +7D. Then they should be given samples of all the lenses for a short period of general play, with a warning that lenses are rather fragile and are easily scratched. After that it is best to provide only those lenses, etc., that are needed for each experiment.

2. The experiments are intended to be carried out as a continuous programme, with pupils moving at their own speed. The division into separate parts (*a*), (*b*), (*c*) . . . in these notes is an artificial one, intended only to help teachers when they are making preparations.

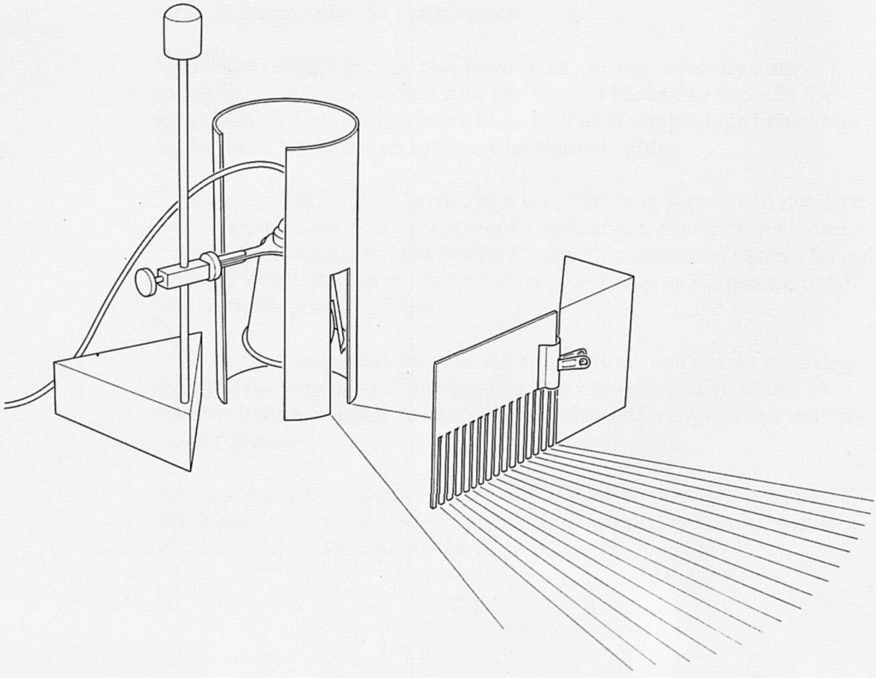
3. For all the experiments, three-quarters blackout is strongly advised.

Procedure

a. *Fan of rays of light*
Light from the lamp shines through the comb and makes 'rays' on the paper. Pupils should arrange the lamp and comb so that they can see the rays.

They should raise or lower the lamp until the rays continue right across the paper. (We do not tell pupils to observe that the rays are straight, nor do we ask them to make a record of such observations.)

If the rays look fuzzy, that may be because the lamp filament is not vertical, parallel to the slits in the comb. Or it may be because the lamp has a crooked filament. In the latter case, the cure is to change lamps. The crooked filament can, in some cases, even give an impression of crooked rays, so such a lamp must be removed. Home-made slits which are not really straight and vertical are apt to produce crooked rays.

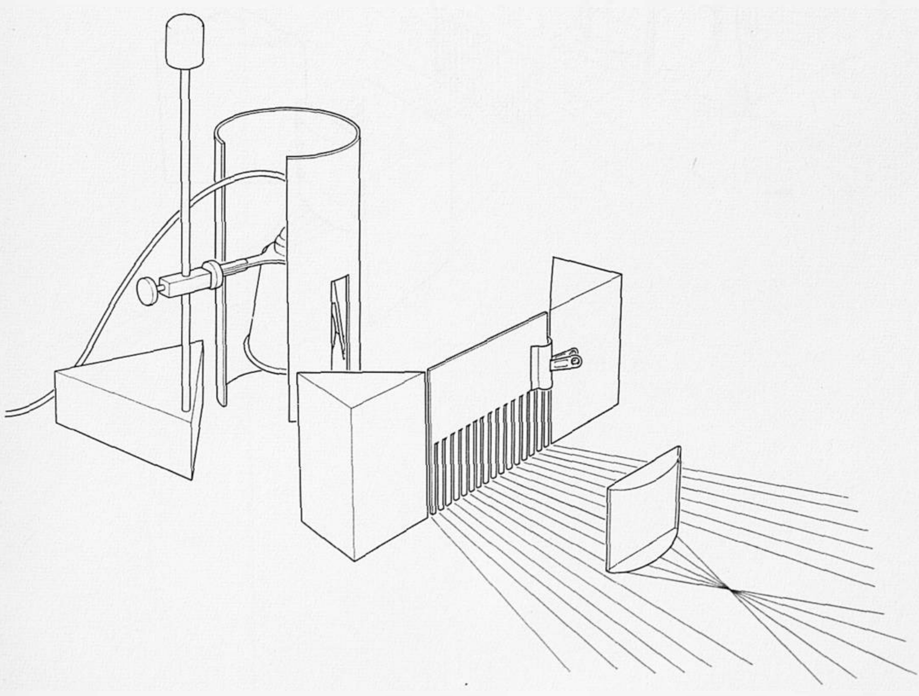


b. *Rays and lenses (first +7D; later various lenses)*
Give pupils a weak positive cylindrical lens, +7D. Ask them to place the lens in the fan of rays, in various positions, and look at what it does.

The teacher should visit the pupils to make sure that they have tried placing the lens so that it is not twisted but receives the rays more or less 'normally'. He should offer pupils small barriers to shut off some edge rays if they wish.

The teacher should give the pupils several other lenses to play with for a short time. This is a new amusing game for young people and they will do many things with the lenses which do not seem sensible or profitable to a physicist. They do not know what properties of lenses and rays they are looking for and we should respect that ignorance and let them play quite freely for a while. Suggested lenses are +17D, −17D, an extra +7D, perhaps a plane mirror.

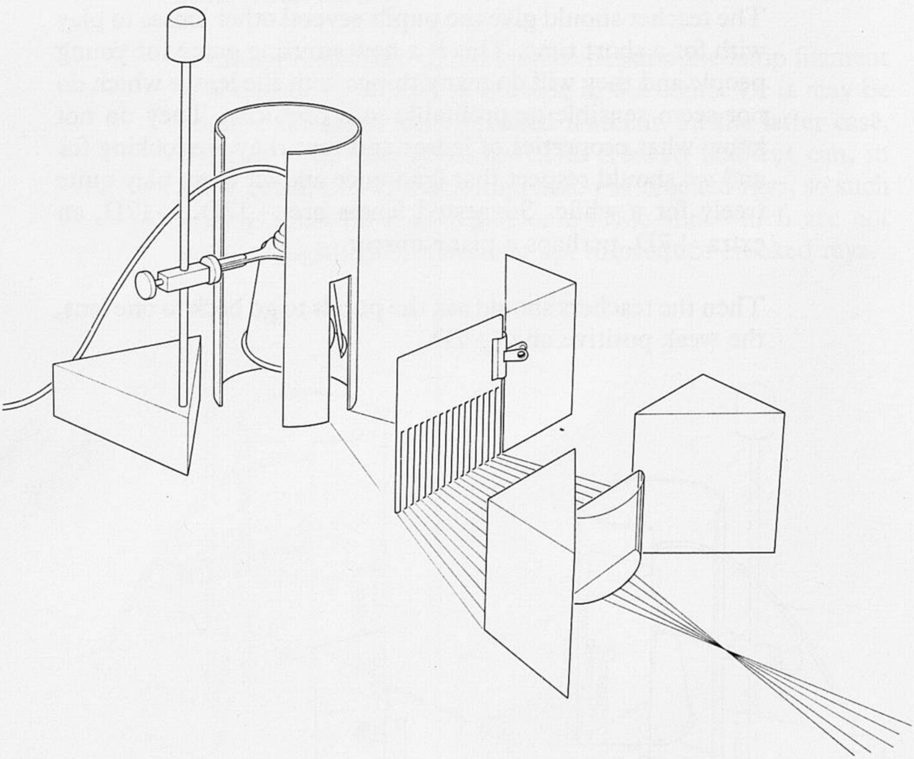
Then the teachers should ask the pupils to go back to one lens, the weak positive one, +7D.



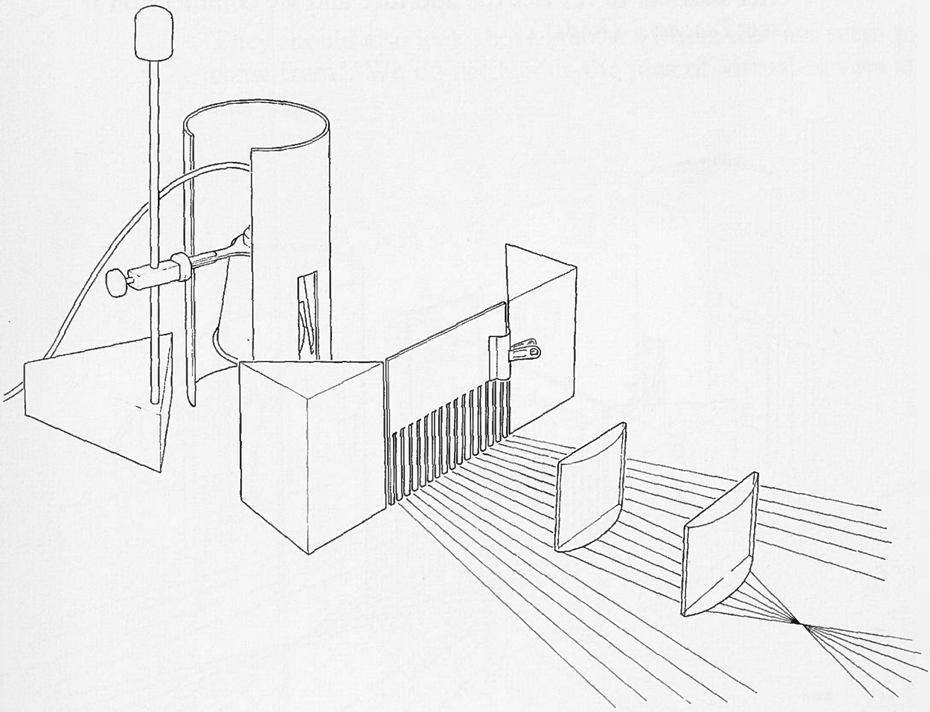
c. *A lens (+7D) forming a real image*

The teacher should ask pupils to treat the lens more carefully, making sure that its face is perpendicular to the central ray, and shutting down the aperture if necessary until all the rays that come through seem to go on through one point. We give the name of that: a real image.

The teacher should encourage pupils to ask for more lenses again.

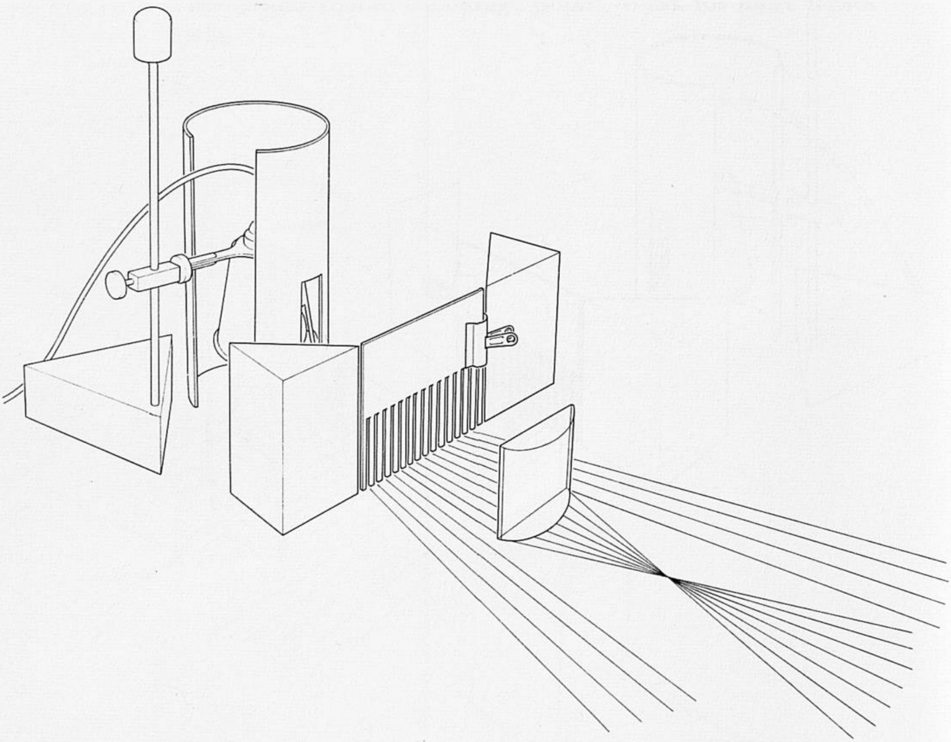


d. *Fan of rays and two lenses (both + 7D)*
The teacher provides a second lens of the same power, +7D, and asks the pupils to try using both lenses together. (They may try them several ways round and we should not hurry that.)



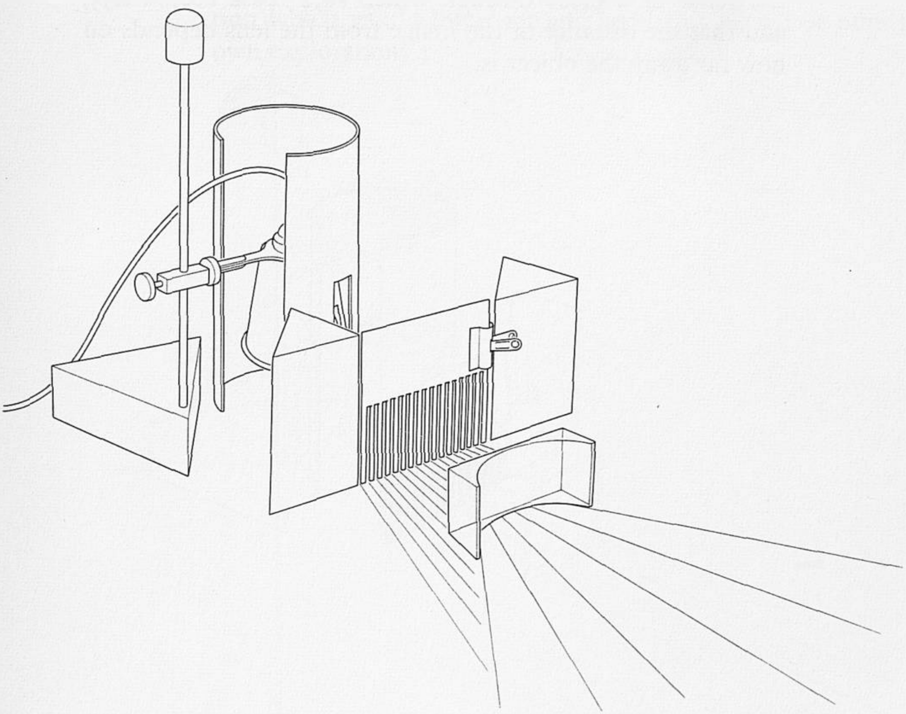
e. *Fan of rays and a stronger lens* (+*17D*)
The teacher then offers a stronger positive lens, +17D, asking pupils to try that lens alone.

When pupils complain about spherical aberration, we offer barriers to restrict the aperture and we comment on it (see *Teachers' Guide*).



f. *Fan of rays and a negative lens* (−17D)
The teacher gives the pupils a negative lens, −17D, to try. This will raise questions of virtual images and we encourage pupils to look along the rays from the outgoing end and see 'where they seem to come from'.

They should also look above and 'see where the rays seem to come from'. We do *not* labour the idea of virtual images at this stage.



g. *Effect on image of changing object distance (using lens +7D, later with +17D)*

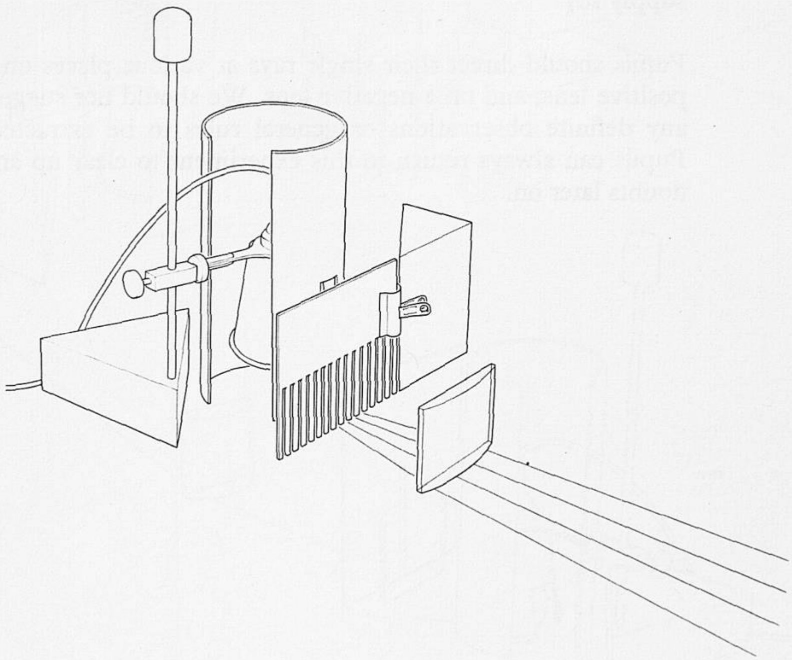
The teacher asks pupils to go back to the weak positive lens, +7D, and try moving the lamp nearer and farther away. They may also try this with the strong positive lens, +17D.

Pupils should not make any record of the changes of image distance. The purpose of this experiment is to let pupils see that a clear image is always formed (using the name image in the sense of a place through which rays cross accurately), and that the distance of the image from the lens depends on how far away the object is.

h. *Virtual images*

The teacher encourages pupils to move the lamp so close to the +7D lens that a virtual image is formed. He asks them to look along the rays from the outgoing end and see where the rays seem to come from and then look at the rays from above and see where they seem to come from.

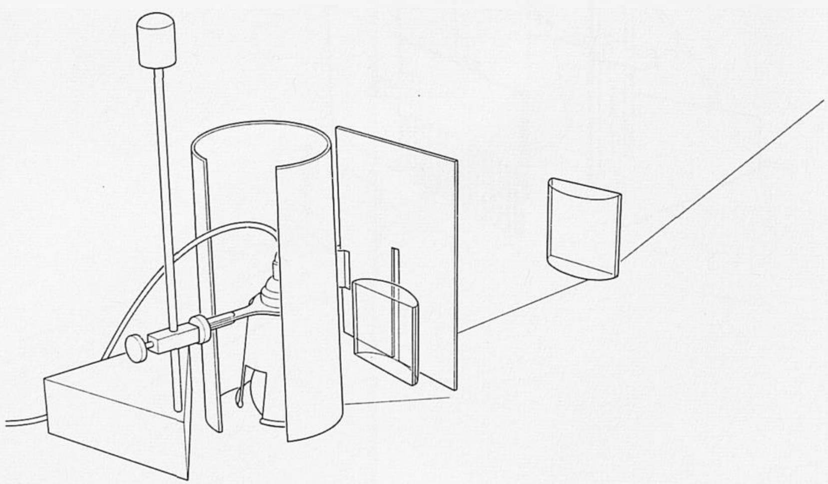
This is a time when the teacher should discuss virtual images with pupils while he and they are looking at their actual lens and rays together. (This is not a good time for a demonstration which would interrupt and spoil this period of pupils' own explorations.)



i. *A single ray hitting a lens* (+ *7D*)
The teacher supplies a screen with a single slit instead of the comb with many slits and asks pupils to watch what happens to a single ray when it hits various places on a lens. (Again, this is not the time for taking notes nor for a demonstration, even if pupils do not seem to learn the detailed story in a way we would like.)

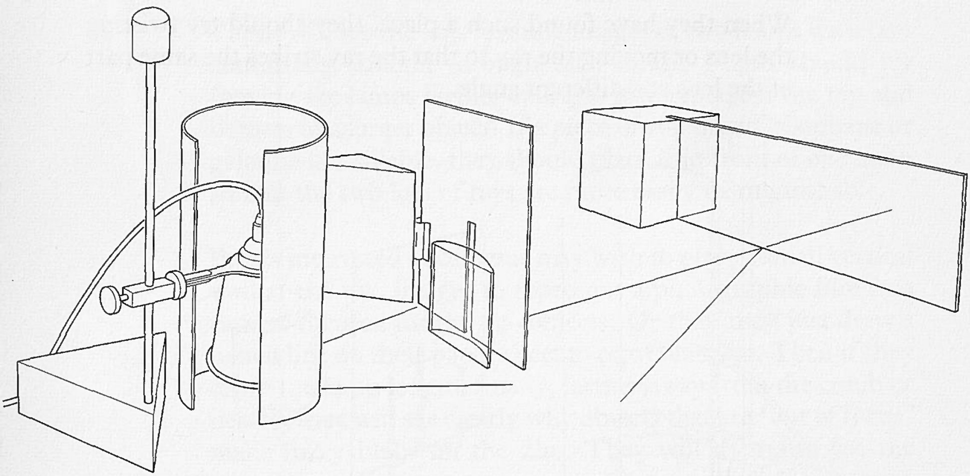
(We may show pupils how to make the 'ray' brighter and thinner by placing a lens between a lamp and single slit, just behind the slits. A +10D lens will do well for this. If pupils seem to be bothered by the addition of this lens we should not supply it.)

Pupils should direct their single rays at various places on a positive lens, and on a negative lens. We should not suggest any definite observations or general rules to be extracted. Pupils can always return to this experiment to clear up any doubts later on.



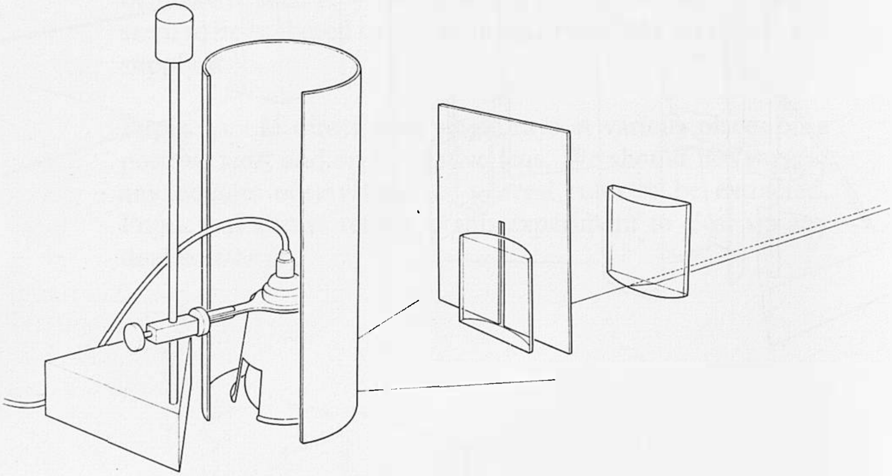
j. *Single rays and plane mirrors*

The teacher asks pupils to direct a single ray at a vertical plane mirror and watch what happens to the ray. Again, he should not ask for measurements or suggest a rule that is to be discovered or tested. We simply leave empirical knowledge to accumulate.



k. *Optical centre : undeviated rays, using +7D lens*
Unless pupils have found the properties of the optical centre of a lens before, we ask them to return to the weak positive lens, +7D, and direct a single ray at various places on it and find out whether there is any place on it such that a ray hitting it emerges with its direction unchanged.

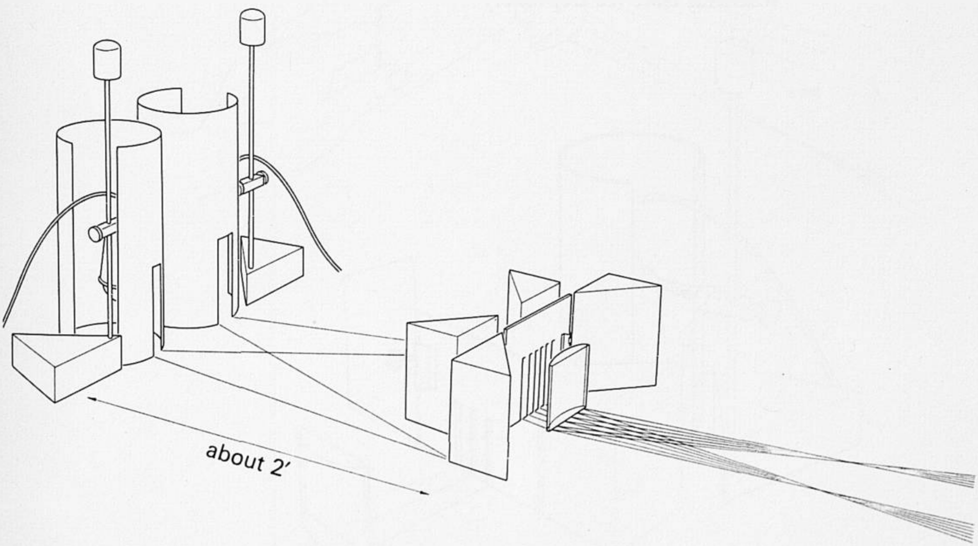
When they have found such a place, they should try twisting the lens or moving the ray so that the ray strikes the same part of the lens at a different angle.



1. *Rays and images with two objects, using + 7D lens*
The teacher provides a second lamp, or ask pupils to double up with neighbours to form a group that has two lamps. These two lamps should be placed side by side a considerable distance away from the comb, and a weak positive +7D lens placed just beyond the comb.

Pupils will see the lens forming images of two lamps with rays continuing straight through each image. Pupils should try moving the lamps farther apart, as if to represent the top and bottom of a larger object. If a piece of coloured Cellophane or gelatine is available, they should place it in front of one lamp so that the two lots of rays are more easily distinguishable.

Pupils interested in cameras may wish to place a small vertical wall at the two images to represent a photographic film in a camera focused for the two objects. Or they may just draw a pencil line on their paper sheet to represent that. Then if they move the lamp longitudinally, farther away from the comb or nearer, they will see clearly why objects that are 'out of focus' make fuzzy blobs on the film. They will then also see the advantage of a cheap camera with a small diameter fixed focus lens if they move in barriers to stop down the lens aperture.

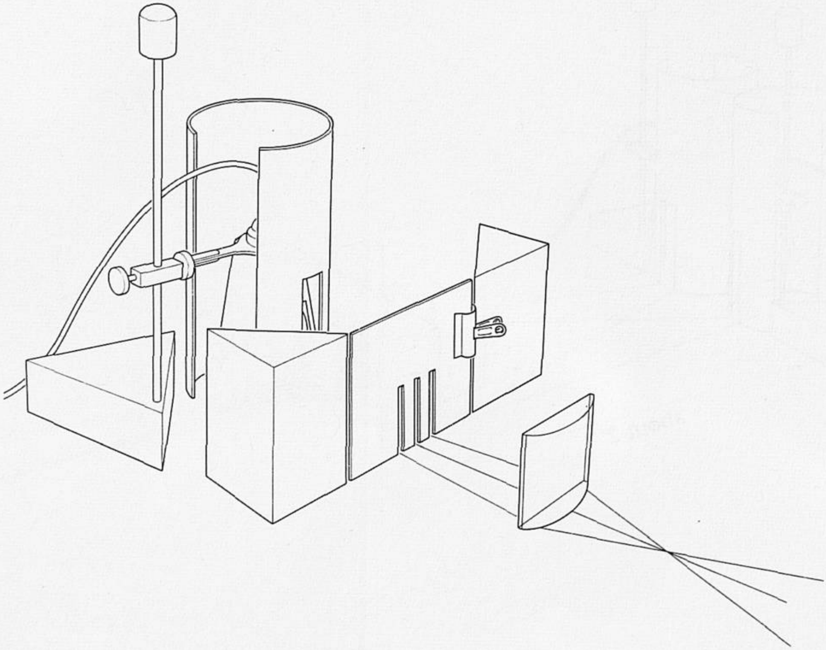


m. *Using only three rays instead of many*

The teacher asks pupils to place a lamp a considerable distance away and then use a strong positive +17D lens to form an image. He asks if the image is a 'good' one: they will tell him that the outside rays are bent too much so that the image is not a good one, until the barriers are added to mask the aperture down to a small central region.

We then tell them there is a clever way of showing the outside rays meeting as if at a proper image but not one that is optically very honest. Whether they guess or not, the teacher provides a screen with three slits instead of the comb. Then pupils arrange for the ray through the centre slit to hit the centre of the lens, and the rays from the outer slits to hit the lens out near its edges.

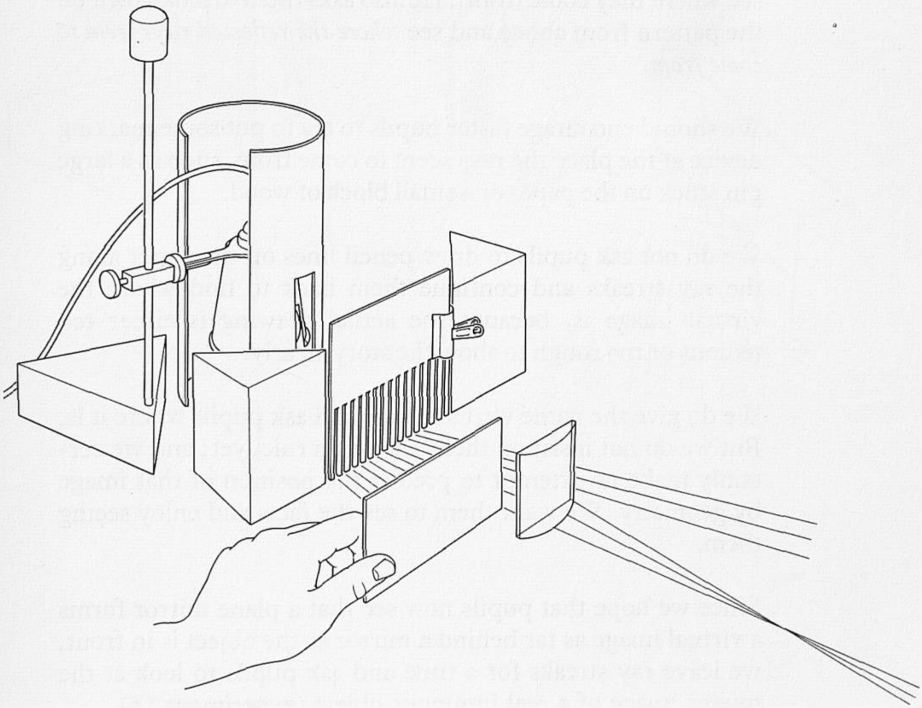
With the intermediate rays missing, these three rays will appear to form a perfect image. This is, of course, cheating; but it is useful for showing simple diagrams of optical instruments with rays. In the case of more complicated models this dishonest trick provides a simplification that is almost essential for a first look. (This untruthful simplification is, of course, used all the time in traditional optical diagrams – usually without any warning to pupils, and it is this lack of warning that we deplore.)



n. *Cutting off rays*

When pupils are doing experiments with lenses receiving a fan of rays, it may help if the teacher moves round amongst them, to straighten a lens or offer an extra lens to try.

He can slide a small piece of cardboard in, across the fan, to cut off ray after ray. That demonstration of successive rays being cut off or admitted seems to help pupils to understand what is going on.



o. *Plane mirror receiving a fan of rays from an object*
A small plane mirror is placed upright on the white paper and the lamp, comb, and barriers arranged so that a fairly narrow fan of rays from the lamp hits the mirror. The lamp should be moved quite close to the paper, probably on the paper itself, so that the virtual image of the lamp is obviously somewhere on the actual paper.

The teacher asks the pupils to 'look along the reflected rays to see where they come from'. He also asks them to look down on the pattern from above and see *where the reflected rays seem to come from.*

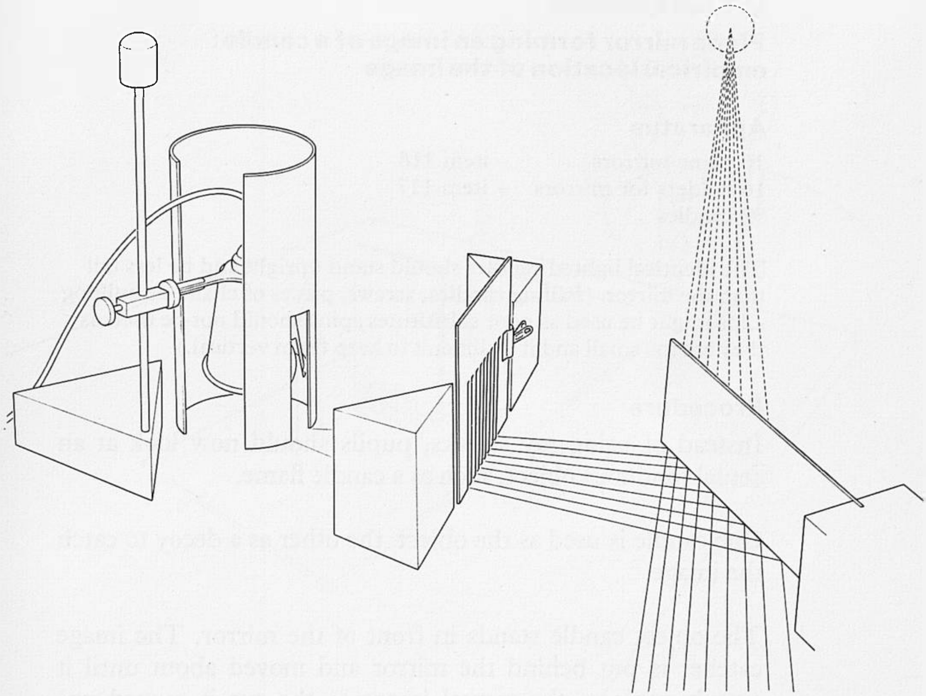
We should encourage faster pupils to try to put some marking device at the place the rays seem to come from, such as a large pin stuck on the paper or a small block of wood.

We do not ask pupils to draw pencil lines on the paper along the ray streaks and continue them back to find where the virtual image is, because the actual drawing is either too tedious or too rough to show the story clearly.

We do give the name virtual image and ask pupils where it is. But we do not insist on their learning a rule, yet; and we certainly make no attempt to predict the position of that image by geometry. We want them to see the facts and enjoy seeing them.

Since we hope that pupils now see that a plane mirror forms a virtual image as far behind a mirror as the object is in front, we leave ray streaks for a time and ask pupils to look at the mirror image of a real luminous object (experiment 15).

For experiment 14p, see p. 102.



15 *Class experiment*

Plane mirror forming an image of a candle: empirical location of the image

Apparatus

16 plane mirrors – item 116
16 holders for mirrors – item 117
32 candles

The identical lighted candles should stand upright and be less tall than the mirror. (Failing candles, screws, pieces of chalk, or bulldog clips might be used as poor substitutes; pins should not be used as they are too small and it is difficult to keep them vertical.)

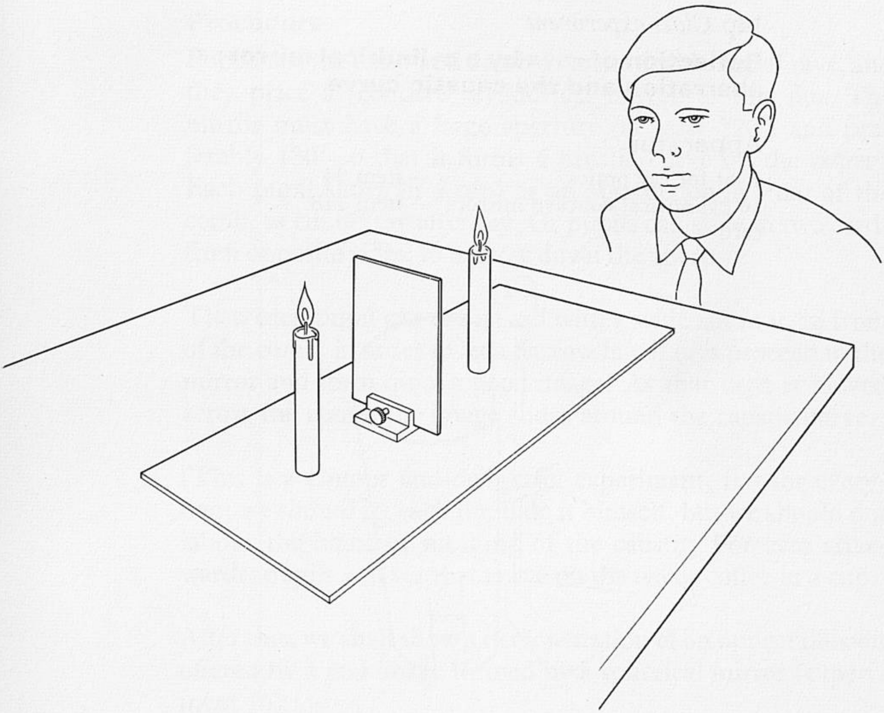
Procedure

Instead of using ray streaks, pupils should now look at an actual luminous object, such as a candle flame.

One candle is used as the object, the other as a decoy to catch the image.

The object candle stands in front of the mirror. The image catcher is put behind the mirror and moved about until it exactly replaces the virtual image as the eye is moved upwards. The arrangement is viewed from other directions to check the position.

We should avoid the quicker no-parallax method here, because it does not teach the important idea of an image so well.

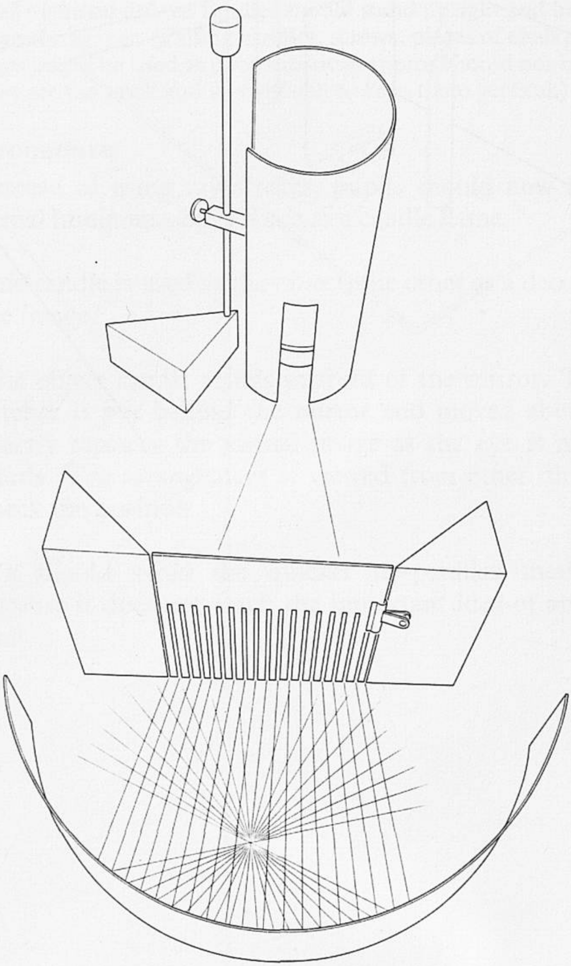


14p *Class experiment*

Reflection of rays by a cylindrical mirror: aberration and the caustic curve

Apparatus

1 kit for ray optics	– item 94
16 cylindrical concave mirrors	– item 118
card	



This illustration shows the arrangement of apparatus and the 'ideal' behaviour of rays that we would like to find. Pupils will be surprised and pleased when they see the real behaviour. Then the continuation of the experiment, with a narrow fan of rays, will show when a proper image is formed.

Procedure

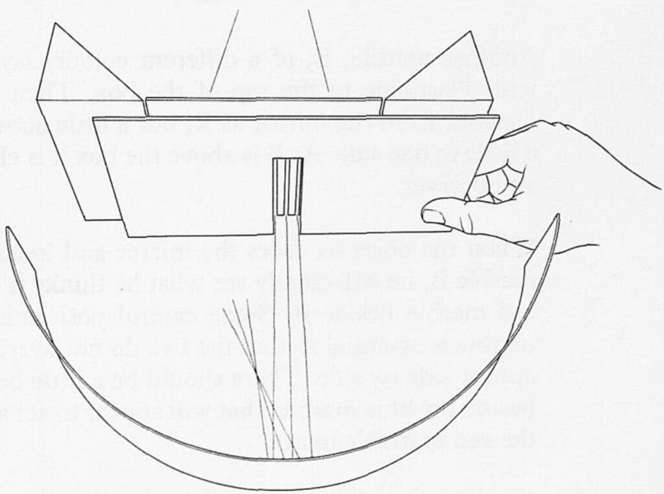
Pupils use the lamp and comb to make a wide fan of rays, and they place a (concave) cylindrical mirror in this fan. The mirror must have a large aperture (at least 120°, and preferably 180° so that it forms a caustic curve on the paper). Each pupil slides in a card as an obstruction in front of the comb, to cut off ray after ray. Or pupils can slide in two cards from opposite sides, to narrow down the aperture.

Then each pupil can use a card with a wide slit in it, in front of the comb, in order to let a narrow fan of rays proceed to the mirror and form quite a good image. As that card is moved across the comb, the image slides around the caustic curve.

(This is a famous and delightful experiment, fun for everyone; we should let each pupil do it himself, but we should not labour the name or meaning of the caustic. For ever afterwards, pupils will see that curve on the tea or coffee in a cup.)

After this, we shall show a demonstration of an optical illusion offered by a real image formed by a spherical mirror (experiment 16).

For experiments 14q–s, see p. 106.



16 *Demonstration*

Image of a marble in a large spherical mirror

Apparatus

1 large concave spherical mirror
1 stand for mirror
1 red marble
1 blue marble
1 small box (2 in cube or smaller)
1 stand for box
1 illuminant
Plasticine

The mirror should be as large as possible and have, if possible, an aluminized front surface. No specific recommendations are made for this: it is left to the teacher to improvise for himself.

Procedure

This demonstration is an optical illusion in which a spherical mirror forms a real image.

A small object such as a red marble, R, is fixed with Plasticine to the *inside* top of the small box. The box is placed on a stand so that the red marble is near the centre of curvature of the large spherical mirror with its open side facing the mirror; it should be a very small distance below the mirror's axis.

Another marble, B, of a different colour, say blue, is fixed with Plasticine to the top of the box. Then B is the same distance from the mirror as R, but a little above the axis and a little to one side. As B is above the box it is clearly visible to an observer.

When the observer faces the mirror and looks at the visible marble B, he will clearly see what he thinks is an equally real red marble beside it. Some careful positioning of the blue marble is essential so that the two do not overlap, but indeed appear side by side. There should be a little bed of Plasticine beside the blue marble, that will appear to act as a support for the red marble's image.

An effective additional touch is to turn on an illuminant or spotlight on the visible blue marble. It will be found that the 'imaginary' marble will be illuminated as well.

In this additional experiment it is essential to have a concave mirror of very large 'aperture', a face with diameter almost as big as the radius of curvature of its concave surface. The lamp or spotlight should be placed beside the observer's head to light up the visible marble B. Any rays from the lamp which hit the image beside the visible marble pass right through that image, continue to the mirror, and are reflected to the concealed marble R. (These rays thus follow, in reverse, the paths of rays that make the illusion.) Therefore, the lamp which illuminates the red marble's *image* also illuminates the red marble itself.

Note

With a concave mirror of small aperture, the concealed marble needs to be illuminated by a lamp concealed somewhere between the marble and the mirror.

For experiment 17, see p. 111.

14q–s *Class experiments*

Rays of light and cylindrical lenses

In addition to making real optical instruments such as a simple telescope and a primitive compound microscope, the pupils should also do the following experiments with ray streaks to illustrate the working of those optical instruments.

Apparatus

1 kit for ray optics – item 94

Procedure

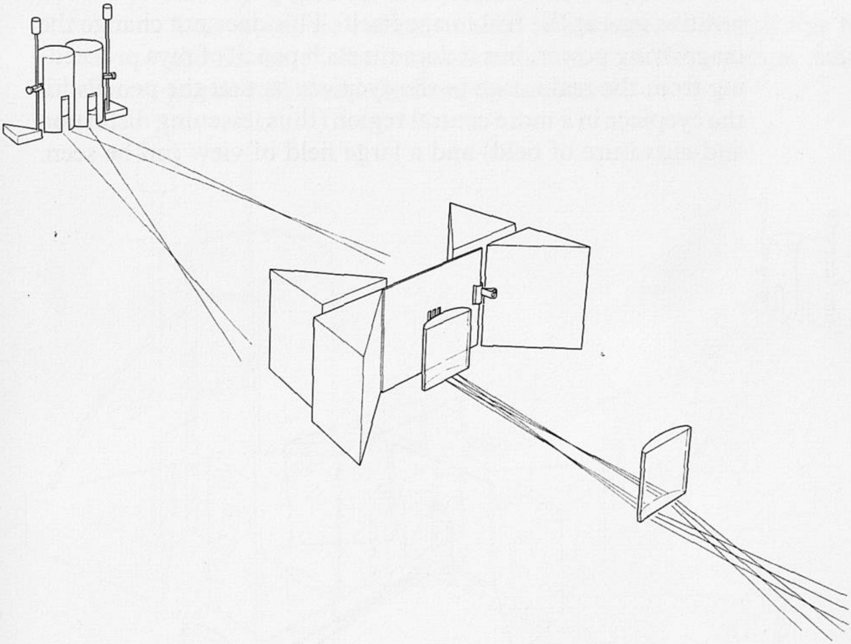
q. *Model of telescope with ray streaks (using +17D and +7D lenses)*
For this experiment, pupils should at first use the screen with three slits, close to the objective lens, and *two* lamps for source, to represent the top and bottom of a distant object. The lamps are placed far away, several feet from the objective.

The objective is a weak positive lens, +7D, with its curved face towards the 'object'. The eyepiece is a strong positive lens, +17D, which should also have its curved face towards the 'object'. The eyepiece is placed so that each lamp's rays that emerge from it form a parallel beam.

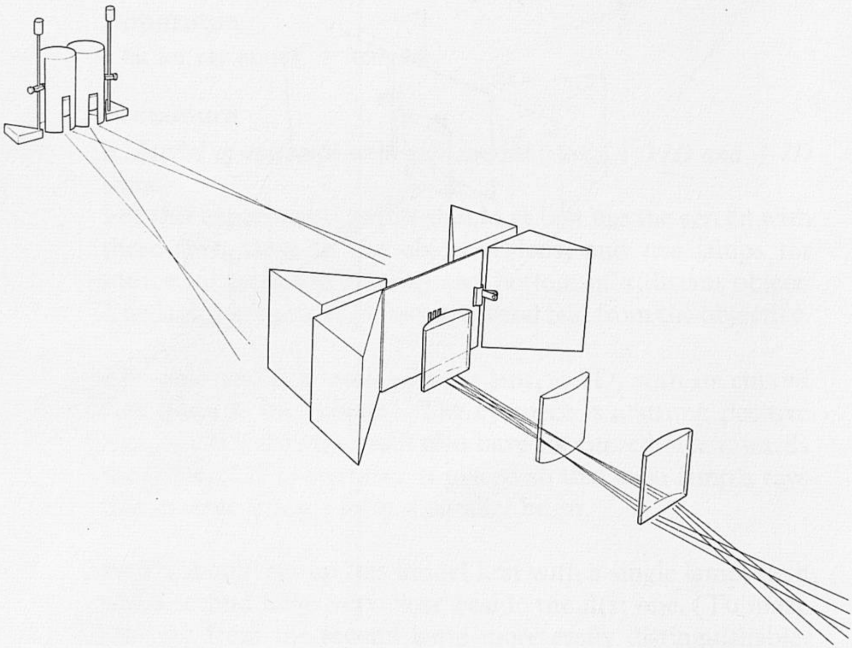
Pupils should set up this model first with a single lamp, then add a second lamp very close beside the first one. (To make the rays from the second lamp more easily distinguishable, place a sheet of pale coloured gelatine or Cellophane in front of that lamp.)

With two lamps, pupils can see that the first (real) image formed by the objective lens is much smaller than the original object (represented by the space between the two lamps). But if they look along the two parallel beams that emerge from the eyepiece, they will see that those seem to come from a distant virtual image which is much bigger than the object.

Instead of using two lamps, pupils may use a single lamp and move it to and fro, perpendicular to the axis of the telescope. Then they will see the emergent beam of parallel rays tilting to and fro much more strongly than the rays that arrive at the objective lens. This too illustrates the magnification, but it is not so convincing to beginners.

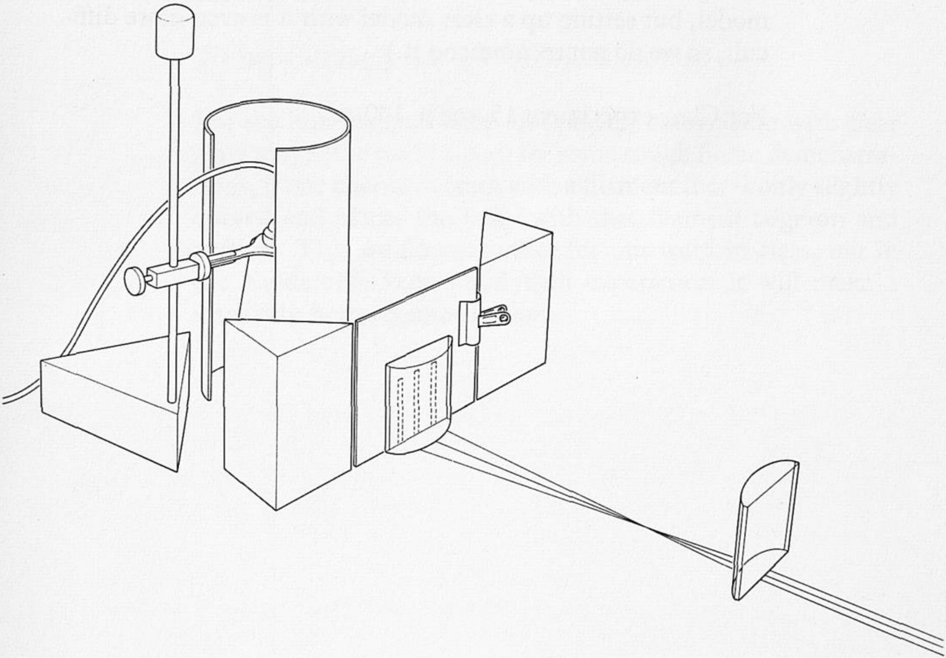


r. *Optional. Use of a field lens in a telescope (using +17D, +7D, and +7D or +10D lenses)*
With a ray streak telescope as in 14q, pupils insert a weak positive lens at the real image itself. This does not change the magnifying power, but it does tilt each pencil of rays proceeding from the real image to the eyepiece so that the pencils hit the eyepiece in a more central region (thus lessening distortion and curvature of field) and a large field of view can be seen.



s. *Model of a microscope with ray streaks (using +10D, +17D lenses)*

This is a more difficult model to arrange. Although this too should be a class experiment, not a demonstration, many pupils will need help from the teacher.



The objective lens is a strong positive lens, +10D. The screen with three slits is placed close to it and the lamp again serves as an object. The curved face of the lens should be away from the lamp.

The lamp is moved up towards the lens until the image distance is two or three times the object distance.

The eyepiece is a strong positive lens, +17D, with its curved face towards the objective.

The general procedure is similar to that for a model of a telescope but the aberrations are more serious, so it is more difficult to arrange a lifelike representation.

In this case, too, it may be possible to crowd two lamps close enough together to serve as top and bottom of the 'object'.

But it is probably more convincing to move a single lamp quickly to and fro perpendicular to the axis and watch the changing tilt of the rays that emerge from the eyepiece. (A stronger objective, +17D, would make a more realistic model, but setting up a clear model with it is even more difficult, so we do not recommend it.)

For Class experiment 15, see p. 100.

17 *Home experiments*

Further experimenting with ray streaks

Some pupils will want to take the apparatus for ray streaks home, either to show other people or to continue their own experiments.

We hope strongly that schools will allow this.

For the line-filament lamp an ordinary mains lamp with clear glass may serve well enough for some rough home demonstrations, if one chooses a lamp with a filament that is only slightly curved and places the lamp with that filament edge-on and vertical. This would not suffice for our work in class, but in the hands of a keen pupil with experience, it will make a satisfying home demonstration.

18 *Class experiment*

Further work with a telescope

Apparatus

16 telescope mounts	– item 115
16 plano-convex lenses (+14D)	– item 113/1
16 plano-convex lenses (+2·5D)	– item 113/3
16 retort stands and bosses	– items 503–505
2 200-watt carbon filament lamps	– item 91C
2 mounted lampholders	– item 91D
1 vertical scale horizontal lines	– see below

Procedure

The carbon filament lamp should be set up high at one end of the room. With a large class, one lamp should be at one end, one at the other. They should be placed high up, well above head-height, so that pupils at one end of the room can view the lamp over the heads of pupils at the other end.

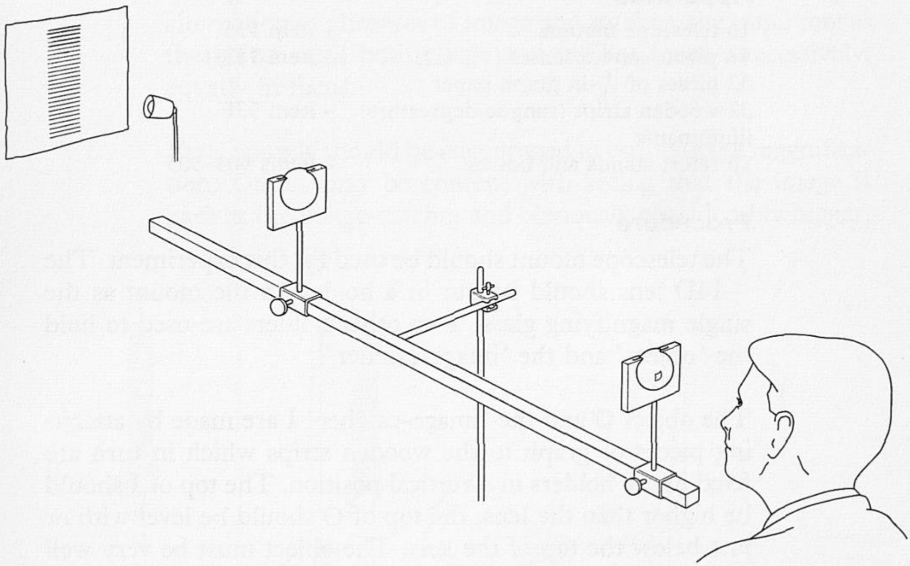
Experiment 12 was intended to provide a quick first look at a telescope. The work with ray streaks should now enable pupils to understand the working of the instrument better. They should learn to place the final image for themselves. See the *Teachers' Guide*.

This time, pupils should themselves succeed in placing the virtual image of the lamp back at the object. (Specially able pupils may also try placing it at 10 in and they will gain in facility with the telescope if they practise placing the image in different positions.)

There should be a vertical scale with horizontal lines on it to act as an object when the pupils estimate the magnification. A long strip of shelf-paper is suitable, or several sheets of foolscap Sellotaped end to end. Thick horizontal lines should be ruled on it, say every 10 cm, to make a coarse scale. It needs to be very well illuminated. It will help if the room is three-quarters blacked out.

The scale should be set up vertically with the lines horizontal and used to estimate magnification. For that, as for placing the final image, the pupil needs to keep both eyes open, looking directly at the scale with one (naked eye), and through the telescope at the virtual image with the other eye.

With faster pupils only, it may be possible to show empirically that the magnification is f_1/f_2 where the focal lengths, f_1 and f_2, are measured crudely by catching the image of a window on a sheet of paper.



19 *Class experiment*

Magnifying glass

Apparatus

16 telescope mounts	– item 115
16 plano-convex lenses (+14D)	– item 113/1
32 pieces of $\frac{1}{10}$-in graph paper	
32 wooden strips (tongue depressors)	– item 53F
illuminants	
16 retort stands and bosses	– items 503–505

Procedure

The telescope mount should be used for this experiment. The +14D lens should be put in a holder on the mount as the single magnifying glass. Two other holders are used to hold the 'object' and the 'image-catcher'.

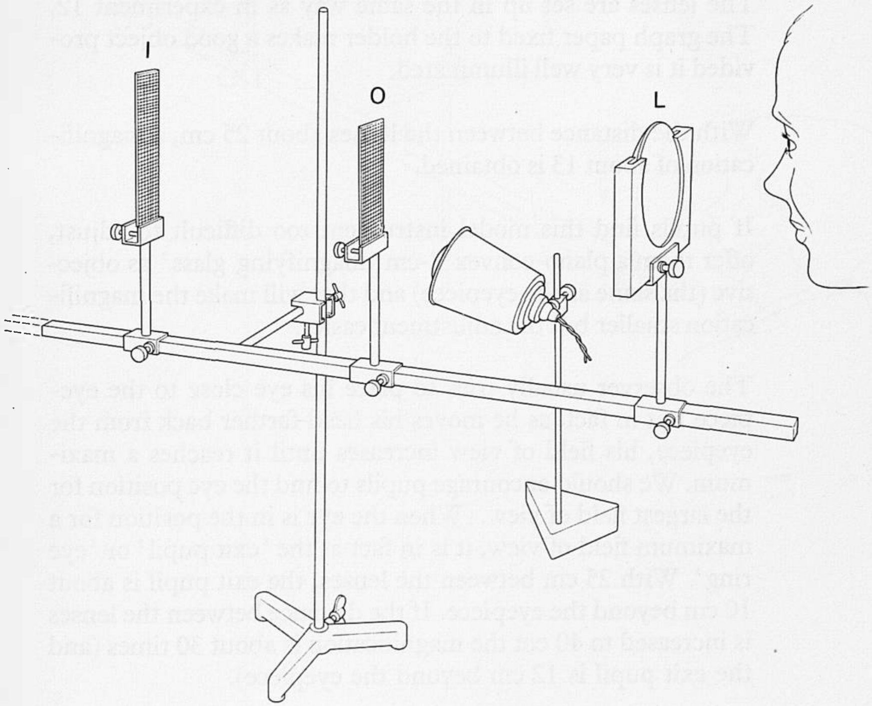
The object O and the 'image-catcher' I are made by attaching pieces of graph to the wooden strips which in turn are fixed in the holders in a vertical position. The top of I should be higher than the lens, the top of O should be level with or just below the top of the lens. The object must be very well illuminated by a lamp close to it.

The image catcher I is put at 10 in (the average near-point of comfortable vision) from the lens. The eye is put close to the lens L and the object O is moved until its image seems to sit clearly on the catcher. To make this adjustment, the pupil keeps both eyes open, looking at the catcher with one (naked) eye and looking through the lens at the virtual image of the object with the other eye. He concentrates his attention on the naked eye, insisting on keeping the catcher in focus. Meanwhile he moves the object nearer and farther until the eye looking at the image sees that image also sharply in focus, 'sitting on the catcher'.

As an alternative method, which is neither so easy nor such good teaching of the meaning of images, some pupils will be helped by trying the 'method of no-parallax'. Keeping both eyes open (and concentrating attention on the naked eye) the pupil moves his head to and fro laterally, moving the object until image and catcher seem to stay together.

There is a poorer method, only to be recommended where a pupil has uneven eyes, or can use only one eye well. The pupil moves his head *up and down* rapidly, looking through the lens at the virtual image, then over the lens at the catcher, then through the lens at the image, and so on. During this rapid alternation of glimpses of image and catcher, the pupil moves the object until both image and catcher seem, successively, equally in focus.

Faster pupils should be encouraged to estimate the magnification. Others may be content with seeing that the image is back at the image-catcher and obviously considerably bigger.



20 *Class experiment*

Compound microscope

Apparatus

16 telescope mounts	– item 115
16 plano-convex lenses (+14D)	– item 113/1
16 plano-convex lenses (+20D)	– item 113/2
16 pieces of $\frac{1}{10}$-in graph paper	
16 wooden strips (tongue depressors)	– item 53F
16 retort stands and bosses	– items 503–505

Procedure

The lenses are set up in the same way as in experiment 12. The graph paper fixed to the holder makes a good object provided it is very well illuminated.

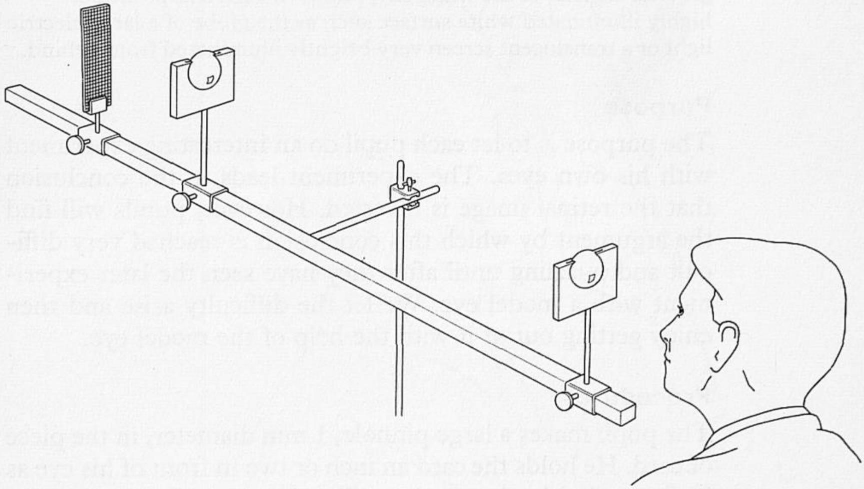
With the distance between the lenses about 25 cm, a magnification of about 13 is obtained.

If pupils find this model instrument too difficult to adjust, offer them a plano-convex 7-cm 'magnifying glass' as objective (the same as the eyepiece) and that will make the magnification smaller but the adjustment easier.

The observer usually tries to place his eye close to the eyepiece but in fact, as he moves his head farther back from the eyepiece, his field of view increases until it reaches a maximum. We should encourage pupils to find the eye position for the largest field of view. (When the eye is in the position for a maximum field of view, it is in fact at the 'exit pupil' or 'eye ring'. With 25 cm between the lenses, the exit pupil is about 10 cm beyond the eyepiece. If the distance between the lenses is increased to 40 cm the magnification is about 30 times (and the exit pupil is 12 cm beyond the eyepiece).

Faster pupils might estimate magnifications but this is tiring and far less important than learning to place the final virtual image suitably. If the graph paper is clearly marked at regular intervals, it is possible to compare the magnified image with the direct image as was done with the magnifying glass (see experiment 19). It is probably simplest to use the same piece of graph paper for object and 'image-catcher' and adjust the position of the paper to make the object and the virtual image coincide. (As the final image is likely to be formed beyond the observer's near-point, we do not find the true 'magnifying power'.)

With the large majority of pupils, we should be satisfied if they can obtain an image and see some magnification.



21a *Class experiment*

Retinal shadow in the pupil's own eyes

Apparatus

32 small pieces of thin card
32 pins

White sky seen through a window is suitable as essential background. Instead of the white sky, pupils can use a large area of highly illuminated white surface such as the globe of a large electric light or a translucent screen very brightly illuminated from behind.

Purpose

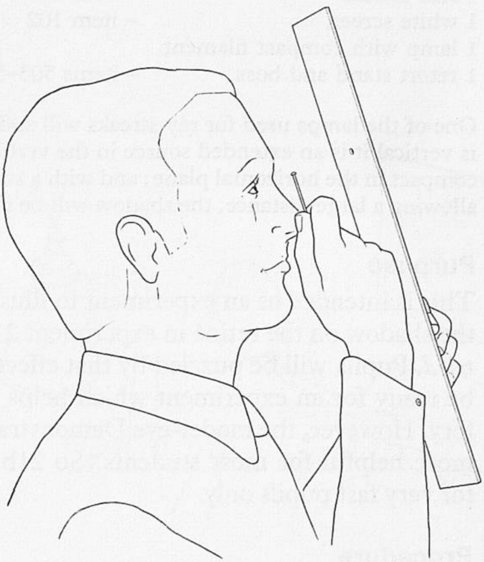
The purpose is to let each pupil do an interesting experiment with his own eyes. The experiment leads to the conclusion that the retinal image is inverted. However, pupils will find the argument by which this conclusion is reached very difficult and puzzling until after they have seen the later experiment with a model eye. We let the difficulty arise and then enjoy getting out of it with the help of the model eye.

Procedure

The pupil makes a large pinhole, 1 mm diameter, in the piece of card. He holds the card an inch or two in front of his eye as he faces a bright sky or a large illuminated surface such as the white shade of a large electric lamp. The pinhole makes a round, bright patch in the field of view. The pupil holds the point of the pin firmly between thumb and finger (so that the point cannot possibly prick his face), and he moves the head of the pin up until it is between the pinhole and his eye, very close to his eye, among his eyelashes. He sees a shadow of the pin's head in the bright patch. The shadow is upside down.

The reason why the shadow appears inverted is that with an object so close to the eye, refraction is unable to form an inverted image on the retina so that there is only a fuzzy upright shadow of the pin on the retina. (The actual image of the pin is nowhere near the retina – it is a virtual image far away in front of the eye.) The brain interprets this upright shadow as a case of the eye 'seeing' an object of that shape but the other way up. This inversion is the brain's natural interpretation of images on the retina, coming from one's learning in early childhood to associate retinal images with objects which can be touched. There is no question of some strange crossing-over of nerves, as pupils sometimes think. We have never known any better.

We do not explain this to pupils here but let them see the fact and proceed at once to the model eye, experiment 22.



21b *Optional extra experiment*

Illustration of retinal shadow using a glass lens

Apparatus

1 lens (+7D)	– item 112
1 lens holder	– item 124/1
1 white screen	– item 102
1 lamp with compact filament	
1 retort stand and boss	– items 503–505

One of the lamps used for ray streaks will suffice. Since its filament is vertical it is an extended source in the vertical plane but it is compact in the horizontal plane; and with a sufficiently weak lens, allowing a large distance, the shadow will be clear enough.

Purpose

This is intended as an experiment to illustrate the problem of the shadow on the retina in experiment 21a *after that has been tried*. Pupils will be puzzled by that effect and faster ones will be ready for an experiment which helps to unravel the mystery. However, the model-eye Demonstration 22b is clear and more helpful for most students. So 21b should be reserved for very fast pupils only.

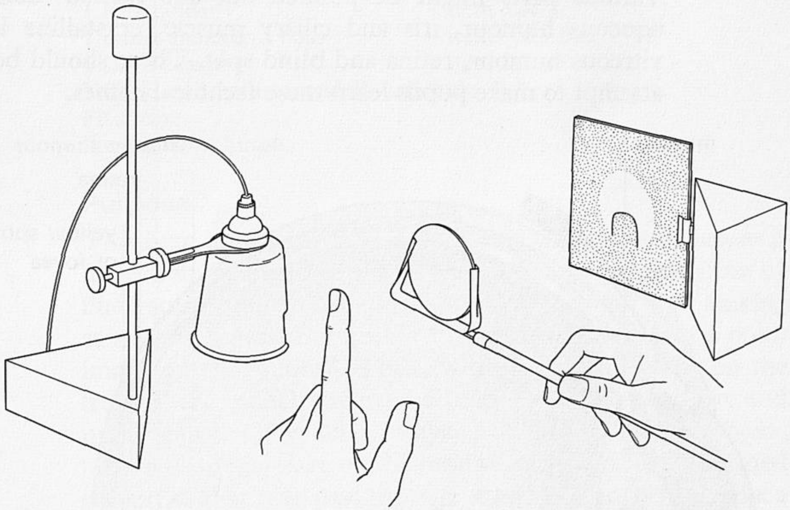
Procedure

The pupil places the lamp in front of the lens and the white screen behind the lens somewhere near the principal focus (anywhere between 0·8f and 1·5f).

With the lamp an equal distance *or less* in front of the lens, the lens does not form an image of the lamp filament on the screen but makes a round illuminated patch on it. (This patch is formed by rays going to or from an image of the filament at a much greater distance. The patch is round because the aperture of the lens is round.) 'The lens is not strong enough to make the rays from the filament converge to a sharp image as close as the screen.'

The pupil brings his own finger in – just in front of the lens, very close to it – to represent the pin's head in 21a. Then he sees a shadow of his finger in the patch of light on the screen, the same way up as the finger itself.

The pupil knows that if the finger and screen were object and retina for a model of an eye looking at something 'in focus', the image on the screen would be upside down. If he wishes, the pupil can try that: he moves the lamp farther away (several focal lengths from lens), places his finger close to the lamp, and moves the screen to catch the real image of the finger.

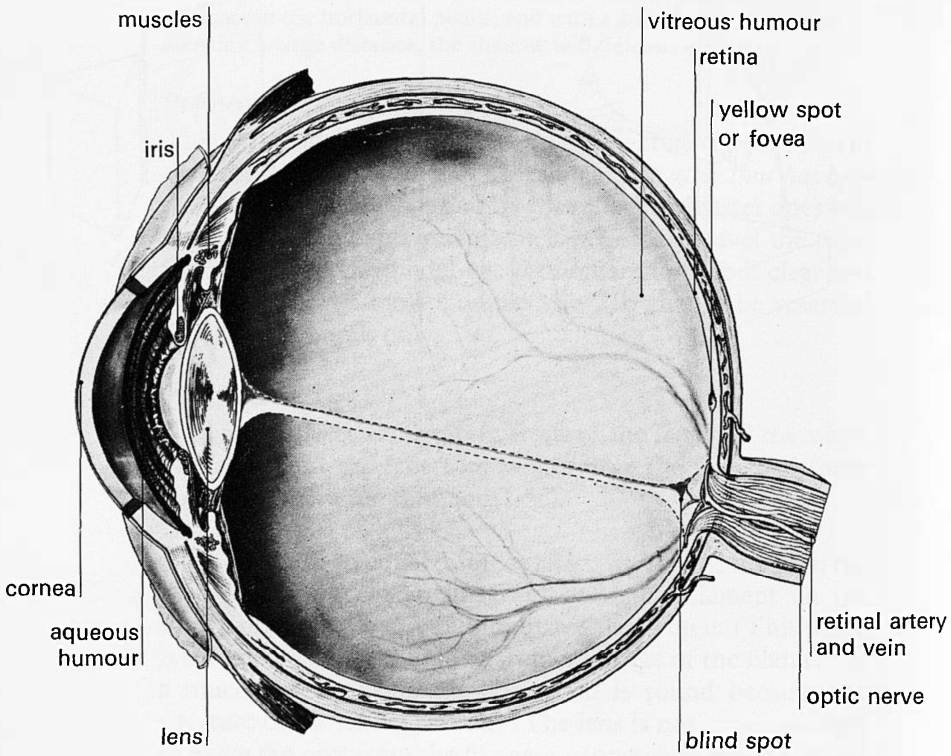


22a *Optional demonstration*

Dissectable model eye

If a school has a dissectable model eye, it could profitably be shown at this stage, though it is not essential.

Various parts might be pointed out and named: cornea, aqueous humour, iris and ciliary muscle, crystalline lens, vitreous humour, retina and blind spot. There should be no attempt to make pupils learn these technical names.



22b *Demonstration*

Model eye demonstration with flask

Apparatus

1 model eye kit – item 114
1 compact light source – item 21
1 L.T. variable voltage supply – item 59
1 lens holder – item 124/1
1 retort stand and boss – items 503–505
1 slotted base – item 30
1 thick card with central 48-mm hole
Plasticine
fluorescein solution

Purpose

This is an important demonstration in which pupils see, as if in section, the path of light in a model eye made visible by fluorescent liquid. The model shows a 'normal' eye looking at a small luminous object, with light converging to a point image on the 'retina'. Then, with a change of lens on the front of the model, the eye becomes a short-sighted eye and pupils can see how such an eye, looking at the same object, fails to form an image on the retina – the image being formed earlier, so that rays pass through it and spread out to make a patch on the retina instead. Then a suitable spectacle lens can be placed in front to correct this short-sighted eye and an image is formed on the retina at the back of the model.

Another change of lens on the front of the model makes a long-sighted eye and another spectacle lens corrects it.

Then we can show a short-sighted eye (or a long-sighted one) seeing clearly without spectacles, when we move the object to a different distance, suitable for that eye.

The choice of lenses

To make a model that shows all these things clearly and easily, the lenses that form the front of the model eye in each of the three cases – normal, short-sighted, long-sighted – must be carefully chosen to combine with a suitable object distance and the size of the flask of water that represents the eyeball, to form an image exactly at the back of the flask. And then the two spectacle lenses for corrections must be chosen to fit those other choices. The lenses suggested have powers calculated to fit a *5-litre-bottomed flask*, whose diameter will be about 21·8 cm.

The flask filled with water would not be a strong enough 'eye' all by itself. For a 'normal' eye viewing an object in front of the flask, a glass lens of power +8D must be fixed to the front of the flask with Plasticine. (The lens should be a meniscus lens, if possible.) A lens of +5·5D is needed, instead of the +8D, for the long-sighted eye model. A lens of +11D for the short-sighted model.

To facilitate the change from one model to another, the three lenses should be attached side by side along the horizontal equator of the flask. Then, twisting the flask by its vertical neck will bring one lens after another into play.

The spectacle lens for correcting the short-sighted eye is one with power —3D, the lens for the long-sighted eye +2·5D.

Procedure

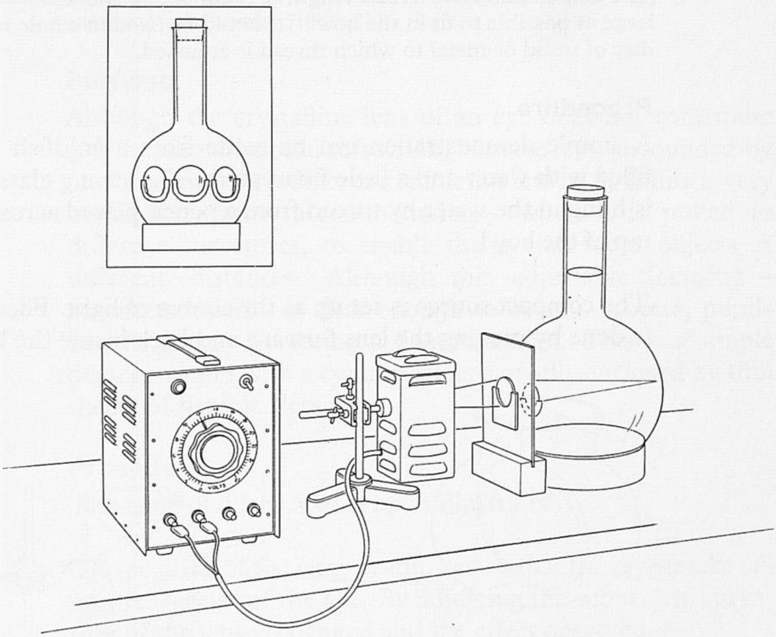
The lenses should be fixed to the flask before the lesson. The flask should be filled with very dilute fluorescein solution and placed on a cork ring as stand. The dilution of the fluorescein must be such that the whole path of the rays in the flask is clearly visible.

Set up the compact light source as the object to be viewed. Erect the card with the hole in it, vertically in front of the flask so that the hole is level with the lenses and serves as an iris. Rotate the flask until the +8D lens is behind the hole and arrange the light source to lie level with the hole and the centre of the flask. Move the light source until a sharp image of it is formed on the surface of the flask. (Some teachers may prefer to put a small piece of wet paper on the back surface of the flask to make the image on that 'retina' easily visible.)

Keeping the light source fixed, rotate the flask bringing first one, then the other of the two extra lenses behind the hole to show long sight and short sight. Show how the —3D lens corrects the short-sighted eye, the +2·5D lens the long-sighted eye.

Then dispense with the correcting lenses and show what the short-sighted eye and the long-sighted eye can see in focus. (It is better to defer this part of the demonstration to this stage. Otherwise, moving the light source is apt to confuse pupils when the correcting spectacle lenses are tried.)

Turn the flask to make a short-sighted eye and move the light source until its image is formed on the back of the flask. Point out that the light source has to be much closer to the eye: it is a 'short-sighted' eye. Similarly show the 'long-sighted' eye.



22c *Optional additional experiment*

Model eye with a goldfish bowl

Apparatus

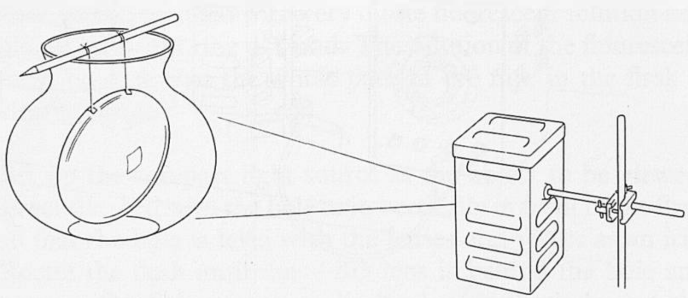
1 goldfish bowl	
1 convex lens	– see below
1 compact light source	– item 21
1 retort stand and boss	– items 503–505
fluorescein	

The lens should have a focal length of 5 cm or less and should be as large as possible to fit in the bowl. It should be fixed in a hole in a disc of wood or metal to which thread is attached.

Procedure

A simple demonstration can be made from a goldfish bowl filled with water and a little fluorescein. The strong glass lens is hung in the water by thread from a pencil placed across the top of the bowl.

The compact source is set up as the source of light. Focusing is done by moving the lens forward and back inside the bowl.



23 *Demonstration*

Variable focus eye

Apparatus

1 Skelton variable focus eye	– item 125
1 lamp, holder and stand	– item 94A
1 transformer	– item 27

The lamp, holder and stand recommended above is the standard ray-streak illuminant. As the experiment is a demonstration one, some teachers may prefer to use the tungsten-iodine lamp (the compact light source, item 21).

Purpose

Although the crystalline lens of an eye does not contribute very much to the total refraction, because it is surrounded by media of not-very-different refractive index, it fulfils a very useful function – accommodation – when it is pulled to different curvatures, to enable the eye to focus objects at different distances. Although this adjustable focusing – accommodation – is clear enough to us as a process, pupils benefit greatly by seeing a demonstration. This is a simple demonstration with a cylindrical lens of jelly enclosed by thin sheets of flexible Perspex.

Procedure

The lamp and lens are set up as illustrated.

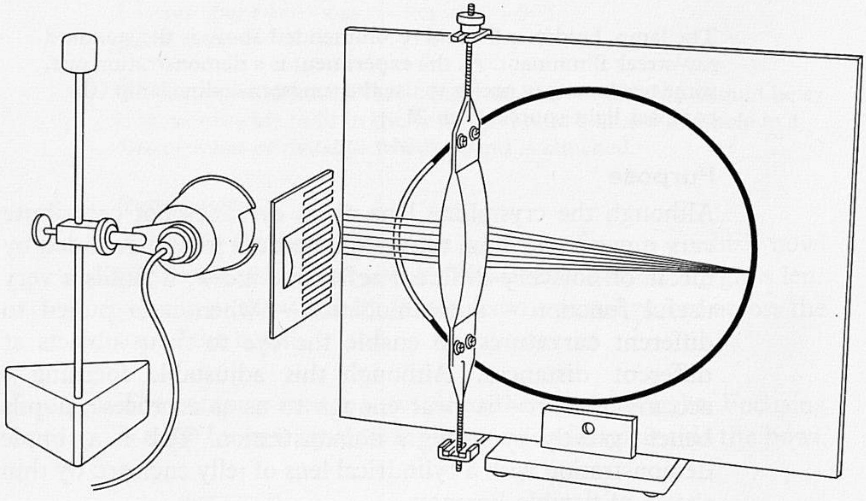
The position of the lamp is adjusted so that the ray streaks fall on the 'retina' of the eye. By adjusting the screw, the curvature of the lens is changed and the effect observed.

Then put the lamp as close as possible to the Skelton eye so that an image is formed on the retina with the lens as fat as possible. Move the lamp farther away and show how the curvature has to be decreased to bring the streaks to a focus on the 'retina'.

Notes

1. Some teachers will prefer to make the apparatus themselves. Details for this are given in one of the apparatus drawing sheets.

2. Once the apparatus has been made, the jelly can be renewed quite easily whenever a demonstration is needed. It is made by warming together the following ingredients (heating in a hot water bath, but never boiling): glycerine (13 parts by volume), water (10 parts by volume), good quality gelatine (3 parts by volume), good quality cane sugar (2 parts by volume).



24 *Demonstration*

Dissecting a bull's eye

Apparatus

3 bull's eyes
1 single-edged razor blade – item 3H
1 petri dish or crystallizing dish – item 528

Cattle eyes can usually be obtained from a butcher or a slaughter house. The eyes should be dissected within a day or two of slaughter, otherwise there will be a confusing cloudiness.

Three bull's eyes are usually necessary for one class and more for each subsequent class. (The teacher needs to practise on one and often needs to dissect two in the class.) Razor blades (single-edged) are easier than a scalpel for the main cutting. Some amateurs prefer to use nail scissors.

Procedure

Unless the teacher is familiar with dissection, he will probably find the following method easiest, though not the neatest:

Using a razor blade (or a *very* sharp scalpel), make a small cut in the white hard part of the eyeball, just behind the iris and clear cornea. Continue, making a circular cut round the eye, with razor blade or scissors. This will remove the clear front window or cornea.

At some stage, according to the exact placing of the cut, the liquid aqueous humour will run out. Or the teacher may puncture the clear cornea first of all to release the aqueous humour.

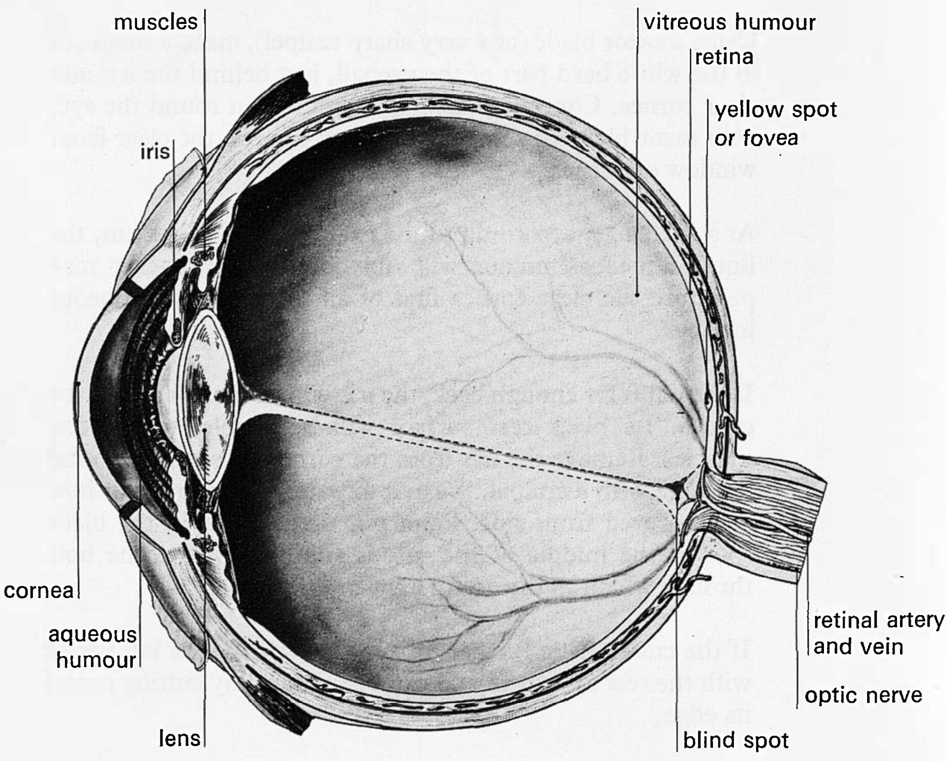
If the cut is far enough back, the iris will be removed with the cornea. Its black rear surface will be visible, with radial muscles. Remove the iris from the cornea by scraping round the edge with a scalpel. Wash it in water, turn it over to show the coloured front side. Point out that the pupil, the black spot in the middle of the iris, is simply a hole – the hole through which all the useful light enters the eye.

If the cut is made further forward the iris will be left inside with the rest of the eye and can be removed by cutting round its edge.

Behind the iris, the small strong 'crystalline' lens rests in a bed of jelly, the 'vitreous humour'. Pick the crystalline lens out with a pin or forceps, or push it out from the very thin sac which retains it.

Then remove the vitreous humour which fills the rest of the eyeball and show the retina with its surface layer of fine blood vessels.

The crystalline lens may be put at the bottom of a flat-bottomed dish or it can be held on a pin. It can be used to show the focusing of a ceiling light on a piece of paper held below it. In the living eye, the crystalline lens is immersed in materials (aqueous and vitreous humours) of not-very-different refractive index, so its contribution to the lens system's refraction is not very great – though it is very important because it is variable. Most of the refraction occurs at the open-air face of the cornea. Therefore, a more realistic demonstration of the dissected-out crystalline lens is to cover it with water and then focus the ceiling light with it.



25 *Optional class experiment*

The longitudinal lens formula

Apparatus

Each pair of pupils that do this experiment will require:

1 telescope mount	– item 115
2 retort stands and bosses	– items 503–504
1 lamp and holder	– item 94A
1 transformer	– item 27
1 metre rule	– item 501
white card for screen	
reciprocal tables	

Purpose

This experiment is suggested with a special aim: to provide an amusing game that will give pupils practice in locating virtual images – the essence of so many optical instruments. Our aim is *not* to encourage a long series of tedious, accurate measurements of object- and image-distances. Our aim is *not* to bring out the longitudinal formula and make it important in our teaching.

Our aim is only to supply the formula ready-made, ask pupils to see whether a few quick measurements with real images fit the formula; and then ask pupils to make some much more difficult measurements with virtual images and see whether those also fit the same formula for the same lens. Able pupils, presented with the problem in that form, may enjoy the challenge of the virtual-image measurements. They will find the necessary change of sign amusing. And they will gain practice in locating virtual images. We should tell them clearly that that practice is the object of the experiment.

We suggest that this should be tried only with a very able group. Other groups are likely to give too much importance to the formula and the arithmetical manipulation, and thus lose more than they gain.

If this experiment is tried, the teacher should make it quite clear that problems involving this formula will *not* be set; nor will geometrical constructions that imply this formula be used. It is only an empirical game to see whether a particular relation can be extended to other cases; and a game which gives useful optical practice.

Procedure

The teacher should start by telling pupils that object distance, u, and image distance, v, are known to be related, for a simple lens, as follows:

$1/u + 1/v$ *has the same value* for all object distances.

Then tell pupils that this constant, $1/u + 1/v$, is a property of lenses. We tell them that this can be predicted by geometry from a knowledge of the way in which rays of light are bent at each surface of a lens. Or, it can be predicted from the way in which a whole lens always bends a fan of rays to pass through an image point. Or, it could be extracted from a large number of experimental measurements. (We might add that it can be predicted by working out geometrically what a lens will do to waves of light.)

We tell pupils that we are not going to ask them to remember the formula or prove it geometrically or verify it experimentally in great detail. We just want them to see whether it does seem to be true for their lens. So, the instructions are as follows:

'Set up the lamp and screen on the axis of the lens; and move them to obtain a clear image of the lamp filament on the screen. Measure v and u. Calculate the value of $1/u + 1/v$. Repeat for several different values of u.'

In all this, the measurements should be quick and rough. Corrections for the thickness of the lens should be omitted. (Pupils should not even repeat the same measurement several times unless they themselves wish to.) The use of a proper optical bench with distance rods and an engraved scale should certainly be avoided: instead measurements should be simple and direct.

'Now move the lamp much closer to the lens so that a real image cannot be formed. Look at the virtual image of the lamp through the lens. Place a retort stand behind the lamp and move it till the virtual image of the lamp is caught on it.

Again measure u and v (negative value) and try them in the same formula. Repeat for one or two different lamp positions.'

We want pupils to calculate the value of $1/u + 1/v$ quickly so that they can see whether their experiment 'works'. Therefore, we should provide reciprocal tables for easy use. If possible, these should be three-figure tables without any columns for differences. Then reciprocals of two-figure or three-figure measurements can be read off easily. (Pupils who find reciprocal tables difficult to use will probably find the whole idea of this experiment confusing; and in that case it would be better not to do it.)

Experimental notes

1. The screen can be made by cutting white cardboard and fixing it in a lens holder on the telescope mount.

2. The lamp run at 12 volts is too bright for viewing directly when looking at virtual images. Operated at 6 volts instead of 12, it works well. Alternatively some teachers may prefer to use pea-lamps. Above all, no special kind of optical bench lamp is required here.

26 *Class experiment*
Law of reflection

Apparatus

16 lamps, holders and stands	– item 94A
16 single slits	– item 94C
16 plane mirrors	– item 116
16 holders for mirrors	– item 117
8 transformers	– item 27
16 protractors	– item 550
white paper	

The protractors should preferably be the 360° paper type.

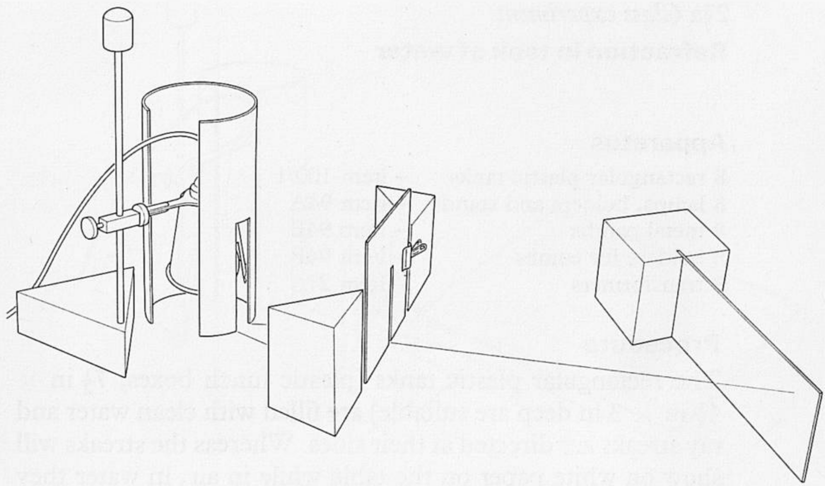
Note

Pupils must see rays of light being reflected at a plane mirror and extract some kind of rule about 'equal angles', though that need not be a formal law of reflection. If that can be done quickly as a class experiment with ray streaks, best of all. Second best: the teacher should demonstrate reflection with some device, such as a 'Hartl disc', which has a protractor and a scheme for showing the behaviour of a single ray. However, this should not turn into a demonstration with a special 'ray box' on a vertical white screen, because it will seem to pupils a quick repetition of their own ray-streak experiments, 'to put things right at last'. Then there would be serious danger of a ray box experiment spoiling the earlier class experiments in retrospect and, in the course of years, even threatening to replace them.

Procedure

Pupils set up the apparatus to produce ray streaks on the paper, and, with the mirror standing on the paper protractor, they will quickly see the 'equal angles'.

See diagram opposite.



27a *Class experiment*

Refraction in tank of water

Apparatus

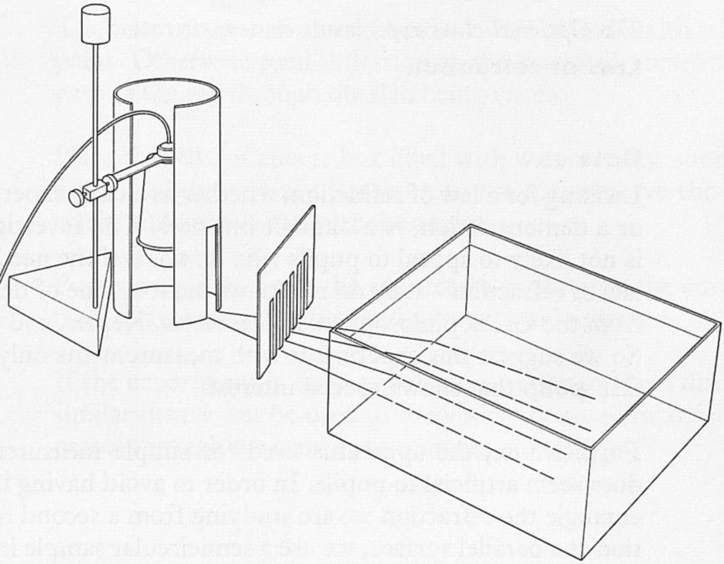
8 rectangular plastic tanks	– item 100/1
8 lamps, holders and stands	– item 94A
8 metal combs	– item 94E
8 holders for combs	– item 94F
8 transformers	– item 27

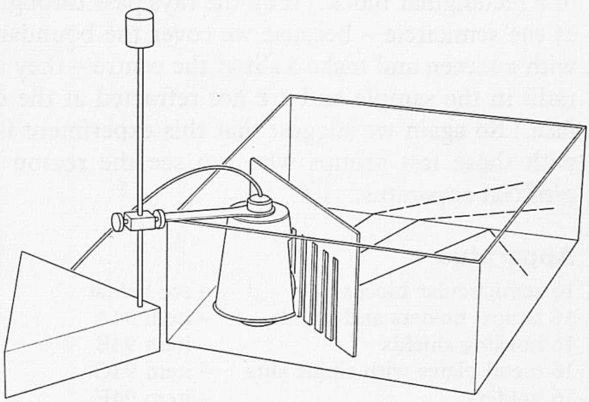
Procedure

The rectangular plastic tanks (plastic lunch boxes, $7\frac{1}{2}$ in $\times$ $4\frac{1}{2}$ in $\times$ 3 in deep are suitable) are filled with clean water and ray streaks are directed at their sides. Whereas the streaks will show on white paper on the table while in air, in water they will not show unless the *inside* surface of the base of the box is painted with flat white paint.

With the lamp outside, sending rays towards the box, pupils see how those rays are bent when they strike the water surface at various angles. (They should not make measurements of those angles.)

Then the lamp is carefully placed inside the tank, under water. With the comb nearby, it will send out ray streaks through the water. Pupils will see what happens when those streaks meet the water-air surface. They will certainly see refraction as they emerge into air and we hope they will also see total internal reflection.





27b *Optional class experiment or demonstration*

Law of refraction

Note

Looking for a law of refraction, whether as a class experiment or a demonstration, is a difficult business. The investigation is not likely to appeal to pupils who do not feel the need for a law of refraction – they do not know the long line of demand from the Greek philosophers to Descartes, Kepler, and Snell. So we suggest this experiment with measurements only for a fast group that shows special interest.

Furthermore, the apparatus used for simple measurements does seem artificial to pupils. In order to avoid having to disentangle the refraction we are studying from a second refraction at a parallel surface, we use a semicircular sample instead of a rectangular block. (If all the rays pass through the centre of the semicircle – because we cover the boundary-diameter with a screen and make a slit at the centre – they travel along radii in the sample and are not refracted at the curved surface.) So again we suggest that this experiment is only done with those fast groups who can see the reason behind the artificial apparatus.

Apparatus

16 semicircular blocks	– see below
16 lamps, holders and stands	– item 94A
16 housing shields	– item 94B
16 metal plates with single slits	– item 94C
16 holders	– item 94F
8 transformers	– item 27
8 scissors	– item 529
white paper	
card and suitable adhesive	

Semicircular blocks of glass and of plastic have long been available in schools. If semicircular boxes of thin transparent plastic are available (such as are sometimes used for small cheeses), these can be filled with water and used for this experiment.

Procedure

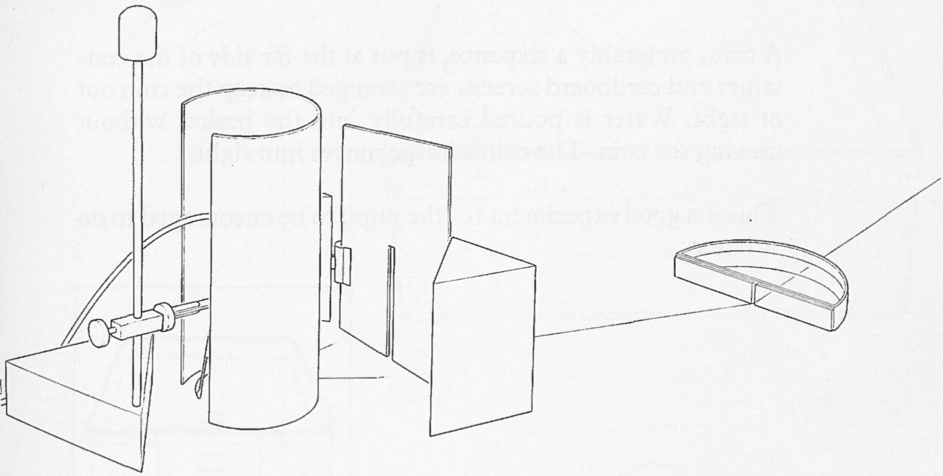
Stick card to the flat face of the semicircular slab (or plastic box) so that only a vertical slit is exposed at the middle of the flat face.

The base of the slab should be frosted or painted with white paint. Otherwise total reflection at the base will prevent the path of the ray through the slab being visible.

Place the slab (or cheese box filled with water) on the sheet of paper and direct a ray streak on to the slit; observe the ray tracks and quickly measure the angles.

Pupils may also direct the ray streaks in through the curved face, to observe refraction and total internal reflection.

If the experiment is done as a demonstration, a Hartl disc or similar device can be used to show a ray being refracted as it passes through the centre of a semicircular slab.



Further refraction experiments

Note

These experiments are listed here as possible demonstration experiments. They might be done as quick demonstrations by the teacher, but the pupils should be strongly encouraged to do them for themselves at home.

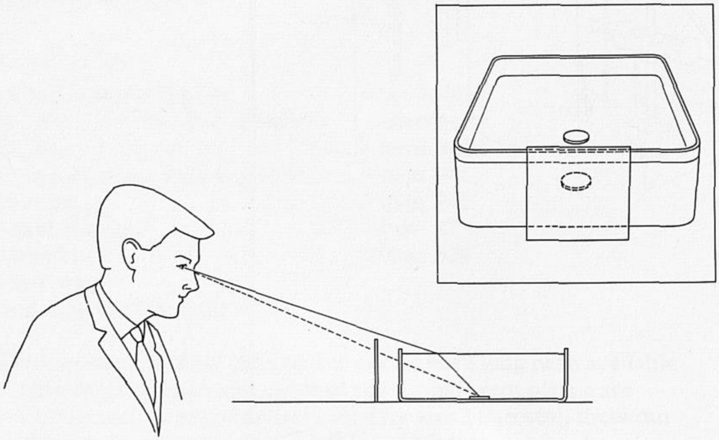
Procedure

a. *Coin in a beaker*

A wide low container of glass, such as a 400 cm^3 beaker or a jam-jar, is suitable for this experiment; a narrow cylinder, such as a test-tube, is not.

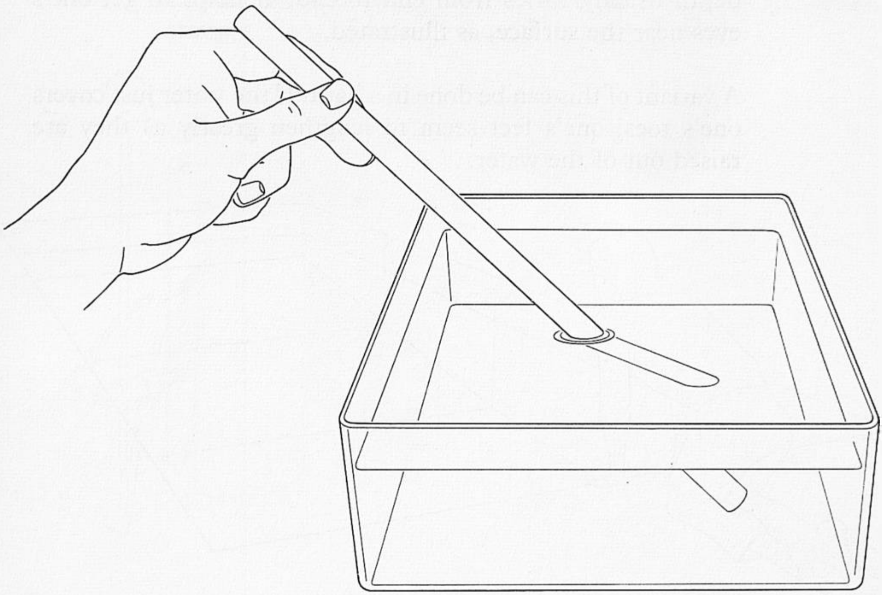
A coin, preferably a sixpence, is put at the far side of the container and cardboard screens are arranged to keep the coin out of sight. Water is poured carefully into the beaker without moving the coin. The coin's image moves into sight.

This is a good experiment for the pupil to be encouraged to do at home.



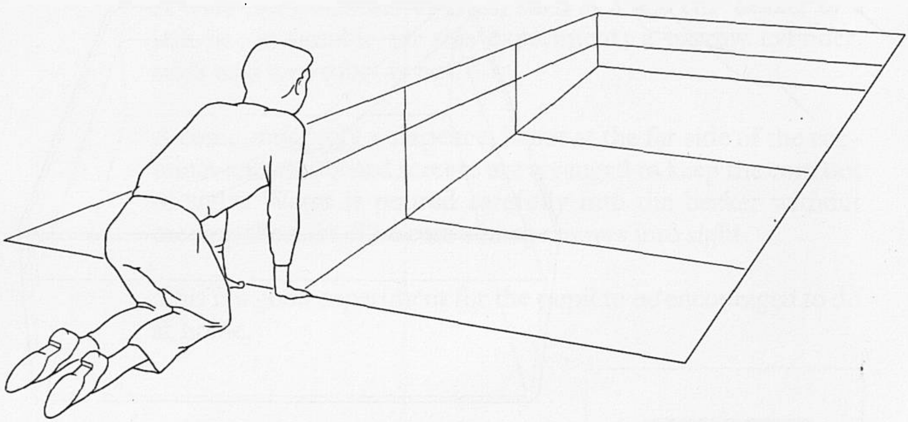
b. *The bent stick*
A straight stick or pencil is put into a tank of water or sink at an angle of about 45° and looked at from one side, and then from above.

This can be tried by the pupils at home.



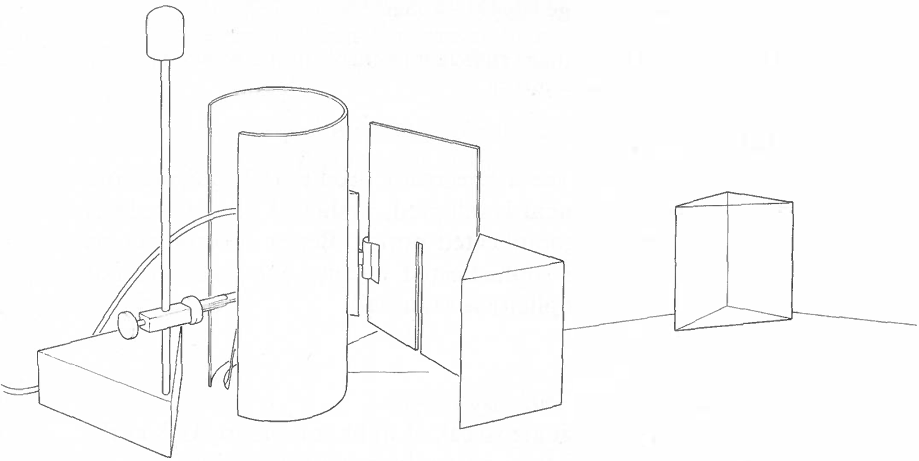
c. *Apparent depth of a pond*
A large sink or swimming bath appears shallower than it really is when filled with water. Besides this, the farther parts of the bottom appear to curve up towards the observer. One can check that this is an illusion by looking from the other side. It is best to look across the swimming bath, as the actual depth usually varies from end to end. It helps to get one's eyes near the surface, as illustrated.

A variant of this can be done in a bath. If the water just covers one's toes, one's feet seem to lengthen greatly as they are raised out of the water.



d. *Ray streaks passing through a prism*
The lamp and single slit are set up on the sheet of white paper as in the ray streak experiments. The 60° prism is placed in the streak and refraction is seen. The effect of rotating the prism may be looked at.

Pupils can look along the ray and they will see it appear straight.



29 Class experiments and demonstrations

The spectrum

Apparatus

1 ray optics kit	– item 94
8 transformers	– item 27
16 60° prisms	– item 111
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59

The ray optics kit contains sufficient to enable pupils to work in pairs in the class experiments.

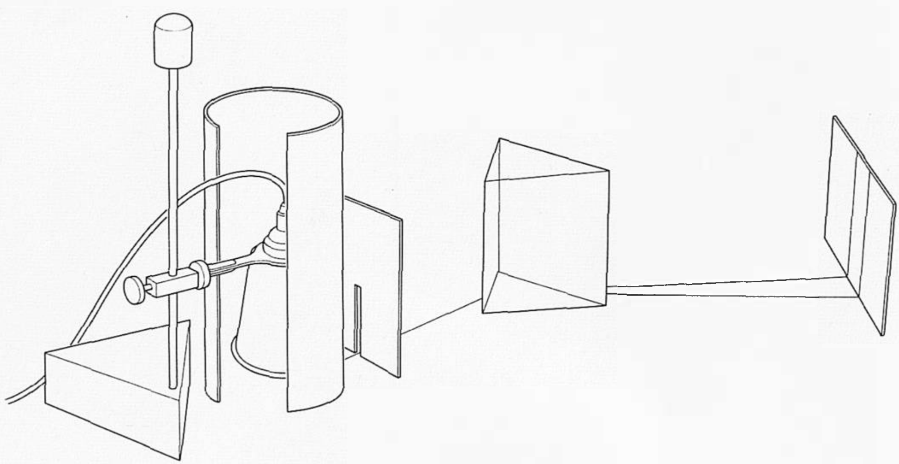
Note

All pupils should see a spectrum produced by dispersion. Whatever arrangement is adopted, it should be as simple as possible, without complicated optics. Better spectra can be produced by more sophisticated means, but these are not advocated here: simplicity is essential.

Procedure

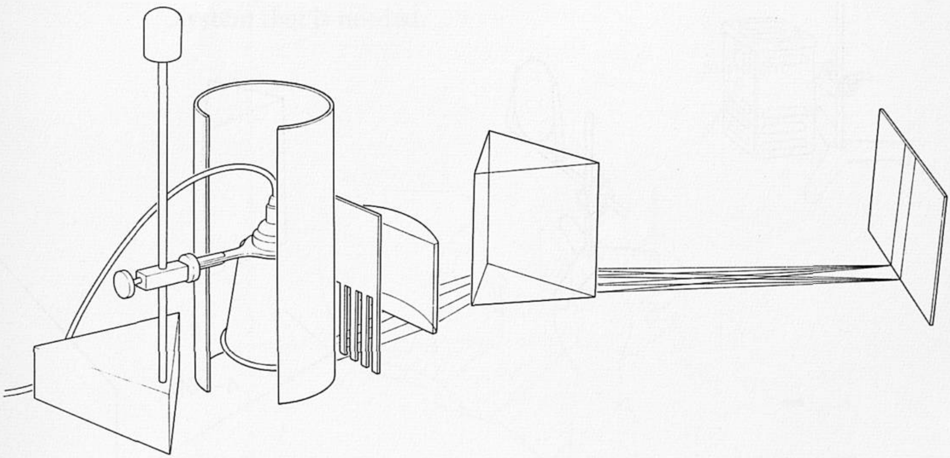
a. *Simple spectrum with ray streaks*

1. Pupils direct a single streak of light at a prism, look at the emerging ray carefully, and try twisting the prism.



2. Pupils direct a fan of rays (from lamp and comb) at a +7D or a +10D cylindrical lens so that the emerging rays pass through an image-point 15 to 20 in away. Then pupils interpose the prism just beyond the lens and look at the effect. A small piece of paper or card held upright to catch the rays above the table will show the spectrum clearly. The spectrum will be nearest to pure if the screen is held at the same optical distance from the lens as the image was before the prism was inserted and the prism is turned to minimum deviation. However, turning the prism to a greater deviation will show a wider spectrum.

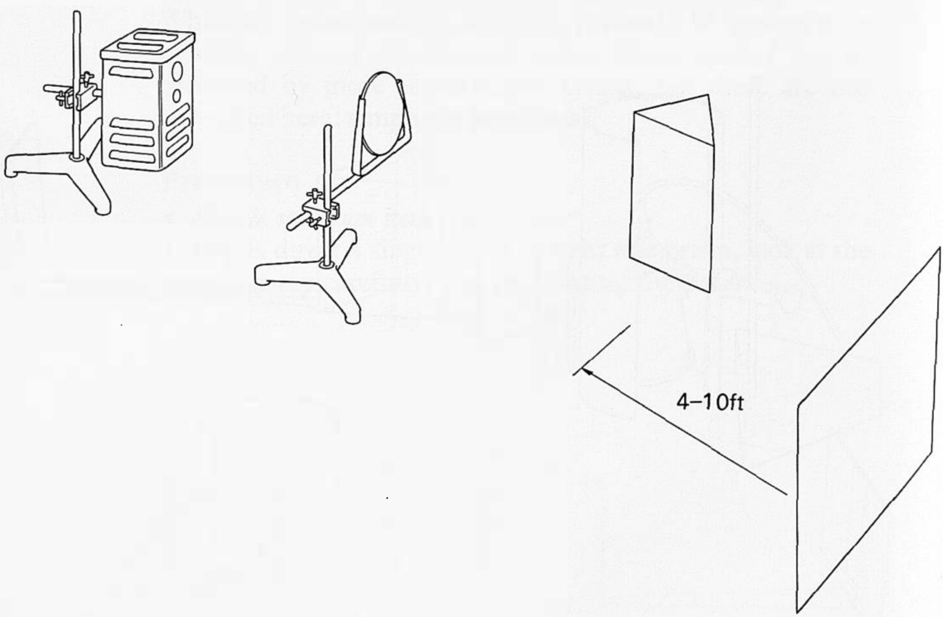
3. If small pieces of colour filter are available, pupils may try placing them in the path of the light.



b. *Demonstration spectrum*
Light from a strong compact source (tungsten–iodine lamp or equivalent) is directed to a lens which forms a large real image of the source on a distant screen, four to ten feet away.

A large, high-dispersion prism is then placed just beyond the lens so that it swings the image of the source round to a new position at approximately the same distance and we see a spectrum there.

Note that no slit is needed if the source is compact or if it is a line filament, parallel to the prism's edge, and this avoids optical complications. The compact light source (item 21), with tungsten-iodine lamp, is ideal for this.

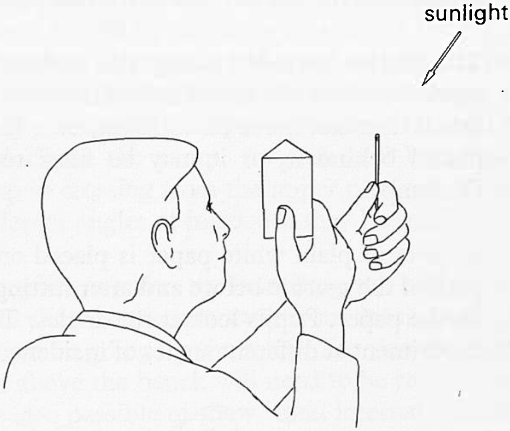


c. *Attempt with second prism*
After showing demonstration (b) the teacher should cut a small hole in the screen receiving the spectrum and place another lens and prism to receive the coloured light that goes through that hole.

The lens forms an image of that hole on another more distant screen, and when the prism is interposed pupils look to see whether the new spectrum shows a new set of colours or not.

d. *Optional class experiment: sunlight spectrum with sewing needle as 'slit'*

Each pupil is given a bright sewing needle and a prism. He holds the needle at arm's length in one hand and the prism in the other hand, close to his eye. He twists the prism until he can see the needle by refraction through the prism. The needle should be brightly illuminated. The needle, which would appear as a bright line but for dispersion, appears drawn out into a bright, white light spectrum. The higher the dispersive power of the prism material, the better, but it will usually only be possible to let pupils have ordinary prisms. Even so, they will see a good spectrum and may even see a hint of absorption lines. In this, the needle forms a bright, narrow line image of the sun, which serves as slit; and the eye, viewing the needle from some distance, provides the only lens system that is needed.



30. *Class experiment*

Particle model of reflection

Apparatus

8 glass blocks
8 marbles
white paper

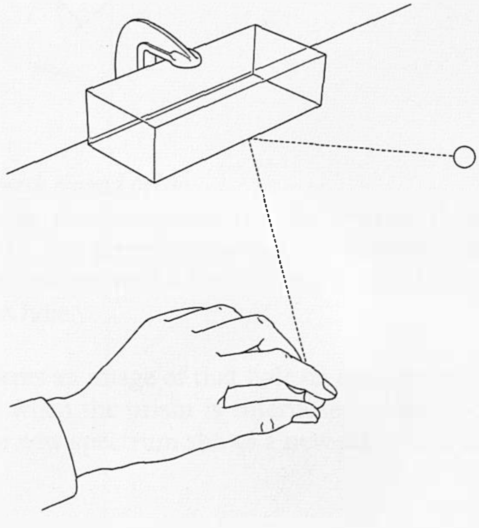
No particular glass blocks are recommended as schools will already have quantities of these: they will doubtless improvise with what they have.

Procedure

This has already been demonstrated with a rubber ball bouncing at various angles. In this experiment the pupils can see the angle relation more carefully because they conduct the experiment themselves in a horizontal plane.

The marble is rolled along the table to bounce against a vertical surface of a glass block. The block must be so massive that it does not move on collision, or a large weight must be placed behind it, or it may be fixed to the bench with a G-clamp.

A sheet of plain white paper is placed on the table, and the path of the marble before and after hitting the wall is marked on the paper. Pupils look at the angles. They may repeat the experiment at different angles of incidence.



31 *Class experiment*

Particle model of refraction

Apparatus

1 kit for particle model of refraction – item 96
supply of white paper
supply of carbon paper

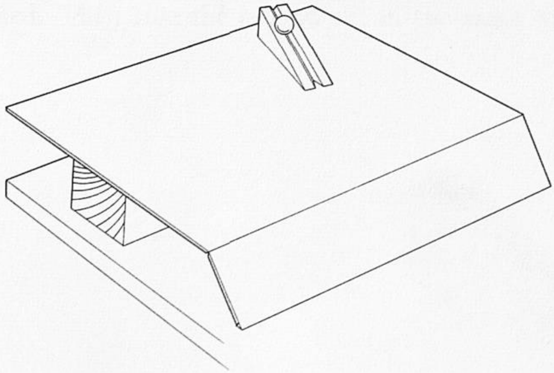
Caribonum handwriting carbon paper (HN 22S) is very suitable for this experiment.

The kit for particle model of refraction (item 96) contains 8 hinged platforms, 8 launching ramps and 8 steel ball bearings. It is sufficient to enable pupils to work in groups of four in this experiment.

Procedure

The two pieces of hardboard have a hinge underneath. The larger piece should be raised on a block (or books) as shown. Carbon paper is placed over a sheet of white paper both on the upper platform and on the bench-top. The edges should be accurately parallel to the edge of the slope. The ball bearing is launched down the ramp. Its path will be refracted as it speeds up in crossing from the upper platform to the bench-top. Different angles of incidence may be tried.

Faster pupils may also try launching the ball on the bottom surface to show 'refraction away from the normal' as the ball slows down on going up the ramp. For this the height of the platform above the bench will need to be reduced to about $\frac{1}{2}$ cm. It is also possible to show 'total internal reflection'. The carbon paper and white paper may be omitted for these experiments done without any measurements.



32 Optional class experiment

Marching model of refraction

Apparatus

Hard road with straight boundary adjoining soft grass*
Squad of boys
Discipline

* Alternatively, areas of asphalt marked with chalk can be used.

Procedure

This is one of those experiments which teachers will read about, smile, and almost certainly not do. This is unfortunate, for those who try it will find the reward great and it will make a lasting impression on the pupils.

The squad should be aligned in fours or sixes, and must first learn to march in step with a uniform pace. They should then be taught to march on the grass with the same frequency, but shorter 'wavelengths' by taking steps half the length.

Then they march on the road meeting the boundary obliquely and refraction will occur. The experiment should be tried again marching from the grass to the road and refraction will occur the opposite way.

Finally, total internal reflection can be tried and, provided the fours try to keep in line, this too can be effective. (It may be better to have each line of four link elbows loosely.)

33a *Demonstration*

Single slit and double slit demonstration

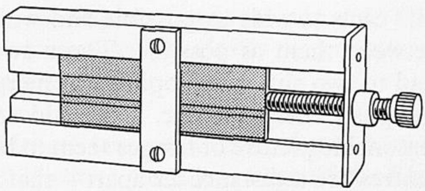
Apparatus

1 compact light source – item 21
1 double slits kit – item 97
1 screen of greaseproof paper
1 L.T. variable voltage supply – item 59

Note

This is intended to be a simple, clear, quick demonstration of Young's fringes as a preliminary to a class experiment. Therefore, the fringes should be clearly and easily visible, or else the demonstration should not be given.

Ruling the slits



The slits are made by coating one side of a microscope slide with Aquadag. The slide is inserted in the holder and a slit ruled on the Aquadag with a blunt needle or pin held up against the brass cross-piece. The edge of a small screwdriver can be used. Even a fine ball-pointed pen works well in practised hands.

To rule a double slit, displace the slide slightly by turning the screw on the end of the simple holder after the single slit has been ruled. Then rule the second slit in the same way as before.

The separation of the double slits

The amount of light reaching the fringe pattern is determined by the width of each slit of the pair. The wider each slit is, the more light. But the width of the region over which the fringe pattern is spread (by diffraction from each slit) varies inversely with the width of the individual slits. Therefore, wide individual slits give more light concentrated into a narrower region, making the fringes much brighter. On the other hand, the narrower the patch formed by diffraction, the fewer fringes there are visible – pupils need to see several dark and bright fringes to be convinced.

The closer the two slits are together, the greater the spacing from fringe to fringe, and the easier the fringes are for pupils to see.

Therefore, we should aim at using a double slit with the two slits each as wide as possible and with as small a separation between them as possible. Those two conditions obviously lead to two slits overlapping and merging into a single slit if we push them too far. The widest slits allowable for a reasonable picture of fringes seem to be slits of width x whose centres are a distance $2x$ apart – that is, two slits of width x with an opaque region of width x between them. That arrangement will give three bright fringes with two dark fringes between them, and little illumination in regions beyond that.

If the slits are too far apart or too wide, the central maxima of the diffraction patterns may not overlap and no fringes will be seen.

The light source

The simplest demonstration of Young's fringes requires a lamp with a line filament. The 100-watt tungsten-iodine lamp in the compact light source (item 21) is very good for this. A carbon arc is suitable but less convenient.

The tungsten–iodine lamp must be shielded so that no stray light reaches the screen: such a housing is provided. It is also very important to avoid stray illumination by light that has passed through the slits and is reflected by the surface of the bench.

The screen

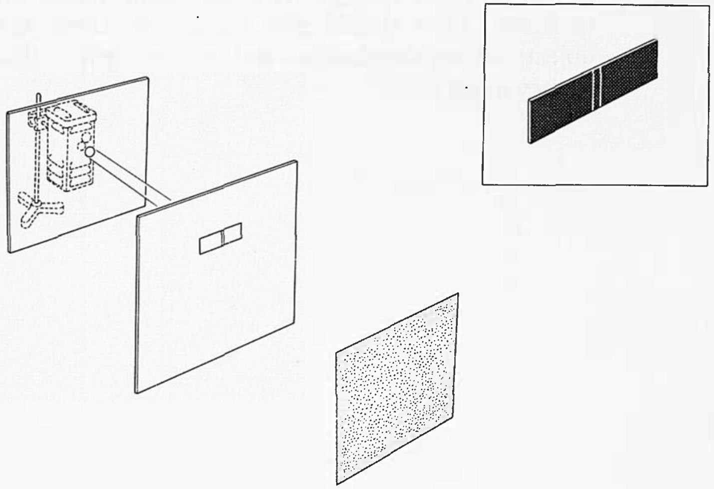
Even with the best of slits and a very bright lamp, the fringe pattern is not so bright that pupils looking at an unfamiliar picture can see it easily. Therefore, although the teacher can see the pattern clearly on a white wall or screen, he should arrange a translucent screen for pupils to view the pattern. Viewing the pattern on that screen from behind makes it far easier to see.

The screen may be of greaseproof paper, or frosted plastic. (The architect's tracing cloth advocated for the translucent screens – item 46/1 – in some demonstrations is not suitable here because it scatters over a wide angle, admirable for silhouetting demonstrations but unsuitable here where we need a small range of scattering.)

Procedure

The lamp should be placed between one and two metres from the slits. The fringes will be clearly seen on the screen placed one to five metres away.

A long focal length lens can be introduced between the lamp and the double slit to form an image of the filament on the screen; but this is not necessary, as fringes can be clearly seen using the above arrangement which has the great advantage of simplicity.



33b *Demonstration*

Diffraction shadows

This demonstration should probably be confined only to fast groups.

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 screen of greaseproof paper	

Procedure

The compact light source is used to cast shadows of various objects: the intense tungsten-iodine lamp is sufficiently compact to make a very suitable source.

The objects – a sewing needle, a pin, a razor blade, a human hair, a screen with small holes drilled in it, a collection of steel balls stuck with wax on a piece of glass plate – are held up about 2 metres from the lamp. The human hair usually proves particularly interesting to the pupils. The pupils catch the shadow on a screen as far away as possible (at least five metres). The screen may be a sheet of white paper to be looked at from the front, or a sheet of kitchen greaseproof paper or other translucent material to be looked at from behind.

Pupils will see strange dark and light bands around the shadows. They should also move the screen towards the objects casting the shadows and see these effects disappearing as they move closer.

34 *Class experiment*

Young's slits with a ripple tank

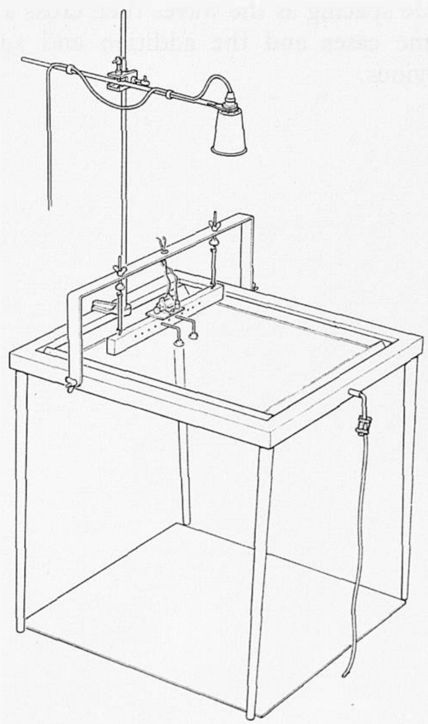
Apparatus

8 ripple tanks	– item 90
8 motors mounted on beams	– item 90L
16 dippers	– item 90G
32 hand stroboscopes	– item 105/1
8 illuminants	– item 47

Procedure

This is a return to experiments 4o and 4p with interference in a ripple tank, which may have been done already. Even so, it is important to repeat them at this stage.

With the ripple tank it might be possible for very able pupils to see that $x = D/d$ is a reasonable formula for the spacing of the fringes though it is not possible to test that accurately. It should not be attempted here or it will spoil our chances of giving clear simple knowledge of interference.



35a *Demonstration*

Interference with plastic wave model

Apparatus

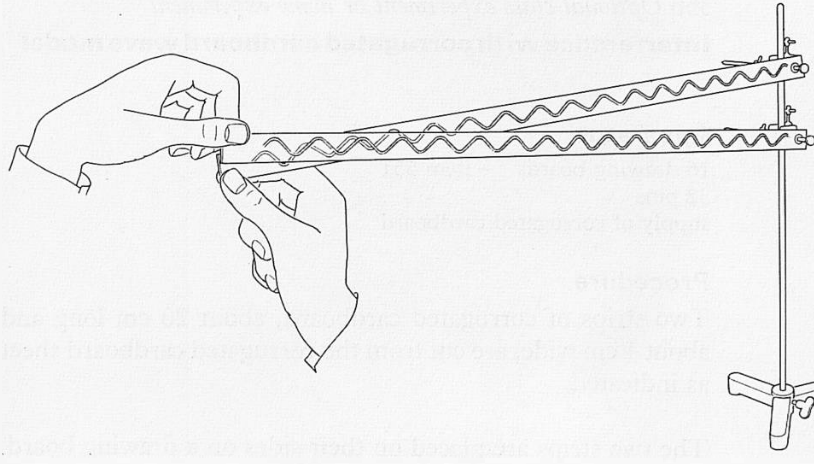
2 plastic waves	– item 126
1 retort stand	– items 503–504
2 bosses	– item 505
2 6-in nails	– item 10H

Procedure

Young's fringes can best be illustrated by crossing the ends of the plastic waves which are supported from the retort stand as shown.

The crossover point is moved up and down to show the illumination which would be received on a screen.

With faster pupils, the spacing of the clamps may be increased to get more lines of nodes. It is not advisable to start with wide spacing as the waves then cross at quite large angles in some cases and the addition and subtraction are not so obvious.



35b *Optional class experiment or home experiment*

Interference with corrugated cardboard wave model

Apparatus

16 drawing boards – item 551
32 pins
supply of corrugated cardboard

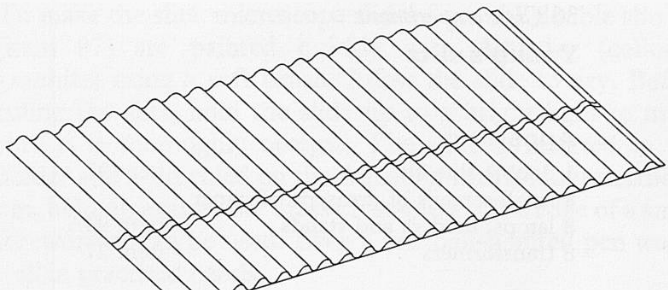
Procedure

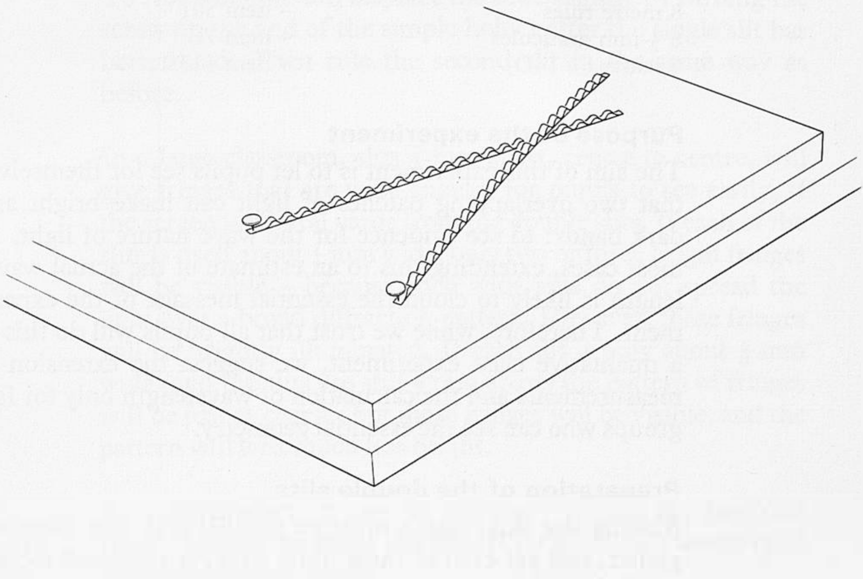
Two strips of corrugated cardboard, about 20 cm long and about $\frac{1}{4}$ cm wide, are cut from the corrugated cardboard sheet as indicated.

The two strips are placed on their sides on a drawing board. Each strip is pinned to the board by a pin through a wave-hump near one end. These anchored ends represent the two sources, one or two inches apart on the board. The pupil pulls the strips taut and uses them to predict 'bright' and 'dark' at a 'screen' marked near the other end of the board. The pupil may, if he likes, stick a pin through two wave humps, one of each strip, to mark a place where they add up to 'bright'.

This is a rough, simple experiment to try, and then to take home, just to give the idea of adding up in some places to a lot and in other places to nothing.

The pupil might also take home his own demonstration of Young's fringes (experiment 36) and the corrugated strips will then be found very useful in 'explaining' the phenomenon of interference. We hope teachers will encourage this.





36 *Class experiment*

Young's slits

Apparatus

1 double slits kit	– item 97
8 small screens of greaseproof paper	
8 lamps, holders and stands	– item 94A
8 transformers	– item 27

Additional apparatus for measurement

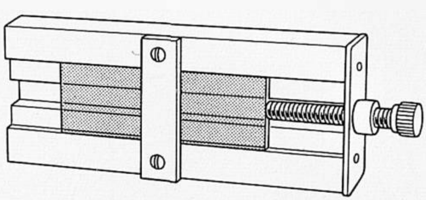
8 metre rules	– item 501
8 $\frac{1}{2}$-mm graticules	– item 7E
8 lenses (+14D)	– item 113/1

Purpose of the experiment

The aim of this experiment is to let pupils see for themselves that two overlapping patches of light can make bright and dark bands: to see evidence for the wave nature of light. In most cases, extending this to an estimate of the actual wavelength is likely to cloud the essential message of the experiment. Therefore, while we trust that all pupils will do this as a qualitative class experiment, we suggest the extension to measurements and the calculation of wavelength only for fast groups who can see the essential geometry.

Preparation of the double slits

Making the slits, which must be parallel and very close together, and yet each of them quite wide, is a difficult job for pupils, and failing to make successful slits is likely to spoil the essential lesson. Therefore, unless pupils have considerable spare time and wish to make their own slits – as they may well do if they repeat the experiment on their own at home – the teacher should prepare plenty of double slits before the lesson.



To make the slits, microscope slides from the double slits kit (item 97) are painted quickly with Aquadag (colloidal graphite) using a soft brush. Allow the slide to dry. Before ruling the slits, hold the slide up to a bright light to make sure it is thoroughly opaque. The slide is inserted in the holder and a slit ruled on the Aquadag with a blunt needle or pin, held up against the brass cross-piece. The edge of a small screwdriver can be used. Even a fine ball-pointed pen works well in practised hands.

To rule a double slit, displace the slide slightly by turning the screw on the end of the simple holder after the single slit has been ruled. Then rule the second slit in the same way as before.

In a large classroom, slits $\frac{1}{2}$ mm apart, centre to centre, will give fringes that are wide enough for pupils to see easily, if the screen is several yards from the double slits. If each of the slits is itself about $\frac{1}{4}$ mm wide, only two or three bright fringes will be visible – because such wide slits do not spread the light over a broad diffraction pattern. However, those fringes will be brightly illuminated. If each slit is only about $\frac{1}{8}$ mm wide (and the slits are still $\frac{1}{2}$ mm apart) the pattern of fringes will be just as coarse; but more fringes will be visible, and the pattern will look much less bright.

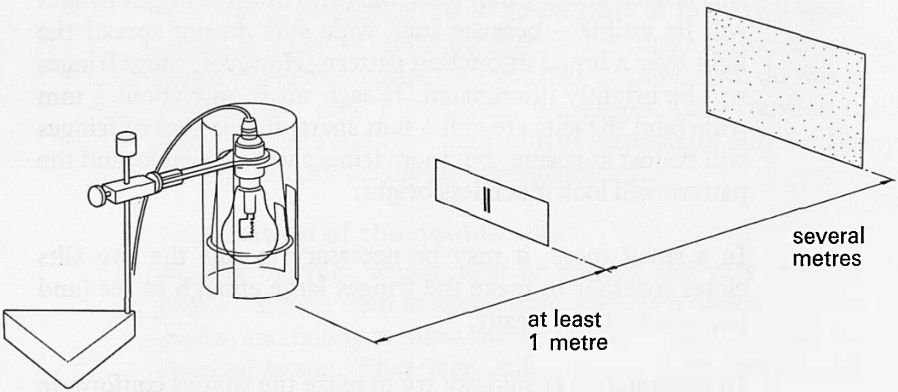
In a small room, it may be necessary to rule the two slits closer together to make the fringes large enough to see (and perhaps measure) easily.

In general, one should not try to make the rulings conform to some exact width. The suggestions above are merely offered as general guides. It is best to rule many pairs of slits and then try them quickly. The best test of all is to set slits up in an actual experiment in a dark room and look at the fringes. A quicker method, in which practice will give skill, is to hold the pair of slits just in front of one's eye and look at a line filament lamp a long way off. Then the eye acts as a 'telescope' focused more or less for infinity, and one sees Young's fringes and can judge the fringes for brightness and separation. However, this arrangement should certainly be avoided *with pupils* because the use of the observer's eye in this way is very confusing and likely to spoil the essential message of the experiment.

Some teachers find it easier to use a special tool for ruling the double slits, but this is apt to make the slits too fine. The tool consists of a holder with a pair of razor blades fixed a short distance (about $\frac{1}{2}$ mm) apart. If this is used, it will be necessary to push it to and fro several times to make wide slits. (Very narrow slits are ideal for making a broad display of many fringes; but that display needs to be observed with a magnifying glass or photographed, because it is so faint.) With a steel rule to act as guide, hold the tool with its pair of razor blades vertical, and with the corners of the two blades touching the corners of the coated surface, engrave the pair of parallel slits.

Procedure

The pupils set up their apparatus as shown. At least a metre should be allowed between the lamp filament and the slits, and several metres from the slits to the screen. A darkened room is essential.



The teacher will find it necessary to help the pupils to orient the slits parallel to the filament of the lamp since this is an important adjustment for obtaining clear fringes.

Pupils should then look at the fringes with the naked eye, viewing the screens from behind. It may be necessary to remind them to pull their heads back to a reasonable distance from the screen.

Some pupils may find a magnifying glass helps them to look at the fringes; but if that is really necessary, the fringes are either fainter or much closer than they need be.

Measurements

Seeing the fringes – 'light + light' making 'more light' in some places but making 'no light' in other places – is the important thing. We should not spoil this surprising observation, which points inescapably to wave motion, by insisting on measurements. However, we should encourage pupils who are interested in gaining more information from the experiment to make some rough measurements. A fast group should certainly try making measurements. In that case they should first measure the fringe spacing. If that is a few millimetres, it is probably best to ask pupils to make marks on the screen with a pencil while they are looking at the fringes with the naked eye. Later, in daylight, they can measure the spacing between the marks.

It will now be necessary to measure the distance from the slits to the screen with a metre rule and then to measure the separation of the slits. The simplest method is to compare the slits with a $\frac{1}{2}$-mm graticule, using a magnifying glass to help.

The teacher should then lead the pupils through the simple form of geometry – see note 1 below – and then ask them to work out a very rough estimate of the wavelength – see also note 2 on page 165.

Notes

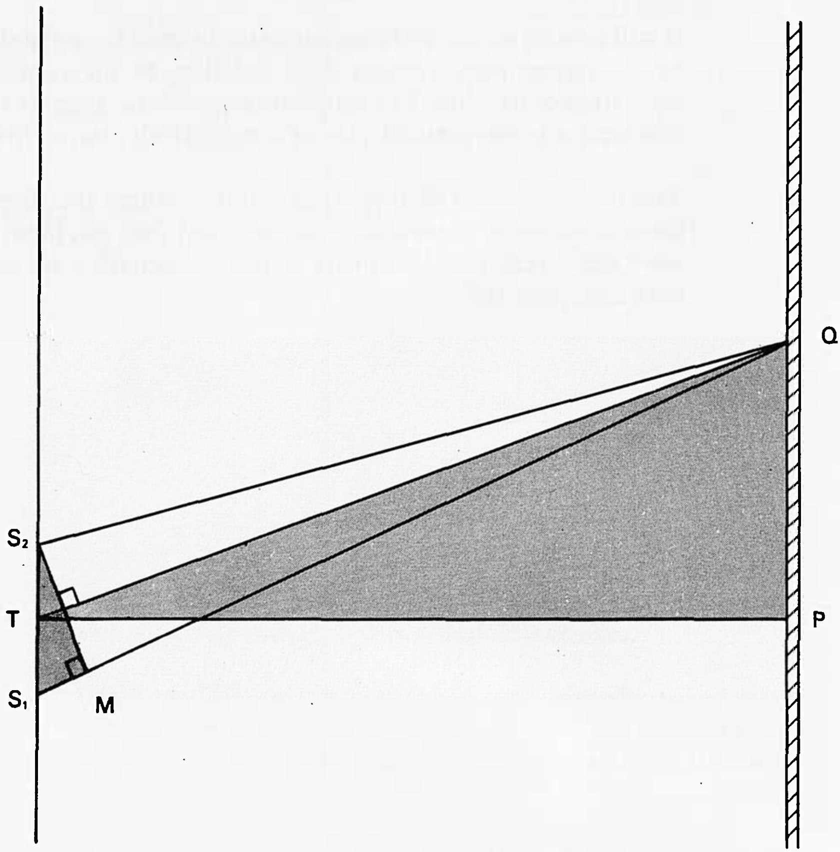
1 *Simple form of geometry*

If the central band is at P and the next bright band at Q, the path-difference, $S_1Q - S_2Q$ must be λ. Draw S_2M perpendicular to TQ. Then S_1M *is* the path-difference λ. With the big distances and small angles involved, the triangle S_1S_2M is practically similar to PQT. Then, by similar triangles:

$$\frac{\lambda}{S_1S_2} = \frac{PQ}{TQ}$$

$$\therefore \lambda = (S_1S_2)(PQ)/(TQ)$$

$$= \frac{\text{(Distance between slits) (Distance between fringes)}}{\text{Distance from slits to fringes}}$$



2 *Note on precision*

As in Year 1, we should explain to pupils that making a rough estimate is often very good science. Progress in physics does not always consist of measuring one more decimal place with great precision. Here, a rough guess at the tiny wavelength of light is worth a great deal because it tells us why light seems to cast sharp shadows; yet it warns us that wave effects will become important when we go into fine detail. Using white light and marking the bright bands, pupils will be estimating an average wavelength for the visible spectrum. The human eye is most sensitive in the green region, and the rough estimate is likely to be near to a value for green light, say about 5,000 Angström units. An estimate that differs from that by a factor as large as 2 is still a valuable hint – desperate measures for desperate circumstances. A fast group may enjoy interposing colour filters of red, green, and blue gelatine, though the blue will probably make the fringes too faint. Switching quickly between green and red will make the fringes seem to grow and shrink, exhibiting the difference of spacing. A very fast group may then want to estimate red light wavelength and green light wavelength.

3. *Home experiment*

It is hoped that teachers will encourage pupils to take this experiment home. That will mean taking home a line-filament lamp and transformer, the pupil's own double slit, and some greaseproof paper. Even though that means making arrangements for borrowing and will certainly involve considerable trouble in setting up the experiment at home, we believe it is well worth while. The corrugated strip model used in experiment 35b, which they should also take, will be found very useful in 'explaining' the phenomenon of interference at home.

37 *Films*

Ripple tank films of refraction and interference

Warning note

Very good short films of ripples or various ripple phenomena are available in cassettes for use on the 800E Technicolor projector. However, where pupils have spent considerable time making ripples in ripple tanks and studying their behaviour for themselves, showing them films to teach 'the right answers after all' is apt to do more harm than good.

In the case of ripple and wave behaviour, we do not need to give pupils reliable knowledge at this stage. Two years later they will need to understand interference; but they can see Young's fringes with water ripples, and with light, again at that time. This year, the chief purpose of the ripple tank experiments has been to give pupils an open opportunity to experiment for themselves and to find things out, and above all to gain a feeling of what it is like to work with experiments in a lab. The latter feeling of understanding is likely to be far more valuable, both to future scientists and to future non-scientists, than reliable factual knowledge of wave behaviour.

Therefore, we hesitate to recommend the use of films at this stage, because they do necessarily give a feeling of putting the pupil's own experimental work into a back seat while the films take charge and show the facts. Where in a later year teachers feel the need for such films for revision the films should be kept in mind.

38 *Demonstration*

Interference patterns in a soap film

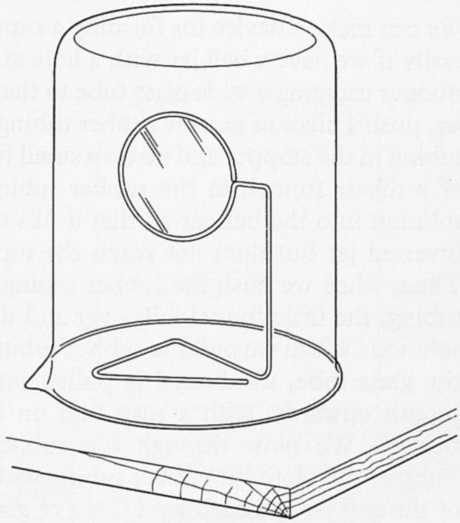
Apparatus

1 beaker (400 cm^3)	– item 512/2
1 large beaker (1,000 cm^3)	– item 513
1 copper wire frame	
soap solution	

The soap solution can conveniently be made from Stergene or other liquid detergent.

Procedure

The frame is bent from a length of copper wire of 16 or 18 swg as shown, the circle at the top having a diameter of at least 2 in, preferably 3 in or more.



The Stergene solution is put into the beaker and a film formed on the frame. This film is then used as a mirror to reflect light from the window to the class. As the film drains interference bands are seen.

The film will last for a long time, even when thin, if evaporation is discouraged. This can be achieved by placing a large beaker, *wet inside*, over the frame carrying the film as it stands on the bench-top.

Just before the film breaks, no light is seen, though the detail of this should not be emphasized too much.
It is preferable to have a black background to see the effects more vividly.

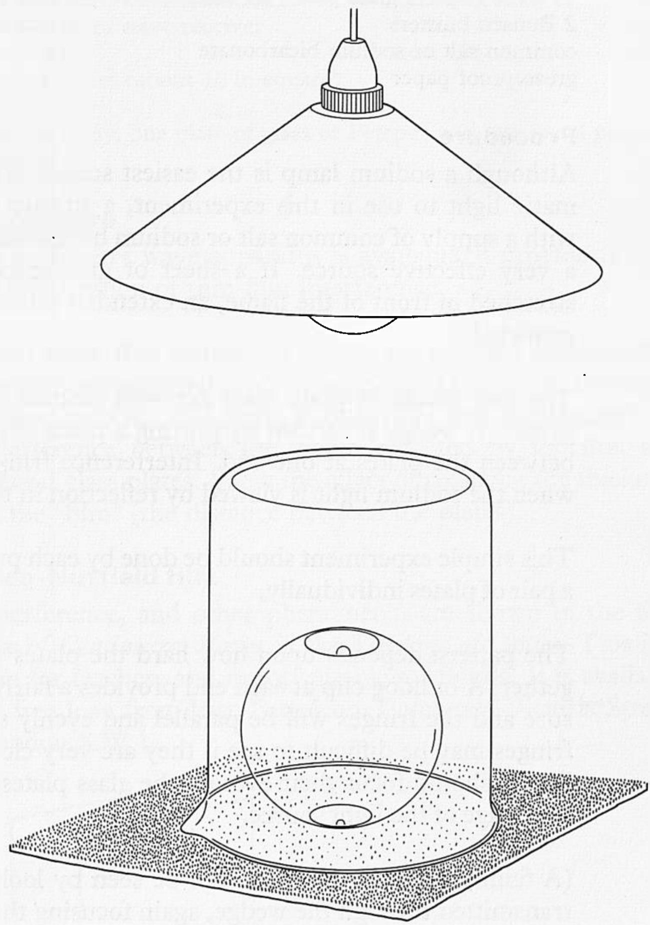
Alternative procedure

As an alternative method, blow a soap bubble and catch it on a small piece of carpet made of synthetic fibre. Place a big beaker over the resting bubble and arrange a large white lamp shade, well illuminated, above the beaker. This will make the bubble still more clearly visible.

A dilution of Stergene of 1 in 10 gives rather a streaky pattern, but the film is strong. 1 in 1,000 gives a film with closely spaced fringes, but the film is rather weak. A dilution of 1 in 100 is probably best.

We can make a device for forming a captive soap bubble very easily if we have a bell jar with a hole at the top. Fit a rubber stopper carrying a wide glass tube to that hole. Invert the bell jar, push a piece of narrow rubber tubing up through the glass tubing in the stopper and insert a small funnel, such as the top of a thistle funnel, in the rubber tubing. Pour a little soap solution into the bell jar so that it fills the neck region of the inverted jar but does not reach the top of the glass tubing. Then, when we push the rubber tubing up through the glass tubing, the little funnel falls over and dips its mouth in soap solution. When we pull the rubber tubing back down through the glass tube, the funnel is pulled into a position with its mouth upwards, with a soap film on it ready to develop a bubble. We blow through the rubber tubing to make a bubble, and close the rubber tubing with a clip. The open top of the bell jar is closed by a sheet of glass and a large, white, conical lamp-shade is placed on top of that to provide a suitable white area to be reflected by the bubble.

Or a convex film can also be made on the top of a beaker which stands on a dark table or sheet of black paper with a bright, white translucent screen behind. As the film drains, circular interference fringes are seen and the black centre is very spectacular just before it breaks. A slight draught may make the experiment more convincing and certainly dispels any idea that the black centre is produced by a hole in the film. But the most convincing test is to poke the black region with a piece of blackboard chalk. (This is a good way of breaking a soap film.)



39a *Class experiment*

Interference in a thin air wedge

Apparatus

16 pairs of plate glass plates for interference	– item 129
2 Bunsen burners	– item 508
common salt or sodium bicarbonate	
greaseproof paper	

Procedure

Although a sodium lamp is the easiest source of monochromatic light to use in this experiment, a Bunsen burner fed with a supply of common salt or sodium bicarbonate provides a very effective source. If a sheet of greaseproof paper is stretched in front of the flame, an extended source of light is provided.

The two pieces of plate glass are well cleaned and put together. A wedge is formed by putting a piece of tissue paper between the plates at one end. Interference fringes are seen when the sodium light is viewed by reflection in the plates.

This simple experiment should be done by each pupil holding a pair of plates individually.

The pattern depends upon how hard the plates are held together. A bulldog clip at each end provides a fairly even pressure and the fringes will be parallel and evenly spaced. The fringes may be difficult to see if they are very close together. Pupils should focus their eyes on the glass plates and not on the image of the light source.

(A faint interference pattern can be seen by looking at light transmitted through the wedge, again focusing the eye on the plates, but this observation should be omitted except in the case of unusually fast pupils.)

39b *Optional demonstration*

Interference using centimetre waves

Apparatus

1 centimetre wave transmitter	– item 184/1
1 centimetre wave receiver	– item 184/2
1 amplifier	– item 181
2 glass plates (about 10 in square)	

Alternatively, one plate of glass or Perspex and one metal plate can be used.

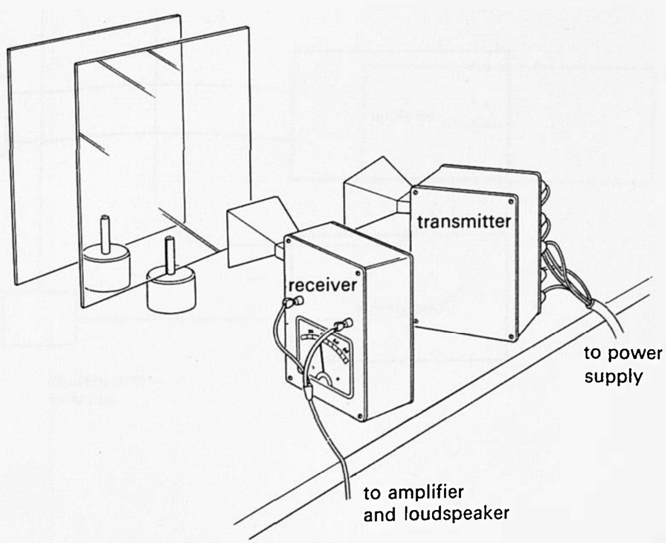
Procedure

If centimetre wave apparatus is available, it provides a good demonstration of thin-film interference.

First show that centimetre waves are partially reflected and partially transmitted by the glass plate. Then set up the transmitter, receiver, and plates as illustrated and demonstrate the interference between the waves reflected by the first and second glass plates. Show the effect of reducing the thickness of the 'film' (the distance between the plates).

Esso-Nuffield film

Interference, and other phenomena, are shown in the film *Use of Centimetre Waves in the Teaching of Optics.* This is a film for teachers and is not suitable for pupils. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.



39c *Optional demonstration*

Interference using sound waves

Apparatus

1 signal generator (audio oscillator)	– item 182
2 small loud speakers	– item 183

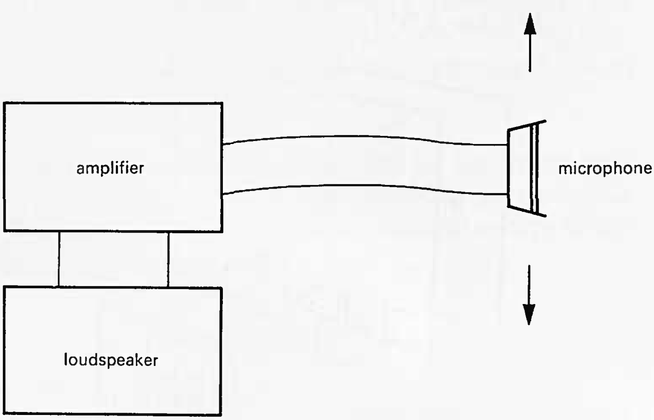
Procedure

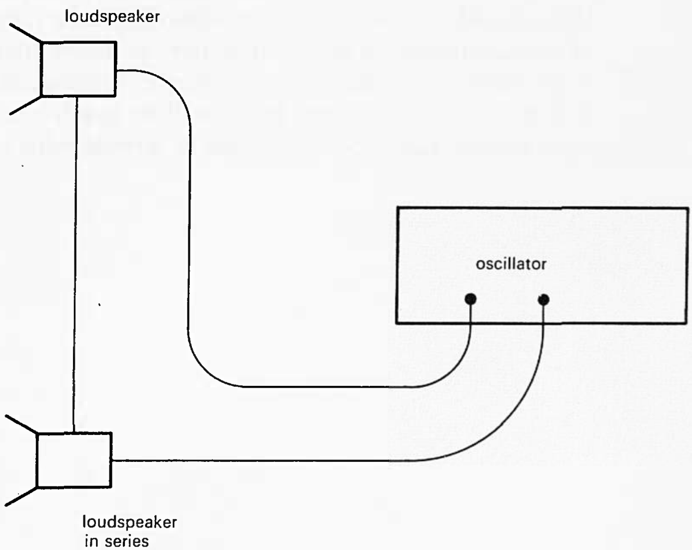
If it is possible to work out of doors so that wall reflections do not spoil the simplicity, sound waves of wavelength several centimetres give an excellent demonstration with the pupils using their ears as detectors.

Sound waves from a single loudspeaker may be directed normally at a sheet of metal that acts as a reflecting wall. In the region in front of the wall, the incident waves and reflected waves interfere to form standing waves.

Sound waves from a single loudspeaker may be directed obliquely at a 'thin film' made by two partially-reflecting sheets of perforated metal. The waves reflected from the two sheets form an interference pattern.

The simplest demonstration, and probably the best, is to use two loud speakers, driven in series by the oscillator. If the two speakers are set up, several wavelengths apart, 'Young's fringes' will be apparent.




loudspeaker
oscillator
loudspeaker
in series

40. *Class demonstration*

Acceleration of ball rolling down a plank

Apparatus

10-ft long plank with one grooved edge
supply of large marbles

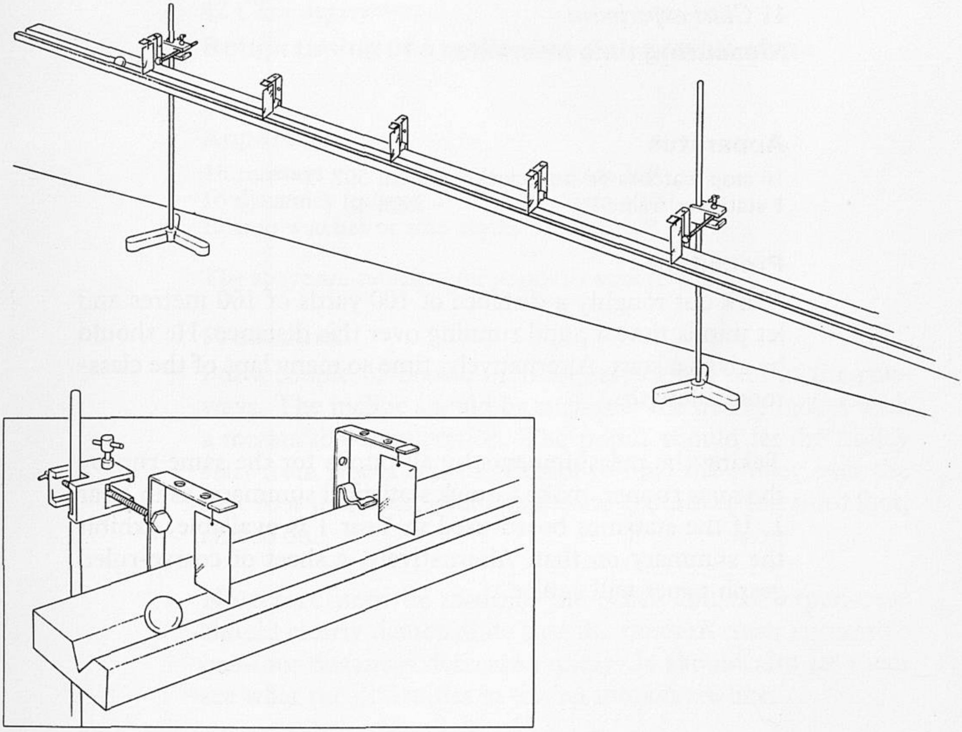
Alternatively, a plain plank could be used with grooved moulding nailed to one edge.

Procedure

Set up the grooved plank inclined so that pupils can allow marbles to roll down the groove. If wall space is available it can conveniently be fixed to the wall.

Small tin pennants hung from simple wire axles can be arranged so that the marbles hit them and make 'clinks'. The pennants could be carried on curtain railway fitted to the side of the plank or may be carried by small 'goalposts' which could sit over the grooved track. The goalposts might be made from stiff pieces of wire held on either side of the track by modelling wax.

Pupils should try placing the pennants at regular intervals: 1 ft, 2 ft, 3 ft, 4 ft . . . from the beginning of the plank. Then they should try placing them so that the clinks seem to come at equal intervals of time. Of course, *we* know that the pennants should be placed in a quadratic spacing, in the ratio 1:4:9 . . . from the start. But it will be much better to pose the problem and leave the pupils to wrestle with it.



41 *Class experiment*

Measuring time intervals

Apparatus

16 stop watches or stop clocks	– item 507
1 statistics frame	– item 48

Procedure

Mark out roughly a distance of 100 yards of 100 metres and let pupils time a pupil running over this distance. He should be given a start. Alternatively, time so many laps of the classroom's length.

Taking the measurements by all pupils for the same run by the *same* runner, make a quick statistical summary, as in Year 1. If the statistics board used in Year 1 is available, exhibit the summary on that. Alternatively, a sheet of coarse-ruled graph paper will suffice.

42 Class experiment

Rough timing of a trolley running down a slope

Apparatus

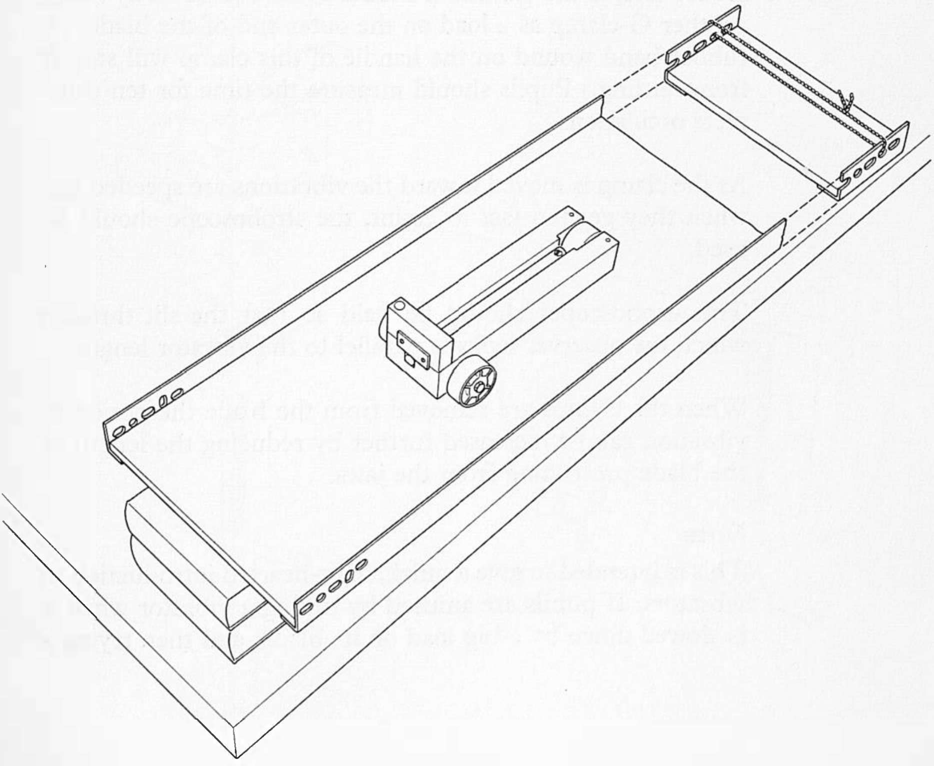
16 runways	– item 107
16 dynamics trolleys	– item 106/1
16 stop watches or stop clocks	– item 507

The above are sufficient for pupils to work in pairs.

Procedure

Put a couple of books, or more, under one end of the runways. The incline should be such that the trolley moves with a measurable acceleration. The pupils should let the trolley start from rest and then attempt to time the trolley over the first foot it travels, over the second foot, over the third foot, and so on.

No record need be made of the times, but the experiment should clearly demonstrate that the times to cover successive one-foot distances decrease rapidly. It should also let them see what the difficulties in timing motion are like.



43 Class experiment

Introduction to vibrators

Apparatus

8 'hack-saw' blades	– item 120
16 small metal strips as jaws	– item 121
32 hand stroboscopes	– item 105/1
8 4-in G-clamps	– item 44/1
16 2-in G-clamps	– item 44/2
4 reels of masking tape	– item 105/2
16 stop clocks or stop watches	– item 507

Procedure

The 'hack-saw' blade (or similar metal strip) should be clamped tightly between the two small metal strips using a G-clamp. It is very important to have the blade held tightly and symmetrically just where the blade emerges from the jaws as otherwise energy is lost too fast and the oscillations are badly damped. The whole set-up is clamped to the edge of the bench as illustrated.

First pupils should see if they can count the vibrations. These are too fast, so the vibrations should be slowed down by fixing another G-clamp as a load on the outer end of the blade. (A rubber band wound on the handle of this clamp will stop it from rattling.) Pupils should measure the time for ten complete oscillations.

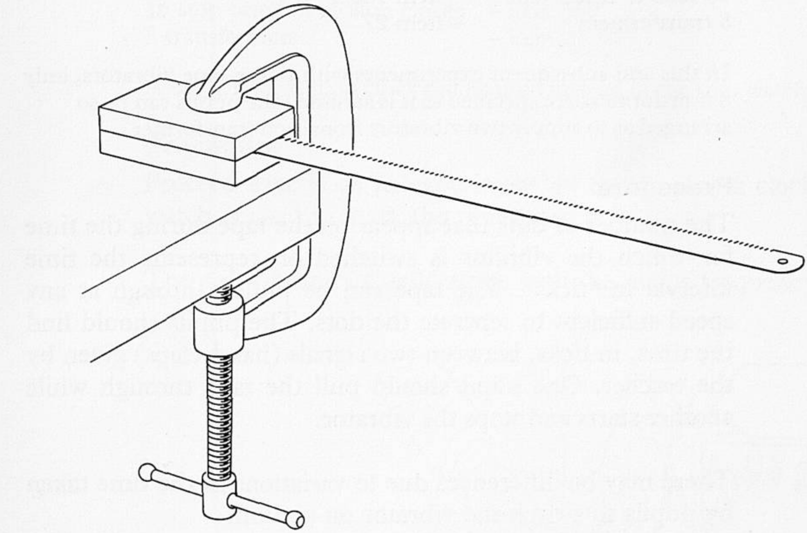
As the clamp is moved inward the vibrations are speeded up; when they get too fast to count, the stroboscope should be used.

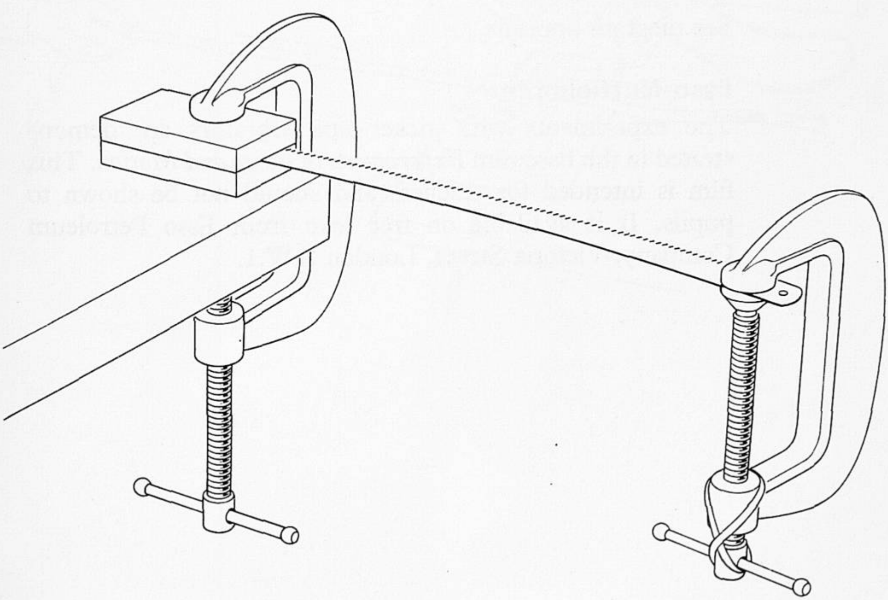
The stroboscopes should be held so that the slit through which the observer looks is parallel to the vibrator length.

When the clamps are removed from the blade the period of vibration can be increased further by reducing the length of the blade protruding from the jaws.

Note

This is intended to give a quick, light-hearted introduction to vibrators. If pupils are amused by timing a vibrator when it is slowed down by a big load on its blade, and then trying a stroboscope with faster motion, well and good. If this becomes a period of drill in studying vibrators, we shall have missed the point and may, indeed, have spoiled the beginning of a series of important experiments. Therefore, we urge that this experiment should be short and light-hearted; or else omitted.





44 *Class experiment*

Time intervals with the vibrator

Apparatus

16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27

In this and subsequent experiments with ticker-tape vibrators, only 8 transformers are specified as it is assumed the pupils can be so arranged as to supply two vibrators from each transformer.

Procedure

The number of dots that appear on the tape during the time for which the vibrator is switched on represents the time interval in 'ticks'. The tape can be pulled through at any speed sufficient to separate the dots. The pupils should find the time, in ticks, between two signals (hand-claps) given by the teacher. One pupil should pull the tape through while another starts and stops the vibrator.

There may be differences due to variations in the time taken by pupils to switch the vibrator on and off.

See diagram opposite

Esso-Nuffield film

The experiments with ticker-tape vibrators are demonstrated in the Esso film *Experiments in Force and Motion*. This film is intended for teachers and should not be shown to pupils. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

45 Class experiment

Number of 'ticks' in 3 seconds

Apparatus

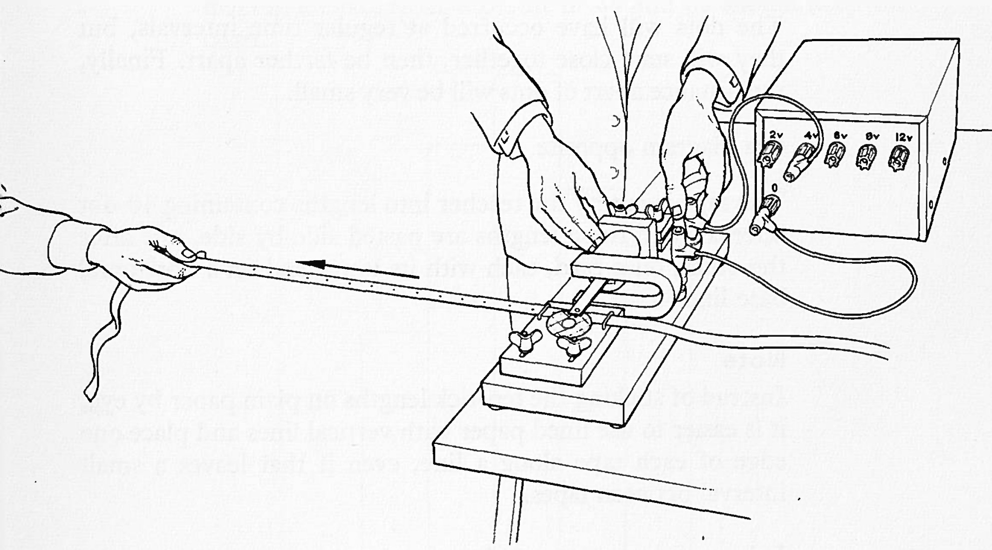
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
16 stop watches or stop clocks	– item 507
8 transformers	– item 27

A big demonstration clock can be used instead of the stop watches.

Procedure

Proceed exactly as in experiment 44 except that a clock or watch is used to mark the time interval.

The a.c. vibrators should agree with the mains frequency.



46 *Demonstration*

Introduction to measuring motion

Apparatus

1 ticker-tape vibrator – item 108/1
1 roll of ticker-tape – item 108/4
1 transformer – item 27

Gummed and plain ticker-tape are both available commercially: the gummed version is more convenient for this experiment.

Procedure

One pupil operates the vibrator while another pulls tape through the vibrator by walking away from it, holding the end of the tape in his hand. After moving some distance the pupil stops.

The dots will have occurred at regular time intervals, but they will start close together, then be farther apart. Finally, the distance apart of dots will be very small.

See diagram opposite.

The tape is cut by the teacher into lengths containing 10-dot intervals and these lengths are pasted side by side, one after the other, on a card, each with its lower end on a horizontal base line.

Note

Instead of sticking the ten-tick lengths on plain paper by eye, it is easier to use lined paper with vertical lines and place one edge of each tape along a line, even if that leaves a small interval between tapes.

It is not wise to use graph paper for this, however easy that makes the demonstration, because that is likely to encourage a rush into graph-plotting instead of use of tapes and that will not give such clear understanding at this stage. See the discussion in the *Teachers' Guide.*

47 Class experiment

Measuring the pupil's own motion

Apparatus

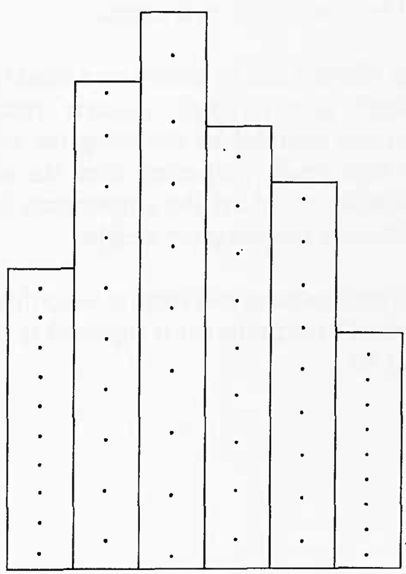
16 ticker-tape vibrators – item 108/1
16 rolls of ticker-tape – item 108/4
8 transformers – item 27

Gummed ticker-tape is the more convenient for this and many of the subsequent experiments. Otherwise paste will be required.

Procedure

This is a class experiment in which pupils produce their own tapes exactly as in the previous demonstration.

Each pupil should analyse his own tape, cutting it up and making a chart as in experiment 46 and he should keep the chart.



48 *Class experiment*

Investigation of free fall

Apparatus

1 brick or stone	
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27
Sellotape	

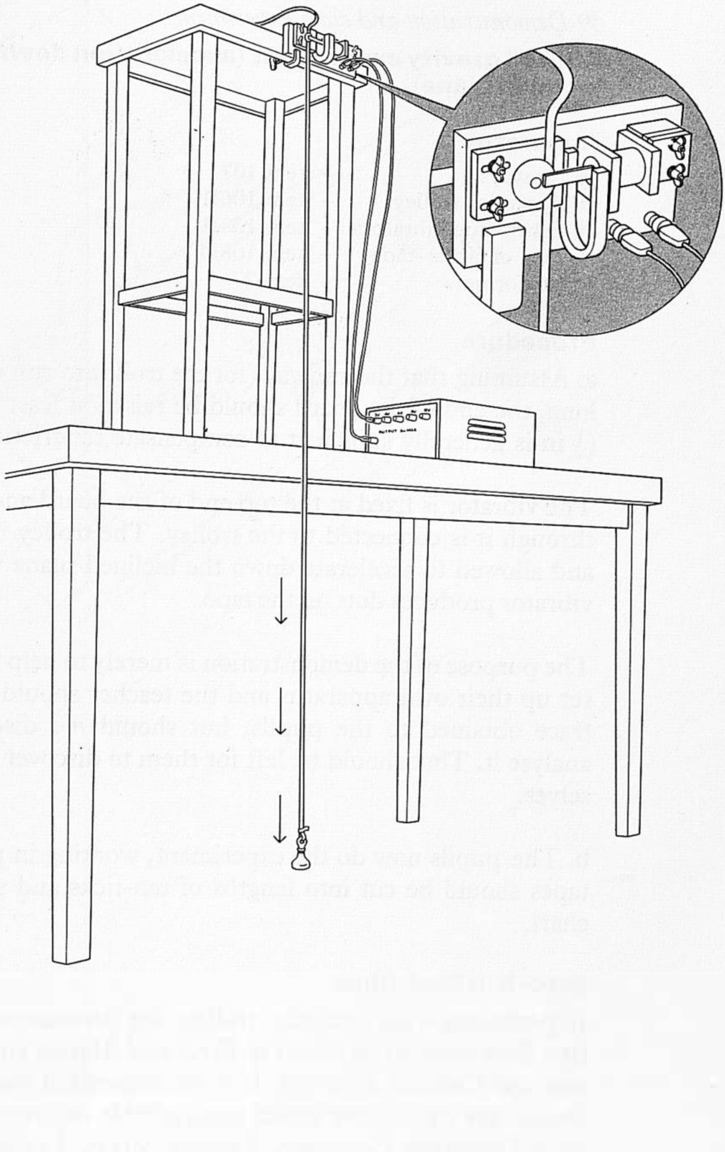
Procedure

a. First the pupils should watch the motion of free fall of a stone or brick.

b. A brass weight (or other suitable object) should be attached to the end of the tape using Sellotape and allowed to fall to the ground pulling the tape through the vibrator. Results will not be very consistent because the acceleration is large and there will be trouble due to friction.

The vibrator can be placed on a stool that is itself standing on a bench so as to obtain a longer trace. Friction can be considerably reduced by clamping the vibrator on its side with the tape guide projecting over the edge of the stool. It is advisable to cut off the appropriate length of tape from the reel before dropping the weight.

It is preferable at this stage to keep this a very rough measurement. The experiment is repeated to obtain a value for 'g' in Year IV.



49 *Demonstration and class experiment*

Diluted gravity experiment (acceleration down an inclined plane)

Apparatus

16 runways	– item 107
16 dynamics trolleys	– item 106/1
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27

Procedure

a. Assuming that the runway (for the trolley to run on) is 6 ft long, the end of the board should be raised at least 3 or 4 in ($\frac{1}{2}$ in is generally sufficient to compensate for friction).

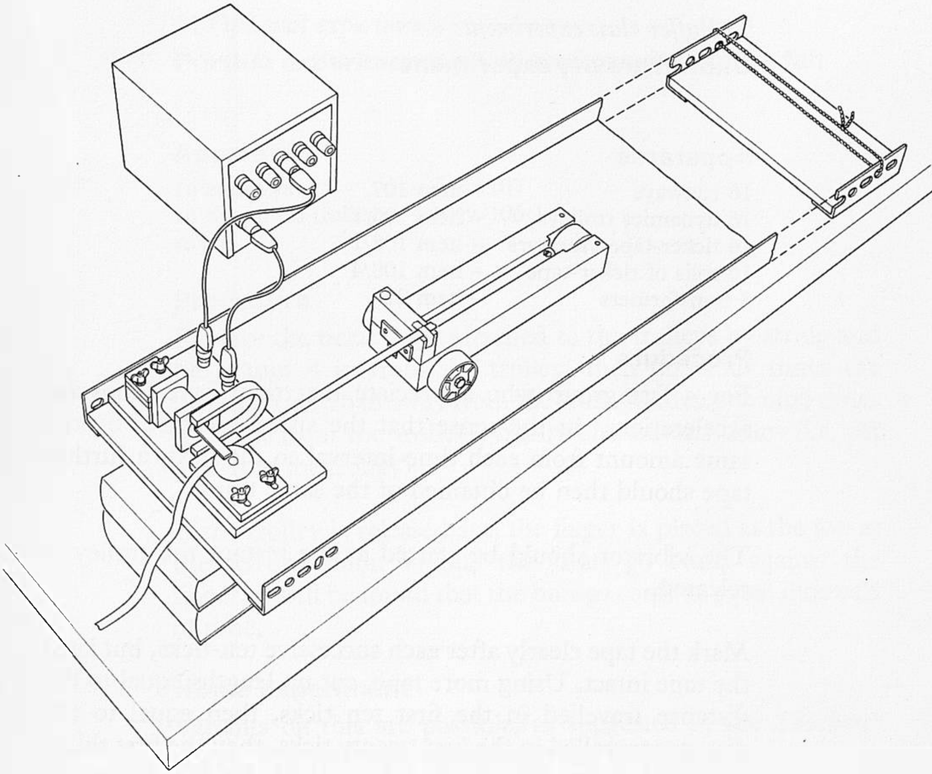
The vibrator is fixed at the top end of the board and the tape through it is connected to the trolley. The trolley is released and allowed to accelerate down the inclined plane whilst the vibrator produces dots on the tape.

The purpose of the demonstration is merely to help the pupils set up their own apparatus and the teacher should show the trace obtained to the pupils, but should *not* discuss it or analyse it. That should be left for them to discover for themselves.

b. The pupils now do the experiment, working in pairs. The tapes should be cut into lengths of ten-ticks and stuck on a chart.

Esso-Nuffield films

Experiments with dynamics trolleys are demonstrated in the two Esso films *Experiments in Force and Motion* and *Momentum and Collision Processes*. It is recommended that teachers should see these films which are available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1. These films, however, are for teachers and should *not* be shown to pupils.



50 *Buffer class experiment*

Diluted gravity experiment

Apparatus

16 runways	– item 107
16 dynamics trolleys	– item 106/1
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27

Procedure

For a fast group who appreciate that they have 'constant accelerations' in the sense that the speed increases by the same amount from each time-interval to the next, a further tape should then be obtained of the same thing.

The vibrator should be started at the instant the trolley is released.

Mark the tape clearly after each successive ten-ticks, but keep the tape intact. Using more tape, cut up lengths equal to the distance travelled in the first ten ticks, then equal to the distance travelled in the first twenty ticks, then the first thirty ticks and so on. See the *Teachers' Guide* for the discussion that might follow on this. For most pupils, it is better to leave this experiment until Year IV.

51 *Optional experiments*

Further experiments on diluted gravity or free fall

Apparatus

16 runways – item 107
16 dynamics trolleys – item 106/1
string

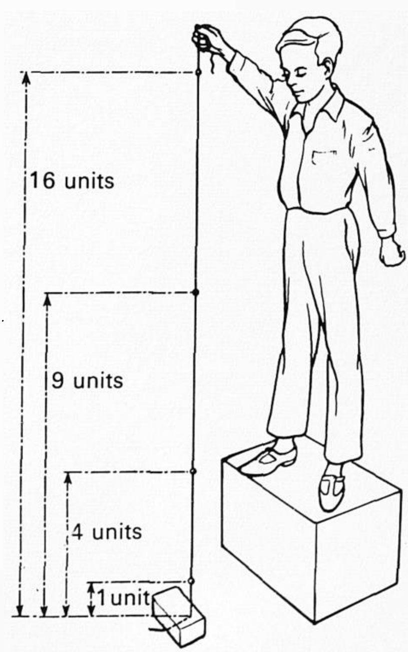
Procedure

Replace the ticker-tape attached to the trolleys by string and tie a knot 4 in from the trolley, then one four times the distance (i.e. 16 in away from the trolley), then one nine times (i.e. 3 ft from the trolley), finally one sixteen times (i.e. 5ft 4 in from the trolley).

If the trolley is released and the finger is placed at the top at the starting point so that the knots go bump against the finger, it will be found that the bumps come at equal intervals of time.

Home experiment

Variants on this are possible, as suggested in the *Teachers' Guide*. The following experiment can be tried at home.



A string is anchored at the end by a brick resting on the floor. The pupil attaches loads to it at suitable distances. He holds the other end of the string high above the floor, keeping it taut, and lets it go.

The easiest loads to attach to the string are the small lead weights used for loading fishing lines. Ping-pong balls make a better noise when they arrive on the floor but need considerable care with Sellotape to attach them to the string. The balls need not be attached directly to the main string but can hang from it by short lengths of string, provided the distance from floor to actual ball is correct, so that they hit the floor at equal intervals of time.

The teacher should avoid doing the planning for the brighter pupils who do these experiments. This work is a useful exercise for their ingenuity and a reward for their intelligence.

52 Buffer class experiment

Trolley running *up* the hill

Apparatus

16 runways	– item 107
16 dynamics trolleys	– item 106/1
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27

Procedure

The teacher should ask what happens if a trolley runs uphill after being given a push. Then the pupils should try it for themselves with inclined runways, trolleys, and ticker-tape timers.

Charts should again be made of the tapes obtained.

53a *Demonstration*

Galileo's experiment with a rolling ball

Apparatus

1 ball bearing (or large marble)	– item 131A
1 flexible curtain rail	– item 119
1 retort stand, boss, and clamp	– items 503–506

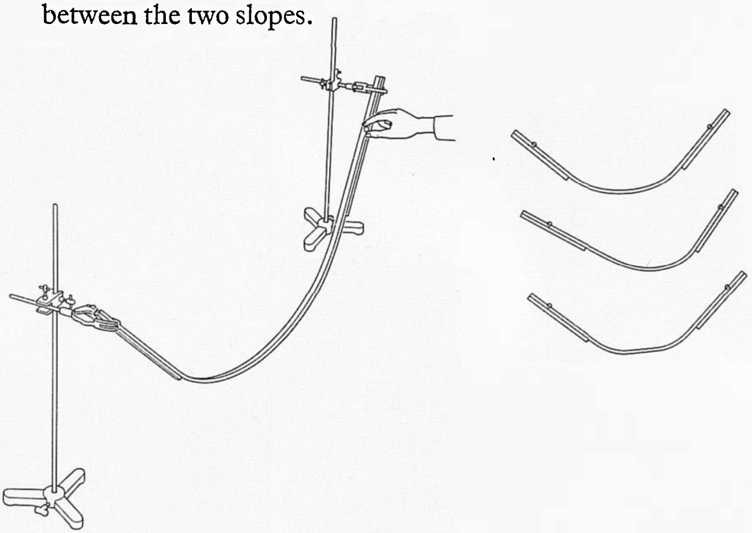
The flexible curtain rail – see *Nuffield Guide to Physics Apparatus* – must not be flimsy, nor the unsymmetrical type. It should be at least 6 ft long, preferably 8 ft.

Procedure

The recommended method for supporting the curtain rail is to glue a 2-ft wooden lath ($\frac{1}{2}$ in $\times$ $\frac{1}{2}$ in) to each end of the underside of the curtain rail. (For an 8-ft rail, the laths might be 3 ft long.) One end is conveniently held with a retort stand and clamp, about 1 ft above the bench. The other end can be held in another retort stand or the teacher may prefer to hold it himself.

The ball bearing is held at the top of one end of the curtain rail and released so that it rolls down one side and then up the other.

As the curtain rail is flexible and easily tilted, various slopes should be tried, both equal and unequal. The ball can be released from each end in turn to see if any difference occurs. The experiment may also be tried with a horizontal length between the two slopes.



53b *Demonstration or class experiment*

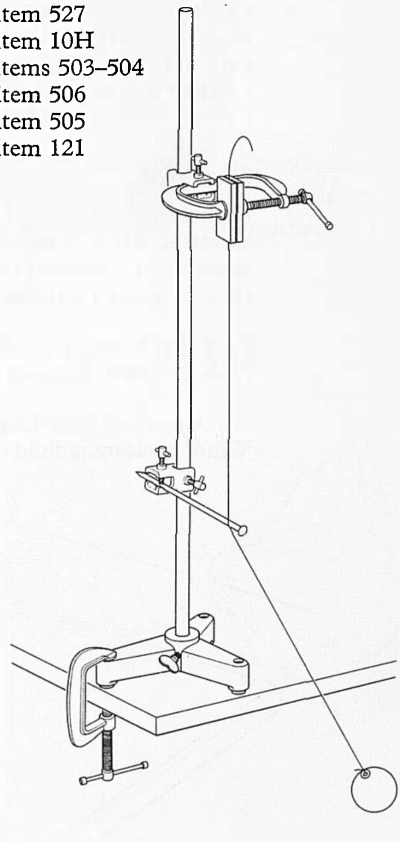
Galileo's pin and pendulum experiment

Apparatus

16 simple pendulums	– item 527
16 6-in nails (or dowel rods)	– item 10H
16 retort stands	– items 503–504
16 clamps	– item 506
32 bosses	– item 505
32 2-in metal strips as jaws	– item 121

Procedure

The pendulum is set up as illustrated opposite.



For success in this experiment it is essential to have a massive and very rigid support for the pendulum and for the 'pin'. Otherwise energy is lost at the support.

The pendulum bob is held to one side and then released. The nail or dowel rod is fixed to interrupt the swing, but it is found that the bob rises to the same level from which it started.

Note

The best arrangement for clamping the pendulum thread is between the two metal plates acting as jaws.

54 *Demonstration*

Frictionless motion

Apparatus

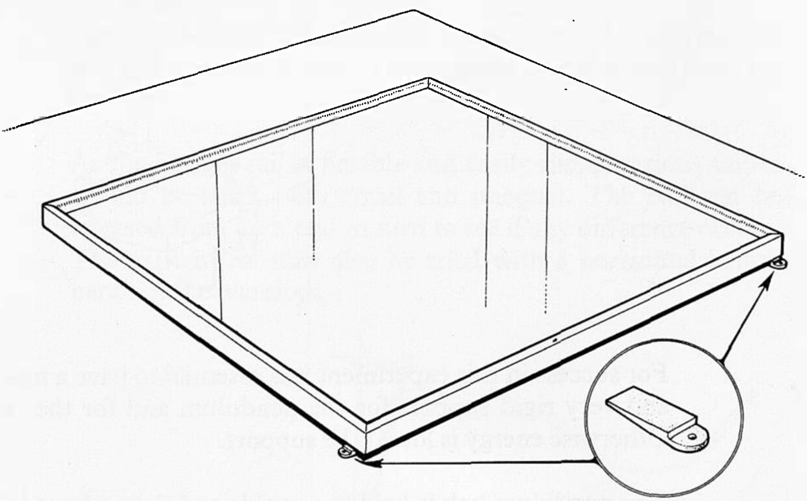
1 Edinburgh CO_2 pucks kit – item 95
1 CO_2 cylinder – item 19/1
1 dry ice attachment – item 19/2
1 large block of solid CO_2 (6-in cube or more)
1 piece of thick metal ($\frac{1}{4}$ in)

Glass plate

At first sight, the special glass plate may seem an unnecessary expense; in fact, it makes all the difference to the success of the experiment. Ordinary table-tops are neither flat enough nor smooth enough. Even a formica top is not always satisfactory.

Levelling is very important and this can conveniently be done with rubber wedges supplied with the plate.

It is important that the glass plate be thoroughly cleaned before use. Window-cleaning fluid or methylated spirits are suitable.



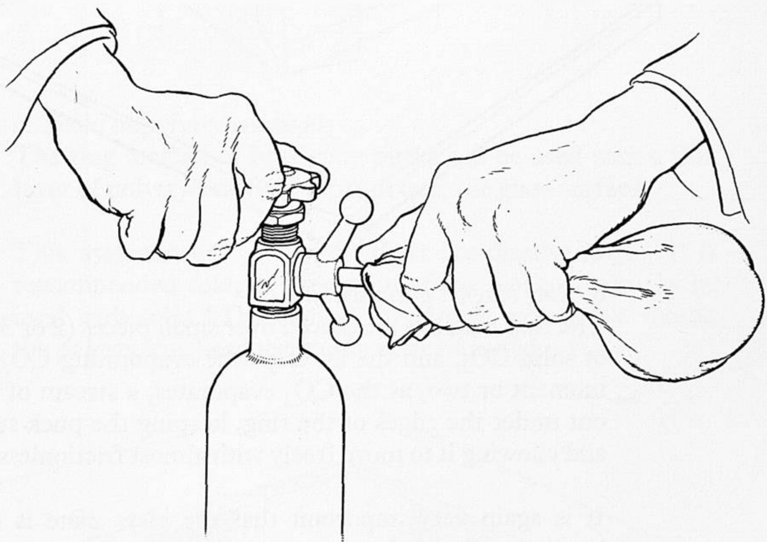
Solid CO_2

Sufficient solid CO_2 to operate the ring pucks can be obtained from the special CO_2 cylinders with dry ice attachment. The cloth provided should be put (double thickness) over the nozzle and a few seconds' burst will provide sufficient.

The CO_2 block should be ordered from the suppliers a week beforehand. For details on the supply of solid carbon dioxide, see Section C of the *Nuffield Guide to Physics Apparatus.*

Esso-Nuffield films

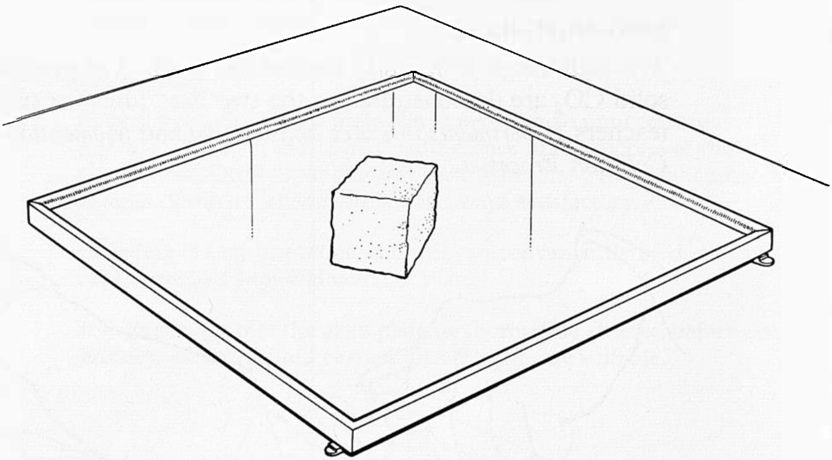
The Edinburgh CO_2 pucks kit and the method of producing solid CO_2 are demonstrated in the two Esso films for science teachers *Experiments in Force and Motion* and *Momentum and Collision Processes.*



Procedure

a. *Block of CO_2 coasting on plate glass*
The piece of thick metal ($\frac{1}{4}$ in) is necessary for ironing the bottom of the CO_2 block to make a flat coasting surface.

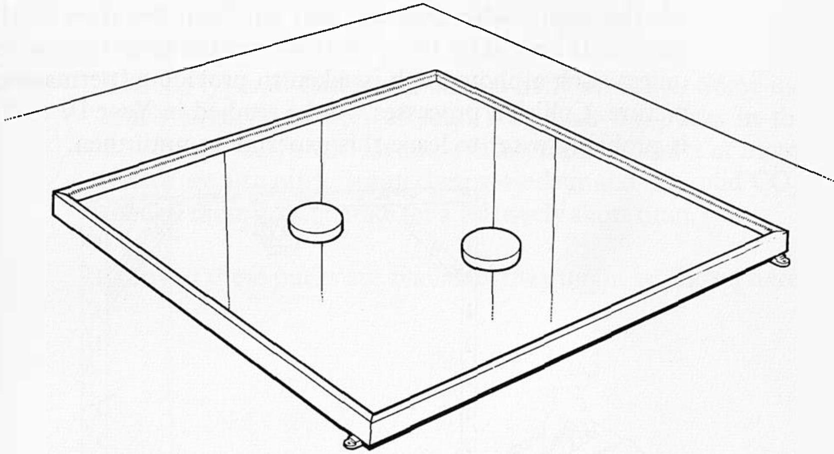
The block is put on the glass plate, which must be previously cleaned as described above. It will coast freely on the hovercraft principle.



b. *Ring magnet pucks with CO_2*
The ring magnets are placed over small pieces (2 or 3 cc each) of solid CO_2, and the lid traps the evaporating CO_2. After a moment or two, as the CO_2 evaporates, a stream of gas runs out under the edges of the ring, keeping the puck supported and allowing it to move freely with almost frictionless motion.

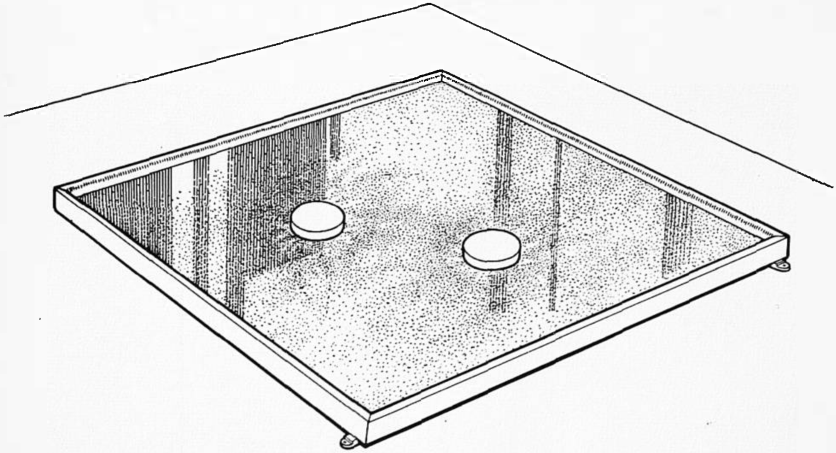
It is again very important that the glass plate is carefully levelled and very clean.

In the kit, both large and small magnetic pucks are provided, as well as non-magnetic brass ones. A brass puck alone should be tried first. Then two brass pucks together so that the pupils see collisions. Then two magnetic pucks should be tried.

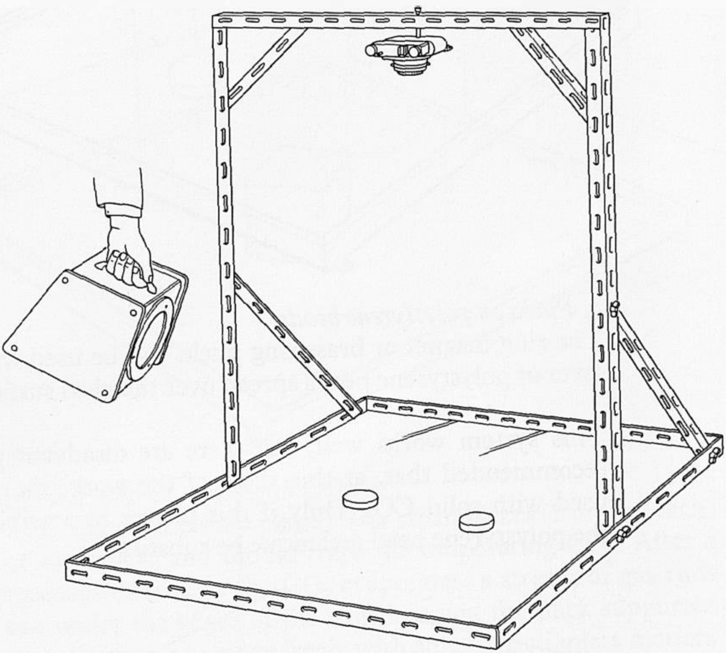


c. *Pucks on polystyrene beads*
The ring magnet or brass ring pucks can be used with a thin layer of polystyrene beads spread over the glass surface.

This system works well, but there are disadvantages. It is recommended that, at this stage of the work, the pucks be used with solid CO_2. Only if this proves impossible should the polystyrene bead technique be substituted.



d. *Collision of ring magnets*
As an optional additional experiment, the teacher might take a stroboscopic photograph of a collision of ring magnets and ask the pupils what they can find out from the clues in the picture. It is unlikely that pupils will see the clues themselves unless such a photograph is taken to provide a 'permanent' picture. Collision processes will be studied in Year IV and it is probably wiser to leave this experiment until then.



55 *Optional demonstration*

Large Pucks

Procedure

Various types of pucks are commercially available. Some use much larger quantities of solid CO_2 than the pucks in the Edinburgh CO_2 pucks kit and will last for 20 minutes or more. There are also pucks using compressed air and not solid CO_2, though these only operate for a relatively short time.

If any of these pucks are available, they might be shown here.

56 *Class demonstration*

Inertia: two tin-can pendulums

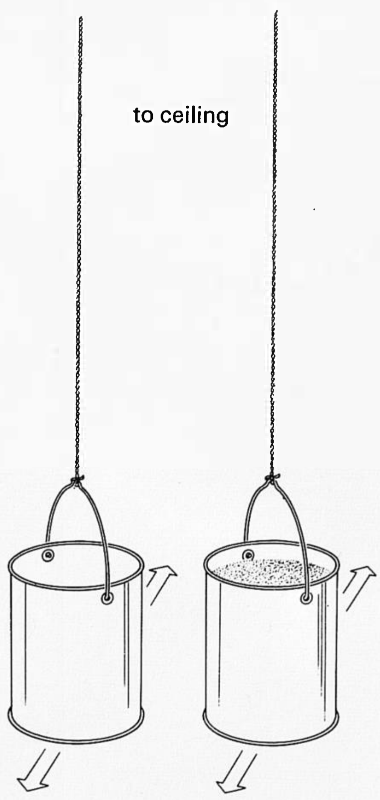
Apparatus

2 tin cans
sand
string

Procedure

One can is suspended empty, the other full of sand. The suspension should be *as long as possible*: long strings from the ceiling would be ideal. The tin cans must be identical; treacle tins are satisfactory though obviously the larger the cans the more effective the demonstration.

The pupils should try pushing each in turn and find what force is necessary to start the cans moving. They should also try stopping them when they are moving.



57 *Optional demonstrations*

Inertia: further demonstration experiments

Apparatus

a coin card tumbler

b 1 retort stand	– item 503
1 boss	– item 505
1 clamp	– item 506
1 large weight (1 Kg or more)	– item 32
thread	

c pile of books

d thread (breaking force, say, 100 gm-wt) and 1 gram weight

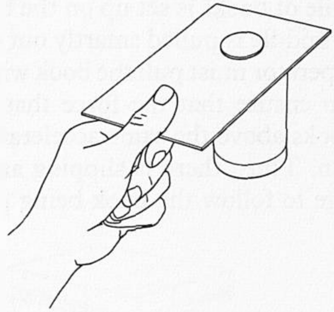
e 5 wooden blocks (say, 4 in × 3 in × 2 in)

Warning

As explained in the *Teachers' Guide*, these experiments are often merely delightful tricks to the children rather than exhibits of the properties of inertia. It is probably better to leave these tricks to a later stage.

Procedure

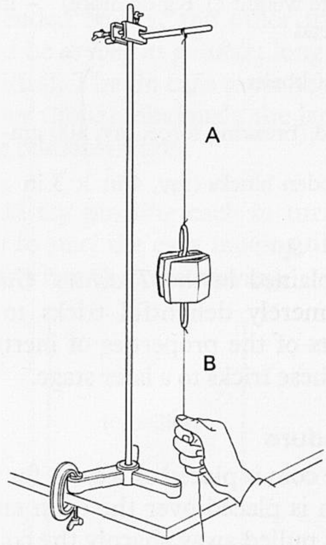
a. The coin is placed on a card (for example, a postcard) which in turn is placed over the open end of a tumbler. When the card is pulled away sharply the coil falls into the tumbler.



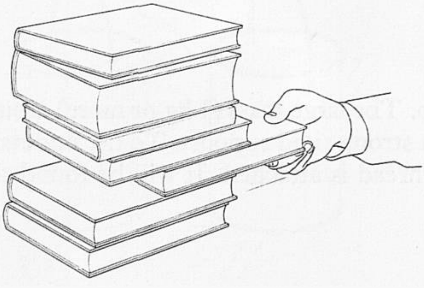
b. The large mass (1 kg or more) is suspended by thread from a strong rigid support. To the underside of the mass a second thread is attached. It will be found that the thread breaks at

A if the thread is pulled slowly and steadily, but it breaks at B if jerked down. Some may prefer to have a single thread for the upper one and have two or three threads of the same kind in parallel for the lower thread.

The extra force of the weight provides a greater tension on the upper thread in the first case, but in the second the inertia of the weight prevents the force of the pull down from being transmitted to the upper thread.

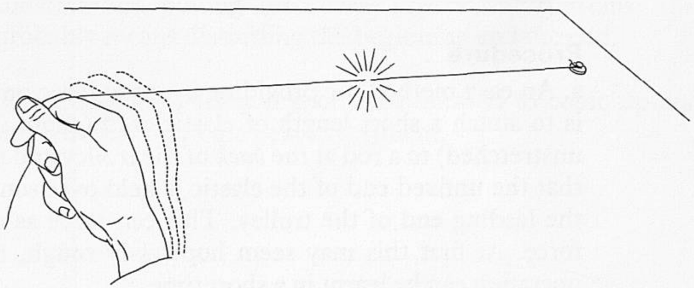


c. A pile of books is set up on the bench and one of the books in the middle is pulled smartly out without upsetting the pile. The operator must pull the book with sufficiently big acceleration to ensure that the force that would be needed to give the books above the same acceleration is bigger than limiting friction. Thus, there is slipping and the pile above does not manage to follow the book being pulled out.



d. Thread (breaking force, say, 100 grams weight) tied to a one-gram mass of brass. With strong sewing cotton, the mass needs to be 5 or even 10 grams for success.

A thread is tested for breaking force and shown to be able to stand a load of, say, 100 grams. A one-gram piece of brass is tied to the thread and placed on the table. Teacher holds the other end of the thread with the thread slack. A very abrupt jerk on the other end of the thread will break it.



e. As a reverse form of (a), we can push a wooden brick in at the bottom of a pile of similar bricks. The bricks should be smooth blocks of wood, say 4 in by 3 in by 2 in, with their edges and corners rounded. We build a pile of 4 bricks, then push a fifth brick quickly at the bottom brick of the pile. The fifth brick goes in and the bottom brick goes out. This is most dramatic if the fifth brick is projected along the table towards the pile by a 'croquet hit' from a small mallet.

58 Class experiment

Investigating acceleration with trolleys

Apparatus

16 runways	– item 107
16 dynamics trolleys	– item 106/1
48 elastic cords for accelerating trolleys	– item 106/2
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27

Procedure

a. An easy method for providing a steady force on the trolley is to attach a short length of elastic cord (about 20 cm long unstretched) to a rod at the *back* of the trolley and extend it so that the unfixed end of the elastic is held over some mark on the leading end of the trolley. This can serve as one unit of force. At first this may seem hopelessly rough, but skill in operation can be learnt in a short time.

Some may prefer to put a pencil or dowel through the eyelet in the free end of cord and hold that level with the pegs in the trolley, but of course not touching them.

In later experiments it will be necessary to stretch several cords at once by the same amount. For this, attach several cords to the pulling post before starting the experiment, then hold the bunch of the eyelets level with the pegs at the other end of the trolley. The elastic cords will then all be stretched approximately the same amount.

The runway on which the trolley will run should be swept clean of any small particles and the wheels of the trolley should also be clean. The smallest irregularities have adverse effects on the results.

The ticker-tape vibrator can be rested on the end of the board.

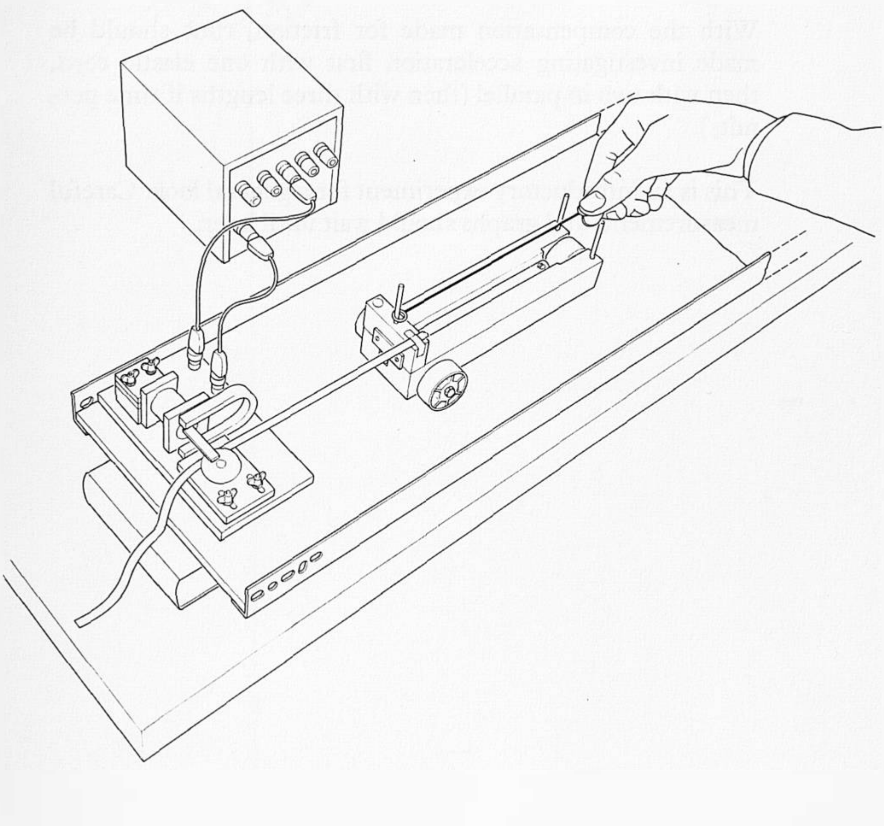
It is desirable to put some sort of stop at the end of the runway to prevent damage to the trolleys: a string across the end can make an effective stop.

Once the apparatus is assembled, it takes a very short time for *each pupil* to obtain a personal tape.

The tapes should be carefully cut up into ten-tick lengths and fixed side by side on lined paper in the usual way. (A ten-tick length may be too long for the page if the trolley is moving fast and in that event five-tick lengths should be used.)

Only that part of the tape should be used for which pupils consider the pulling force was kept fairly constant: this probably means discarding the beginning and the end.

The question of friction should be allowed to come up and this will lead on to the next experiment.



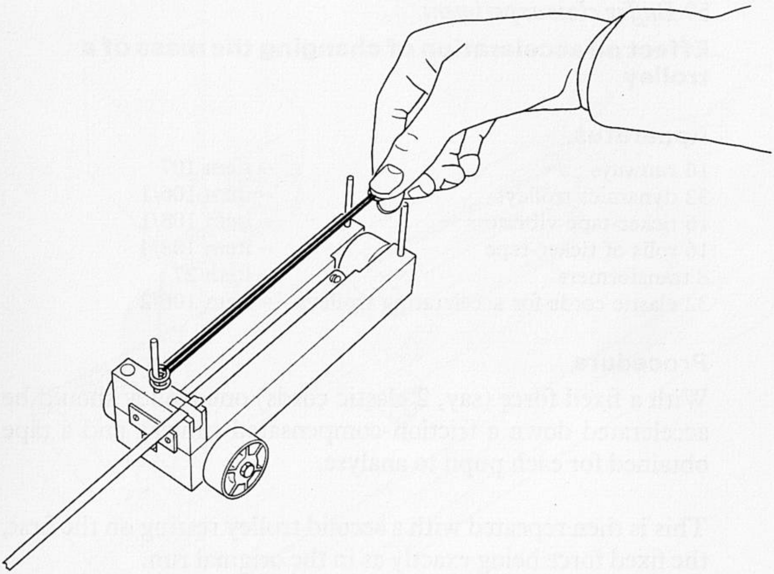
b. Discussion of friction should elicit the suggestion that the board should be inclined slightly to compensate for friction.

The pupils should find which angle enables a moving trolley just to keep moving down the slope *once given a start*. They should then test it with a run of the trolley using tape. In this test, the trolley should be given a push and pupils should satisfy themselves that the distance between the dots is nearly constant for any particular run.

It has been found that most pupils tilt the board at too great an angle if they have not checked it with timers and tape. The teacher is advised to check this adjustment by watching a trial run.

With the compensation made for friction, runs should be made investigating acceleration first with one elastic cord, then with two in parallel (then with three lengths if time permits).

This is an introductory experiment for a general look. Careful measurements and graphs should wait until later.



59 Buffer class experiment

Effect on acceleration of changing the mass of a trolley

Apparatus

16 runways	– item 107
32 dynamics trolleys	– item 106/1
16 ticker-tape vibrators	– item 108/1
16 rolls of ticker-tape	– item 108/4
8 transformers	– item 27
32 elastic cords for accelerating trolleys	– item 106/2

Procedure

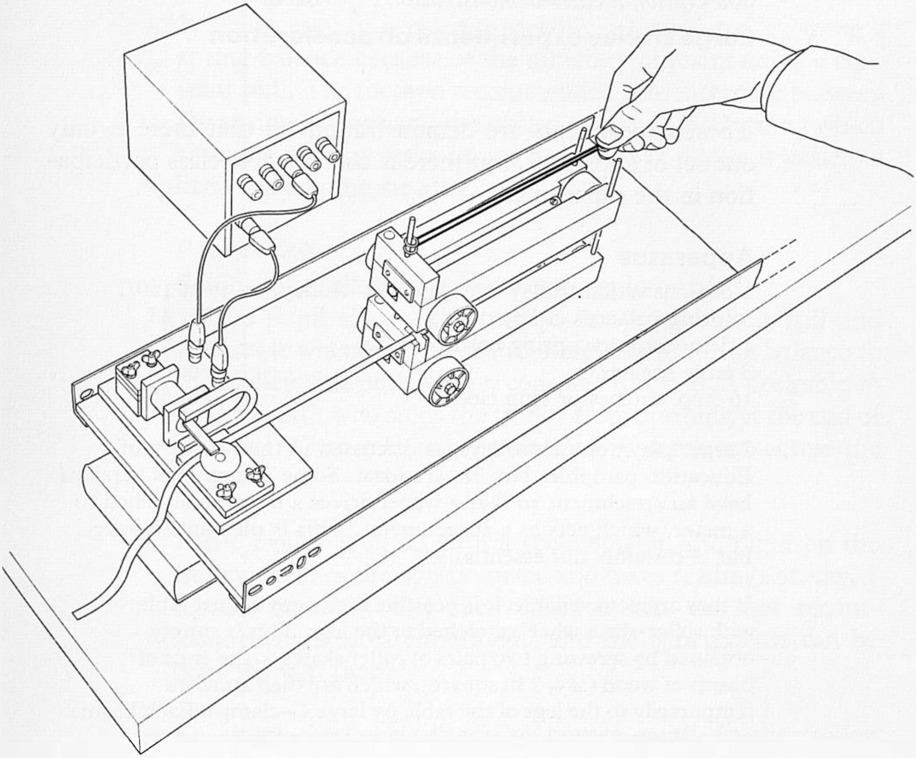
With a fixed force (say, 2 elastic cords) one trolley should be accelerated down a friction-compensated runway and a tape obtained for each pupil to analyse.

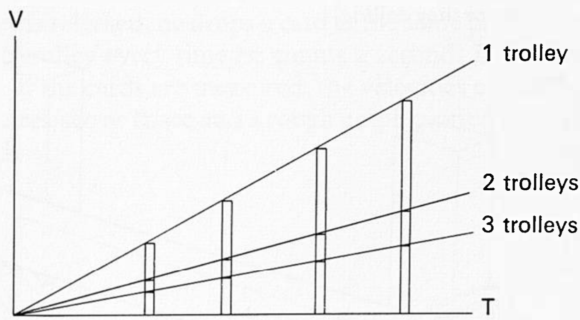
This is then repeated with a second trolley resting on the first, the fixed force being exactly as in the original run.

If time and enthusiasm allow, a third trolley can be borrowed from a neighbouring group so that two trolleys can be stacked on the first and a run obtained.

The tapes so acquired should be fixed in a chart as before, not converted to graphs. If the tapes for each run can be marked distinctively (with crayons) and pasted over each other on the same chart using the same axes, the effect of the increase mass may be made clear.

At the end of these experiments, the pupils should be left with a general idea that a constant force produces constant acceleration and that two trolleys need twice as much force as one for the same acceleration.




V
1 trolley
2 trolleys
3 trolleys
T

60a *Optional class-demonstration experiment*

Large trolley experiments on acceleration

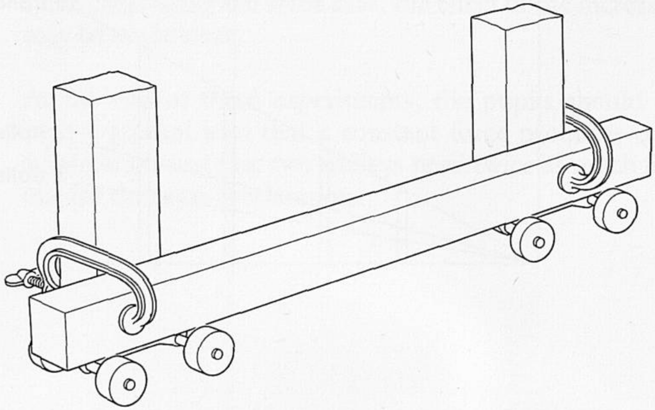
These experiments are demonstrations in that there is only one set of apparatus, but there is considerable class participation in the experiments.

Apparatus

1 demonstration trolley ('playground' trolley)	– item 160/1
3 spring balances (1 kg)	– item 43
1 demonstration spring balance (5 kg)	– item 85
3 large springs	– item 88
16 stop watches or stop clocks	– item 507

Large 'playground' trolleys, as discussed in the Ministry of Education pamphlet No. 38, are ideal. Some commercial versions have an attachment so that a wheel drives a dynamo attached to a meter, which acts as a speedometer. This is pleasant to have, but is certainly not essential.

If they are not available, it is possible to use any robust table with roller-skate wheels attached to the legs. This is simply obtained by screwing two pairs of roller skates to the ends of beams of wood (say, 3 in square), which are then attached temporarily to the legs of the table by large G-clamps. Each beam of wood must be as long as the table and the wheels must be carefully aligned. Such tables also need buffer pads at the top where they collide.



Technique for accelerating trolleys

It is not easy to accelerate steadily a loaded trolley using a spring balance because of the difficulty of maintaining a constant pull. The method recommended is to interpose between the spring balance and the trolley a strong spiral spring which smooths out any jerks in the motion and makes it easier to keep the reading steadier.

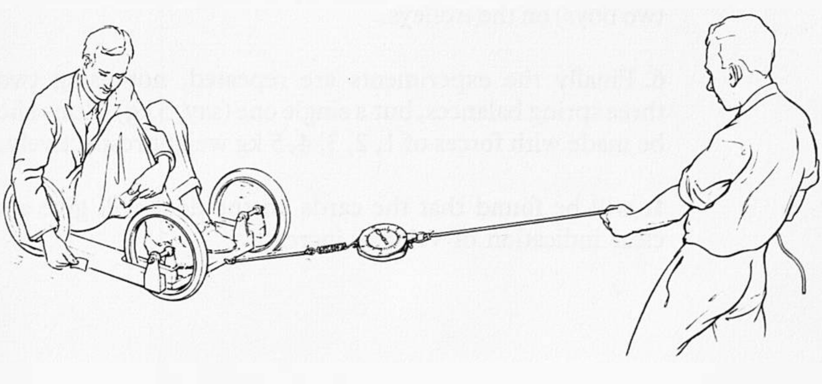
Procedure

Some of the following experiments might be tried:

1. One pupil sits on the trolley. Another holds it still and releases it when ready. A third attaches the spring balance to the trolley and pulls with a constant force. It is desirable to have a fourth who stops the trolley from crashing at the end of the run! When released the trolley will accelerate across the room.

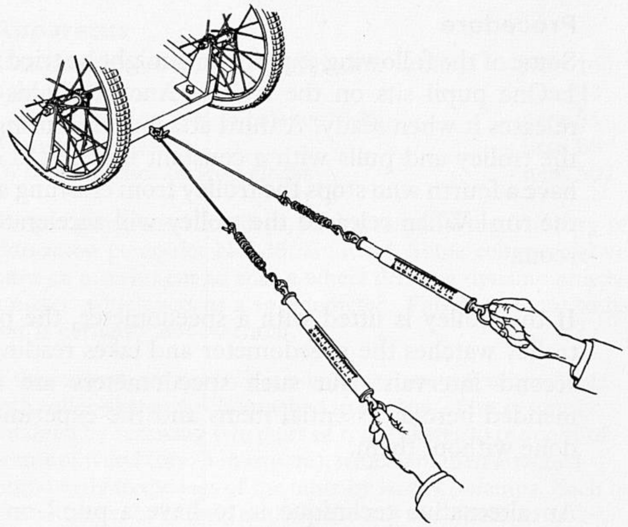
If the trolley is fitted with a speedometer, the pupil on the trolley watches the speedometer and takes readings at, say, 1 second intervals. But such speedometers are not recommended here as essential items and the experiments can be done without them.

An alternative technique is to have a pupil on the trolley counting seconds. He is given a pile of cards and when the trolley is released, he drops a card at the same position relative to the trolley every time he counts a second. If the distances apart of the cards are measured, the velocities can be deduced in metres/sec or ft/sec and a rough graph plotted on the blackboard.



2. Whilst the above experiment is being done, other pupils can measure the total time for the trolley to cover a standard distance, say 30 ft, from rest.

3. The above experiments are now repeated with two pupils in parallel, each pulling with the same force of, say, 1 kg weight.

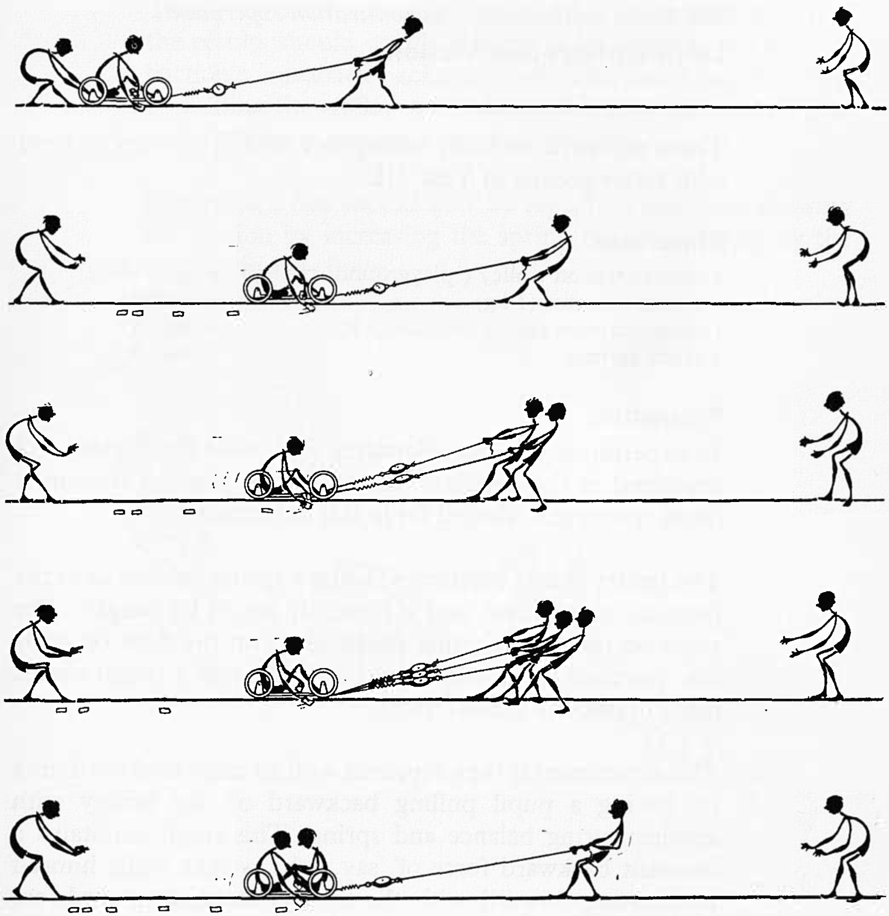


4. They are then repeated with three equal pulls of, say, 1 kg weight in parallel. It is not easy to apply the three forces in this way, but a little practice (and the avoidance of large boys) makes it possible.

5. The experiments are then repeated with a larger mass (e.g. two boys) on the trolleys.

6. Finally the experiments are repeated, not using two or three spring balances, but a single one (say, 5 kg). Runs should be made with forces of 1, 2, 3, 4, 5 kg weight respectively.

It will be found that the cards on the floor will give a very clear indication of velocity increase.



60b *Extra optional class-demonstration experiments*

Large trolleys and friction

These experiments really belong to Year IV, but may be tried with faster groups in Year III.

Apparatus

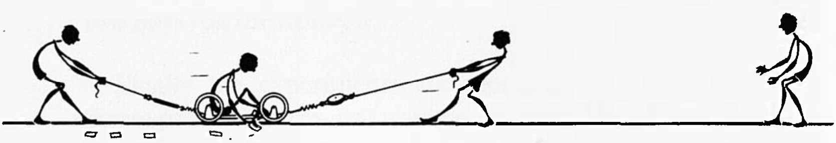
1 demonstration trolley ('playground' trolley)	– item 160/1
3 spring balances (1 kg)	– item 43
1 demonstration spring balance (5 kg)	– item 85
3 spiral springs	– item 88

Procedure

In experiment 60a, no allowance was made for friction. As explained in the *Teachers' Guide*, the problem of friction is faced openly and allowed for in this experiment.

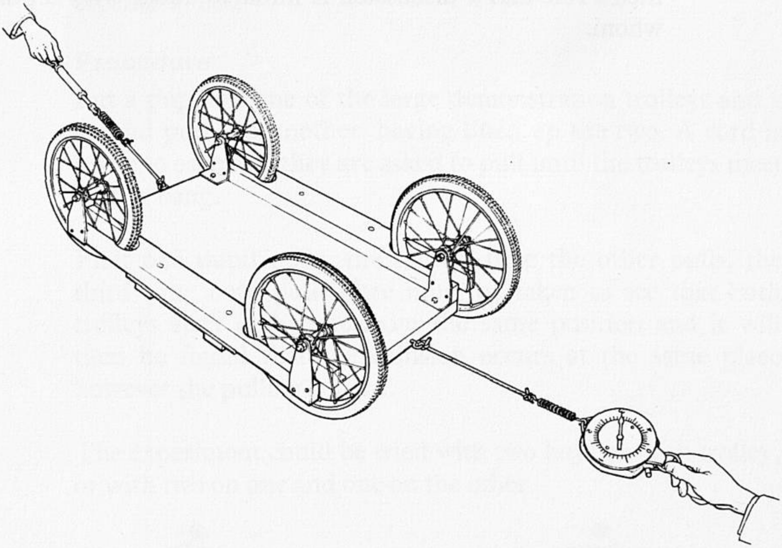
The trolley is first accelerated using a spring balance as in the previous experiment and a force of, say, 3 kg weight. The pupil on the trolley either drops cards on the floor or reads the speedometer at one second intervals and a rough plot is made of velocity against time.

The experiment is then repeated with an extra backward drag by having a pupil pulling backward on the trolley with another spring balance and spring. This pupil maintains a constant backward force of, say, 1 kg weight while himself progressing forward with the trolley. Once again cards are dropped and a plot is made of velocity.



This is repeated with other backward drags and discussion of the results should enable a guess to be made at the force of friction's concealed backward pull. The result can be tested by pulling the trolley with exactly this amount to see if it is just the force to maintain constant velocity.

Experiment 60a should now be repeated, this time allowing for friction by increasing the spring balance reading by the amount found above.



Note

Where the floor is smooth and unyielding, and the trolley wheels are of good quality, friction may be allowed for by pulling the trolley by hand and also by a string which runs along to a pulley fixed near to the bottom of a wall, up to the ceiling, and over a second pulley to a small load. This load should be just enough to keep the trolley moving steadily, thereby compensating for friction.

61 *Demonstration*

Action and reaction with a metre rule

Apparatus

1 metre rule – item 501

Procedure

The teacher and a pupil (or two pupils) pull at either end of a metre rule and a discussion is initiated about who is pulling whom.

62 *Optional demonstration*

Action and reaction: trolleys

Apparatus

2 demonstration trolleys ('playground' trolleys) – item 160/1
1 length of rope

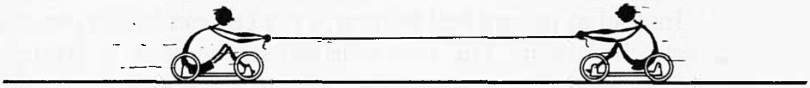
For details of the demonstration trolleys and how they can be constructed from a robust table and roller skate wheels, see experiment 60a.

Procedure

Put a pupil on one of the large demonstration trolleys and a second pupil on another, having lined up the two. A cord is given to each and they are asked to pull until the trolleys meet with a bang.

First one pupil pulls, the second time the other pulls, the third time both pull. Care must be taken to see that both trolleys start each time from the same position and it will then be found that the collision occurs at the same place however the pulling is done.

The experiment could be tried with two boys on each trolley, or with two on one and one on the other.



63 *Optional demonstration*

Multiflash photographs of free fall

This is an experiment for Year IV, but if schools have the apparatus, it can be an optional experiment in Year III.

Apparatus

1 steel ball (1 in or $\frac{3}{4}$ in diameter)	– item 131A
1 camera	– item 133
1 motor-driven stroboscope	– item 134/1
1 retort stand and boss	– items 503–505
1 lamp	

A polystyrene ball (item 3B) can be used instead of the steel ball. Whichever is used, it must be strongly illuminated.

Procedure

The motor-driven stroboscope is set up in front of the camera. The ball bearing should be strongly illuminated and the rest of the room is three-quarters blacked out.

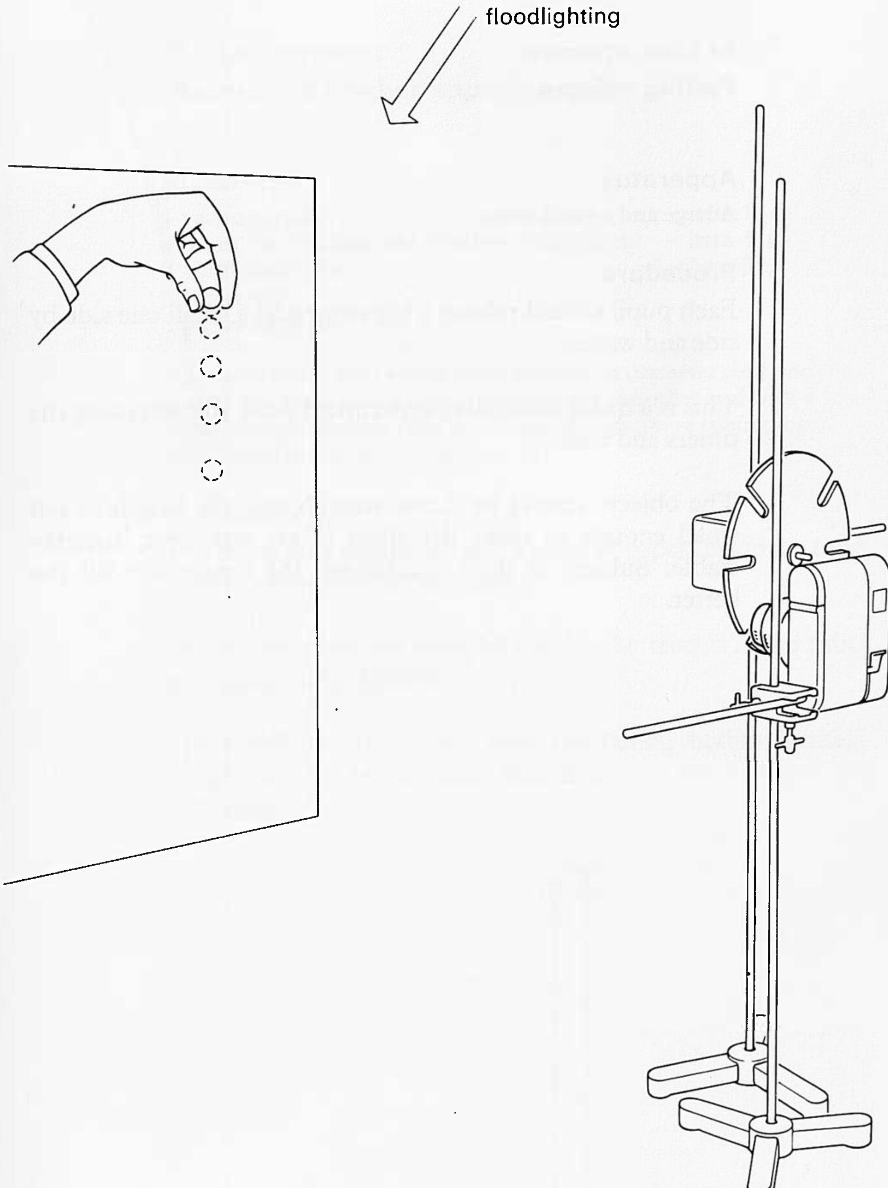
The motor stroboscope is set rotating. One pupil should operate the camera whilst another drops the ball bearing. After a count-down, the camera shutter is opened just before the ball is dropped.

Instead of using a ball bearing, a dry cell can have a pea-lamp attached to it. The motor-driven stroboscope is set up in front of the camera and the cell is dropped by hand. Some cushioning on the floor is necessary to prevent breakage of the lamp. Good blackout is advisable for good photographs with this technique.

The distances between successive images of the object should be carefully measured on any convenient scale and plotted at equal intervals so that the ends of each line can be joined to show the uniform increase, which is the object of this experiment.

Note

See Appendix I at the end of the Year IV *Guide to Experiments* for full details on multiflash photography.


floodlighting

64 *Class experiment*

Falling objects

Apparatus

A large and a small stone

Procedure

Each pupil should release a big stone and a small one side by side and watch.

This is a quick qualitative experiment done without using the timers and tape.

The objects should be dense enough and the length of fall small enough to make the effect of air resistance inappreciable. Subject to these conditions, the longer the fall the better.

65 *Class experiment*

'Guinea and feather' experiment

Apparatus

1 vacuum pump	– item 13
8 tubes for 'Guinea and Feather' experiment	– item 110
8 Hoffmann clips	– item 522
8 sixpences	
8 pieces of paper	

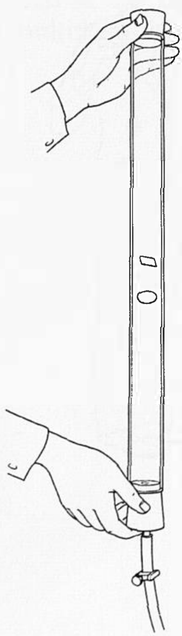
The tubes (item 110) are 24 in by 2 inches in diameter; one end should be closed with a plain rubber bung, the other end with a bung through which a tube is connected to pressure tubing for attachment to the vacuum pump.

Procedure

The pupil puts a sixpence and a piece of paper inside the tube, which he closes with the bungs.

Successive tubes are pumped out by the teacher. The tubes are sealed with a Hoffmann clip.

The pupil can then play with the falling bodies himself. Finally he can let air back into the tube and observe the difference.



66a *Class experiment*

Independence of vertical and horizontal motions

Apparatus

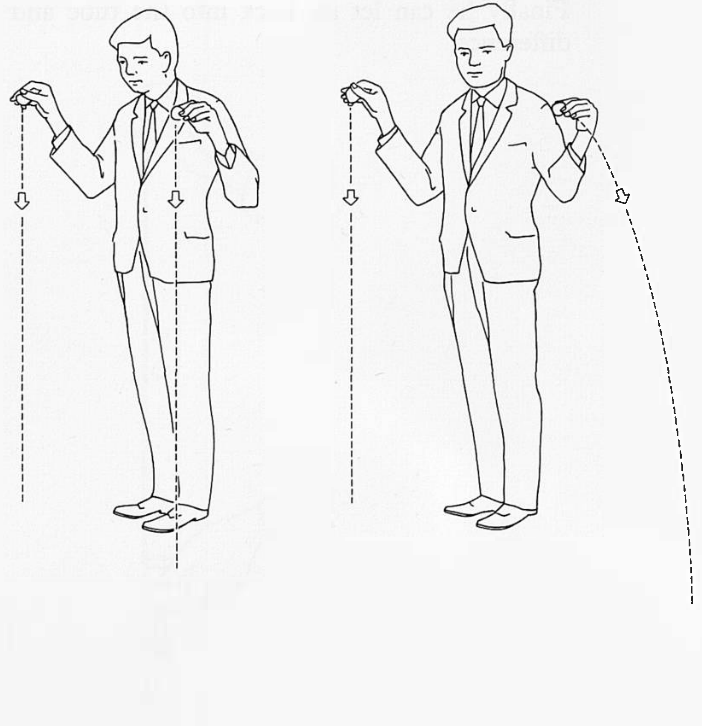
Stones

Procedure

Pupils should do a class experiment themselves, dropping two stones, one from each hand. First they should drop both vertically and thereby practise releasing them simultaneously (as evidenced by hearing them fall together). Secondly they should give one of the stones a horizontal motion by moving one of their hands sideways as they release both. Thirdly they should throw both stones out sideways with different velocities.

They should also try different heights of fall, and with stones of unequal size.

There may be some advantage in doing these experiments in the open. They might also be tried out of an open window.



66b *Optional demonstration*

Multiflash photographs of projectiles

The multiflash photography techniques are intended for Year IV, but if schools have the apparatus this can be an optional experiment in Year III.

Apparatus

1 steel ball (1 in or $\frac{3}{4}$ in diameter)	– item 131A
1 camera	– item 133
1 motor-driven stroboscope	– item 134/1
1 retort stand and boss	– items 503–505
1 lamp	

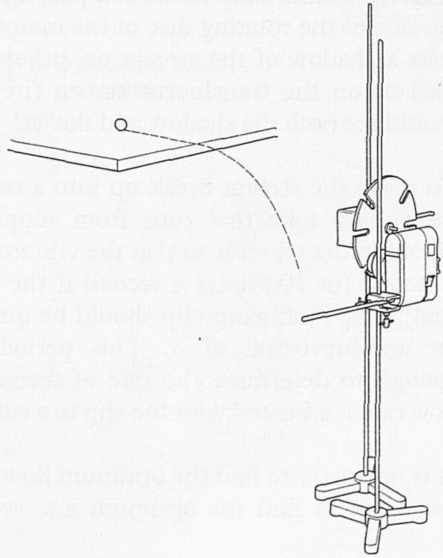
Procedure

The motor-driven stroboscope is set up in front of the camera. The steel ball should be very strongly illuminated and the rest of the room three-quarter blacked out.

The motor stroboscope is set rotating. One pupil should operate the camera, whilst another launches the ball. After a count-down, the camera shutter is opened as the steel ball is launched from the top of a bench by rolling it along the top.

Note

See Appendix I at the end of the Year IV *Guide to Experiments* for full details of multiflash photography.



67 Demonstration

Pulsed water drop experiment

Apparatus

1 compact light source	– item 21
1 motor-driven stroboscope (with disc of 5 slits)	– item 134/1
1 ticker-tape vibrator	– item 108/1
1 constant head of pressure apparatus	– item 166
1 L.T. variable voltage supply	– item 59
4 retort stands, bosses and clamps	– items 503–506
1 Hoffmann clip	– item 522
1 translucent screen	– item 46/1
1 converging lens (focal length 10–15 cm, large aperture)	– item 93B
1 lens holder (for item 93B)	– item 124/2
1 bucket	– item 533

Procedure

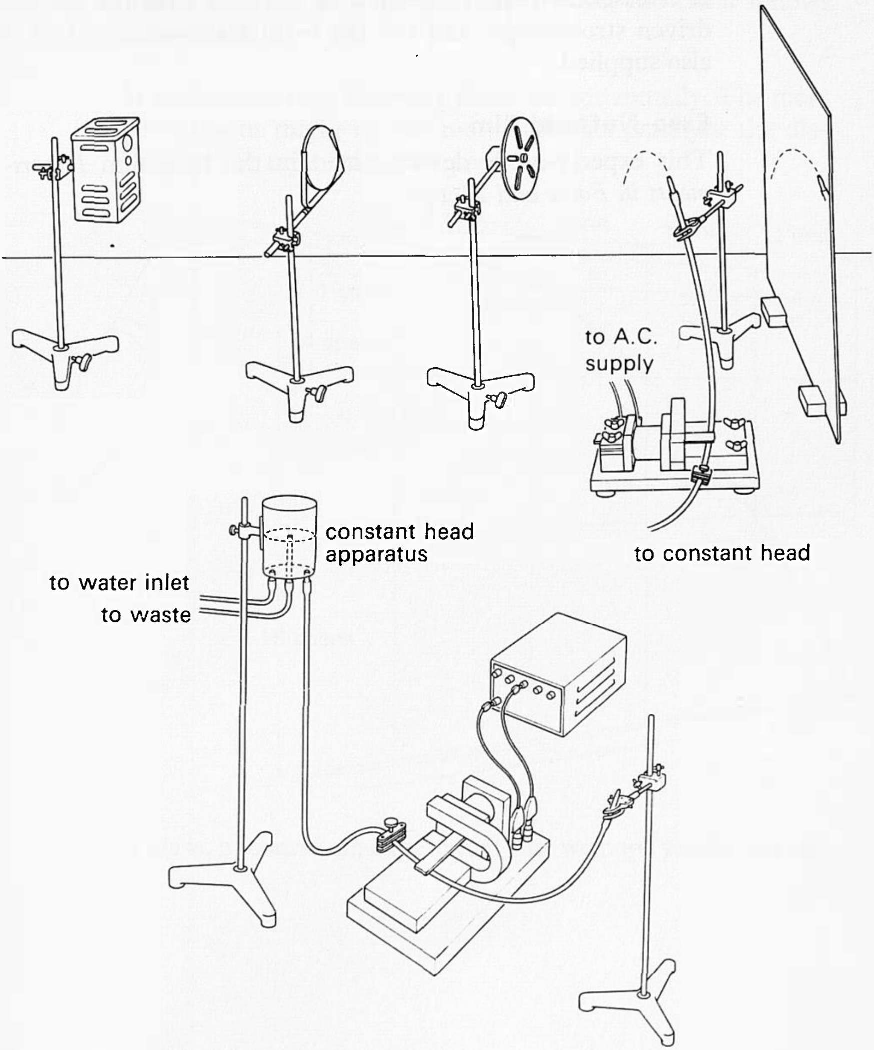
Water from a constant pressure supply, held high above the bench, flows out through a rubber tube squeezed by a Hoffmann clip to reduce the flow to a small stream. At the end of the tube there is a short piece of glass tubing drawn out to make a jet. The height of the constant pressure supply should be such that if the stream is directed vertically upward it rises to a height of 6 to 12 in above the jet.

The lens is placed so that a sharp image of the filament of the tungsten-iodine lamp in the compact light source is formed on the slits of the rotating disc of the motor stroboscope. It then casts a shadow of the stream on either a white screen (item 102) or on the translucent screen (item 46/1). The pupils should see both the shadow and the jet.

To make the stream break up into a regular series of drops, the rubber tube that runs from supply to the glass jet is placed in the vibrator so that the vibrator squeezes it 50 times a second (or 100 times a second if the vibrator is not polarized). The Hoffmann clip should be quite close to the vibrator and upstream of it. This periodic encouragement is enough to determine the rate of formation of drops, if the flow rate is adjusted with the clip to a suitable value.

It is necessary to find the optimum flow rate by trial. It is also necessary to find the optimum a.c. voltage to apply to the vibrator by trial. It is convenient to run the vibrator from the a.c. terminals of the L.T. variable voltage supply.

Viewed without the stroboscope, the stream will look continuous. When the stroboscope is switched on so that the 5 slits of the disc interrupt the beam of light 25 times a second (the synchronous motor runs at 300 r.p.m.), the stream is seen as a series of separate drops, which can be 'frozen' in the shadow cast on the screen. For sharp freezing of drops, it is essential to make the stroboscope cut the light off sharply. Therefore a lens must be used to form a compact image of the filament at the slit of the stroboscope.



The above will have shown that the vertical motion is accelerated. To demonstrate that the horizontal motion has constant velocity, impose a rectangular grid or project the shadow on a screen ruled with squares.

The easiest way is to install a rectangular grid of wires, vertical and horizontal sets 1 in apart. Adjust the angle of the jet or the speed of the water by means of the clip, so that the shadow of each drop (or every second or third drop) falls on the shadow of a wire. Even horizontal spacing will be found.

Note

It is essential that the 5-slit disc be used with the motor-driven stroboscope, and not the 6-slit disc with which it is also supplied.

Esso-Nuffield film

This experiment is demonstrated in the Esso film *Experiments in Force and Motion.*

68a *Optional buffer demonstration*

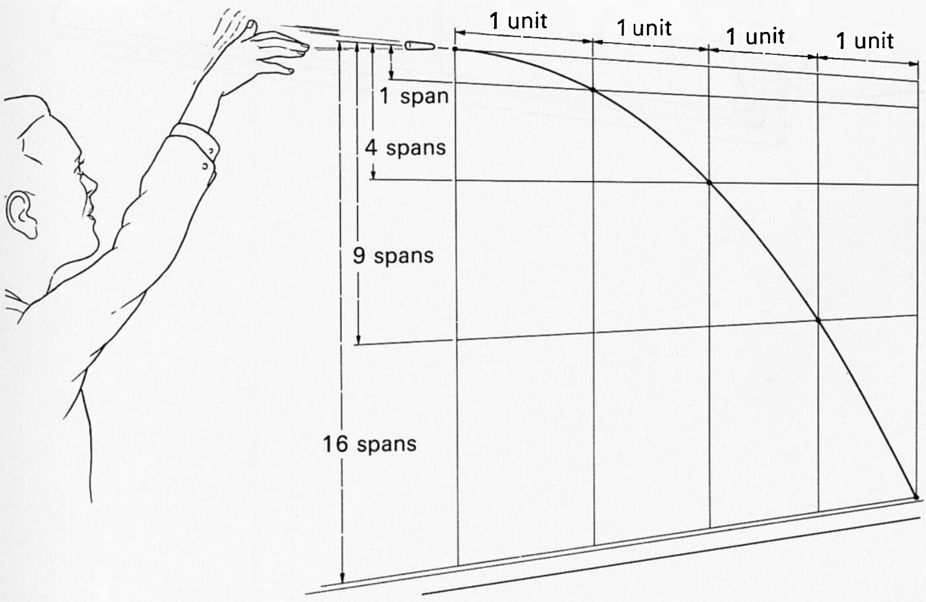
Testing projectile motion with a parabola drawn on the blackboard

This demonstration is recommended for fast groups; it should be optional for slower ones.

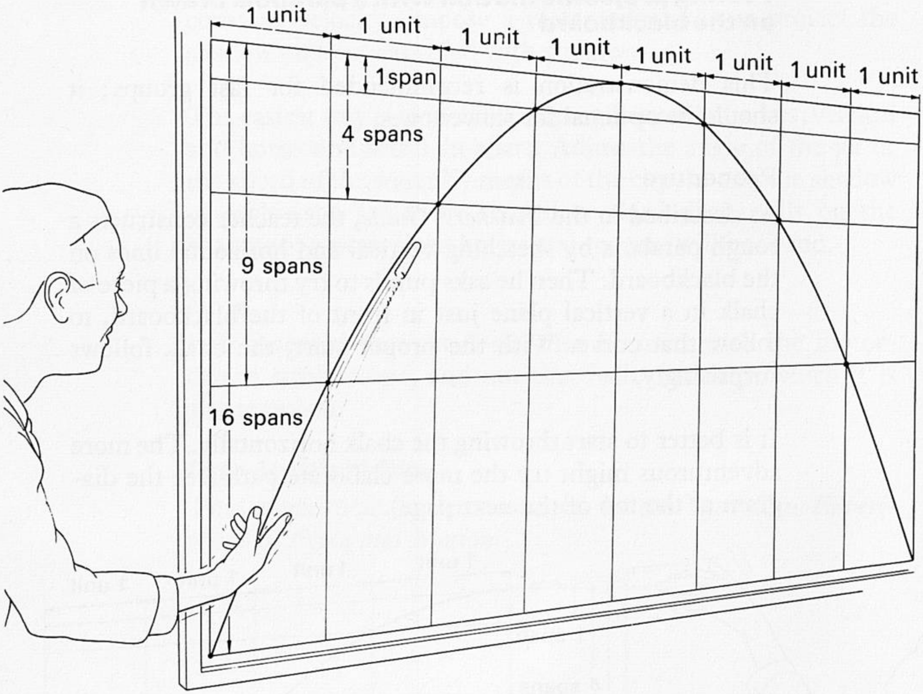
Procedure

As described in the *Teachers' Guide*, the teacher constructs a rough parabola by sketching vertical and horizontal lines on the blackboard. Then he asks pupils to try throwing a piece of chalk in a vertical plane just in front of the blackboard, to follow that curve. With the proper start, the chalk follows surprisingly.

It is better to start throwing the chalk horizontally. The more adventurous might try the more elaborate path (see the diagram at the top of the next page).



This is, of course, an experiment that we hope pupils will also do at home and manufacture there for their own amusement.



68b *Optional demonstration*

Water jet following a parabola drawn on the blackboard

Procedure

Instead of asking pupils to throw pieces of chalk, throw a stream of water drops up in front of a constructed parabola.

To obtain a uniform stream that behaves well, use water drops from a pulsed jet. See experiment 67 for details of the pulsed water drop technique.

69a *Demonstration*

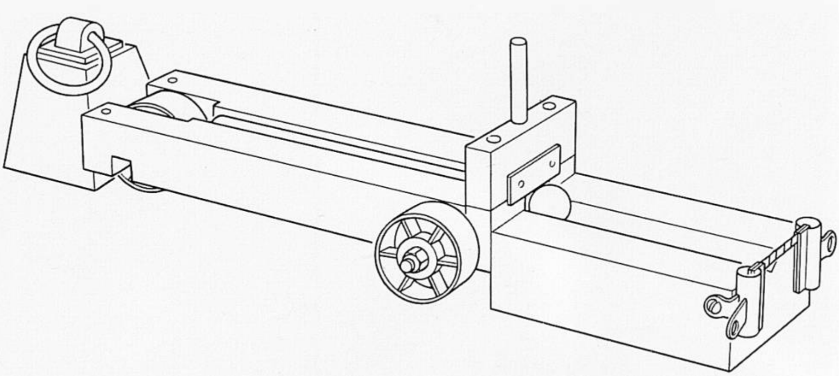
The 'monkey and hunter' experiment

Apparatus

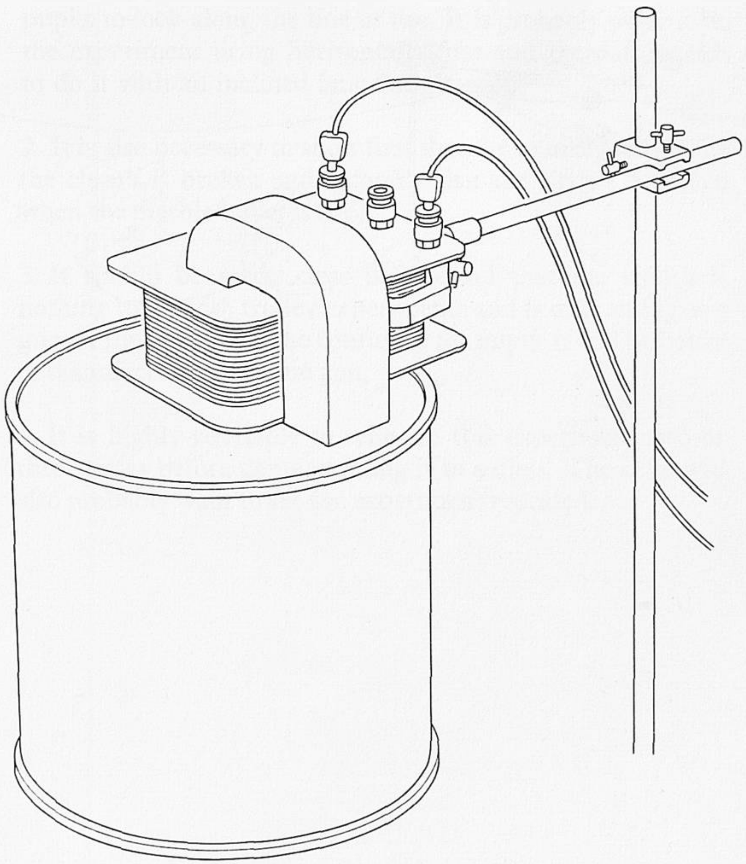
1 dynamics trolley	– item 106/1
1 launching ramp	– item 123
1 L.T. variable voltage supply	– item 59
1 coil (120 turns)	– item 127
1 C-core	– item 92G
1 drawing board	– item 551
1 retort stand, boss and clamp	– items 503–506
1 marble	– item 12B
1 tin (about 4 in diameter)	
1 d.c. ammeter (0–1 amp)	– item 79
2 long connecting leads (8 ft)	
2 crocodile clips	
G-clamps	
aluminium cooking foil	

Procedure

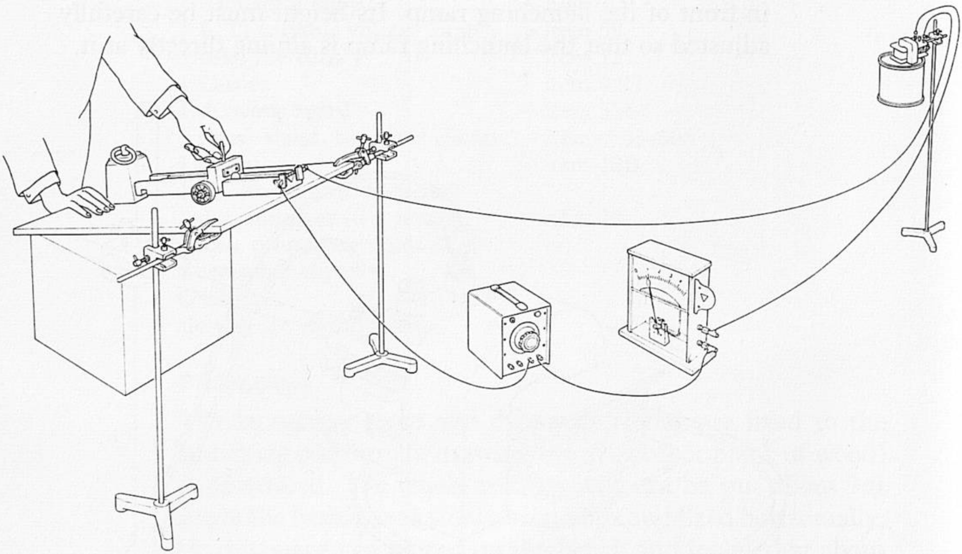
The launching ramp and dynamics trolley are fixed to the launching platform (a drawing board or other plank of wood) as illustrated. The whole arrangement can be put about 3 ft above the bench, on a stool or rigid box and fixed horizontally. Or the board can be put on the bench and inclined at about 15° upwards from the bench. The projectile is an ordinary marble, placed in the groove of the launching ramp, level with the rod of the trolley which is cocked ready for firing. On release of the trigger, the dowel springs along the ramp striking the marble which is projected forward.



The 'monkey' is provided by the tin can which is held in place using the C-core and 120 turn coil, through which a current flows provided by the L.T. variable voltage supply. It is convenient to include an ammeter in the circuit: the tin will be supported (open end downwards) when a current of about 0·7A flows. The 'monkey' should be set up about 2–3 metres in front of the launching ramp. Its height must be carefully adjusted so that the launching ramp is aiming directly at it.



The trigger mechanism to release the 'monkey' is a strip of aluminium foil, across the end of the launching ramp. This strip is included in the circuit of the electromagnet holding up the tin. The position of the foil is such that the marble breaks it at the moment it leaves the ramp.



Notes

1. The demonstration is meant to show that the bullet and the monkey both fall equal amounts vertically in the same time. Therefore it is essential for pupils to see clearly beforehand that the gun is aimed straight at the monkey. It does not give this essential fact enough importance if we simply state it. If the launching ramp is horizontal this will be more obvious, but if the experiment is done with the drawing board and launching mechanism inclined, it will be necessary to get the pupils to look along the line of fire. It is probably wiser to do the experiment firing horizontally first and then afterwards to do it with an inclined launching ramp.

2. It is also necessary to show first that the monkey falls when the circuit is broken and secondly that the circuit is broken when the marble bullet is fired.

3. It should be made clear beforehand that the trolley is nothing to do with trolley experiments and is only acting as a gun. If this is found to be confusing for pupils it will be better to manufacture a separate gun.

4. It is highly advisable to rehearse this experiment two or three times before demonstrating it to a class. The class will also probably want to see the experiment repeated.

69b *Optional additional demonstration*

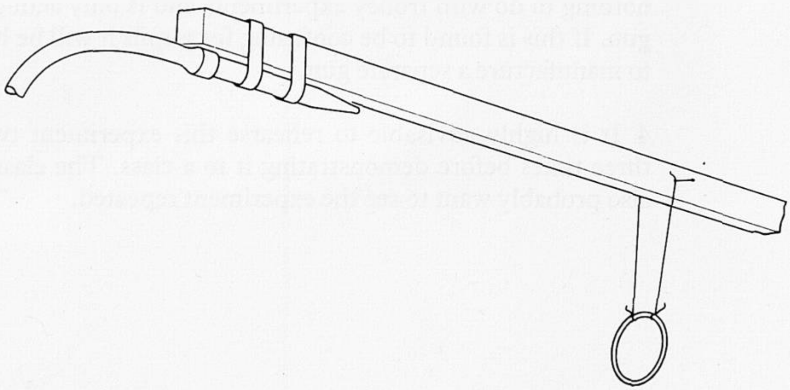
Water jet through rings

Apparatus

1 glass tube drawn to a jet
1 rigid wood pole or beam at least 7 ft long
3 rings, about 3 in–4 in diameter
1 constant head of pressure apparatus – item 166
2 retort stands, bosses and clamps – items 503–504
1 bucket – item 533
thread
panel pins
rubber tubing

Procedure

The glass jet is securely strapped to one end of the pole or beam so that water emerging from the jet will do so in a direction parallel to the length of the pole.



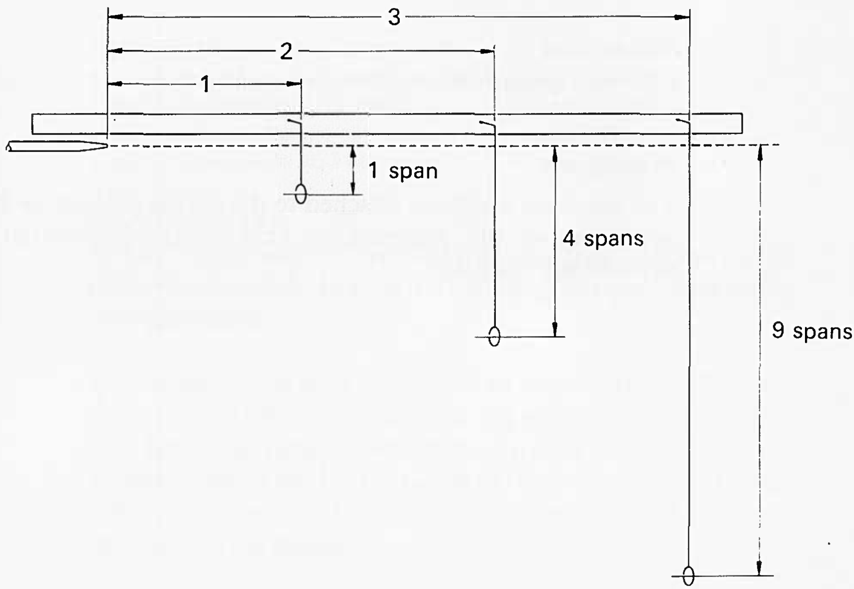
At equal distances from the end of the jet, pairs of panel pins are hammered into the pole or beam as shown.

These pins serve to support the rings by bifilar threads whose lengths between the levels indicated are 6 in ($\frac{1}{2}$ ft), 2 ft ($4 \times \frac{1}{2}$ ft), and 4 ft 6 in ($9 \times \frac{1}{2}$ ft).

The rod is mounted horizontally near to a sink and the jet connected to the constant pressure head high above the bench.

The water is turned on and adjusted until a jet of water passes through each of the rings on its way to the sink or bucket.

The whole device can now be tilted to other angles, showing that the water stream will continue to pass through the rings.



70 *Class experiment*

Gravitational field strength

Apparatus

8 Newton spring balances (10n)	– item 81
8 1-kg weights	– item 32

Procedure

The kilogram weight is attached to the spring balance so that pupils can see the 'gravitational field strength' measured in newtons per kilogram.

71a *Demonstration*

Model for kinetic theory of a gas

Apparatus

1 three-dimensional kinetic model kit	– item 11
1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
1 retort stand, boss and clamp	– items 503–506

Procedure

1. The rubber base is fixed over the lower end of the plastic tube, which is held in a vertical position using a retort stand, boss and clamp.

The height of the tube is adjusted so that the rubber base is a millimetre or two above the vibrating rod in its mean position. The fractional horse-power motor is used for activating the vibrating rod. The d.c. terminals of the L.T. variable voltage supply are connected in parallel to the field and armature terminals of the motor.

The small phosphor bronze ball bearings are put inside the long tube so that they rest on the bottom. The most effective number will cover about two-thirds of the base. The brass cap should be put over the top of the tube: it prevents balls from coming out and it cuts down the noise.

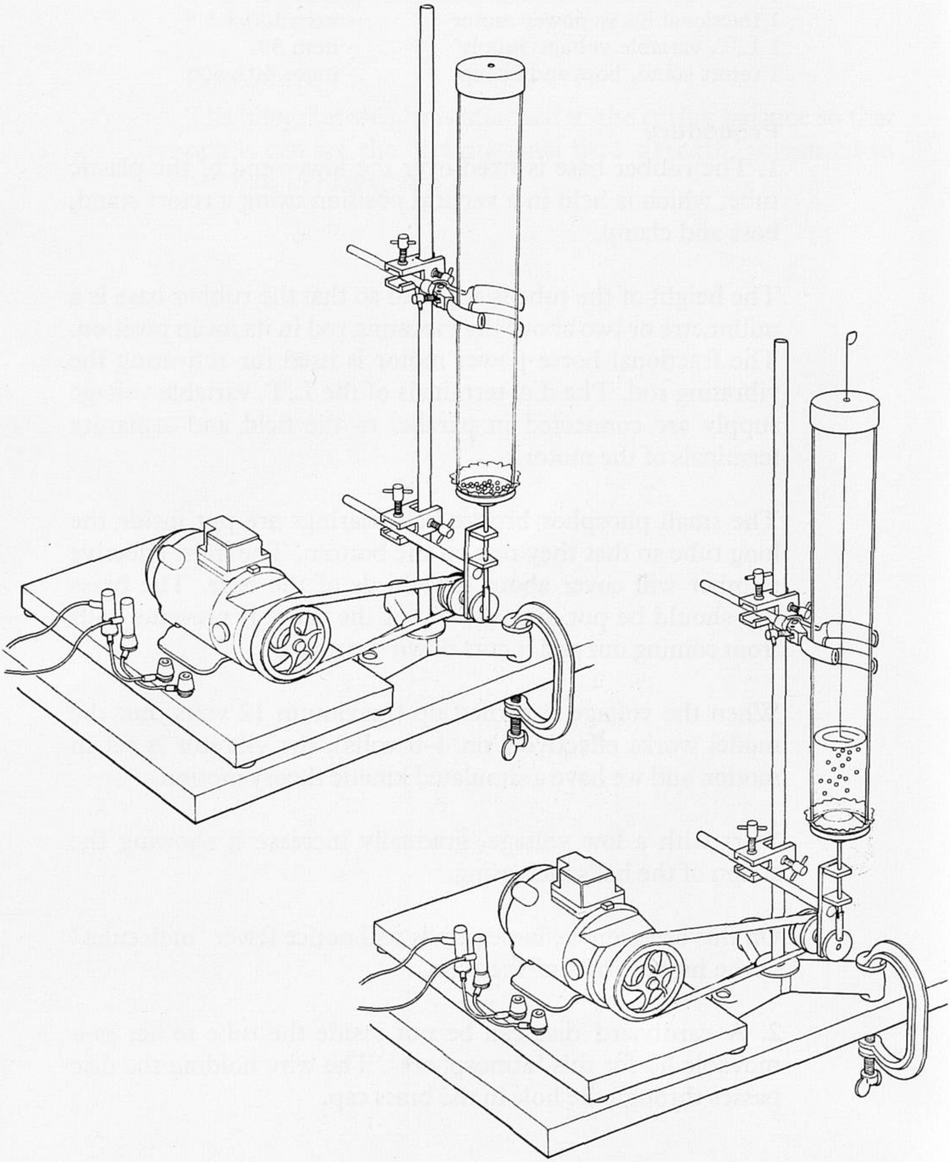
When the voltage is turned up (maximum 12 volts, but the model works effectively on 4–6 volts), the vibrator is set in motion and we have a simulated kinetic theory motion.

Start with a low voltage, gradually increase it showing the action of the balls increasing.

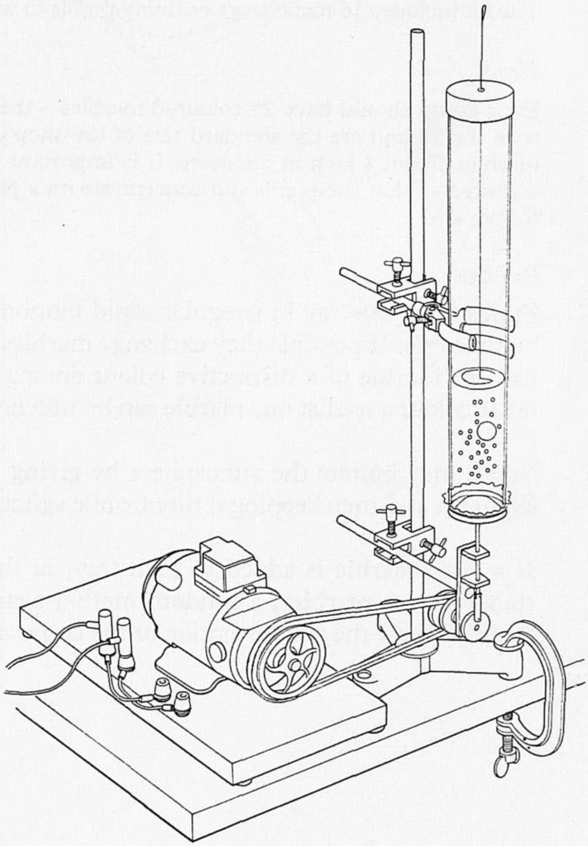
On this occasion we hope pupils will notice fewer 'molecules' in the higher parts of the tube.

2. A cardboard disc can be put inside the tube to act as a movable lid for this 'atmosphere'. The wire holding the disc passes through the hole in the brass cap.

This disc falls to the bottom when the vibrator is switched off. When the vibrator is switched on, the disc rises again to a position where its weight is just balanced by the force due to the pressure of the 'atmosphere'. Various small cardboard weights can be added on top of the disc.



3. Brownian motion can be imitated by suspending a foamed polystyrene sphere (item 51D) among the small 'gas molecules' of this model. (Note that this is not an exact model as 'buoyancy' and gravity play important parts, but the irregular motions of the large ball do essentially show a large-scale version of Brownian motion.)



Notes

1. Some teachers will find the translucent screen (item 46/1) and lamp very helpful in demonstrating this experiment. The model is then silhouetted against a bright background.

2. In some Nuffield trials, teachers used a different vibrator than that illustrated above. They found the rubber base was soon damaged, but that its life was prolonged considerably by sticking a small disc of aluminium foil on the rubber.

71b *Class experiment*

Tray of marbles in constant agitation as a two-dimensional kinetic model

Apparatus

1 two-dimensional kinetic model kit – item 12

The kit includes 16 metal trays enabling pupils to work in pairs.

Note

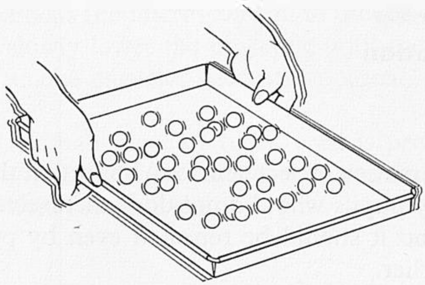
Each group should have 25 coloured marbles – these are included with the kit and are the standard size of toy-shop coloured marbles, about $\frac{5}{8}$ inch in diameter. It is important that these are coloured so that the pupils can concentrate on a particular one if they wish.

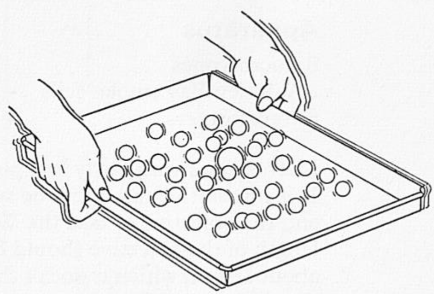
Procedure

Pupils keep the tray in irregular rapid motion keeping it flat on the table. If possible they exchange marbles until each tray has one marble of a distinctive colour among a collection of other colours, so that one marble can be watched.

Pupils may imitate the atmosphere by giving the tray a very slight tilt and then keeping it tilted while agitating it.

If a large marble is added to each tray, in the midst of the standard-size marbles, a random motion again given to the tray will show the slower motion of the larger marble.





72 Class experiment

Brownian motion

Note

The Brownian motion experiment is so important that it must be done by any pupils who did not do it themselves at some earlier stage and it should be repeated even by pupils who have seen it earlier.

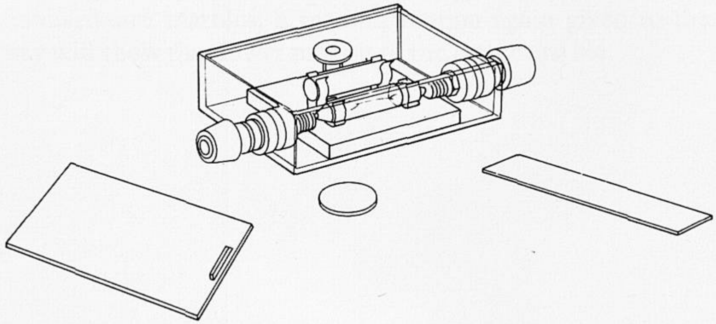
Apparatus

8 microscopes	– item 23
8 Whitley Bay smoke cells	– item 29
8 transformers	– item 27

Microscopes with fairly low power but large apertures are required. It is imperative that there be sufficient clearance between the stage and the objective to take the Whitley Bay smoke cells. The focal length of the objective should be between 10 and 30 mm, preferably about 18 mm which is one of the standard values. A $\times 10$ eyepiece should be used.

Procedure

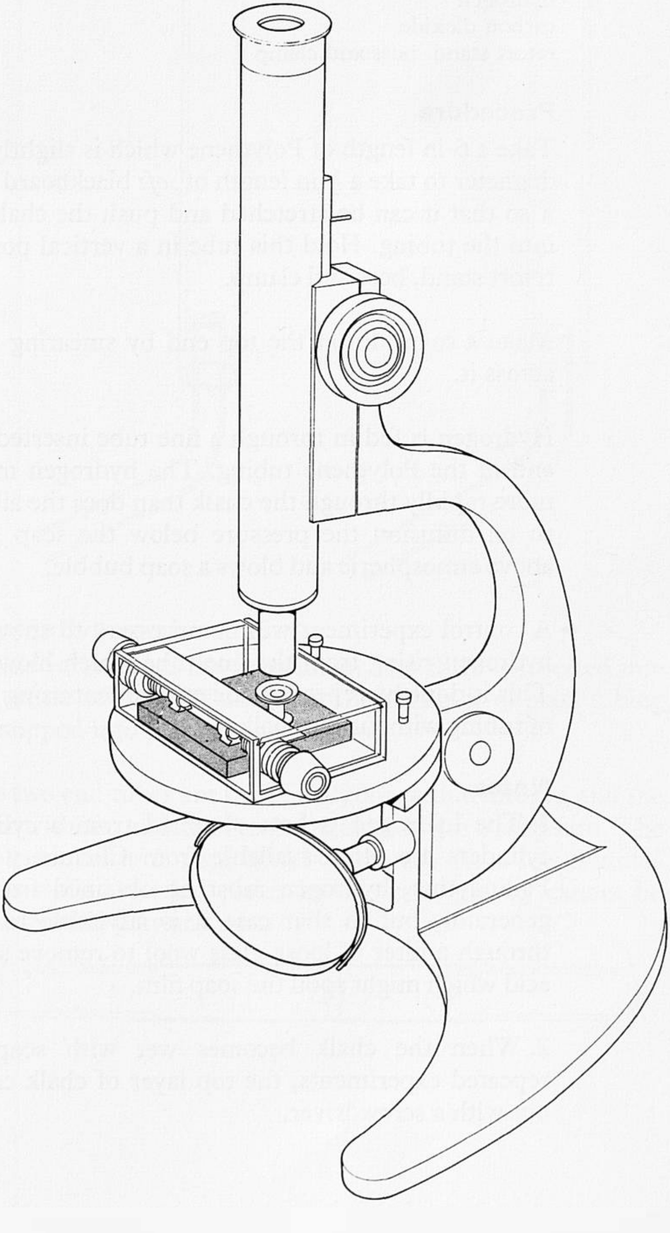
Remove the cover from the smoke cell assembly and place on the microscope stage. Connect 12 volts from the transformer to the terminals provided on the smoke cell.



Light the end of a piece of cord (sash cord, clothes line, or a drinking straw are suitable) and allow to burn for a few seconds. Blow out the flame and fill the dropper with smoke from the smouldering cord. Inject the smoke slowly from the dropper into the glass cell. When it is full, seal with the cover slip provided.

Focus the microscope on to the top of the cover slip and then slowly lower the objective until the Brownian motion of the smoke particles becomes apparent.

A small piece of black card is provided with the cell, and this should be placed over the festoon lamp to avoid stray light reaching the eye.



73 *Optional demonstration*
Diffusion of hydrogen in air

Apparatus
Polythene tubing (two 6-in lengths)
blackboard chalk (soft)
soap solution
hydrogen
carbon dioxide
retort stand, boss and clamp

Procedure
Take a 6-in length of Polythene which is slightly too small in diameter to take a $\frac{1}{2}$-in length of *soft* blackboard chalk. Warm it so that it can be stretched and push the chalk a little way into the tubing. Hold this tube in a vertical position using a retort stand, boss and clamp.

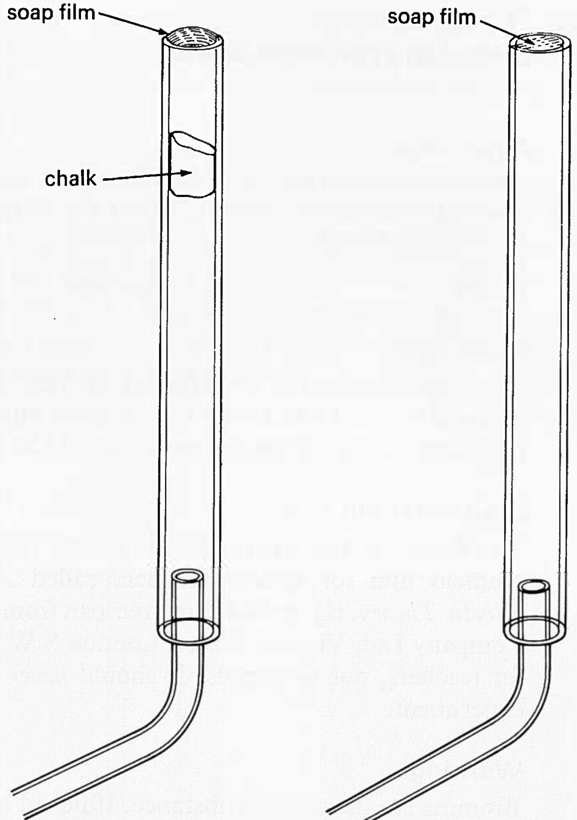
Make a soap film at the top end by smearing soap solution across it.

Hydrogen is fed in through a fine tube inserted in the lower end of the Polythene tubing. The hydrogen molecules pass more rapidly through the chalk than does the air downwards, so on diffusion the pressure below the soap solution rises above atmospheric and blows a soap bubble.

A control experiment will be necessary to show it is not the hydrogen rising from the fine tube which blows the bubble. This is done by repeating the experiment using another piece of tubing without the chalk.

Notes
1. The hydrogen is best obtained from a cylinder – small cylinders are often available from Chemistry departments. Failing that, hydrogen must be obtained from a chemical generator, but in that case it is advisable to pass the gas through a filter of loose glass wool to remove small drops of acid which might spoil the soap film.

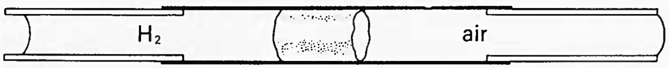
2. When the chalk becomes wet with soap solution in repeated experiments, the top layer of chalk can be scraped out with a screwdriver.



Alternative version

In this variation of the experiment, the chalk is inserted into the centre of the tube and then short lengths of glass tubing are slipped into place at the two ends.

The two end tubes are then filled, one with hydrogen and the other with air, and both ends are closed with a soap film. The whole apparatus is then held horizontally for a few minutes whilst diffusion takes place. In this case, gravity cannot be considered to play any part.



74 *Demonstration*

Diffusion of bromine into air

Apparatus

1 bromine diffusion kit	– item 8
1 retort stand, boss and clamp	– items 503–506
1 translucent screen	– item 46/1
1 lamp	– item 46/2
1 pliers	– item 530

Note

This experiment will be repeated in Year IV and on that occasion it will be followed by diffusion into a vacuum. On this occasion only diffusion into air should be shown.

Esso-Nuffield film

The details of this experiment are clearly shown in the Esso-Nuffield film for science teachers called *An Approach to Kinetic Theory*. It is available on free loan from Esso Petroleum Company Ltd, Victoria Street, London S.W.1. This is a film for teachers, not for pupils. It should *never* replace the real experiment.

Warning

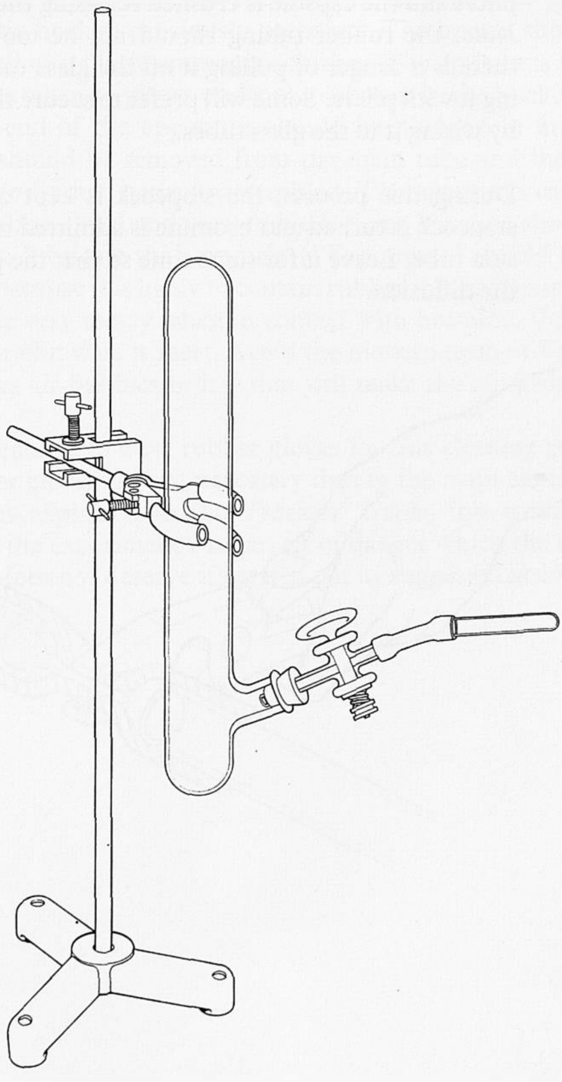
Bromine is a dangerous substance. If liquid bromine splashes onto the skin it makes a bad blister. Bromine vapour will also attack the skin and will produce a sore throat if used carelessly. In general, bromine attacks almost anything except glass and paraffin wax. Great care should therefore be taken with this important experiment.

The apparatus

The main diffusion tube is a closed glass tube (18 in long, 2 in diameter) with only one opening. A rubber bung fits into the opening, but the glass tube through it ensures that only bromine vapour and not liquid comes into contact with it. In any case the bung should be replaced by a new one as soon as the bromine has hardened its face. A bung can be used for several experiments in the course of a few days, but if it is then kept for a week or two the rubber will harden and may crack—a new bung must then be used.

The bung must make good contact with the glass side-tube. To ensure that, it may be advisable to moisten it with saliva. Vaseline should on no account be used, or the bung may slip out of the tube.

A glass stopcock with large bore – 8 mm Interkey stopcock, spring held – separates the main diffusion tube from the region where the bromine capsule is broken. The stopcock is ordinary quality and not a high-vacuum stopcock. To the other end of the stopcock is attached a short length of rubber tubing, to which in turn is attached a glass 'cap-tube' with a 1-ml bromine capsule inside.

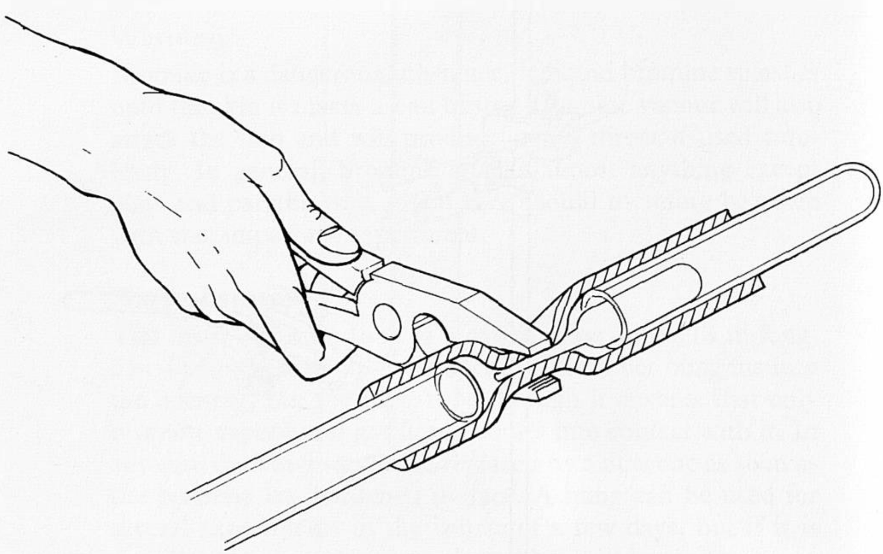


Procedure

The main diffusion tube is held firmly in a vertical position using a retort stand, boss and clamp. A translucent screen and lamp is set up behind it so that the tube is silhouetted against a bright background. The bung is fixed in place and the rubber tubing is fitted tightly on to the other end of the glass tubing. This tubing must be the right size to fit tightly. A bromine capsule is put inside the glass cap-tube and this in turn is connected to the rubber tubing.

The glass tube is raised and tapped until the capsule slides into the rubber tubing. The rubber tubing is squeezed with pliers and the capsule is crushed releasing the liquid bromine. *Note*: the rubber tubing should not be too short otherwise there is a danger of pulling it off the glass tube when squeezing it with pliers. Some will prefer to secure the rubber tubing by wiring it to the glass tubes.

During this process, the stopcock is kept closed. Then the stopcock is turned and bromine is admitted to the main diffusion tube. Leave it for some time so that the pupils can watch the diffusion.



Safety precautions

Both when preparing the experiment and when doing it, the experimenter should have a beaker of strong ammonia solution at hand: ammonia combines with bromine to form harmless ammonium bromide. Strong ammonia solution '0·880', diluted to half or quarter strength, provides an excellent safety precaution. If bromine splashes on table or skin, pour ammonia solution on at once. Ammonia should of course not be used near eyes, for which plenty of cold water is the treatment.

Cleaning the apparatus

After the experiment the whole apparatus should be put into a plastic bucket, previously prepared. The bucket should be half full of a dilute ammonia solution. The apparatus should then be taken to pieces under the solution in the bucket. The lower end of the apparatus should be plunged in first, the bung should be removed from the main tube and the stopcock, and other items unassembled. The apparatus can later be washed, dried and reassembled. Some Vaseline should be used to lubricate the stopcock. ('Tap grease' should not be used, because it is likely to contain rubber in which case it will become very messy when in contact with bromine. Vaseline, like paraffin wax, is inert. Avoid the modern form of Vaseline that has air bubbles in it – that will make the tap leak.)

It is sensible to wear rubber gloves for this cleaning process. Rubber gloves are not necessary during the main experiment and, as explained in the *Teachers' Guide*, this would only invest the experiment with an air of danger which the experiment does not deserve if carried out as suggested above.

75 Demonstration

Increase of pressure of a gas with temperature

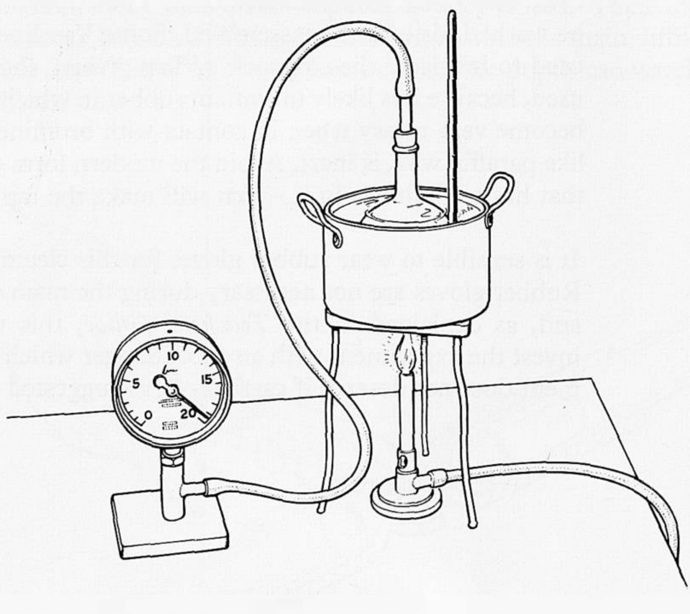
Apparatus

1 Bourdon gauge	– item 67
1 250-ml flask	– item 548
1 bung with glass tube and rubber tubing	– item 549/2
1 aluminium container	– item 76
1 Bunsen burner	– item 508
1 tripod	– item 511

Procedure

The flask is connected by the rubber tubing to the Bourdon gauge. Water is boiled in the container and the flask plunged into it. The pressure change is observed on the gauge.

If ice is available, the flask should be removed from the hot water, cooled, and then placed in a container of ice and water.



The flask should be tilted (or placed in a deep container) so that it is fully covered by water, right up to the top of the neck. That is not essential in this *qualitative* demonstration, but it should be done here to set a good example for the *quantitative* class experiment that follows soon, (77).

76 *Optional demonstration*

Increase of pressure of a gas with temperature

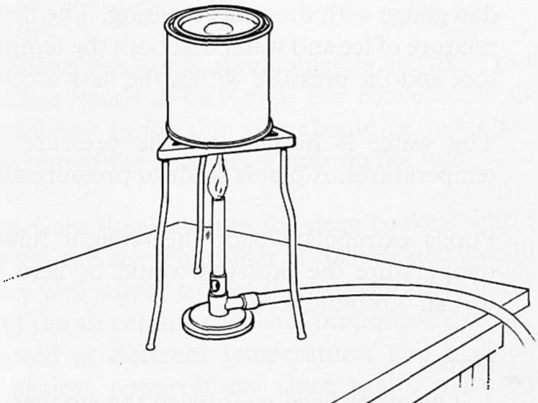
Apparatus

1 Bunsen burner – item 508
1 tin with lid
1 tripod – item 511

The tin should have a well-fitting, push-in lid: a Nescafé type is suitable.

Procedure

The tin is firmly closed and then heated over the Bunsen burner until the pressure within is sufficient to blow the lid off.



77 Class experiment

Variation of pressure with temperature leading to the concept of absolute zero

Apparatus

8 Bourdon gauges	– item 67
8 250-ml round-bottom flasks	– item 548
8 bungs with glass tubes and rubber tubing	– item 549/2
8 deep beakers	– item 513
8 Bunsen burners	– item 508
8 tripods	– item 511
8 thermometers	– item 542
ice	
8 retort stands, bosses and clamps	– items 503–505

Procedure

The 250-ml round-bottomed flask is connected to the Bourdon gauge with the rubber tubing. The flask is immersed in a mixture of ice and water and both the temperature of the mixture and the pressure within the flask are recorded.

The water is heated and the pressure noted at different temperatures. A plot is made of pressure against temperature.

Pupils extrapolate back the straight line to find at which temperature the pressure would be zero. This temperature we call 'absolute zero'.

Notes

1. The water level *must* reach the stopper. A firm method of clamping the flasks must be devised.

2. The water *must* be stirred vigorously. Before any reading, remove the Bunsen and stir well.

3. With melting ice, try to trap some ice below the flask and then add more on top.

4. The Nuffield trials revealed that this experiment gives trouble unless these warnings are heeded.

78 *Class experiment*

Expansion of air at constant pressure

Apparatus

16 deep beakers	– item 513
16 Bunsen burners	– item 508
16 capillary tubes with mercury index	– see below
16 foot rules	– item 502
32 rubber bands	
16 thermometers	– item 542
16 tripods	– item 511

The capillary tubes should be about 8 in long, of 1 mm bore, closed at one end and open at the other. They should each have a mercury index in them, about $\frac{1}{4}$ in long and about 5 in from the closed end. For details of filling see below.

Procedure

The capillary tubes and thermometers are fixed to the rules with rubber bands at each end. For convenience the end of the air column inside the tube should be made to coincide with the zero of the centimetre scale on the rule.

The tubes are then put into the deep beakers with the open end free to the air. The water is then heated steadily and is kept very well stirred so that its temperature is uniform. The length of the air column (which is proportional to the volume) is observed at different temperatures and a plot made of length against temperature. Once again, there should be extrapolation back to find the temperature at which 'the volume would be zero'.

Preparing the tubes

The tubes should be provided with the index before the lesson begins. All the tubes should be put into a deep beaker of strong brine which is then boiled, thus ensuring that the tubes are dry internally as well as hot. The open end of each tube is then dipped into a vessel of dry mercury so that a $\frac{1}{4}$-in length of mercury is drawn in to the tube as it cools. Further cooling will draw the index to a suitable position in the tube.

79 Demonstration

Boyle's Law

Apparatus

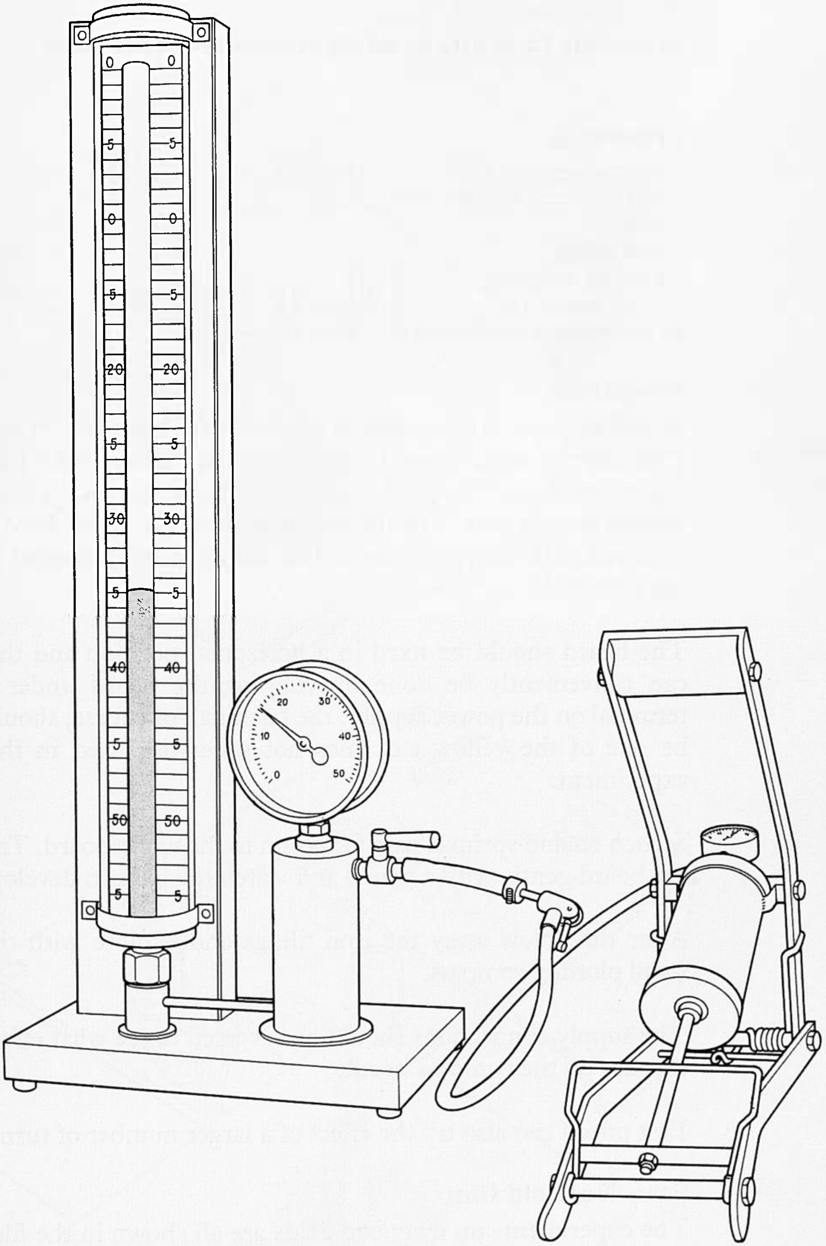
1 Boyle's Law apparatus – item 109
1 footpump and adaptor – item 45

Procedure

Pressure is applied to the oil in the reservoir by gentle use of the footpump. Readings of the Bourdon gauge and of the corresponding length of the air column are then recorded.

Note

To fill the apparatus with oil, unscrew the Bourdon gauge with a spanner. Fill with oil (it should be an oil with low vapour pressure – Redex is suitable and clearly visible to the class). It will be necessary to incline the apparatus in the final stage of filling in order to get enough oil into the main tube. When refixing the gauge, tighten enough to get a good seal, but not too tight to damage the thread.


0
5
0
5
20
5
30
5
40
5
50
5
10
20
30
40
50
0

80a *Class experiment*

Magnetic field due to an electric current in a wire

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
board	
iron filings	
plotting compass	
16 wire strippers	– item 84
16 low-voltage power units	– item 104

Procedure

A hole is made in the centre of the board. A length of 26 swg PVC copper wire, about 10 in long, is put through the hole and connected to the black and red d.c. terminals on the low-voltage supply unit. The insulation at the ends of the wire is removed with wire strippers so that they can be connected to the terminals.

The board should be fixed in a horizontal position and this can conveniently be done by clipping the board under a terminal on the power supply: the terminal, of course, should be one of the yellow a.c. ones not otherwise used in this experiment.

Switch on and sprinkle iron filings on to the white board. Tap the board gently with a pencil and watch the pattern develop.

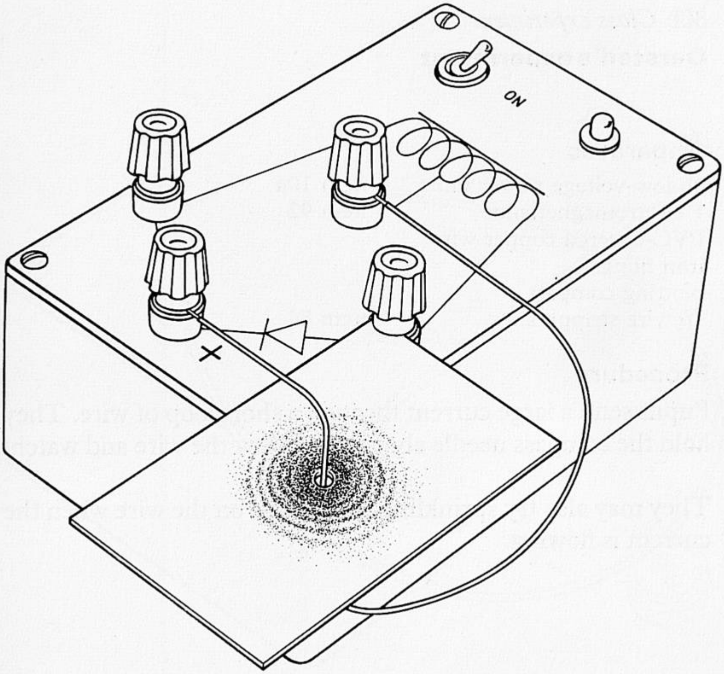
After this, blow away the iron filings and explore with the small plotting compass.

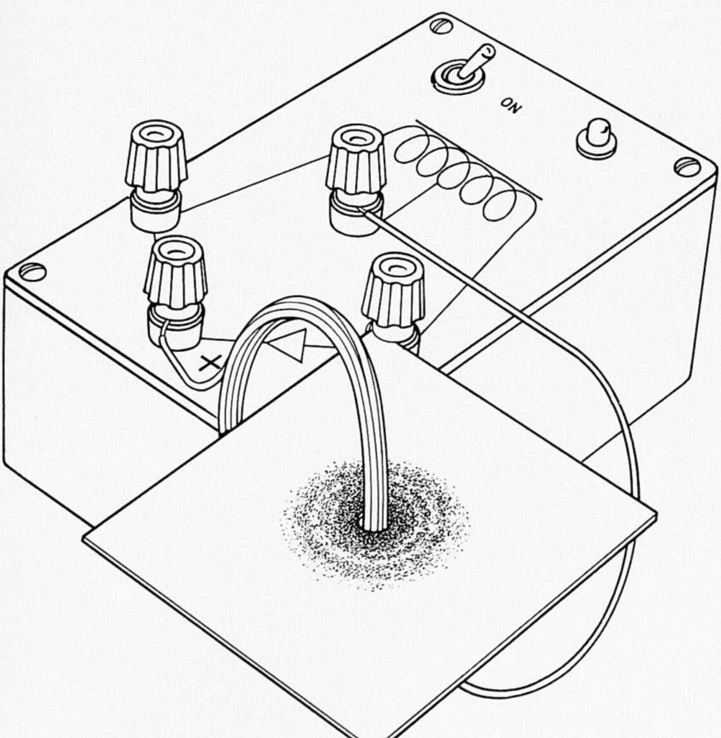
The supply connections should be reversed to see what effect this has on the compass needle.

Fast pupils can also try the effect of a larger number of turns.

Esso-Nuffield film

The experiments on magnetic fields are all shown in the film for science teachers, *The Electromagnetic Kit*.


ON
+


ON
+

80b *Class experiment*

Oersted's experiment

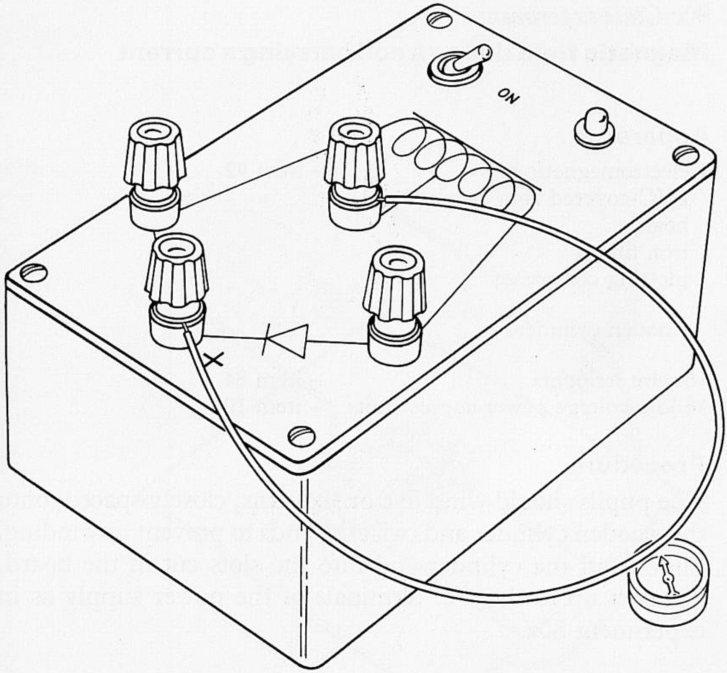
Apparatus

16 low-voltage power units	– item 104
1 electromagnetic kit	– item 92
PVC-covered copper wire	
iron filings	
plotting compass	
16 wire strippers	– item 84

Procedure

Pupils send a large current through a short loop of wire. They hold the compass needle above and below the wire and watch.

They may also try sprinkling iron filings on the wire when the current is flowing.


ON

80c *Class experiment*

Magnetic field due to a coil carrying a current

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
board	
iron filings	
plotting compasses	
wooden cylinders	
16 wire strippers	– item 84
16 low-voltage power supply units	– item 104

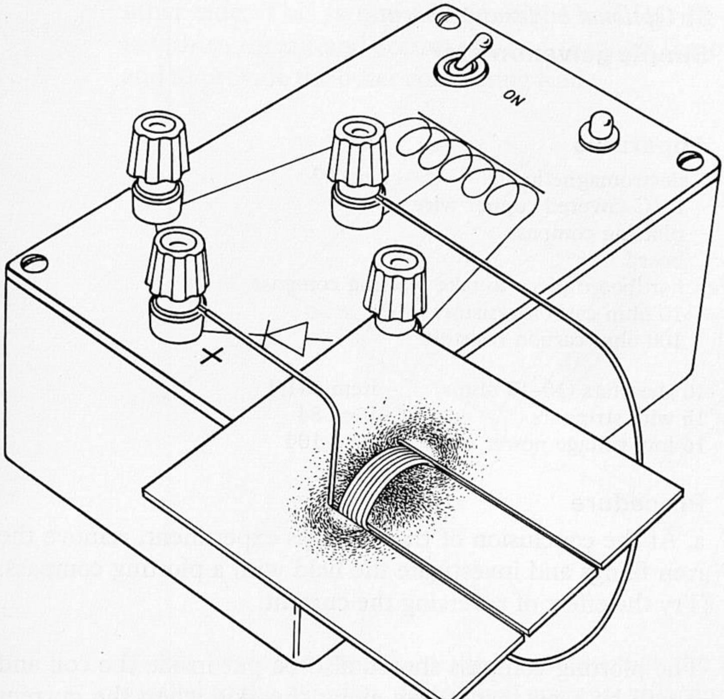
Procedure

The pupils should wind five or six turns, closely spaced, onto the wooden cylinder and twist the ends to prevent unwinding. Slide it off the cylinder and into the slots cut in the board. Connect up to the d.c. terminals of the power supply as in experiment 80a.

The pupils should find whether there is a field when there is no current.

Sprinkle the board lightly with iron filings, switch on the current, tap the board gently with a pencil, and note the pattern.

For experiment 80d, see p. 264.


ON
+

81 *Optional buffer experiment*

Simple galvanometer

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
plotting compass	
board	
hardboard piece to take plotting compass	
10 ohm carbon resistors	
100 ohm carbon resistors	
16 rheostats (10–15 ohms)	– item 541/1
16 wire strippers	– item 84
16 low-voltage power units	– item 104

Procedure

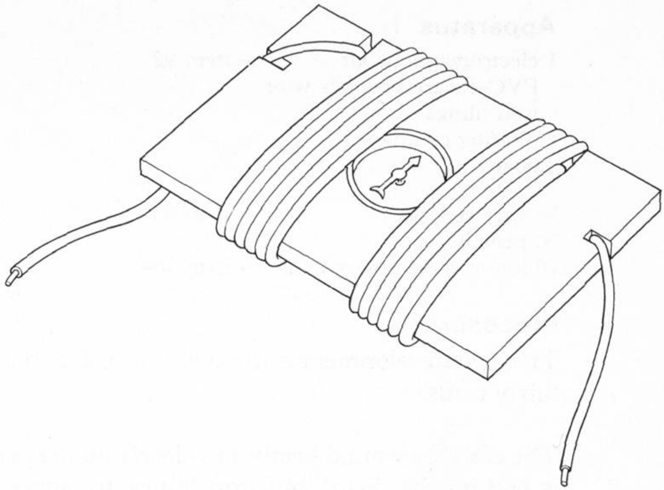
a. At the conclusion of the previous experiment, remove the iron filings and investigate the field with a plotting compass. Try the effect of reversing the current.

The plotting compass should also be put inside the coil and it will be seen that it sets along the axis when the current flows. To make this the more effective set the plane of the coil N-S to start with.

Switching the current on and off causes violent motion of the compass needle. Put a rheostat in series with the supply to reduce the current. Gradually increasing the current will cause the needle to deflect from the original N-S direction towards the E-W axis of the coil: an introduction to a current-indicating device.

b. The above experiment suggested a simple current measuring device. This can be made using the special piece of hardboard provided in the electromagnetic kit.

The compass is inserted into the hole in the board. Using the PVC-covered copper wire, a length of about a foot is left for making connections to the power supply, a couple of turns are made around the slots to secure the end (a twist will help to prevent it coming undone), and then five turns are wound over one side of the compass. A gap is left through which to observe the needle and a further five turns wound on the other side. This is now cut from the reel leaving sufficient length to thread and secure the end through the other slots and to provide the other connecting lead.



If this device is placed on the bench so that the needle is parallel to the winding, quite small currents will cause readily observable deflections to E or W according to the direction of the current. If connection is made to the power supply through a 100-ohm carbon resistor, the small current (about 10 mA) gives an observable deflection. The pupils should also try with a 10-ohm carbon resistor. Direct connection with no resistor sets the needle spinning.

80d *Class experiment*

Magnetic field due to a long close-wound coil

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
iron filings	
plotting compasses	
board	
16 wire strippers	– item 84
16 pencils	
16 low-voltage power units	– item 104

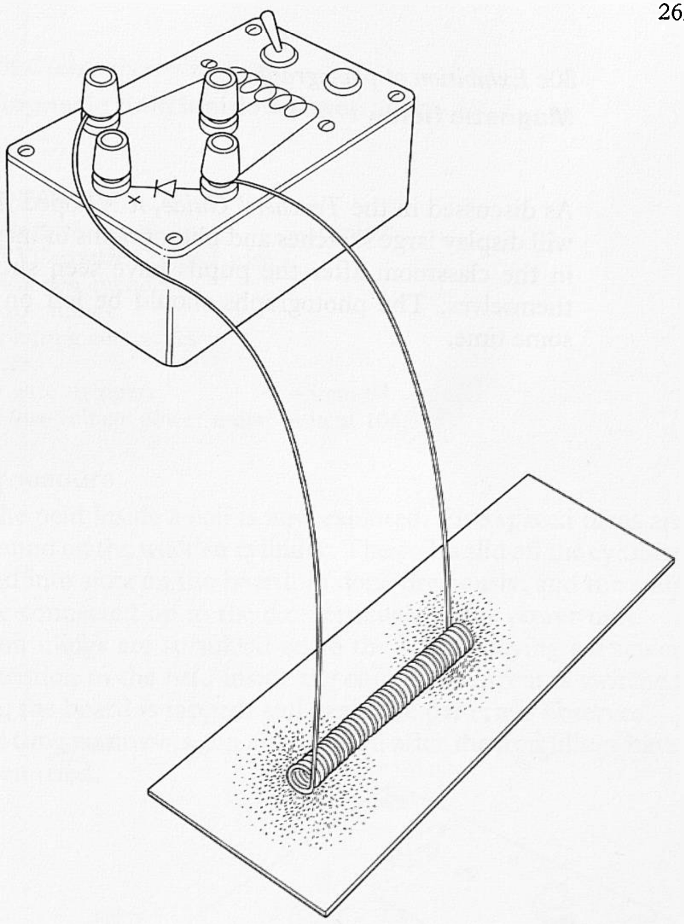
Procedure

The next development is to extend the coil to one of twenty or thirty turns.

The coils are wound firmly and closely on the pencil. The coil is laid on the board and iron filings are sprinkled onto the board.

The current is switched on, the board is tapped, and again the pattern is observed.

Plotting compasses can also be used after the iron filings have been tried.



80e *Exhibition of photographs*

Magnetic fields

As discussed in the *Teachers' Guide*, it is hoped that teachers will display large sketches and photographs of magnetic fields in the classroom after the pupils have seen such fields for themselves. The photographs should be left on display for some time.

80f *Class experiment*

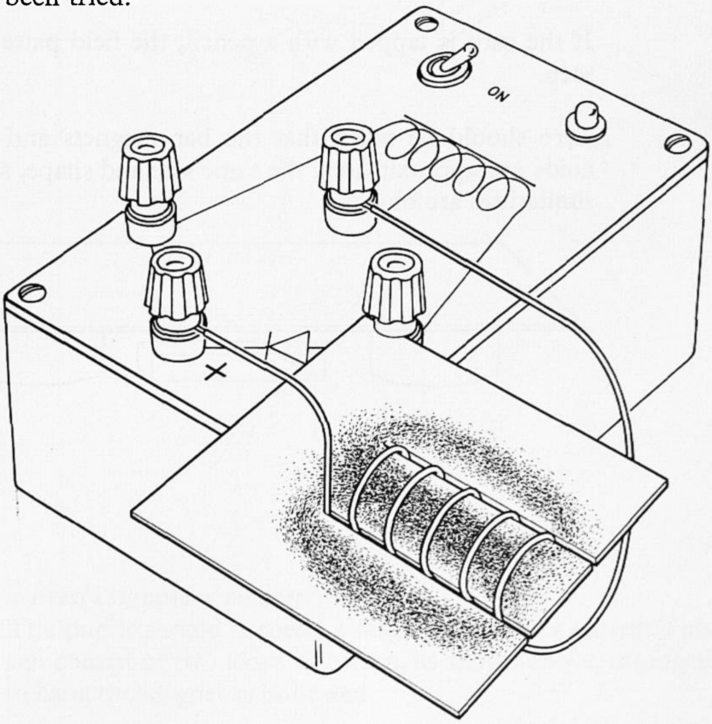
Magnetic field inside an open coil

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
wooden cylinders	
iron filings	
plotting compasses	
card	
16 wire strippers	– item 84
16 low-voltage power units	– item 104

Procedure

The field inside a coil is now explored. Five spaced turns are wound on the wooden cylinder. The coil is slid off the cylinder and into slots on the board, as done previously, and the ends are connected up to the d.c. terminals of the power unit. Iron filings are sprinkled on to the board, paying particular attention to the field inside the coil. The current is switched on, the board is tapped, and again the pattern is observed. Plotting compasses can also be used after the iron filings have been tried.



80g *Class experiment*

Field of a bar magnet

Apparatus

1 electromagnetic kit – item 92
ticonal magnets
cards
iron filings
aluminium rings

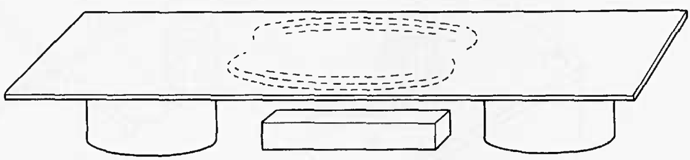
Procedure

After seeing the field due to a solenoid, pupils should look at the field due to a bar magnet of the same shape and size. The magnet is placed on the bench.

Iron filings are sprinkled on to the card after which the card is placed over the magnet. The card should be supported on the aluminium rings so that it is above the magnet. If it is in contact with the magnet the filings from the vicinity are attracted over the magnet, for the field is a strong one and changes rapidly with distance, leaving a bald patch round the magnet.

If the card is tapped with a pencil, the field pattern will be seen.

Care should be taken that the bar magnets and the solenoids are approximately the same size and shape, so that the similarities are obvious.



80h–k *Class experiments*

Play with magnets

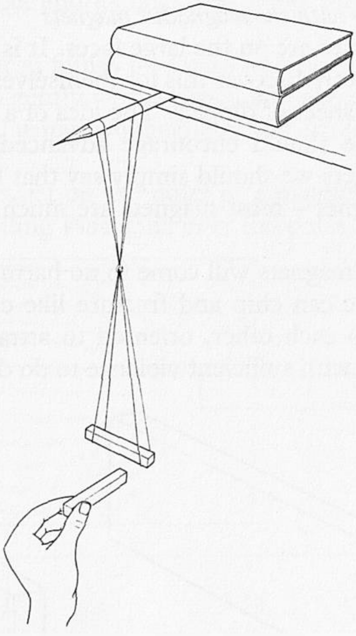
If pupils have not done these experiments before they should certainly do them now.

Apparatus

1 electromagnetic kit – item 92
ticonal magnets
cotton
plotting compasses
magnadur magnets

Procedure

h. *Feeling magnetic forces*
Let the pupils play with ticonal magnets studying the feel of attraction and repulsion. They should avoid banging the magnets together or forcing them very close together against their mutual repulsion as this might ultimately weaken them.



i. *Freely suspended magnet*
The pupils should suspend a magnet freely in a stirrup. This can consist of two loops of cotton, as shown above, arranged to hang the magnet as indicated.

A pencil projecting over the edge of a desk or bench and held by weights (for example, books) serves for a support. Alternatively a pencil or wooden rod can be fixed in a non-magnetic retort stand (brass, wood or stainless steel).

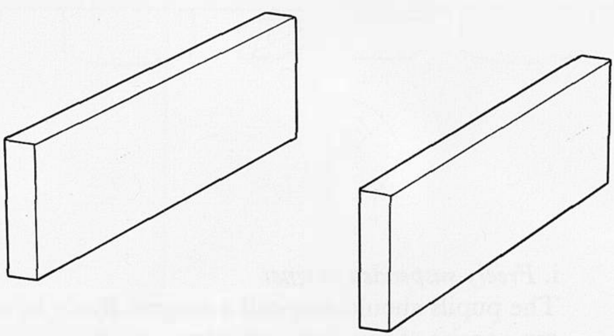
This should be used to see how the magnet sets by itself. Let them find the effect of bringing another magnet near by.

j. *Compass near a magnet*
Use the small compass instead of the suspended magnet. This is more convenient. It can be moved around the bigger magnet to show the direction of pull at different places.

These compasses are very cheap. Badly balanced ones or those with sticky pivots should be discarded. Polarity is easily reversed and pupils should check which is the north seeking pole of the compass needle. If the magnetism is weak (slow oscillation in the Earth's Field) place in a strong field, for example between poles of a pair of ticonal magnets.

k. *Play with the magnadur magnets*
The poles are on the large faces. It is interesting to see if the pupils can discover this for themselves. The magnet is practically a sheet of dipoles. The idea of a dipole is a valuable one that we should encourage advanced pupils to use. But to beginners we should simply say that this is an unusual shape of magnet – most magnets are much longer and narrow.

These magnets will come to no harm magnetically but being ceramic can chip and fracture like china. If two are placed near to each other, oriented to attract, they may move together with sufficient violence to do damage.



801 *Class experiment*

Magnetic fields due to arrangements of magnets

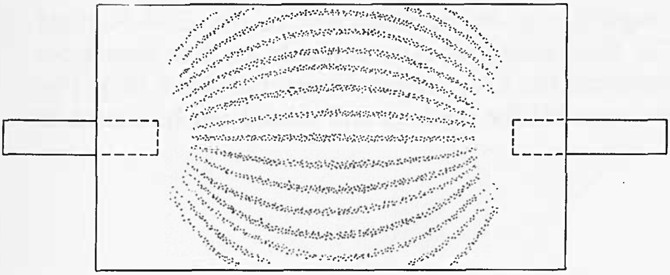
Apparatus

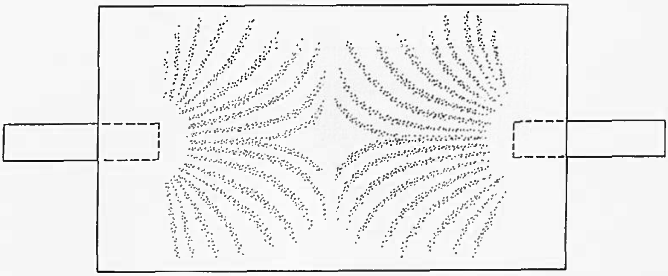
1 electromagnetic kit – item 92
ticonal magnets
magnadur magnets
steel yokes
cards
iron filings
plotting compasses
C-cores
aluminium rings

Procedure

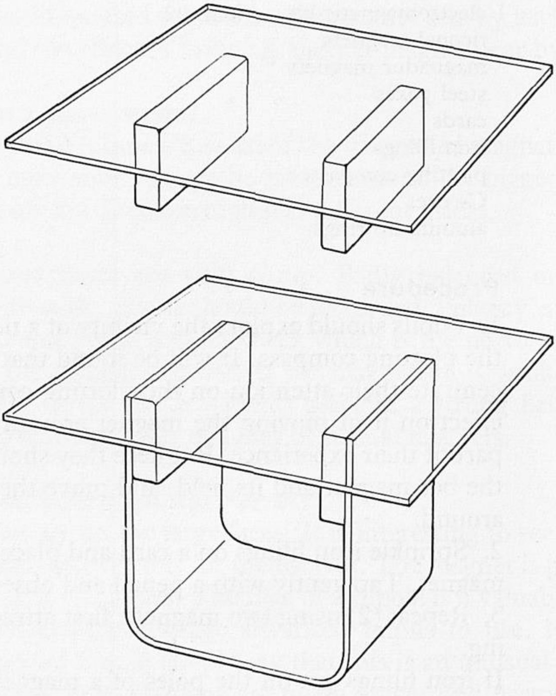
1. Pupils should explore the vicinity of a ticonal magnet with the plotting compass. It will be found that they usually concentrate their attention on the plotting compass and see the effect on it of moving the magnet around: this is of course part of their experience. But here they should concentrate on the bar magnet and its field, and move the plotting compass around.
2. Sprinkle iron filings on a card and place the card over the magnet. Tap gently with a pencil and observe the pattern.
3. Repeat (2) using two magnets, first attracting, then repelling.

If iron filings get on the poles of a magnet, they can be removed by rolling Plasticine over the poles.





4. Instead of the ticonal magnets, use two magnadur magnets. Again investigate the field using both iron filings sprinkled on card and the exploring compass. The magnadur magnets can be put on the bench as shown, or attached to the iron yoke.



Esso-Nuffield film

These experiments are demonstrated in the Esso-Nuffield film *The Electromagnetic Kit*, available on free loan from Esso Petroleum Co. Ltd, Victoria Street, London S.W.1. The films are intended for teachers and should not be shown to pupils.

80m *Class experiment*

Electromagnets : field pattern

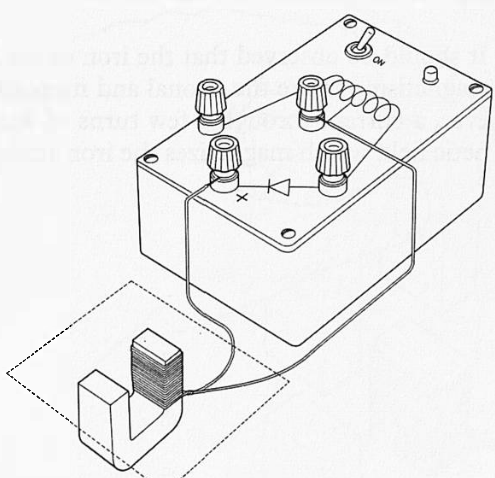
Apparatus

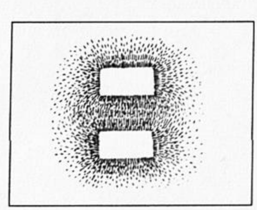
1 electromagnetic kit	– item 92
C-core	
cards	
PVC-covered copper wire	
iron filings	
16 low-voltage power units	– item 104
16 wire strippers	– item 84

Procedure

The pupils should take a C-core of iron, place a card on top, and sprinkle with iron filings. The field is non-existent or very weak.

They should then wind twenty turns of PVC-covered copper wire round one limb and connect to the d.c. terminals of the low-voltage power supply. The pupils will notice the strong field between the ends of the C-core using the card and iron filings. They can use a plotting compass to identify N and S poles.





80n *Class experiment*

Electromagnets: forces

Apparatus

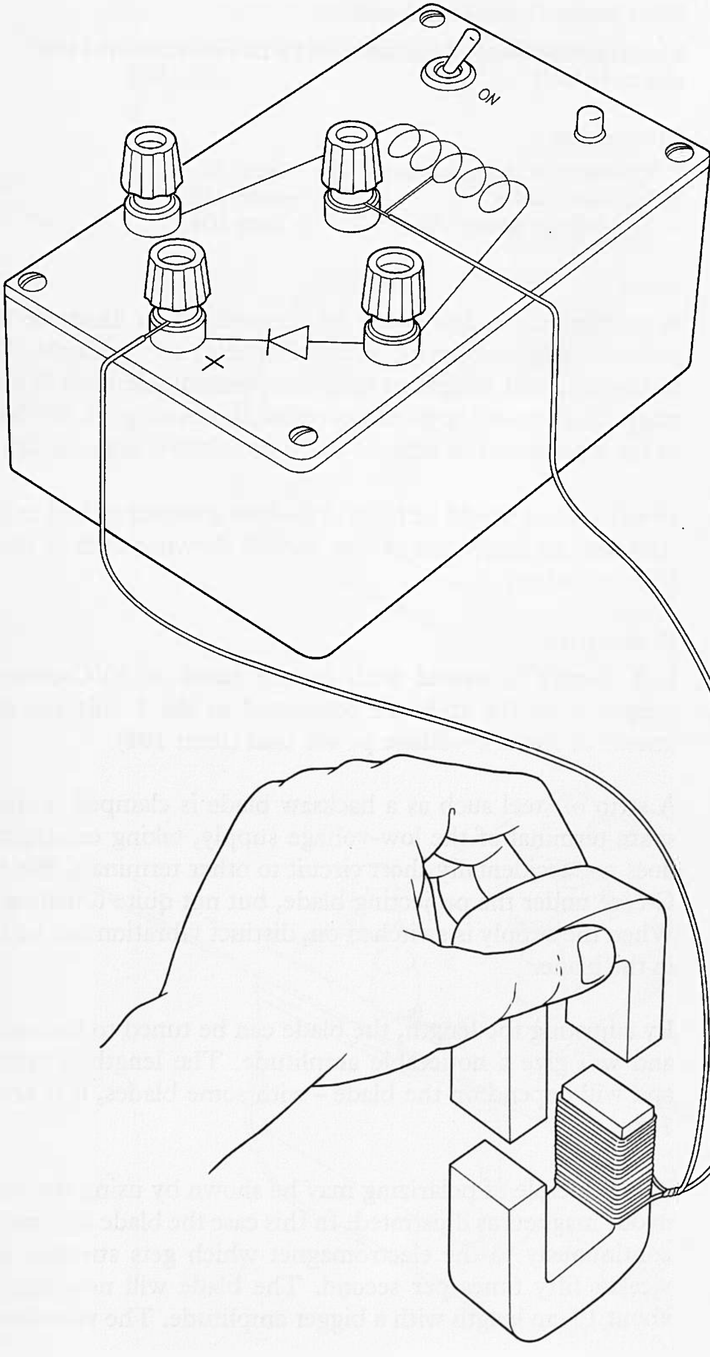
1 electromagnetic kit	– item 92
C-cores	
PVC-covered copper wire	
16 wire strippers	– item 84
16 low-voltage power units	– item 104

Procedure

With the same turns round one C-core as in experiment 80m, bring up another C-core which will be strongly attracted. Once they have joined, try to separate the C-cores. Switch off the current and try again.

Note that for this experiment to be effective it is imperative that there be no grit, such as iron powder, between the touching faces of the two C-cores. If necessary slide a clean piece of paper between the faces (with the current off) and withdraw while gripping it gently with the faces, which are thus wiped clean. Alternatively, remove grit, dust, or iron filings by wiping the faces clean with the thumb.

It should be observed that the iron of the C-cores retains no magnetism, unlike the ticonal and magnadur magnets. However, a current through a few turns of wire produces a magnetic field which magnetizes the iron strongly.


ON

80o *Optional class experiment*

Electromagnets: application to the buzzer and the electric bell

Apparatus

1 Westminster electromagnetic kit	– item 92
16 hacksaw blades	– item 120
16 low-voltage power units	– item 104

Note

A number of models could be constructed to illustrate the practical applications of electromagnets: for example, the buzzer, the bell, telephone earpieces, control solenoids. These might be given to the pupils as optional project work for them to see what they can achieve using the electromagnetic kit.

In any case, it would be helpful to show a buzzer or bell to the class and an indication of one way of showing each of these is given below.

Procedure

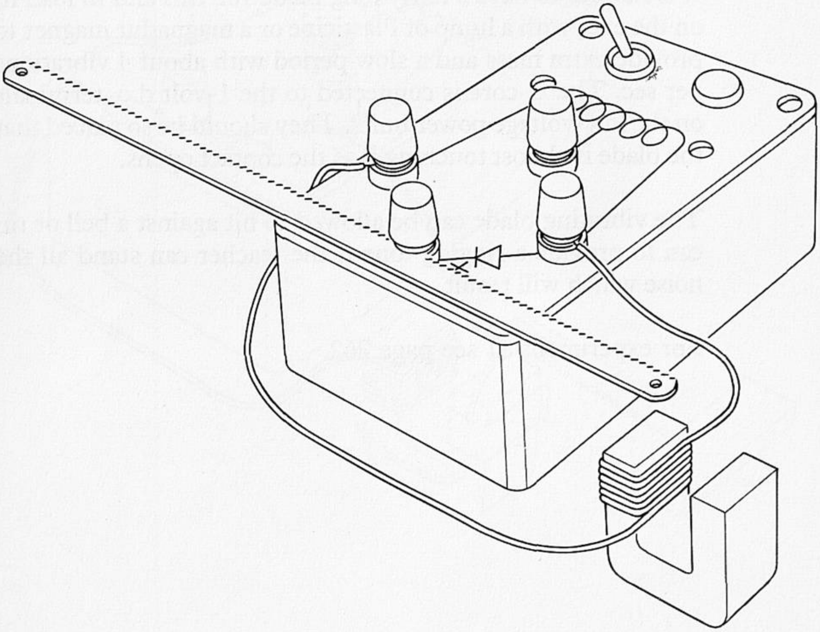
1. A C-core is wound with twenty turns of PVC-covered copper wire, the ends are connected to the 1 volt a.c. terminals of the low-voltage power unit (item 104).

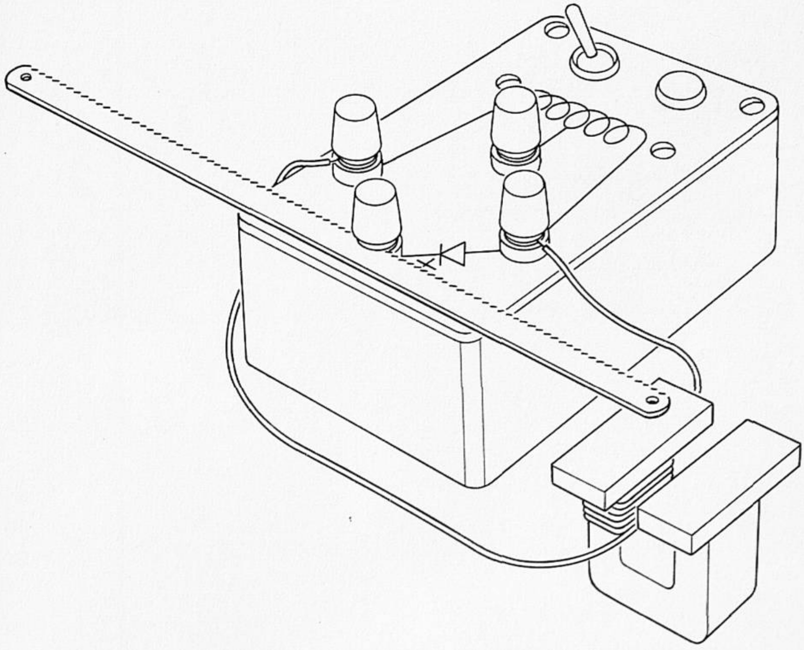
A strip of steel such as a hacksaw blade is clamped under a spare terminal of the low-voltage supply, taking care that it does not accidentally short circuit to other terminals. Put the C-core under the projecting blade, but not quite touching it. When the supply is switched on, distinct vibration can be felt in the blade.

By adjusting the length, the blade can be tuned to resonance and will give a noticeable amplitude. The length is critical and will depend on the blade – with some blades, it is about 7 cm.

The principle of polarizing may be shown by using the magnadur magnets as illustrated. In this case the blade is attracted continuously to the electromagnet which gets stronger and weaker fifty times per second. The blade will now tune at about 10 cm length with a bigger amplitude. The vibration is

50 c.p.s., whereas with the polarizing magnets, the C-core will attract whichever way the current flows, so that the vibration is 100 c.p.s.



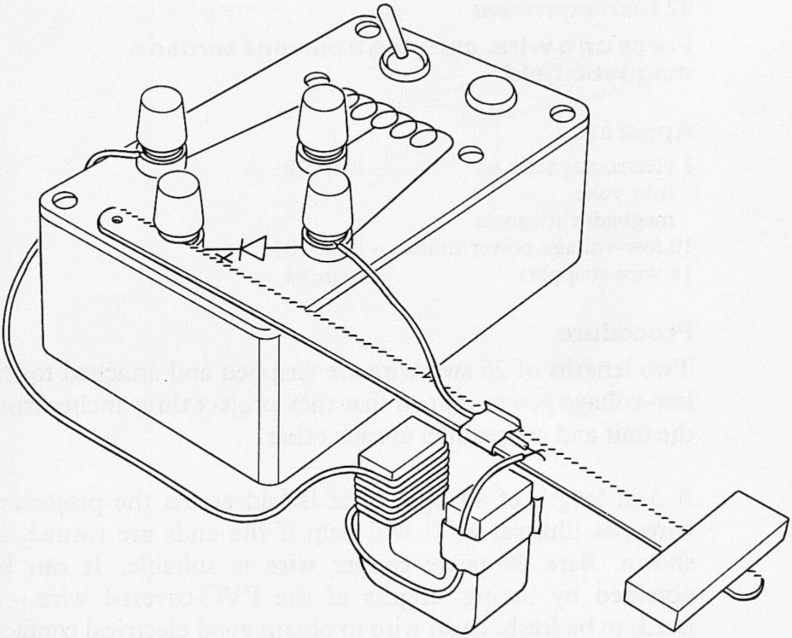


2. To make a contact breaker as in an electric bell, wires may be Sellotaped as shown opposite.

It is helpful to have a fairly long blade for this and to load it, on the end, with a lump of Plasticine or a magnadur magnet to provide extra mass and a slow period with about 4 vibrations per sec. The C-core is connected to the 1-volt d.c. terminals on the low-voltage power units. They should be so placed that the blade is almost touching it as the contact opens.

The vibrating blade can be allowed to hit against a bell or tin can to provide a ringing tone if the teacher can stand all the noise which will result.

For experiment 81 see page 262.



82 *Class experiment*

Force on a wire, carrying a current across a magnetic field

Apparatus

1 electromagnetic kit	– item 92
iron yoke	
magnadur magnets	
16 low-voltage power units	– item 104
16 wire strippers	– item 84

Procedure

Two lengths of 26 swg wire are stripped and attached to the low-voltage power unit so that they project three inches from the unit and are parallel to each other.

A 3-in length of stripped wire is laid across the projecting wires, as illustrated. It will help if the ends are turned, as shown. Bare 26-gauge copper wire is suitable. It can be obtained by baring lengths of the PVC-covered wire – it needs to be fresh, clean wire to obtain good electrical contact.

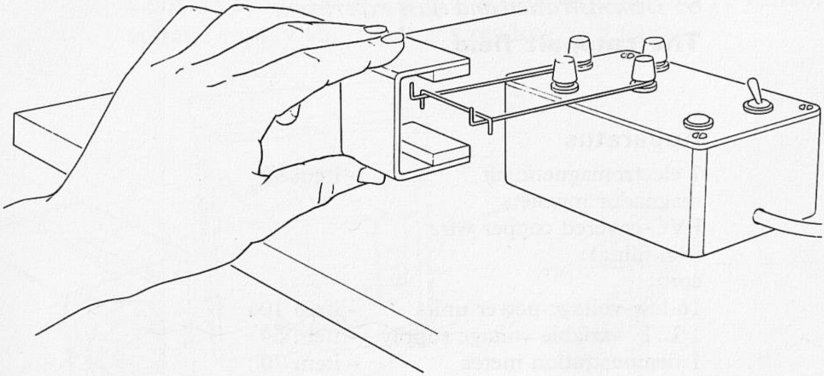
When the yoke with magnadur magnets attached is brought up, the wire lying across the fixed projecting wires will be projected along the rails. Repeat with the magnetic field reversed.

Alternatively, position the magnets first and then note the movement when the current is switched on.

This experiment should be done as a pure investigation. See the discussion in the *Teachers' Guide*.

Note

This experiment can be seen in the Esso–Nuffield film, *The Electromagnetic Kit*.



reduce to 83mm

F37

83 *Demonstration and class experiment*

The 'catapult' field

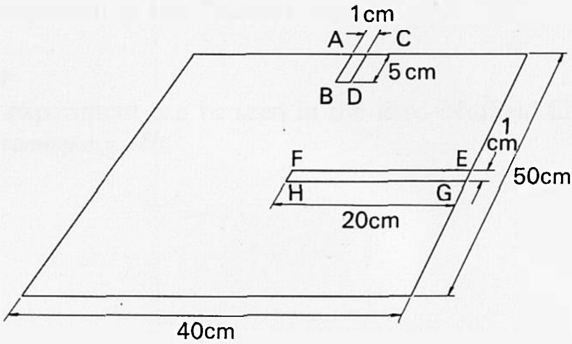
Apparatus

1 electromagnetic kit	– item 92
magnadur magnets	
PVC-covered copper wire	
iron filings	
cord	
16 low-voltage power units	– item 104
1 L.T. variable voltage supply	– item 59
1 demonstration meter	– item 70
1 d.c. dial (5 amp)	– item 71/2

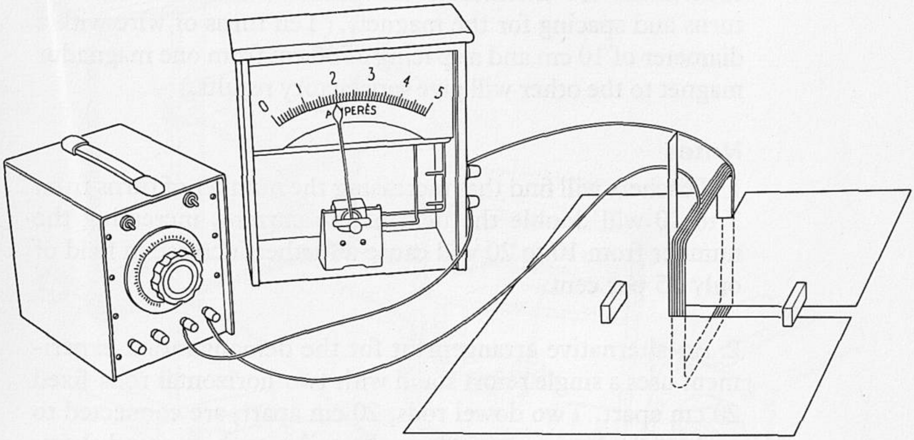
Procedure

a. Find a box with approximately 80 cm periphery and, leaving ends of 1 metre, wind on 50 turns of PVC-covered copper wire from the electromagnetic kit, loosely enough so that the coil so formed may be slid off the end of the box. Before sliding the coil off, tie it in at least four places with thin string so that it does not spring apart. Slide off and form it into a square coil of side 20 cm.

Take a piece of cardboard, 40 cm × 50 cm, and cut along AB, CD, EF and GH, but *not* along BD and FH. Bend up the two flaps so formed and cut 15 cm off the longer flap EFHG. Slide the coil into position as shown and tie it with thin string to the upturned flaps. Stand the cardboard on blocks at least 10 cm high.

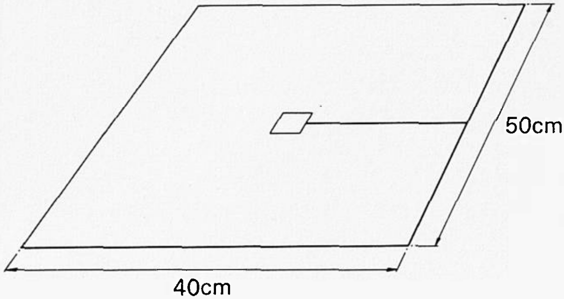


Connect the ends to the d.c. terminals of the L.T. variable voltage supply via the meter reading to 5 amp.



Put a piece of paper with a slit in it on the hardboard. Place on it two magnadur magnets 15 cm apart with unlike poles facing. Sprinkle iron filings on the paper. Switch on and turn up the voltage until 3 amps flow. Tap the paper sharply with a pencil.

When the catapult field is clearly visible, turn down the current to avoid the wire becoming excessively hot. The field pattern will remain.

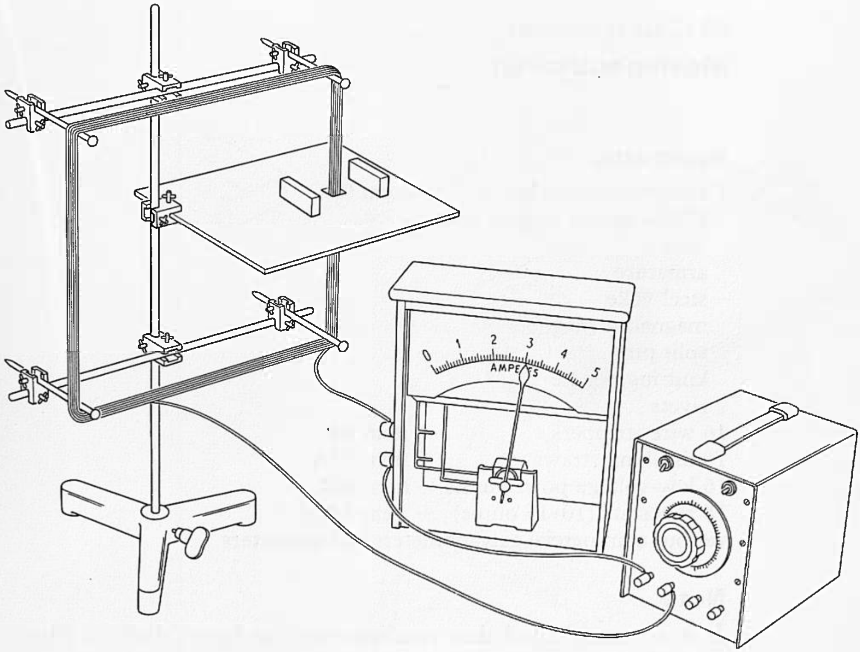


b. After pupils have seen the demonstration, they will want to try it using the low-voltage power units. Pupils should experiment for themselves and find a suitable number of turns and spacing for the magnets. (Ten turns of wire with a diameter of 10 cm and a spacing of 30 cm from one magnadur magnet to the other will give satisfactory results.)

Notes

1. Teachers will find that increasing the number of turns from 3 to 10 will double the field of the current, increasing the number from 10 to 20 will cause a further increase in field of only 25 per cent.

2. An alternative arrangement for the demonstration experiment uses a single retort stand with two horizontal rods fixed 20 cm apart. Two dowel rods, 20 cm apart, are connected to each of the horizontal rods as the coil is wound round them. The experiment can then be done without removing the coil. See illustration below.


0 1 2 3 4 5
AMPERES

84 *Class experiment*

Moving coil meter

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
base	
armature	
steel yoke	
magnadur magnets	
split pins	
knitting needle	
rivets	
16 wire strippers	– item 84
16 drinking straws	– item 53A
16 low-voltage power units	– item 104
16 rheostats (10–15 ohms)	– item 541/1
various commercial galvanometers and ammeters	

Note

It is recommended that teachers see the Esso–Nuffield film, *The Electromagnetic Kit*, which is available on free loan from Esso Petroleum Company, Ltd, Victoria Street, London S.W.1. This shows in detail this moving coil meter being made.

Procedure

The armature is made from a wooden block with an aluminium tube through the clearance hole drilled through the wood. A coil of ten turns of PVC-covered copper wire is wound on the armature block with a couple of tight turns round the tube at the end in order to fix the ends. Plenty of wire should be left at each end.

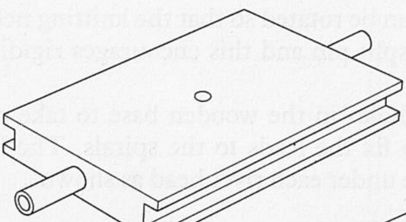
Coil each end into a loose spiral of four to five turns. A good length must be used for each spiral for if they are too tight (because the overall length is too short), the meter will be insensitive.

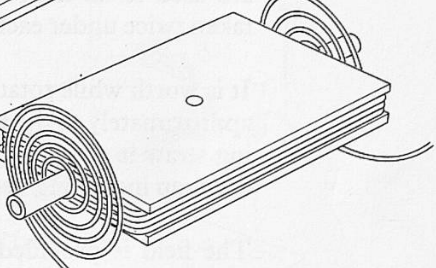
The knitting needle is put through the aluminium tube in the block and in turn is supported from the wooden base by the two split pins. This arrangement provides a convenient (though not frictionless) bearing. It should be noted that the

T18a

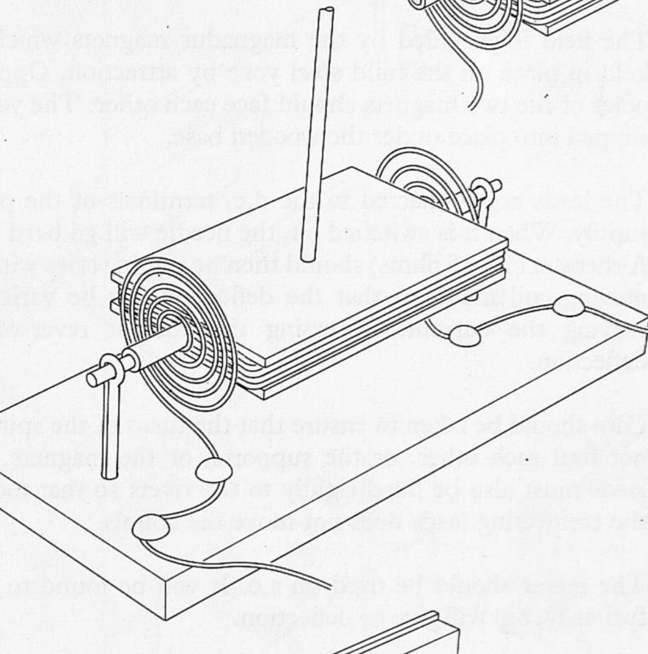
reduce to 38mm 84.4mm

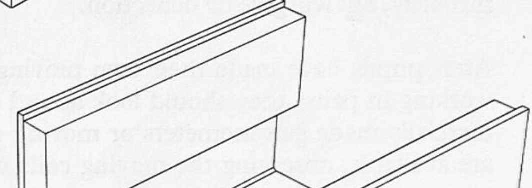
85.25 reduce to 26mm





reduce to 69mm 86.8% and another one to 50mm 62.9%





don't bother with this one

split pins can be rotated so that the knitting needle jams in the eye of the split pin and this encourages rigidity.

There are holes in the wooden base to take rivets and these are used to fix the leads to the spirals. The leads should be taken twice under each rivet head as shown.

It is worth while rotating the armature so that it springs back approximately to the horizontal position. Then insert a drinking straw in the hole in the wood block so that it sticks up to act as an indicating needle.

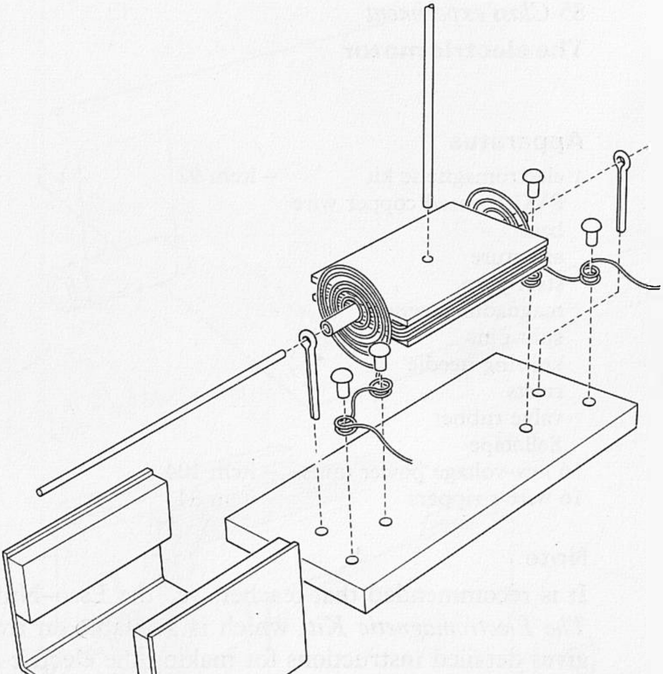
The field is provided by the magnadur magnets which are held in place on the mild steel yoke by attraction. Opposite poles of the two magnets should face each other. The yoke is slipped into place under the wooden base.

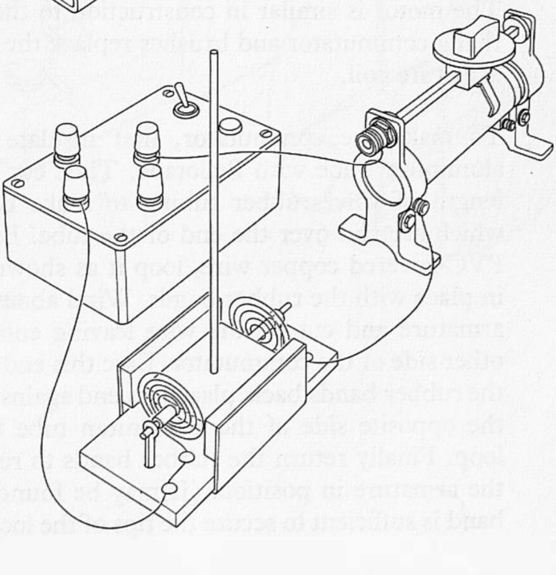
The leads are connected to the d.c. terminals of the power supply. When it is switched on, the needle will go hard over. A rheostat (10–15 ohms) should then be put in series with the moving coil meter so that the deflection can be varied by varying the current. Reversing the current reverses the deflection.

Care should be taken to ensure that the turns of the spiral do not foul each other, or the supports, or the magnets. The leads must also be fixed rigidly to the rivets so that moving the connecting leads does not move the spirals.

The meter should be tried on a.c. It will be found to buzz furiously, but will give no deflection.

After pupils have made their own moving coil instruments, working in pairs, they should look at and examine any commercially made galvanometers or moving coil ammeters that are available, observing the moving coils within them.





85 *Class experiment*

The electric motor

Apparatus

1 electromagnetic kit	– item 92
PVC-covered copper wire	
base	
armature	
steel yoke	
magnadur magnets	
split pins	
knitting needle	
rivets	
valve rubber	
Sellotape	
16 low-voltage power units	– item 104
16 wire strippers	– item 84

Note

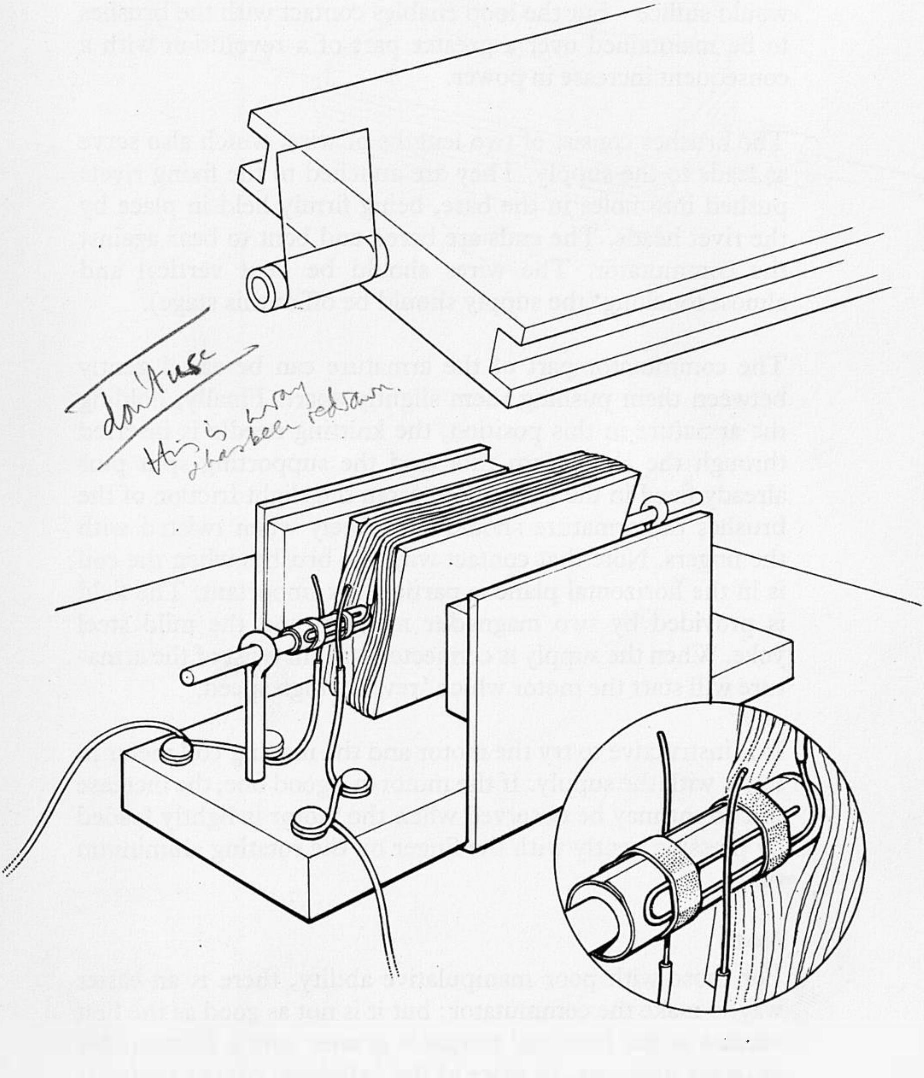
It is recommended that teachers see the Esso–Nuffield film, *The Electromagnetic Kit*, which is available on free loan. It gives detailed instructions for making the electric motor.

Procedure

The motor is similar in construction to the ammeter except that a commutator and brushes replace the spiral ends of the armature coil.

To make the commutator, first insulate one end of the aluminium tube with Sellotape. Then cut two slices off the length of valve-rubber tubing to make two rubber bands which are slid over the end of the tube. Bare an end of the PVC-covered copper wire, loop it as shown above and fix it in place with the rubber bands. Wind about ten turns on the armature and cut off the wire leaving enough to finish the other side of the commutator. Bare this end and loop it. Slide the rubber bands back, place this end against the Sellotape on the opposite side of the aluminium tube from the original loop. Finally return the rubber bands to retain both ends of the armature in position. (It may be found that one rubber band is sufficient to secure the tips of the looped ends.)

The looped ends are not strictly necessary – a straight end



don't use

this is wrong & has been redrawn.

would suffice – but the loop enables contact with the brushes to be maintained over a greater part of a revolution with a consequent increase in power.

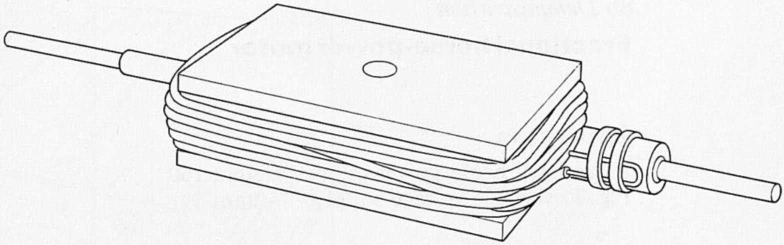
The brushes consist of two lengths of wire, which also serve as leads to the supply. They are attached to the fixing rivets pushed into holes in the base, being firmly held in place by the rivet heads. The ends are bared and bent to bear against the commutator. The wires should be bent vertical and almost touching (the supply should be off at this stage).

The commutator part of the armature can be eased gently between them pushing them slightly apart. Finally, holding the armature in this position, the knitting needle is inserted through the aluminium tube and the supporting split pins already fixed in the base. Apart from the slight friction of the brushes the armature should spin freely when twisted with the fingers. Note that contact with the brushes when the coil is in the horizontal plane is particularly important. The field is provided by two magnadur magnets and the mild steel yoke. When the supply is connected a slight twist of the armature will start the motor which 'revs' at high speed.

It is instructive to try the motor and the moving coil meter in series with the supply. If the motor is a good one, the increase in current may be observed when the motor is lightly loaded by pressing gently with the finger on the rotating aluminium tube.

Note

For those with poor manipulative ability, there is an easier way to make the commutator; but it is not as good as the first version as the frictional torque is greater with a commutator of larger diameter. In place of the Sellotape, rubber tubing is slid over the aluminium tube to provide insulation. Larger rubber bands are needed to secure the bared wire loops, and the assembly proceeds as before.



86 *Demonstration*

Fractional horse-power motor

Apparatus

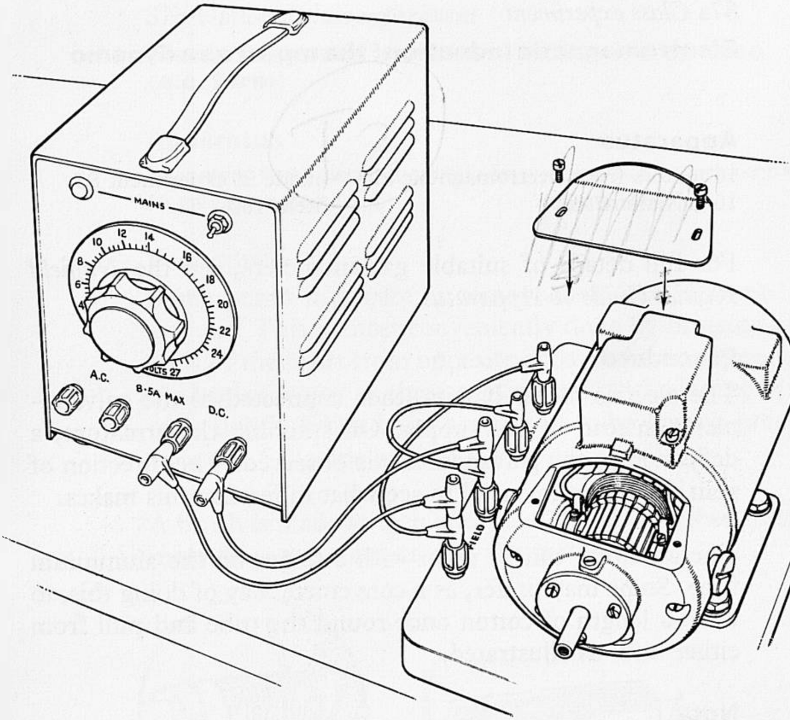
1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59

Procedure

The fractional horse-power motor recommended for use elsewhere in the course operates from 12 volts d.c., which is conveniently obtainable from the L.T. variable voltage supply. The field and armature connections should each be connected, in parallel, to the voltage supply.

The motor recommended has a convenient plate on the end which can be removed by the teacher to show the brushes and internal movement. Pupils should look at this to see whether they can identify the parts.

Reduce to 41mm



T2

87a *Class experiment*

Electromagnetic induction: the motor as a dynamo

Apparatus

16 motors from electromagnetic kit	– made in experiment 85
16 galvanometers	– item 180

For full details of suitable galvanometers, see the *Nuffield Physics Guide to Apparatus.*

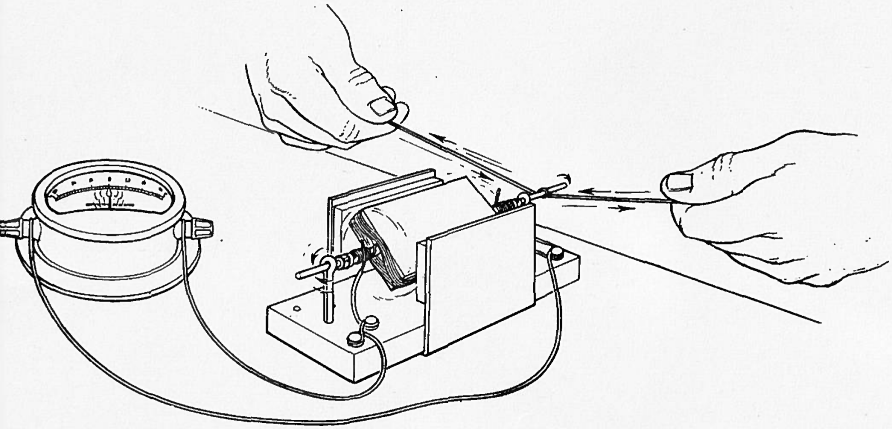
Procedure

The electric motor has its leads connected to the galvanometer instead of the supply. On spinning the armature, a deflection of the galvanometer is observed. The direction of spin should be reversed to see what difference this makes.

The armature can be spun with a finger on the aluminium tube. Some may prefer, as a convenient way of doing this, to wrap a length of cotton once round the tube and pull from either end, as illustrated.

Note

If the motor has run for an appreciable time, the brushes and commutator will be dirty and have a high resistance. Strip down and scrape the brushes and commutator with sandpaper to clean them. Avoid finger grease. Taking these precautions may increase the galvanometer deflection several times.



87b *Optional class experiment*

Electromagnetic induction: motor as a dynamo (a.c. form)

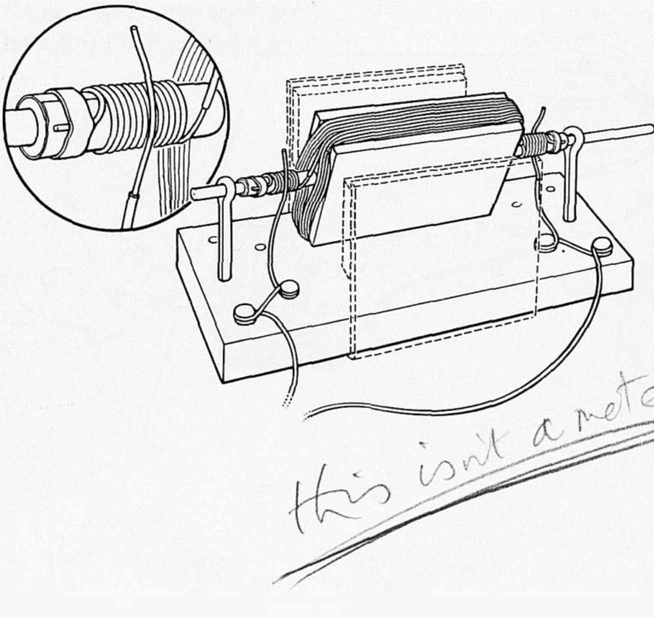
Apparatus

16 motors from electromagnetic kit – made in experiment 85
16 galvanometers – item 180

Procedure

Some pupils may care to convert their 'd.c. dynamo' to an a.c. one. This is most conveniently done by bringing out the ends of the leads from opposite ends of the armature, baring the leads for two or three centimetres, and winding the bare ends tightly around the aluminium tube having previously wrapped Sellotape around it to insulate it.

A brush is made at each end – as already described in experiment 85 – and connected to the meter.



this isn't a meter

88a *Class experiment*

Electromagnetic induction: magnet and coil

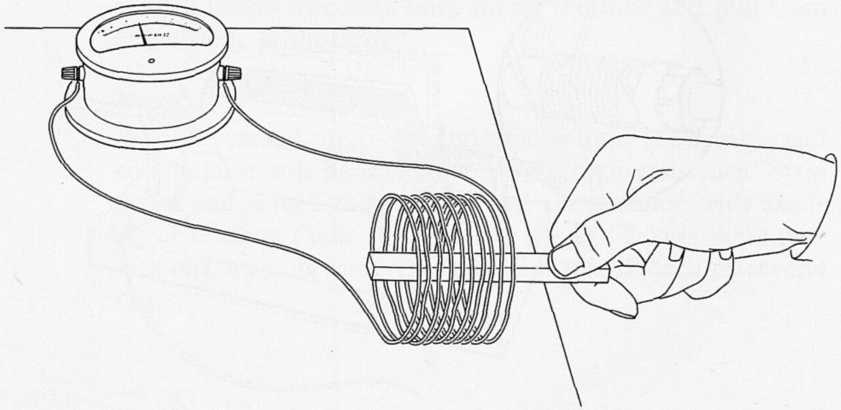
Apparatus

1 electromagnetic kit – item 92
  ticonal magnets
  PVC-covered copper wire
16 galvanometers – item 180

Procedure

The pupils should be asked to wind a coil of 10 to 20 turns with long leads (say 2 ft). The coils should be such that a ticonal magnet can pass freely through. The long leads are connected to the galvanometer.

The pupils should be allowed plenty of time to find out for themselves what is happening when they move the magnet relatively to the coil.



88b *Class experiment*

Electromagnetic induction: wire moving across magnetic gap

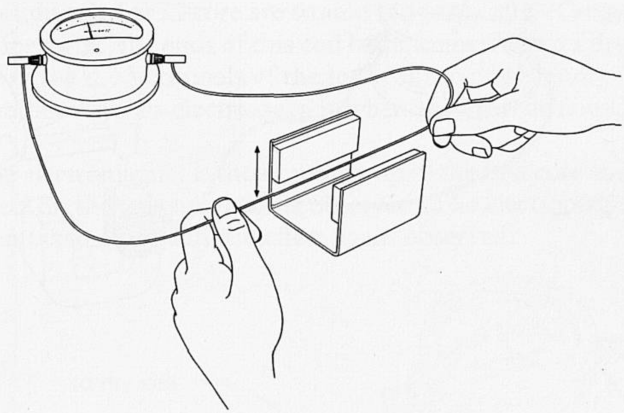
Apparatus

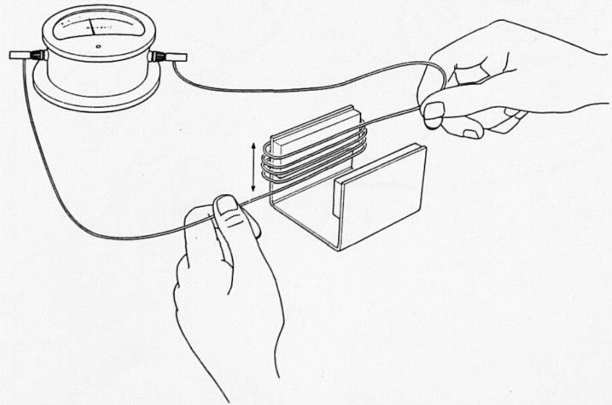
1 electromagnetic kit – item 92
  PVC-covered copper wire
  steel yoke
  magnadur magnets
16 wire strippers – item 84
16 galvanometers – item 180

Procedure

Two magnadur magnets are attached to the mild steel yoke with opposite poles facing each other. A long lead of PVC-covered copper wire is connected to the commercial galvanometers. The pupils should try moving the wire through the field between the permanent magnets.

Some pupils may try the effect of a coil of many turns and see how this changes the deflection.





88c *Class experiment*

Electromagnetic induction: magnet and coil on iron core

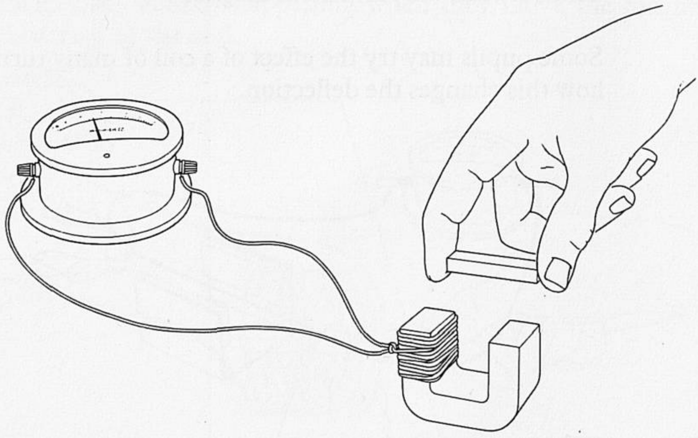
Apparatus

1 electromagnetic kit – item 92
  PVC-covered copper wire
  C-cores
  ticonal magnets
16 galvanometers – item 180

Procedure

Wind a coil of twenty turns on one arm of a C-core. Connect the coil by long leads to a galvanometer.

Place a magnet across the ends of the core. Observe the effect. Then remove the magnet. Again observe the effect. Repeat.



88d *Class experiment*

Electromagnetic induction using an electromagnet

Apparatus

1 electromagnetic kit – item 92
PVC-covered copper wire
C-cores
16 galvanometers – item 180
16 dry cells*

*It is suggested that dry cells be used for this experiment. It is however possible to use the low-voltage power units (item 104), but the ripple on the d.c. output can lead to confusion.

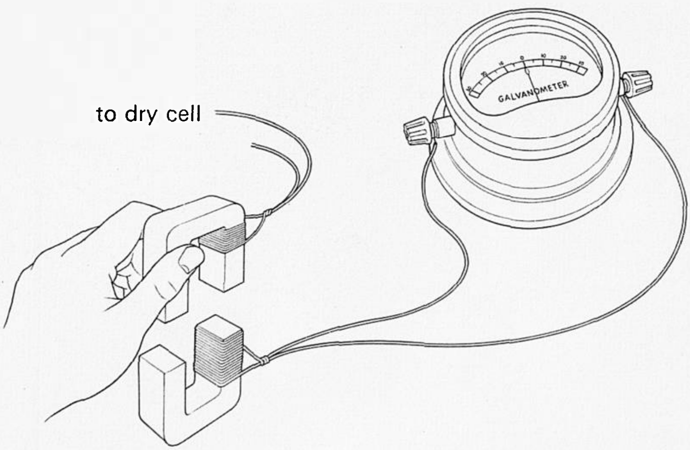
Procedure

This experiment is similar to the previous one except that the permanent magnet is replaced by an electromagnet.

A coil of ten to twenty turns is wound on one arm of a C-core and the coil is connected by long leads to a galvanometer.

Around another C-core are wound ten turns of PVC-covered copper wire, the ends of this coil being connected to a dry cell (or to the d.c. terminals of the low-voltage power unit). This core becomes an electromagnet when the current flows.

The electromagnet is then brought up to the first core and the effect on the galvanometer is observed. The electromagnet is then taken away and the effect again observed.



88e *Class experiment*

Electromagnetic induction: switching an electro-magnet

Apparatus

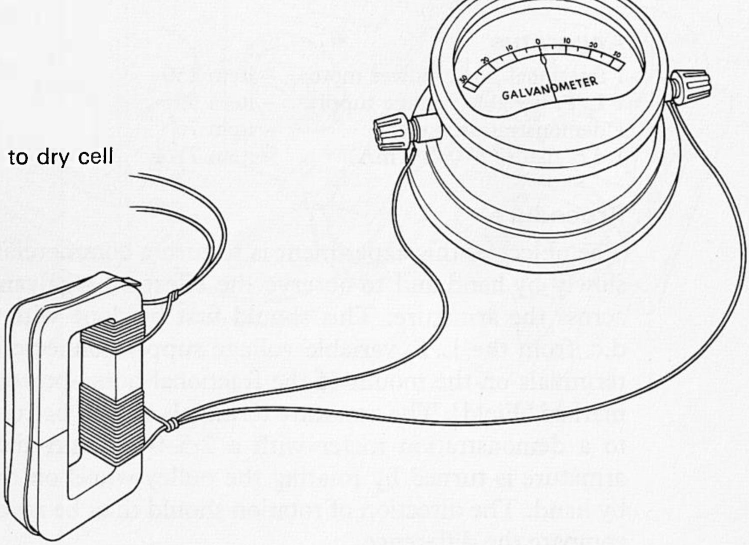
1 electromagnetic kit – item 92
PVC-covered copper wire
C-cores
16 galvanometers – item 180
16 dry cells

Procedure

As a conclusion to the previous experiment, the pupils should leave the two halves of the C-cores together – held if they wish by the clip provided. The battery is now switched off and on and this will be found equivalent to 'removing' and 'restoring' the electromagnet.

Note

The low-voltage power units can be used in place of the dry cells, but the ripple on the d.c. output will probably lead to confusion. There will be a deflection of the galvanometer even when the electromagnet is left switched on. Dry cells are therefore to be preferred.


to dry cell
GALVANOMETER
30
20
10
0
10
20
30

88f *Demonstration*

Electromagnetic induction: FHP motor connected to galvanometer

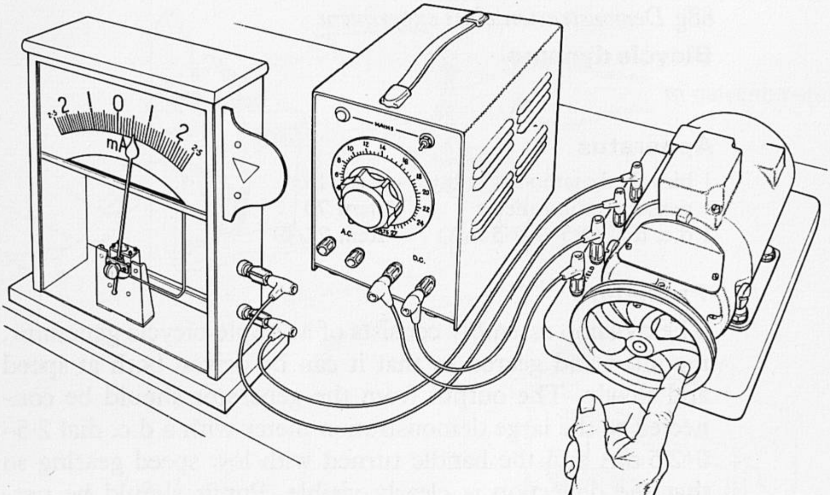
Apparatus

1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
1 demonstration meter	– item 70
1 d.c. dial (2·5–0–2·5 mA)	– item 71/4

Procedure

The object of this experiment is to turn a commercial motor slowly by hand and to observe the effect on a galvanometer across the armature. This should first be done with 2 volts d.c. from the L.T. variable voltage supply connected to the terminals on the mount of the fractional horse-power motor marked 'Field'. The armature terminals should be connected to a demonstration meter with a 2·5–0–2·5 mA dial. The armature is turned by rotating the pulley wheel on the shaft by hand. The direction of rotation should then be reversed to compare the difference.

The experiment should also be tried without any voltage applied to the field terminals.


mA
A.C.
D.C.

88g *Demonstration/class experiment*

Bicycle dynamo

Apparatus

1 bicycle dynamo assembly – item 103
1 demonstration meter – item 70
1 d.c. dial (2·5–0–2·5 mA) – item 71/4

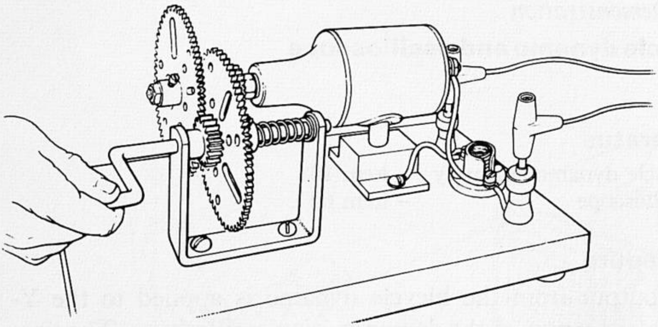
Procedure

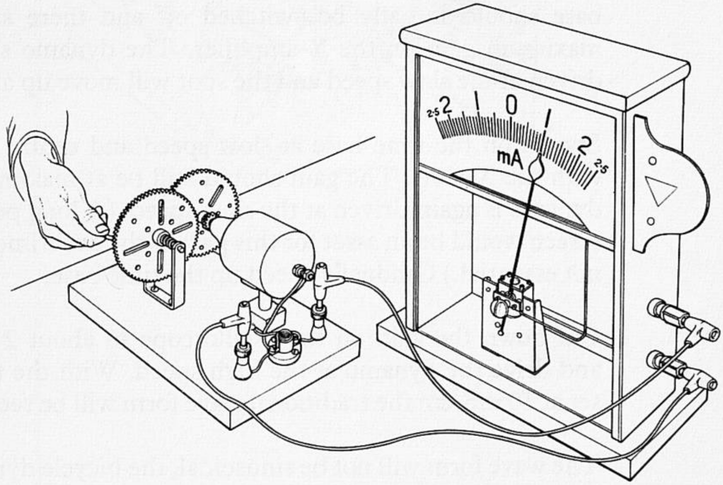
The dynamo assembly consists of a simple bicycle generator, mounted and geared so that it can be driven both at speed and slowly. The output from the generator should be connected to the large demonstration meter with a d.c. dial 2·5–0–2·5 mA and the handle turned with low speed gearing so that the deflection is clearly visible. Pupils should be permitted to do this for themselves using the low-speed gearing. They should notice the effect of increasing the speed of rotation and note how, at higher speeds, the pointer merely vibrates over a very small range about the zero position since the output is a.c.

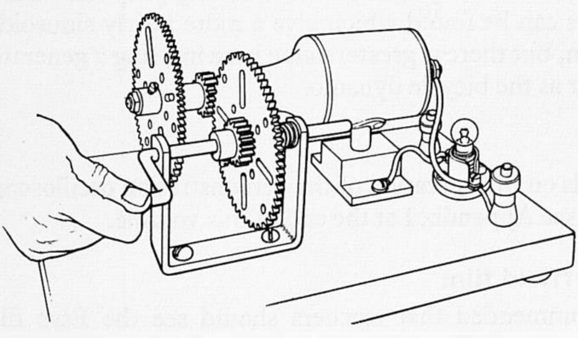
The dynamo should also be driven at high speed using the other gears provided. The output will be sufficient to light the pea-lamp across it.

Note

The demonstration meter with dial is suggested so that it is clearly visible to the whole class. It is likely that a teacher will want to leave the dynamo at the side of the class for pupils to use for themselves: in this case, one of the recommended galvanometers (item 553) will give a better deflection as they have a greater voltage sensitivity. However, there is a danger that the high-speed gearing will be used and the meter damaged. It may be better to confine this experiment at the side of the class merely to lighting the lamp.


to galvanometer


2·5
2
1
0
1
2
2·5
mA



89a *Demonstration*

Bicycle dynamo and oscilloscope

Apparatus

1 bicycle dynamo assembly	– item 103
1 oscilloscope	– item 64

Procedure

The output from the bicycle dynamo is applied to the Y-plates (the input) of the demonstration oscilloscope. The time base should initially be switched off and there should be maximum gain on the Y-amplifier. The dynamo should be driven at the slow speed and the spot will move up and down.

Switch on the time base at slow speed and centre the trace with the X-shift. The gain should still be at maximum. The dynamo is again driven at the slow speed. (A long persistence screen would be an asset for this part of the experiment, but is not essential.) Gradually speed up the time base.

Cut down the gain on the oscilloscope to about 2 volts/cm and drive the dynamo at the high speed. With the time base set at 10 mS/cm the traditional wave form will be seen.

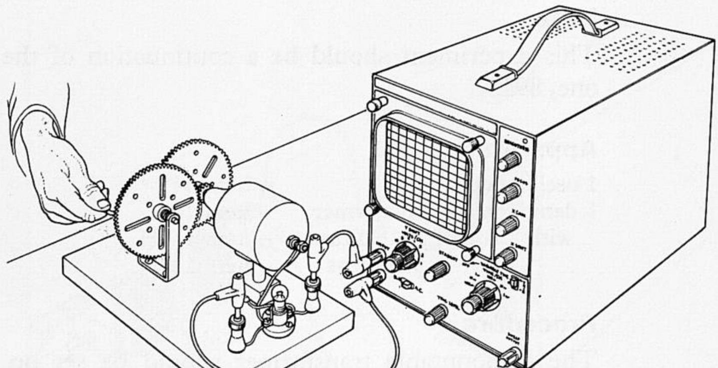
The wave form will not be sinusoidal, the bicycle dynamo was designed for efficiency and not for teaching purposes. Other generators can be found which give a more nearly sinusoidal wave form, but there is greater value here in using a generator as familiar as the bicycle dynamo.

Note

For details on the operation of the demonstration oscilloscope (item 64) see Appendix I at the end of this volume.

Esso-Nuffield film

It is recommended that teachers should see the Esso film *Oscilloscopes and Slow A.C.* which is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1. This film is for teachers and should *not* be shown to pupils.



89b *Demonstration*

Oscilloscope and a.c. voltage from transformer

Note

This experiment should be a continuation of the previous one, 89a.

Apparatus

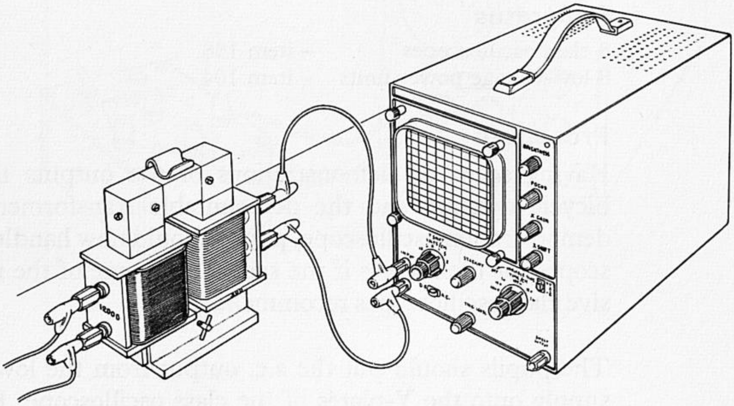
1 oscilloscope	– item 64
1 demountable transformer	– item 147
with 1 coil of 12,000 turns	– item 147H
1 coil of 300 turns	– item 147D

Procedure

The demountable transformer should be set up with the 12,000-turn coil on one side of the U-core and the 300-turn coil on the other. The mains can be connected to the 12,000-turn coil and there will then be about 6 volts across the secondary coil when the core is completed.

Without changing the time base on the oscilloscope from its setting in the previous experiment 89a, the dynamo is disconnected from the input and the low-voltage output from the secondary of the demountable transformer is put on to the Y-plates instead by direct connection to the input terminals of the oscilloscope.

The pupils will doubtless raise the problem of a change of frequency from the dynamo to the transformer. The time base can then be readjusted.



89c *Class experiment*

Class oscilloscope

Apparatus

8 class oscilloscopes – item 158
8 low-voltage power units – item 104

Procedure

Having seen the demonstrations of the outputs from the bicycle dynamo and the demountable transformer on the demonstration oscilloscope, pupils should now handle oscilloscopes for themselves if the school has some of the inexpensive class oscilloscopes recommended.

The pupils should put the a.c. output from the low-voltage supply onto the Y-plates of the class oscilloscope. First the time base should be switched off, then switched on to range 2. The gain-setting should be about 1. The wave form will be seen.

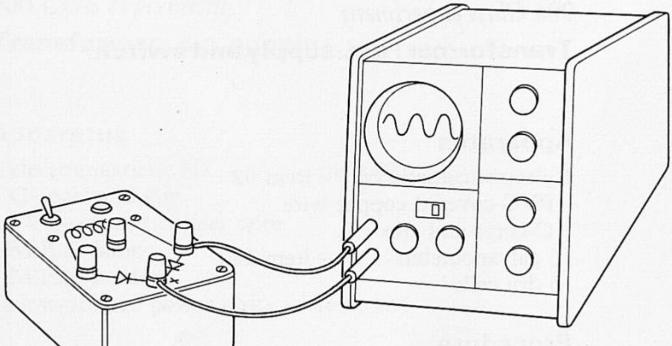
This will be a first experience for most of the children with the oscilloscopes and they should have time to enjoy this first encounter. This experiment should be an open-ended one: some will doubtless try doubling the voltage output, some will change the gain, some the frequency of the time base. Some will also try the d.c. outputs from the low-voltage supply and will observe full-wave and half-wave rectification.

Note

For details on the use and operation of the class oscilloscope (item 158) see Appendix II at the end of this volume.

Esso-Nuffield film

Teachers are again advised to see the Esso film for science teachers *Oscilloscopes and Slow A.C.*



90a *Class experiment*

Transformer: d.c. supply and switch

Apparatus

1 electromagnetic kit – item 92
  PVC-covered copper wire
  C-cores and clip
16 galvanometers – item 180
16 dry cells

Procedure

Twenty-five turns of PVC-covered wire are wound round one of the C-cores to form the secondary of the transformer. The ends of the coil are connected to the galvanometer.

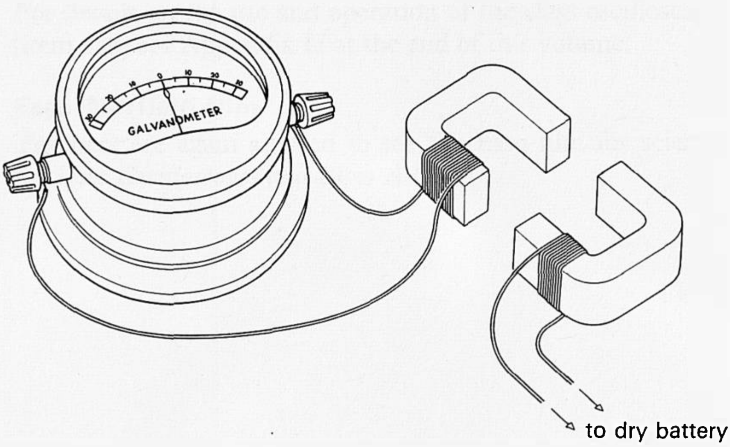
Ten turns are wound round the other core to form the primary. The ends are connected to a dry cell. A switch is necessary in the primary circuit; either an actual switch or disconnecting the lead to the dry cell will serve.

The two C-cores are put together and held with the clip provided.

Switching the primary current on or off causes a momentary flash of the lamp in the secondary circuit.

Note

Care should be taken not to leave the dry cell on for any length of time.



90b *Class experiment*

Transformer: a.c. supply

Apparatus

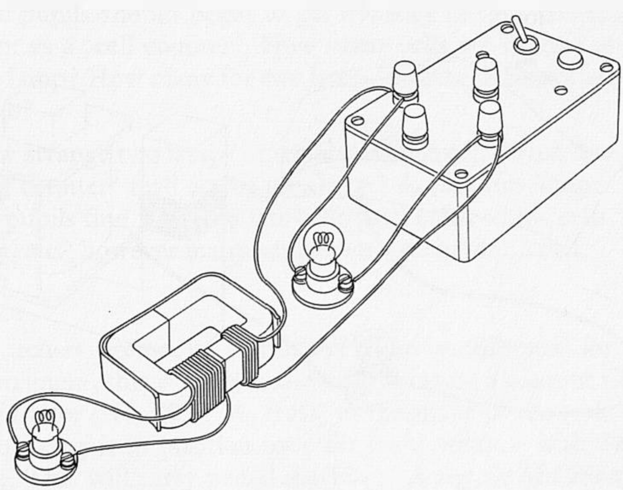
1 electromagnetic kit – item 92
  C-cores and clip
  PVC-covered copper wire
  M.E.S. lamps
  M.E.S. holders
16 low-voltage power units – item 104

Procedure

Following the previous experiment, the d.c. supply and switch are replaced by an a.c. supply.

The secondary coil consists of 25 turns and the ends are connected to the lampholder with a pea-lamp in it. The primary has 10 turns and is connected to the 1-volt a.c. terminals of the low-voltage power units.

The use of the transformer will be apparent if a second pea-lamp is put across the power unit. This lamp will only glow faintly, whereas the lamp across the secondary glows brightly. To confirm that this is not due to a difference in the two lamps, these should then be interchanged.



90c *Demonstration*

Transformer: dependence on number of turns

Apparatus

1 demountable transformer	– item 147
with 1 coil of 1,200 turns	– item 147F
1 MES bulb	– item 92R
1 MES holder	– item 92T
PVC-covered copper wire	– item 92X

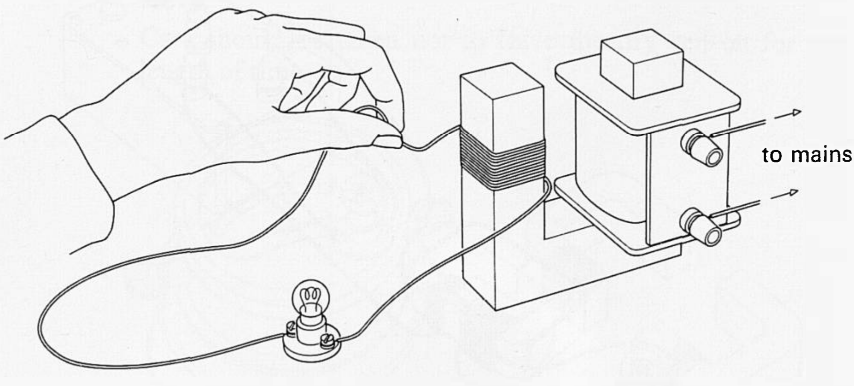
Procedure

The 1,200-turn coil is placed on one limb of the laminated U-core of the demountable transformer. This is connected to the a.c. mains.

A long lead (4 metres of PVC-covered copper wire) is connected to the lampholder and pea-lamp. With the mains switched on, the lead is wound turn by turn round the other leg of the U-core. As more and more turns are wound on, the lamp begins to glow and then to get brighter and brighter. At least 20 turns will be necessary for this.

Note

The 1,200-turn coil will be operating at twice its rated current (four times its power). It is liable to overheat if left on for long.



91 *Class experiment*

Introduction to a voltmeter as a cell counter.
This experiment may have been done in Year II, slow groups probably postponed it and should do it now.

Apparatus

16 Worcester circuit boards	– item 52C
Each group requires:	
3 U2 cells	– item 52B
3 bulbs	– item 52A
3 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J
16 d.c. voltmeters (0–5 volts)	– item 80
cinemoid filter (frost)	– item 57J

Procedure

Ask the pupils to connect three lamps in series with three cells.

Then put the voltmeter provided across one of the lamps. Then across another. Then across the third. Ask what happens if the leads are connected the wrong way round.

Then put the meter across two of the lamps. Then across three.

The pupils should begin to get the idea of this new instrument as a 'cell counter'. How many cells are needed to run one lamp? How many for two lamps together? How many for three?

Now arrange two lamps in series with one cell. What does the 'cell counter' read across one lamp? Across two lamps? Let the pupils find it still counts cells (half cells, whole cells, two cells, etc.) however many lamps there are in the circuit.

Note

If teachers prefer the voltmeters to be uncalibrated for this experiment, this is easily achieved by cutting a piece of Cinemoid filter (No. 29 or 31, frost) to the shape of the scale and then fixing it in position over the front window with Sellotape. This will carry pencil markings. A supply of Cinemoid filter is included in the Year II General Kit (item 57J). Alternatively, 'write on' Sellotape can be used.

92a *Demonstration*

Water circuit board

Apparatus

1 water circuit board – item 89
1 L.T. variable voltage supply – item 59

Procedure

The water circuit board should be set up vertically. The electric motor, which constitutes the water pump, should be connected to the a.c. terminals of the L.T. variable voltage supply (*not* d.c.). The motors can be operated up to 18 volts, but it is recommended that the voltage should not exceed 16 volts.

The tubes should be filled with water: a little fluorescein or a few drops of methyl orange can be added to make the water more clearly visible. The water is conveniently poured in at the funnel – see diagram below.

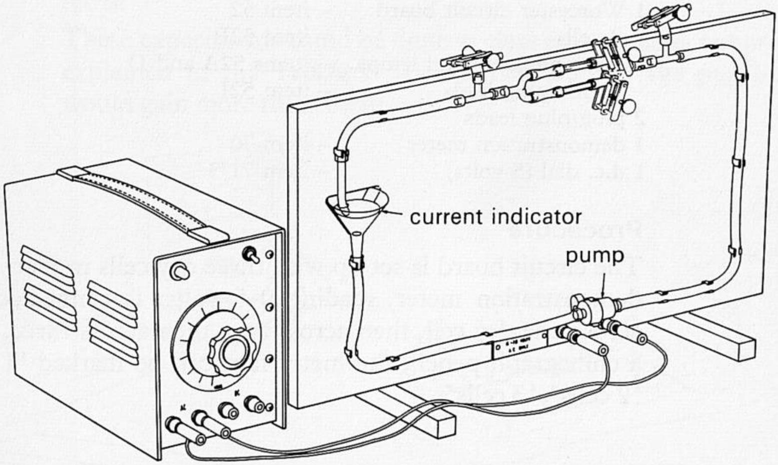
The pump will drive water round the circuit of glass tubing attached to the board, the pressure being dependent on the voltage applied to the motor.

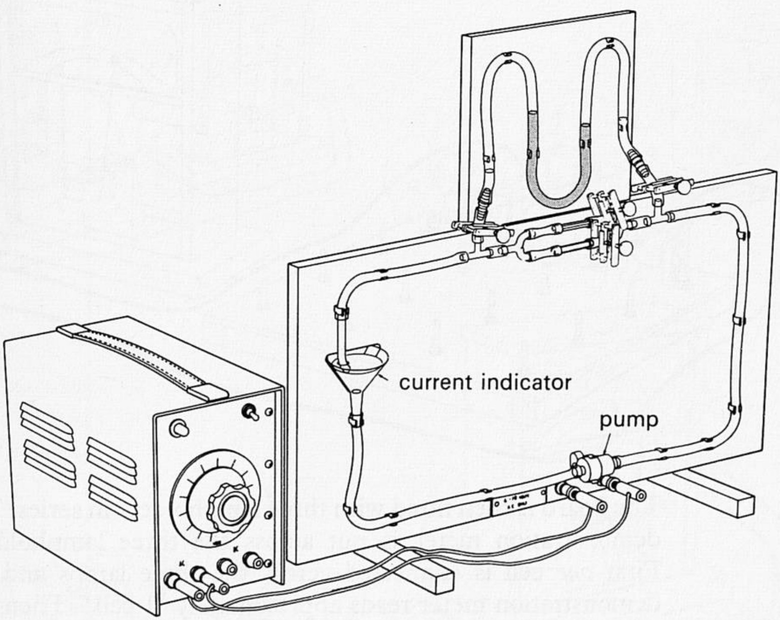
At one point, the tube divides. The two sections represent different resistances: one tube has a much finer bore than the other. Clips enable one or other or both sections to be opened at once: thus the effect on the current of different 'resistances' can be seen.

The pressure gauge consists of a U-tube connected as illustrated and filled with coloured water.

Where there is a break in the circuit, the funnel catches the water flowing down from the tube above. The rate of flow of water is apparent and this indicates the current. Alternatively, if there is a pool of water in the funnel the faster the flow of water the more rapid the swirling motion in the funnel. A small piece of cork floating on the water in the funnel acts as an indicator of the rate of swirling, which thus shows the current.

The teacher will doubtless demonstrate the change in current with pressure and also the change in current which results from increasing or decreasing the resistance, keeping the pressure difference constant.





92b *Demonstration*

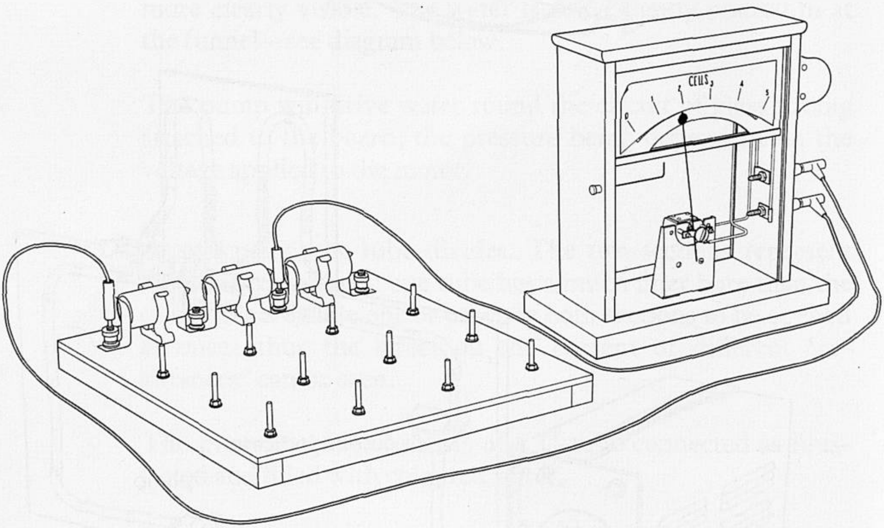
The voltmeter as a cell counter

Apparatus

1 Worcester circuit board	– item 52
3 cells	– item 52B
3 lampholders and lamps	– items 52A and D
4 croc/plug leads	– item 52I
2 plug/plug leads	
1 demonstration meter	– item 70
1 d.c. dial (5 volts)	– item 71/3

Procedure

The circuit board is set up with three dry cells in place. The demonstration meter, reading 0–5 volts, is connected first across one dry cell, then across two, then across three. With a chinagraph pencil, the meter face can be marked '1 cell', '2 cells', '3 cells'.

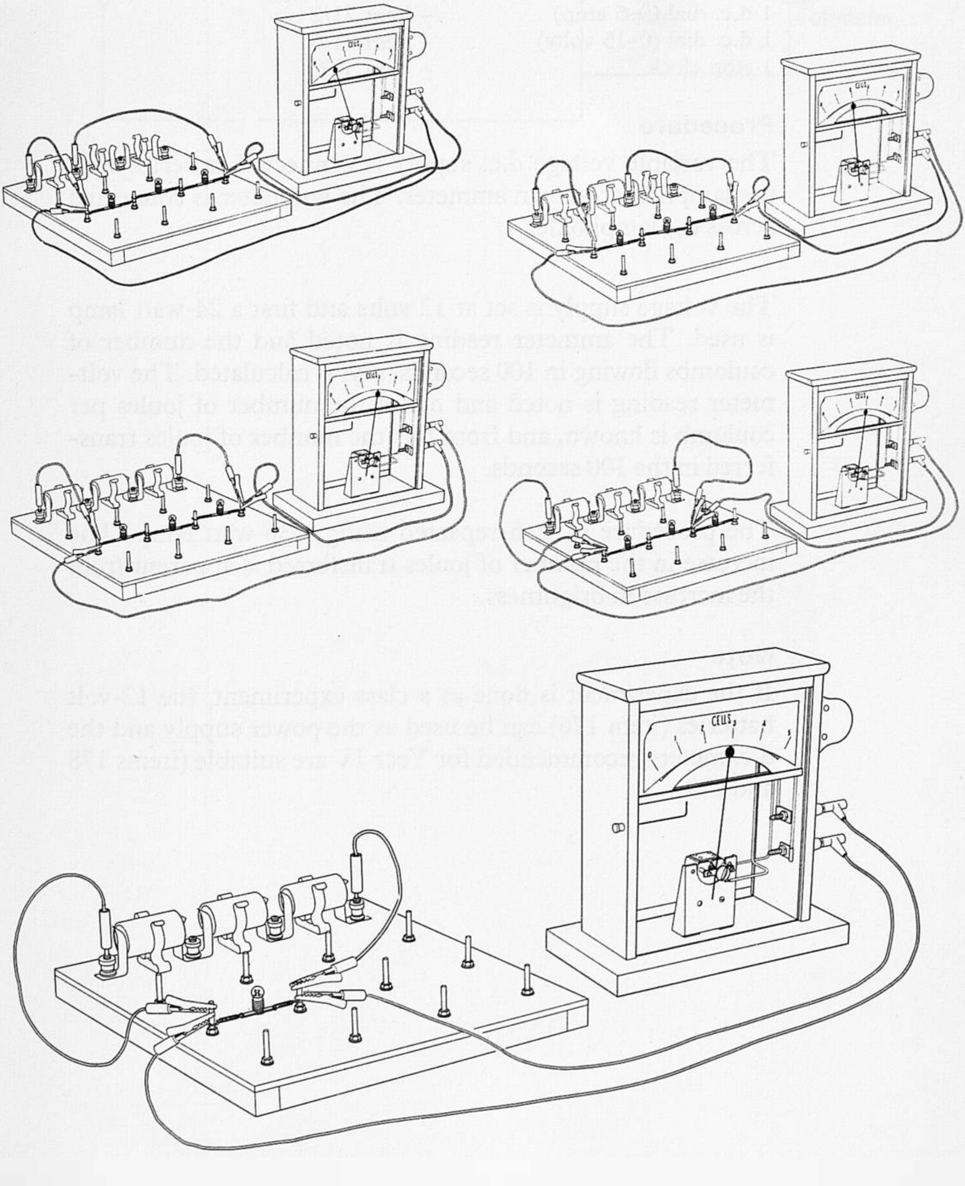


The board is then fitted with three lampholders in series. The demonstration meter is put across the three lampholders. First *one* cell is connected across the three lamps and the demonstration meter reads approximately '1 cell'. Then two cells are connected across the three lamps and the demonstration meter reads approximately '2 cells'. Then three cells across the three lamps.

Finally the three cells are put successively across three lamps, across two lamps, across one lamp. These experiments show the voltmeter is a cell counter and not a lamp counter.

Note

These experiments could be done as class experiments, but as explained in the *Teachers' Guide*, it is unlikely the pupils would gain more from them.



93 *Optional buffer experiment*

Using a voltmeter to measure power transferred

Apparatus

2 lampholders (SBC) on bases	– item 74
1 lamp (12 volt, 24 watt)	– item 72
1 lamp (12 volt, 36 watt)	– item 73
1 L.T. variable voltage supply	– item 59
2 demonstration meters	– item 70
1 d.c. dial (0–5 amp)	– item 71/2
1 d.c. dial (0–15 volts)	– item 71/6
1 stop clock	– item 507

Procedure

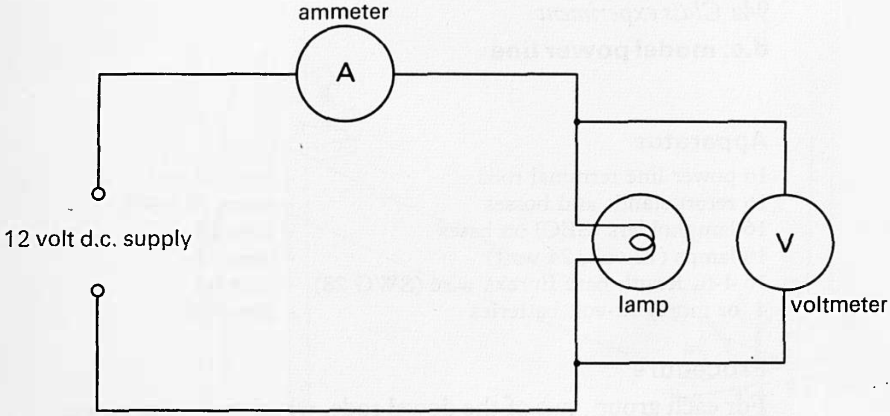
The variable voltage d.c. supply is connected in series with the lampholder and an ammeter. The voltmeter is connected across the lampholder.

The voltage supply is set at 12 volts and first a 24-watt lamp is used. The ammeter reading is noted and the number of coulombs flowing in 100 seconds, say, is calculated. The voltmeter reading is noted and hence the number of joules per coulomb is known, and from this the number of joules transferred in the 100 seconds.

The procedure is then repeated using a 36-watt lamp. The increase in the number of joules transferred is apparent from the increase in brightness.

Note

If the experiment is done as a class experiment, the 12-volt batteries (item 176) can be used as the power supply and the d.c. meters recommended for Year IV are suitable (items 178 and 179).


ammeter
A
12 volt d.c. supply
lamp
V
voltmeter

94a *Class experiment*

d.c. model power line

Apparatus

16 power line terminal rods	– item 99
16 retort stands and bosses	– items 503–505
16 lampholders (SBC) on bases	– item 74
16 lamps (12 volt, 24 watt)	– item 72
16 4-ft. length bare Eureka wire (SWG 28)	– item 98
4 (or more) 12-volt batteries	– item 176

Procedure

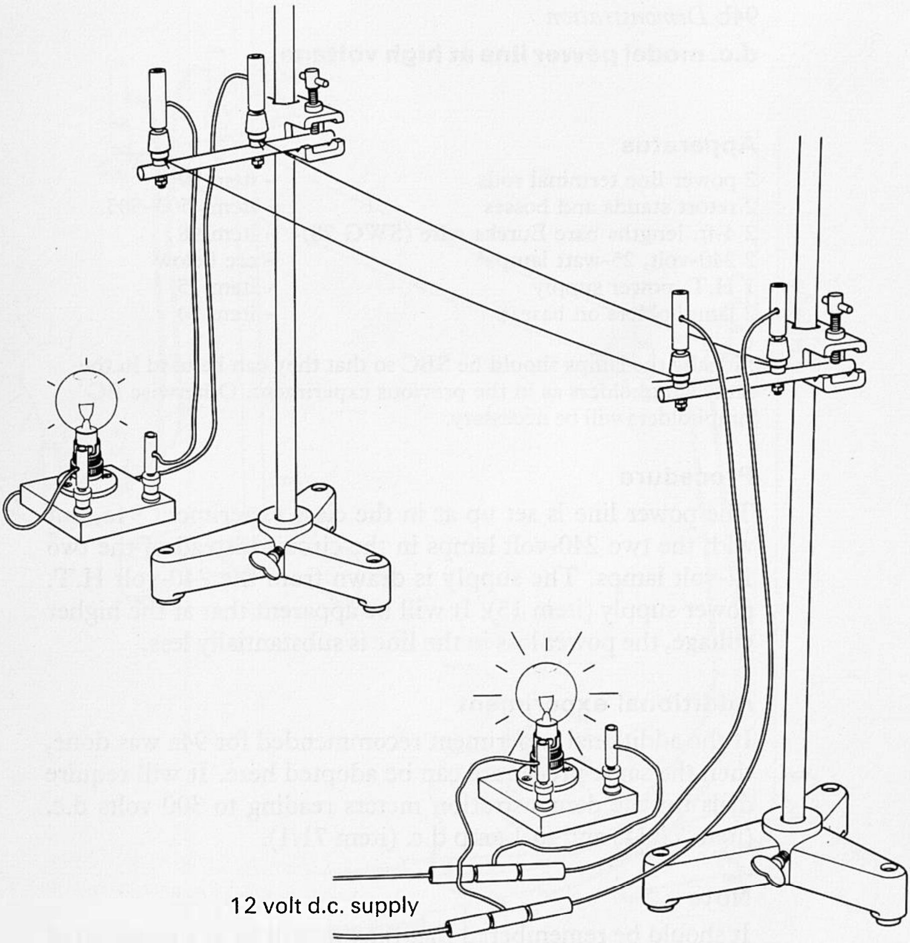
For each group, two of the dowel rods, which form the power line terminal rods, are held horizontally in two bosses at a height of about 1 ft above the bench and 3 to 4 ft apart. Two lengths of resistance wire (Eureka SWG 28) are stretched between the terminals to form the power line.

One of the two lampholders with a 12-volt, 24-watt SBC lamp is connected straight to the 12-volt supply at the 'power station' end. The supply is also connected direct to one of the terminal rods.

The second lamp is connected to the other end of the power line where it represents the 'village'. With the values given, the 'village' lamp will just glow, in contrast with the fully-lit pilot lamp at the 'power station'. If a second lamp is added in parallel to the single 'village' lamp, neither will glow.

Additional experiment

With a very fast group, who understand a voltmeter, it is possible to make measurements. An ammeter (reading to at least 2 amp) – item 178 – is connected into the supply line. The voltmeter (reading to at least 12 volts) – item 179 – is first connected across the 'village' lamp to measure the energy transfer in joules per coulomb; it is then connected across the supply at the 'power station' to measure the energy transfer there. The pupils can then calculate 'the power used by the village' and 'the power used by (power line + village)'.


12 volt d.c. supply

94b *Demonstration*

d.c. model power line at high voltage

Apparatus

2 power line terminal rods	– item 99
2 retort stands and bosses	– items 503–505
2 4-ft. lengths bare Eureka wire (SWG 28)	– item 98
2 240-volt, 25-watt lamps*	– see below
1 H.T. power supply	– item 15
2 lampholders on bases*	– item 74

*Ideally the lamps should be SBC so that they can be used in the same lampholders as in the previous experiment. Otherwise BC lampholders will be necessary.

Procedure

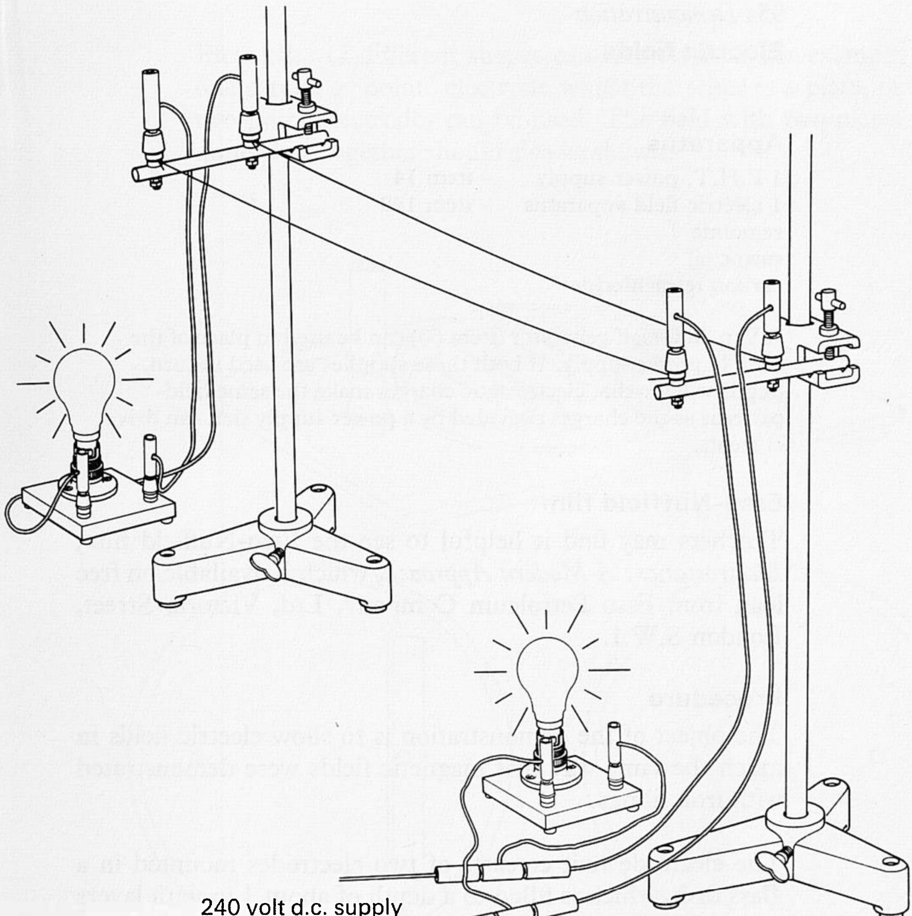
The power line is set up as in the class experiment 94a, but with the two 240-volt lamps in the circuit instead of the two 12-volt lamps. The supply is drawn from the 240-volt H.T. power supply (item 15). It will be apparent that at the higher voltage, the power loss in the line is substantially less.

Additional experiment

If the additional experiment recommended for 94a was done, then the same procedure can be adopted here. It will require dials for the demonstration meters reading to 300 volts d.c. (item 71/11) and to 1 amp d.c. (item 71/1).

Note

It should be remembered that the line will be at a potential of 240 volts – and that a considerable shock can be obtained even though the supply is limited. It follows that this experiment is essentially a demonstration one which compares directly with the preceding class experiment.


240 volt d.c. supply

95a *Demonstration*

Electric fields

Apparatus

1 E.H.T. power supply	– item 14
1 electric field apparatus	– item 149
semolina	
castor oil	
carbon tetrachloride	

A Van de Graaff generator (item 60) can be used in place of the E.H.T. power supply. If both these supplies are used in turn, pupils will see that electrostatic charges make the same field-patterns as the charges provided by a power supply that can drive currents.

Esso-Nuffield film

Teachers may find it helpful to see the Esso-Nuffield film, *Electrostatics: A Modern Approach*, which is available on free loan from Esso Petroleum Company, Ltd, Victoria Street, London S.W.1.

Procedure

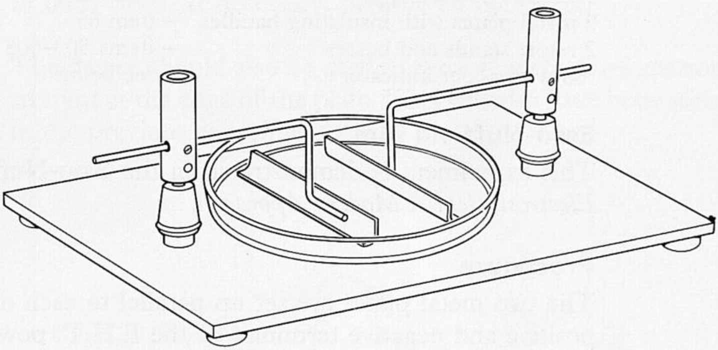
The object of the demonstration is to show electric fields in much the same way that magnetic fields were demonstrated with iron filings.

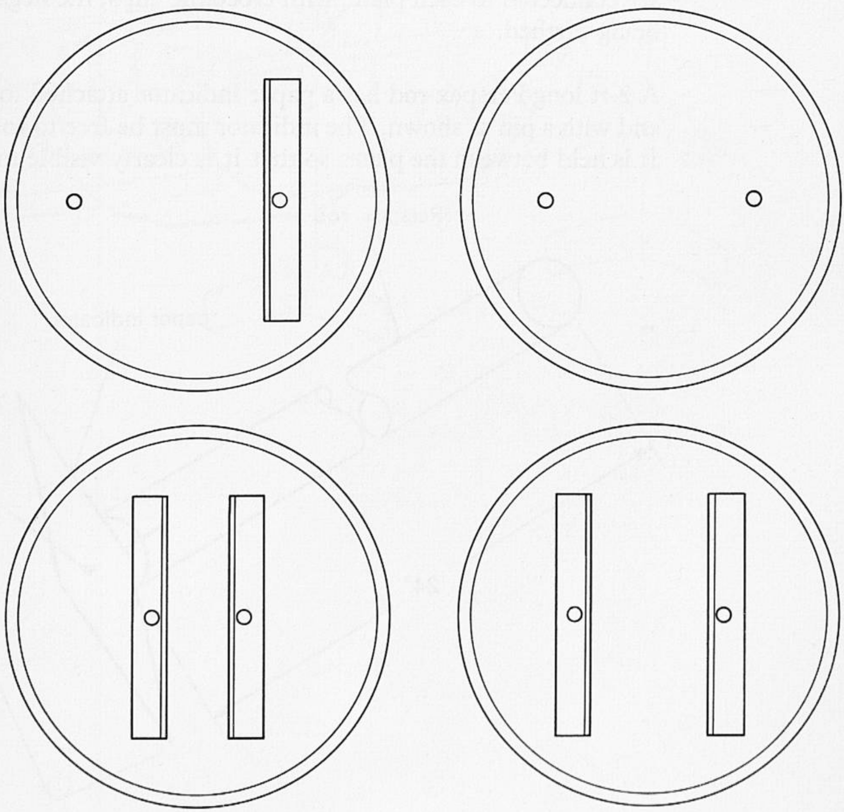
The electrode unit consists of two electrodes mounted in a glass dish, which is filled to a depth of about $\frac{1}{4}$ in with layers of castor oil and carbon tetrachloride. A thin sprinkling of semolina is made over the surface. A thin piece of glass tubing drawn out to give a fine pointed stirrer is helpful so that the semolina is evenly distributed. It is better to start with too little semolina and to increase the quantity later, than to start with too much.

The electrodes are placed in the castor oil. These can be made from aluminium sheet or can be purchased complete with dish. Apart from the care which needs to be taken with the insulation, this unit is readily improvised.

The positive and negative terminals of the E.H.T. power supply are connected to the electrodes. The supply is adjusted to give 3,000 to 4,000 volts. When the voltage is switched on, the field lines will be clearly visible.

Electrodes of different shapes can also be tried, for example one can be a 'point' electrode whilst the other is a plate, or two point electrodes can be used. The field with two plates quite close together should also be shown.





95b *Demonstration*

Electric fields shown with paper indicator

Apparatus

1 E.H.T. power supply	– item 14
2 metal plates with insulating handles	– item 65
2 retort stands and bosses	– items 503–505
rod with paper indicator	– see below

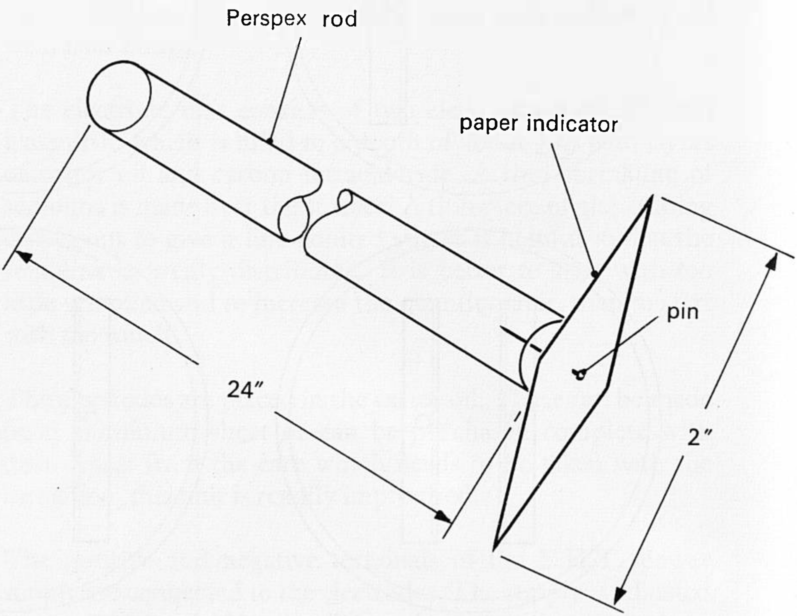
Esso-Nuffield film

This experiment is demonstrated in the Esso-Nuffield film, *Electrostatics: A Modern Approach.*

Procedure

The two metal plates are set up parallel to each other. The positive and negative terminals of the E.H.T. power supply are connected to each plate, with crocodile clips, the negative being earthed.

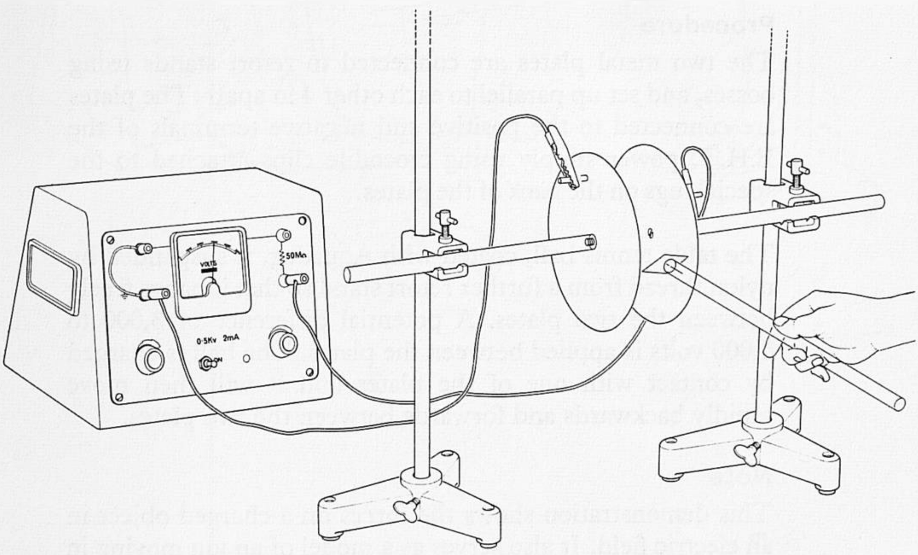
A 2-ft long Perspex rod has a paper indicator attached to the end with a pin as shown. The indicator must be free to rotate. It is held between the plates so that it is clearly visible to the



class. The E.H.T. power supply is switched on and the indicator sets along the field lines.

The paper indicator acts by developing induced charges in the field. Therefore it must conduct although it need not conduct well. Paper is hygroscopic enough to ensure conduction in most cases. If necessary, breathe on the paper.

The device should also be used to show that the lines are not straight at the edge of the plate. This will also have been seen in the previous experiment 95a.



96 *Demonstration*

Forces in an electrostatic field

Apparatus

1 E.H.T. power supply	– item 14
2 metal plates with insulating handles	– item 65
1 table tennis ball, coated with Aquadag	– item 57L
1 reel nylon thread	– item 57K
3 retort stands and bosses	– items 503–505
1 clamp	– item 506

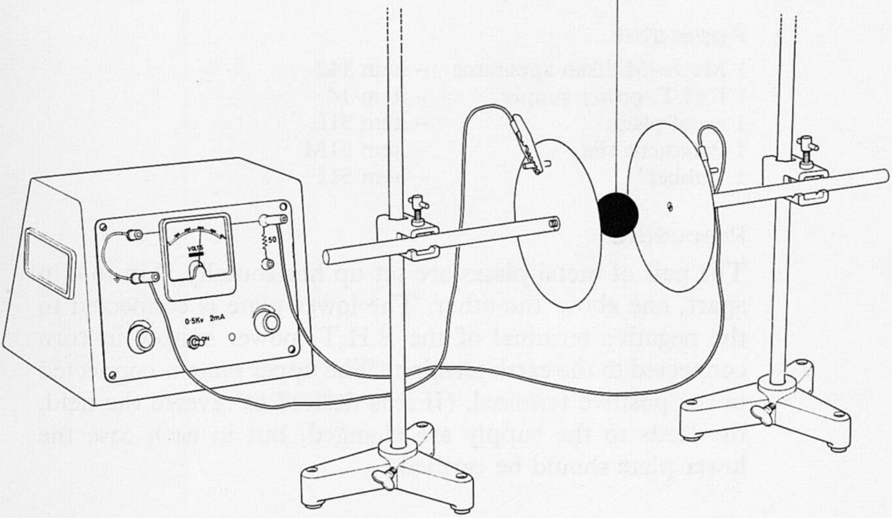
Procedure

The two metal plates are connected to retort stands using bosses, and set up parallel to each other 4 in apart. The plates are connected to the positive and negative terminals of the E.H.T. power supply using crocodile clips attached to the special lugs on the back of the plates.

The table tennis ball, coated with Aquadag, is suspended by nylon thread from a further retort stand so that it hangs freely between the two plates. A potential difference of 3,000 to 4,000 volts is applied between the plates. The ball is charged by contact with one of the plates and it will then move rapidly backwards and forwards between the two plates.

Note

This demonstration shows the forces on a charged object in an electric field. It also serves as a model of an ion moving in an electric field; as the ball moves to and fro between the plates, it represents a positive ion moving one way and then a negative ion moving the other.


VOLTS
0·5Kv 2mA
50

97 *Demonstration*

Macro-Millikan apparatus

Apparatus

1 Macro-Millikan apparatus	– item 142
1 E.H.T. power supply	– item 14
1 proof plane	– item 51L
1 Polythene tile	– item 51M
1 'rubber'	– item 51I

Procedure

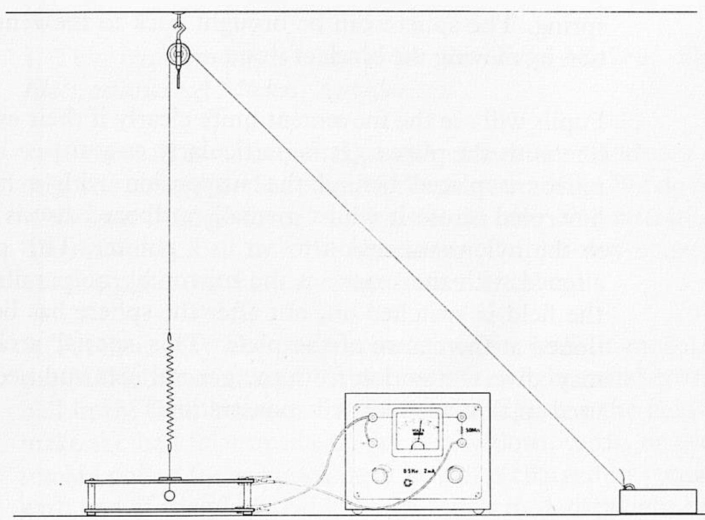
The pair of metal plates are set up horizontally, 3 in to 4 in apart, one above the other. The lower plate is connected to the negative terminal of the E.H.T. power supply in turn connected to the earth terminal. The upper plate is connected to the positive terminal. (If it is desired to reverse the field, the leads to the supply are changed, but in each case the lower plate should be earthed.)

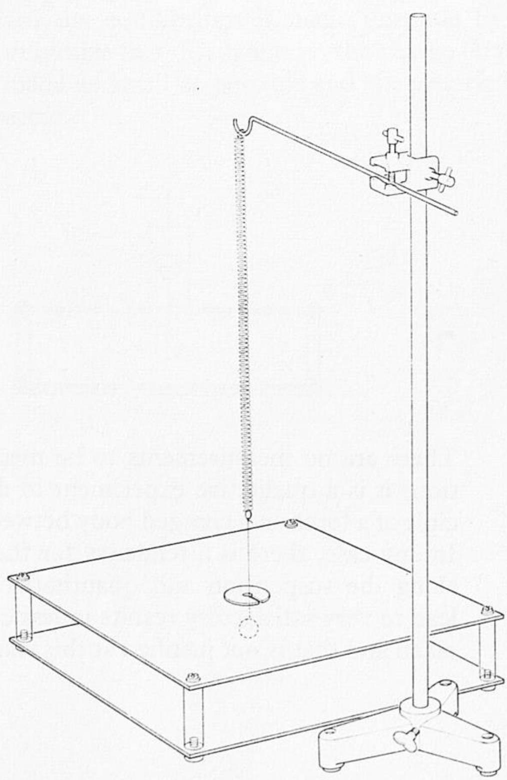
Through the hole in the upper plate is lowered the small conducting sphere with its nylon suspension. The upper end of the nylon suspension is looped and connected to the Pyrex glass spring.

The best arrangement for securing the upper end of the spring is to attach it to another loop in a nylon thread which is taken up over a pulley connected to the ceiling, and then to an eyelet on a block of wood. Alternatively, a support from a long retort stand rod can be used, as shown, and brought up over the plates forming a hooked support.

Rub the Polythene tile and put the proof plane on it, touching to charge the proof plane by induction. Without touching the plates, bring the proof plane up to the conducting sphere to charge it by contact. Adjust the suspension so that the sphere is almost exactly half-way between the two plates. This is most conveniently done in the first arrangement described above: by moving the block of wood nearer to or away from the apparatus, the sphere can be lowered or raised.

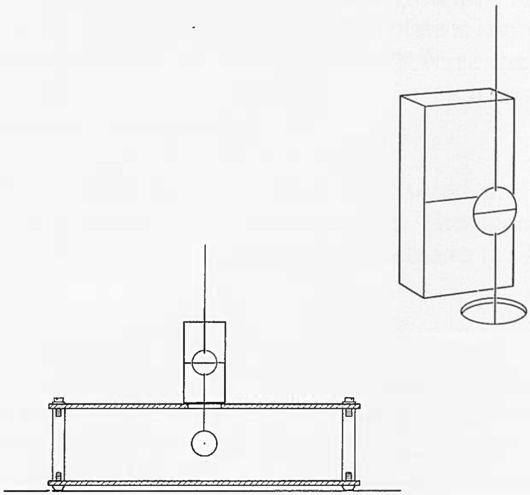
Switch on the EHT supply with 2,000 to 4,000 volts. The sphere will be seen to move as the extra force stretches the





spring. The sphere can be brought back to the central position by moving the block of wood.

Pupils will see the movement quite clearly if their eyes are in line with the plates. (It is particularly easy to see if a plane mirror is placed behind the suspension with a horizontal line ruled across it whilst a small cardboard disc is attached to the nylon suspension to act as a pointer. This pointer is aligned with the mark on the mirror by no parallax before the field is switched on, but after the sphere has been positioned at the centre of the plate. This special arrangement may divert attention from the general idea and need not be used in this qualitative demonstration.)



There are no measurements to be made in this demonstration: it is a qualitative experiment to demonstrate the principle of a force on a charged body between two parallel plates. In any case, there is a tendency for the charge to leak away along the suspension and quantitative experiments do not lead to very satisfactory results unless considerable trouble is taken and that is not justified at this stage of the course.

Note

1. This experiment is shown in the Esso–Nuffield film, *Electrostatics : A Modern Approach.*

2. If the ball is near one plate the charge on it induces an opposite charge on that plate, so there is attraction. We do not wish that 'image-force' to appear in the demonstration. Therefore the ball must be almost exactly half-way between the two plates, so that the image forces cancel out.

3. Teachers may like to experiment with a realistic model of the Millikan experiment by placing a very light metal-coated ball in the field between the plates and adjusting the field to make the ball float upwards, fall slowly downwards, or even remain poised for a short time. The ball is charged by contact with one of the plates, which then repels it. A *very* light ball is needed, or perhaps a scrap of aluminium leaf. When the ball is poised, its equilibrium is made unstable by image forces – to minimize that disadvantage, the charge on the ball should be made as small as possible and the electric field as large as possible.

98 *Optional demonstration*

Forces on charged polystyrene spheres: models of ions in motion

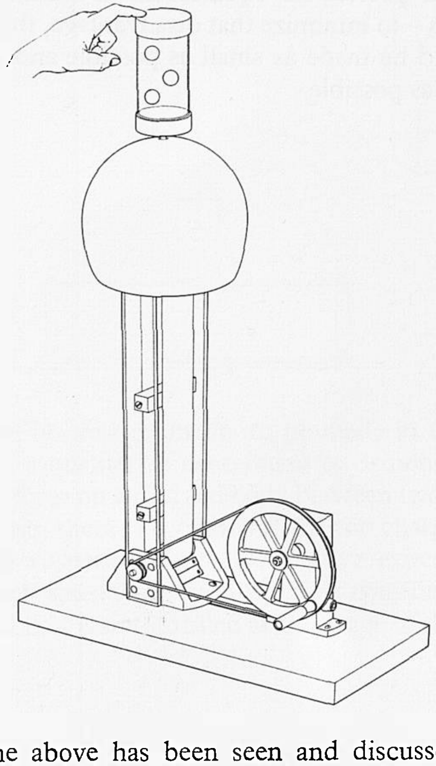
Apparatus

1 Van de Graaff generator	– item 60/1
1 cylinder and spheres	– item 60/2

Procedure

A Perspex cylinder with a metal top and a metal base and three or four conducting spheres inside it is placed on the top of the Van de Graaff generator.

When the generator is driven the spheres, initially lying on the metal base, become charged and rise up the cylinder until they are supported between the two parallel plates formed by the two caps.



After the above has been seen and discussed, the teacher should put his finger on the top metal cap keeping it there. The spheres will be set in motion as they carry charge across.

99a *Class experiment*

Electrostatic forces

Apparatus

1 Malvern electrostatic kit	– item 51
cellulose acetate strip	– item 51F
Polythene strip	– item 51G
'rubber'	– item 51I
metallized polystyrene spheres	– item 51D
nylon suspension	– item 51E
wire stirrup	– item 51H
16 retort stands, bosses and clamps	– items 503–506

The kit contains sufficient for pupils to work in pairs.

Note

It is important that all the following experiments on electrostatic forces be done qualitatively. They are intended to increase the pupils' experience: no measurements should be made.

General

Before the lesson the teacher should thread the nylon suspension through the metallized polystyrene spheres. Each sphere should have a 2-ft length attached to it.

It is helpful to have a small Bunsen flame through which rods can be drawn to discharge them.

Procedure

The pupils, working in pairs, make loops in the ends of the nylon and hang two spheres from the retort stand. They must be at the same height and 3 to 4 cm apart. The pupils should make their own investigations and should not be given precise instructions. When pupils have tried as many things as they can think of, a general discussion will show that some of them have tried each of the following:

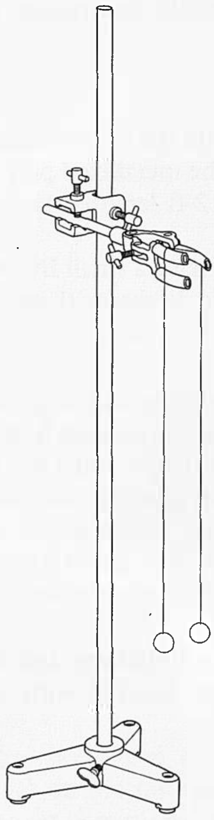
1. Rubbing the Polythene rod with the 'rubber' provided. Touching both spheres with the Polythene and showing repulsion.

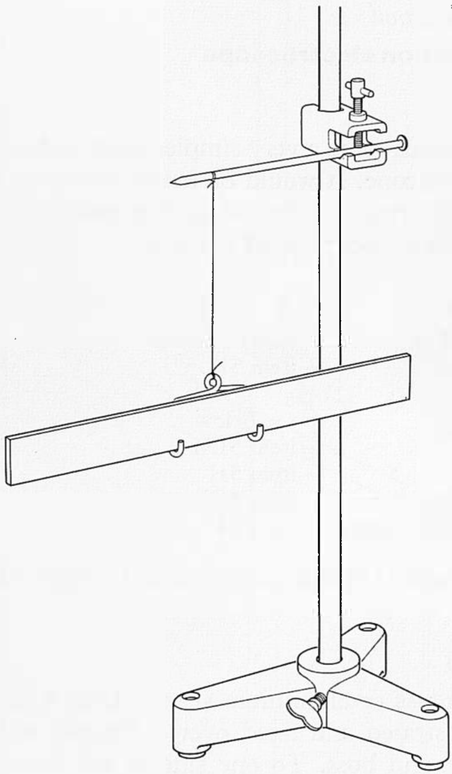
2. Rubbing the cellulose acetate with the 'rubber'. Touching both spheres with the cellulose acetate and showing repulsion.

3. Then touching one sphere with the rubbed Polythene rod, the other with the cellulose acetate strip, and showing attraction.

4. Repeating the above without using the 'rubber', but merely rubbing the Polythene and cellulose acetate together.

5. Hanging up the wire stirrup with a nylon suspension from the retort stand, rubbing the Polythene rod, and fixing it in the stirrup. Charged spheres brought up will have attracted or repelled the suspended rod, as will have other charged rods. Investigations with the stirrup will confirm in the pupil's mind the conclusions he has drawn as a result of (1) to (4).





99b *Demonstration*

Demonstration electroscope

This is intended to be a very simple, large-scale introduction to the electroscope. It would be better not to do the experiment than to bring in refinements that make it look troublesome to make or complicated to show.

Apparatus

1 retort stand and boss	– items 503–505
1 Perspex rod	– item 51L
1 brass strip	
Melinex	– see below
1 Polythene tile	– item 51M
1 'rubber'	– item 51I
1 electrophorus plate	– item 51K
1 E.H.T. power supply	– item 14

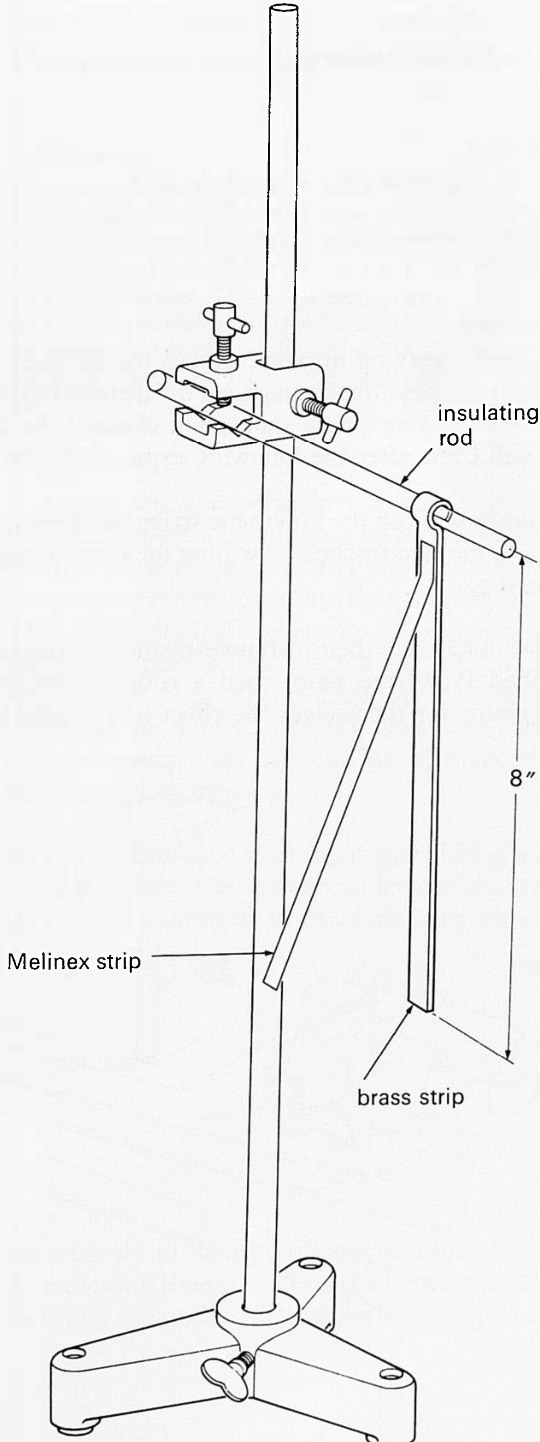
25-gauge metallized Melinex (coated on both sides) is ideal for this experiment.

Procedure

A strip of brass or aluminium sheet (about 8 in by $\frac{5}{8}$ in) is bent as illustrated and fixed over a Perspex rod held in a retort stand and boss. To one side of the brass, a strip of Melinex is attached. The Melinex can be cut with a razor blade into a strip about 7 in by $\frac{1}{2}$ in.

It can be charged to a high potential using the electrophorus from the Malvern electrostatics kit. The Polythene tile is rubbed, the plate put on the tile, touched with a finger, and then removed by the insulating handle and brought into contact with the model electroscope. This charging process should be repeated several times.

The plate can also be charged by connecting it to the E.H.T. power supply in series with the 50 mΩ resistor incorporated in that supply. In this case the other terminal of the supply should be connected to the retort stand base.



insulating rod
8″
Melinex strip
brass strip

99c *Class experiment*

Gold leaf electroscope

Apparatus

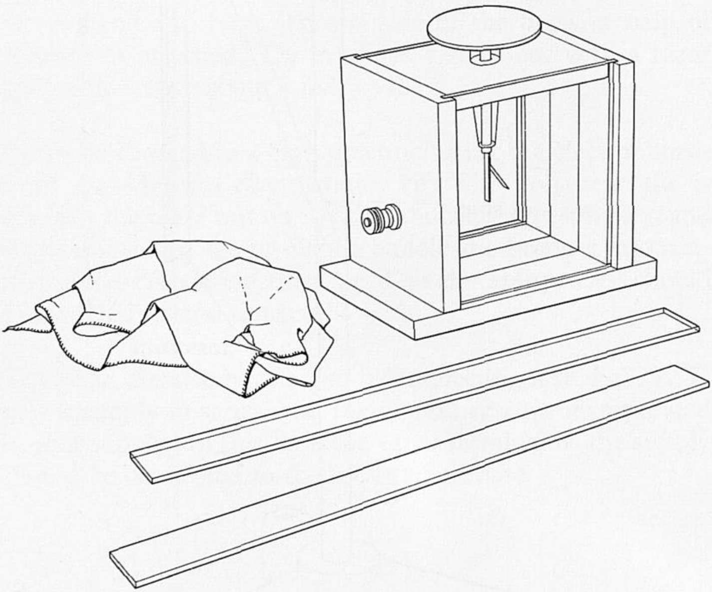
16 gold leaf electroscopes	– item 51A and B
16 Polythene strips	– item 51G
16 cellulose acetate strips	– item 51F
16 'rubbers'	– item 51 I

Procedure

The pupils, working in pairs, should handle their own gold leaf electroscopes after having seen the demonstration electroscope. At this stage, they should not charge it by induction. That will come after the following experiment, 99d.

The pupils will rub the Polythene strips and then transfer the charge to the electroscope by wiping the strips along the plate on the top.

They should make their own investigations, bringing up first a rubbed Polythene strip, then a rubbed cellulose acetate strip, seeing for themselves the effect on the gold leaf.



99d *Class experiment*

Electrostatic induction

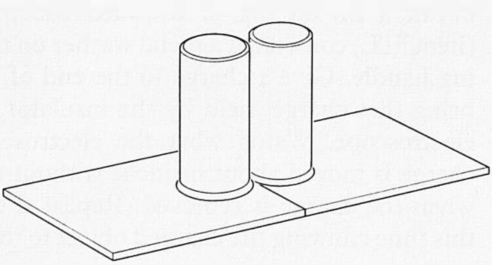
Apparatus

16 gold leaf electroscopes	– item 51A and B
16 Polythene strips	– item 51G
16 cellulose acetate strips	– item 51F
16 'rubbers' (duster)	– item 51I
32 Polythene tiles	– item 51M
32 small calorimeters	– item 51N
16 electrophorus plates	– item 51K
16 proof planes	– item 51L
16 tins	

Procedure

1. Before doing experiments 2 and 3 to enable pupils to see what happens in charging by induction, they should first see the phenomena as a mysterious surprise. Ask them to charge their electroscope and then discharge it by touching it. Then make its leaf swing out by bringing a charged Polythene strip near it, but without touching it. Then touch the electroscope plate with a finger so that the leaf falls. Then take away the finger, then take away the charged Polythene strip and watch what happens. At this stage, the result should be a surprising mystery.

2. The electroscope is charged by rubbing a Polythene strip along the plate. The leaf should hang at about 45°. Two of the canisters are inverted on two Polythene tiles and brought up



successively to the electroscope to show they are uncharged. The tiles are then placed on the bench with the two canisters touching each other. The Polythene strip is rubbed with the 'rubber' and brought up near to one of the canisters, which are then separated while the strip is still there. The canisters are then brought up successively to the gold leaf electroscope. With one the leaf will rise, with the other it will fall showing the charges are opposite.

3. The above can then be repeated, but this time when the charged strip is brought up near one of the two canisters, the second canister should be earthed by touching with the finger. Again each canister is tested.

4. The pupils are now ready to understand charging by induction. With the gold leaf electroscope discharged, they bring up a rubbed Polythene strip near the plate, they touch the plate momentarily so that the leaf falls, then they remove the Polythene strip.

5. They should then rub one of the tiles with the duster and use the electrophorus plate as a further example of induction. The electrophorus plate is placed on the tile and then removed and tested against the electroscope. This is then repeated, this time earthing the plate with the finger whilst in contact with the tile before testing against the electroscope.

Further experiments

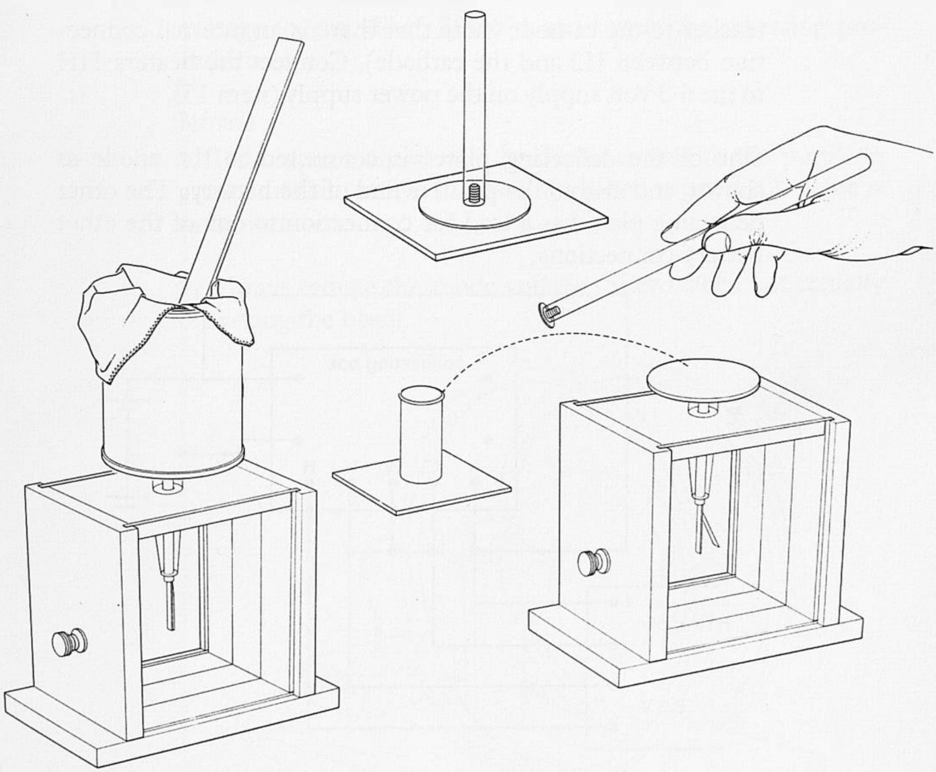
With a fast stream it is possible at this stage to let them make further investigations of their own. The following are suggestions:

6. Put a tin on top of the electroscope. The proof plane (item 51L) consists of a metal washer on the end of an insulating handle. Give a charge to the end of the proof plane and bring that charge, held by the insulator, into the tin on the electroscope. Watch what the electroscope does when the charge is moved about inside it without touching it and then when the charge is removed. Repeat the whole experiment, this time allowing the charged object to touch the inside of the can.

7. Put a tin on top of the electroscope. Into the tin insert a duster, if necessary weighing it down with a weight. Insert the Polythene strip into the duster (having previously discharged the strip by pulling it through a Bunsen flame). The

electroscope should be discharged with the leaf down. Then pull out the strip rubbing it against the duster in the process. The leaf will rise. Then re-insert the strip and the leaf will fall back completely.

8. The proof plane can be used to investigate the distribution of charge over a charged conductor. One of the canisters is placed on a tile and charged by repeated contact with the electrophorus plate. The metal washer on the end of the Perspex rod, which forms the proof plane, can then be brought into contact successively with different parts of the canister and tested against the charged electroscope. The sides, the edges, the bottom of the inside should all be tried and compared.



100 *Demonstration*

Deflection of electron beam in an electrostatic field

Apparatus

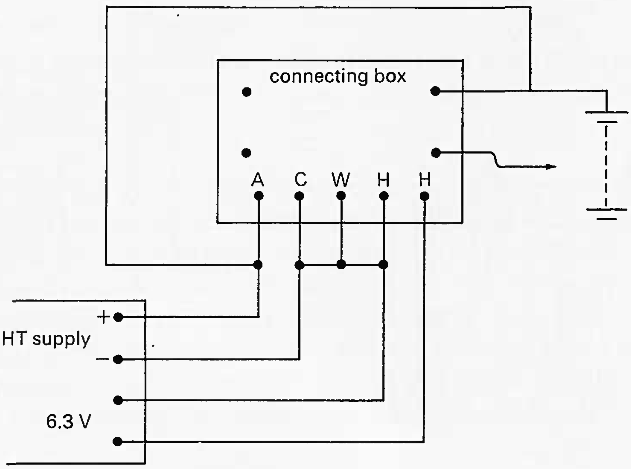
1 fine beam tube and base – items 61–62
1 H.T. power supply – item 15
4 12-volt batteries – item 176

Some power supplies (item 15) have moving coil voltmeters incorporated in them and this is helpful in this experiment.

Procedure

The tube is connected, by means of the connecting box, to the H.T. power supply so that 0 to 150–200 volts can be applied to the anode. The Wehnelt cylinder is connected by the teacher to the cathode (note that there is an internal connection between H2 and the cathode). Connect the heaters HH to the 6·3 volt supply on the power supply (item 15).

One of the deflecting plates is connected to the anode as shown, and also to the positive end of the battery. The other deflecting plate has a lead for connection to one of the other battery connections.



Before switching on check that the power supply potentiometers are set so that the anode potential will be zero. Turn the tube so that the electron gun points vertically upwards.

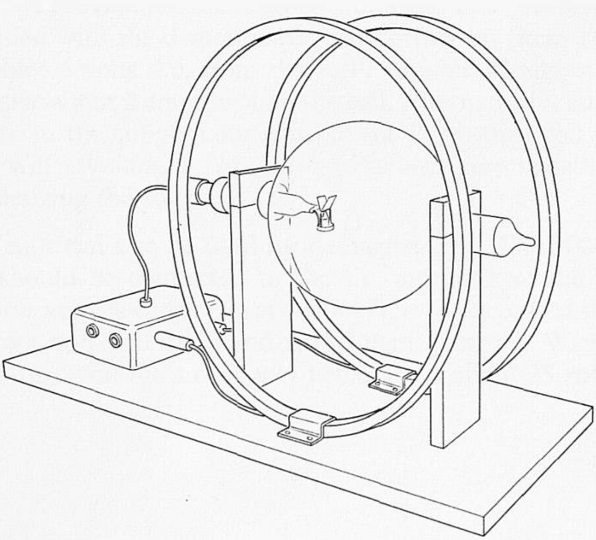
When the filament is glowing, carefully increase the anode voltage. At a voltage which may be as low as 50 watts, the fine blue beam should be seen. With some tubes, it may take three or four minutes for it to be clearly visible. As the voltage is slowly increased, the beam will lengthen and strike the glass envelope of the tube. Reduce the voltage and show this transition several times.

With the beam striking the wall apply 10 to 20 volts (d.c.) to the deflecting plates and observe the movement of the beam. Reverse the connections to the deflecting plates. Increase the voltage to, say, 40 to 50 volts and repeat the reversing procedure.

Notes

1. This experiment should be demonstrated to the pupils in groups of four to five in a well darkened room if full value is to be obtained.

2. Always reduce the anode voltage to zero when not actually observing the beam.



3. Should the beam appear very diffuse at all voltages between 150 and 250, apply up to +6 volts to the Wehnelt cylinder – this may sharpen the beam. Should the trouble continue, return the tube to the makers as it is not doing them justice.

The tubes recommended are very carefully manufactured and most reliable. If you are in any doubt about the performance of your tube, consult the suppliers whose technical advice is always available to maintain the high reputation of these tubes.

Additional experiment

The L.T. variable voltage supply can be used for showing the effect on the beam of an alternating voltage. This should be shown to fast groups. The terminals of the L.T. supply are connected direct to the deflecting plates.

101 *Class experiment*

Breaking bar magnets

Apparatus

1 magnetization kit	– item 122
iron filings	– item 92W
For magnetizing and demagnetizing rods,	
1 L.T. variable voltage supply	– item 59
1 demonstration meter	– item 70
1 d.c. dial (1 amp or 5 amp)	– item 71/1 or item 71/2
1 coil	– item 147D or item 128

Procedure

Each pupil should have a rod from the magnetization kit which has already been magnetized. They should test it by dipping it in a pile of iron filings on a sheet of paper. Then they should try to obtain a single, isolated pole by breaking the rod. After testing the pieces with a pile of iron filings, they can try breaking again.

See the special instructions below for magnetizing (and demagnetizing) rods such as those in the magnetization kit. If there is time, pupils may see how this is done.

Magnetizing and demagnetizing

About 600 ampere-turns are necessary in the coil to magnetize the rods provided in the magnetization kit. The 300-turn coil included with the demountable transformer kit (item 147) is suitable: 4 volts d.c. from the L.T. variable voltage supply will give about 2 amp through the coil. Alternatively, 20 volts d.c. from the supply connected to the 2,400-turn coil (item 128) will give about 1/4 amp and is also very suitable for magnetizing the rods.

The coils can also be used for demagnetizing. The 300-turn coil should be connected to the a.c. terminals of the L.T. variable voltage supply set at 6 volts. The rod is passed slowly through and will be found to be demagnetized. With the 2,400-turn coil the a.c. supply necessary is about 25 volts.

102a *Demonstration*

Model of a magnet

Apparatus

Plotting compasses – item 92D
Bar magnet

Procedure

As many compass needles as possible – obtained from the Westminster electromagnetic kit – are arranged in a regular crowd to fill a rectangle on the bench top. They represent a model of a bar magnet.

See diagram on the opposite page.

To 'magnetize' the model move a large magnet over the compass needles several times until the needles are aligned. To 'demagnetize' wave the large magnet arbitrarily over the model, taking the magnet farther and farther away whilst waving it.

This model, which illustrates an early, simple theory of a magnet (but does not do justice in detail to the modern domain theory) is so important that pupils should see it clearly at close range – not at a distance on a remote high lecture bench. Pupils should be encouraged to take turns in small groups to try it.

Before trying the model, they should be warned not to bring the large 'magnetizing' magnet very near the compass needles. However, if some compass needles are given reverse magnetization, it is easy to cure that – see note below.

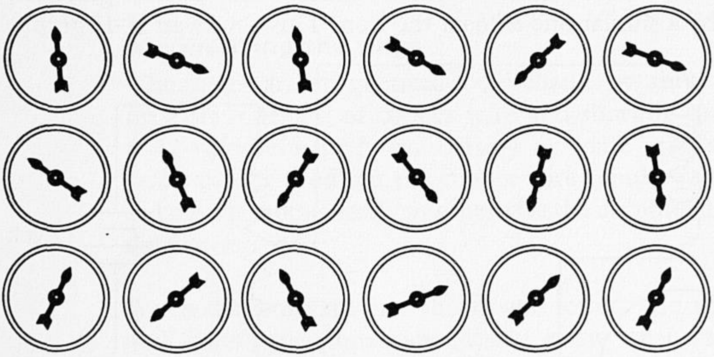
Note

If compass needles acquire reverse magnetization, demagnetize them and remagnetize them by placing in a coil in which a direct current is turned on momentarily. There is a 50 per cent chance of magnetizing them the right way at the first try; that chance can be raised to 100 per cent by bringing a small magnet near the compasses before the current is turned on.

102b *Optional film*

Domain film

Some private films showing magnetic domains have been made and it is to be hoped that similar films may eventually be available commercially. When they are available, one might profitably be shown at this stage of the course.



103 *Optional demonstration*

Magnetization saturation

Apparatus

1 demonstration oscilloscope (if available)
1 rheostat (10–15 ohms) – item 541/1
1 L.T. variable voltage supply – item 59
2 600-turn coils – item 147E
iron rods

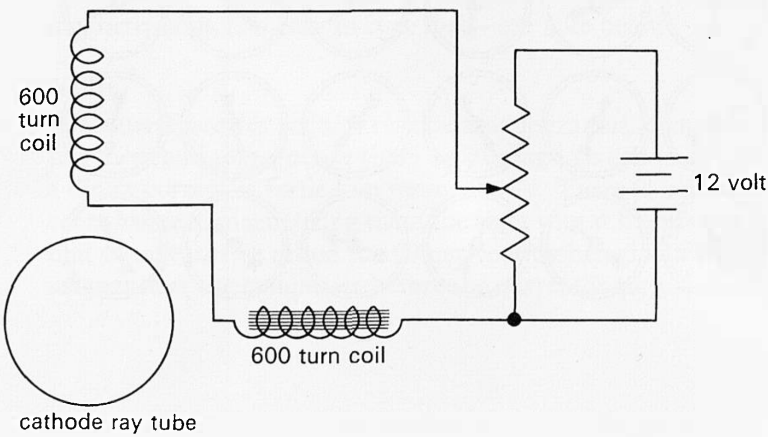
Procedure

If a demonstration oscilloscope is available (or any other type without magnetic screening), the hysteresis of a bundle of iron rods may be demonstrated, provided the coils can have access to the tube itself.

The coils carry the same current so that the coil on top produces horizontal deflections proportional to H while the side coil with the iron produces vertical deflection proportional to B. The distance of the coils from the tube should be adjusted so that the line on the screen is deflected a small amount.

The iron should first be demagnetized by passing it through the centre of a 600-turn coil carrying 1 amp a.c. With the coils in position, the current is gradually increased and the spot should follow the normal BH curve. If the spot moves in the wrong direction, one or both coils should be turned round.

The demonstration is perhaps more vivid if it is preceded by a similar one *without* the iron. This shows an H-H graph.



104 *Class experiment*
Breaking ring magnets

Apparatus

1 magnetization kit	– item 122
1 12-volt battery	– item 176
iron filings	– item 92W

Procedure

As suggested in the *Teachers' Guide*, the teacher produces a number of rings which have previously been magnetized. He tells the pupils he has tried to magnetize the rings and gives each pupil one. Each pupil tests his ring by offering it iron filings from a heap on a sheet of paper. Then he breaks his ring in half with his fingers and tests the fragments with filings.

Note

1. This experiment should be put to the pupils as a problem as discussed in the *Teachers' Guide*. They should certainly have time to think about it and to decide for themselves how one might decide if the rings are magnetized.

2. The rings must be supplied in 'glass-hard' condition so that a pupil can break them fairly easily with his fingers. A ring should snap in two when a pupil tries to bend it. If the rings are not sufficiently brittle, they must be hardened beforehand by heating them to cherry-red temperature in a flame and dropping them into cold water or oil.

Magnetizing the rings

The rings are magnetized beforehand by threading them on a short length of copper wire and shorting that across a 6–12-volt battery. A car battery or some accumulators in series can be used but the copper wire should only complete the circuit momentarily as otherwise the accumulators will be damaged.

When the rings are first shown and tested, and then broken and tested, the pupils should not know what was done to magnetize them. Afterwards they should be shown the method.

Appendices

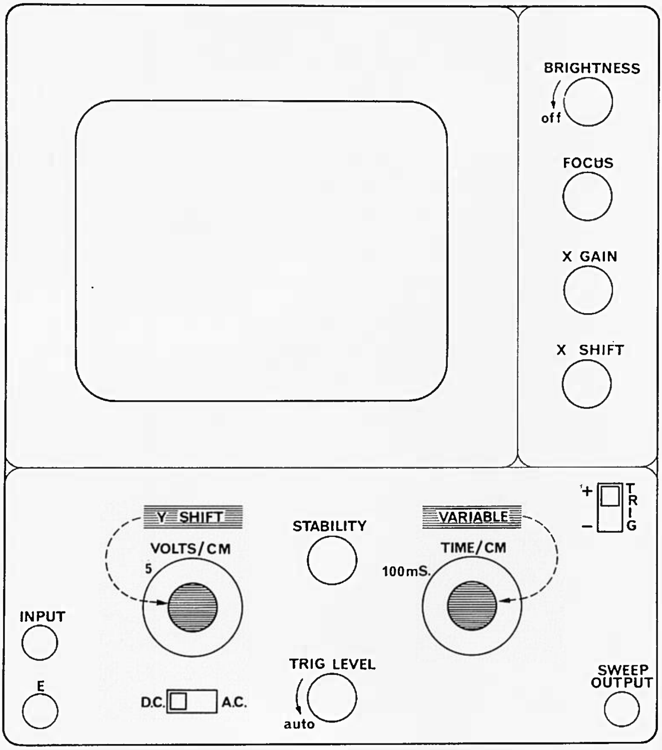
Appendix I

Operating instructions for the demonstration oscilloscope

The details and operating instructions given below refer to the Telequipment S 51 E cathode ray oscilloscope, which was the instrument used in the Nuffield O-level Physics trials. For other instruments, these details should be read in conjunction with the maker's instructions.

Procedure

The oscilloscope controls are as shown in the diagram.



Note that the Y-shift and Time Base Variable controls are the red knobs on the front panel.

To prepare the oscilloscope for use, plug into the mains supply and set the controls as follows:

Brightness to OFF
Focus to the mid-position
X-gain fully anticlockwise
X-shift to the mid-position
Trig control to +
Time base: time/cm control to 1 ms.
Time base: variable control fully clockwise
Stability control fully clockwise
Trig level control fully clockwise
Amplifier: volts/cm control to ·5
Y-shift to the mid-position
Input switch to d.c.

Switch on by means of the Brightness control. After warming up for about 1 minute, turn 'Brightness' clockwise until a trace appears and set the control so that the trace is clearly visible but not excessively bright. If no trace appears, leave the 'Brightness' in the fully clockwise position, and adjust 'X-shift' and 'Y-shift' until the trace appears.

This is best done by rotating 'X-shift' backwards and forwards whilst slowly advancing 'Y-shift' from the fully anticlockwise position. Immediately the trace is found, reduce 'Brightness' to a convenient level.

Now centre the trace with the 'X-shift' and 'Y-shift' controls, and adjust 'Focus' to give a sharp trace.

Slowly turn 'Stability' anticlockwise until the trace *just* disappears and, finally, rotate 'Trig Level' anticlockwise and switch it to the Auto position. The trace (which reappears when 'Trig Level' is rotated) may dim when this is done but will brighten again when an input is applied.

The oscilloscope is now ready for use, but it is important to be familiar with the function of the various controls. This experience is best gained using a 50 cps wave-form and then exploring the action of the various controls (excepting 'Stability' and 'Trig Level' controls which are set by the above procedure).

A possible routine for those unfamiliar with such instruments is to put 2–4 volts, 50 cps a.c. on the input – change volts/cm back to 5 – turn variable time base control (the red knob) fully anticlockwise and then back to the calibrated position (fully clockwise) – change time base to 100 μS – return to 1 ms – change Trig + to − (if the sine curve trace is not inverted by this, turn the Stability control very slightly anticlockwise until it is). Further work should bring increasing confidence.

Details regarding the use of 'Stability' and 'Trig Level' controls are given in the oscilloscope handbook. For most experiments – and all those in the Nuffield O-level course, the Trig Level can be left at AUTO. To give a steady trace, the Stability should be turned as far as possible counter-clockwise without losing the trace. This setting may vary a little with different time-base speeds.

Note

To avoid screen damage, do not use excessive brightness. With the time base off, do not leave the spot in a fixed position longer than necessary.

Esso-Nuffield film

It is particularly recommended that teachers should see the film *Oscilloscopes and Slow A.C.* in which the above oscilloscope is discussed in detail.

Appendix II

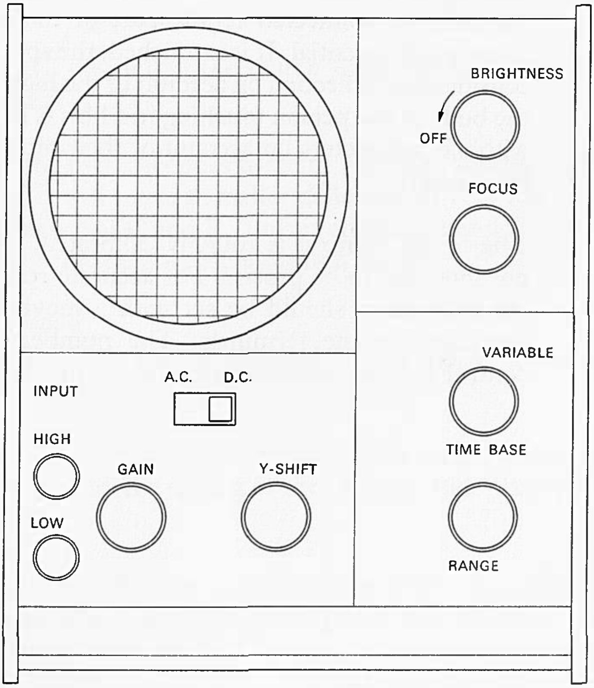
Operating instructions for the class oscilloscope

The details and operating instructions given below refer to the Telequipment Serviscope Minor cathode ray oscilloscope, which is the instrument used by the pupils in the Nuffield O-level Physics trials.

Procedure

The oscilloscope controls are as shown in the diagram.

To prepare it for use, plug into the mains supply and set the controls as follows:
Brightness to OFF
Focus to the mid-position
Y-shift to the mid-position
Y-gain to 1 division/volt
A.C.–D.C. switch to D.C.
Time base range switch to 2
Time base switch to OFF



Brightness and focus

Switch the oscilloscope on by means of the brightness control. After allowing $\frac{1}{4}$ of a minute for the oscilloscope to warm up, turn the brightness control clockwise and move the Y-shift control gently about its central position until a trace appears. Then adjust the brightness and focus controls until a clear, sharply focused trace is seen. (With the time base switched off, do not allow the spot to be too bright.)

It may be found impossible to obtain a sharp focus when the brightness control is set near maximum and, if this is the case, the brightness control should be turned anticlockwise until a sharp focus is obtained.

Input

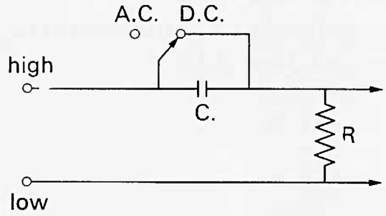
The input terminal labelled 'low' should normally be connected to the part of a circuit, if any, which is at earth potential. (As the terminal is not directly connected to earth it does not matter if it is connected to a point which is above earth potential.)

The input terminal labelled 'high' is sensitive and should normally be connected to the part of the circuit which is above earth potential. If it is touched, the spot will often show considerable deflection on account of the high a.c. potential of the body of the person touching it. (This is not normally seen with a.c. voltmeters on account of their much lower internal resistance.)

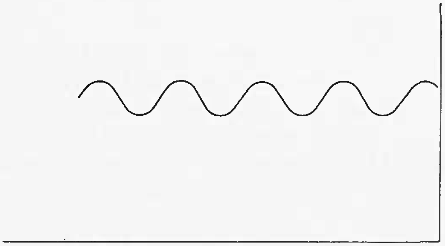
The 'Gain' control is roughly calibrated, the markings are not intended to be precise. For accurate readings of voltage, the calibration should be set with a moving-coil voltmeter connected to the terminals. The numbers on the 'Gain' control indicate approximately 'scale divisions per volt'.

A.C. - D.C. switch

The A.C.–D.C. switch should normally be set to D.C., even when the oscilloscope is used for a.c. work.



In the A.C. position there is a capacitor in series with the input and this will separate the a.c. component from a wave form such as:



The A.C. position of the switch should be used only for this purpose.

When the oscilloscope is used for pure a.c., setting the switch to 'A.C.' will cause a smaller deflection at very low frequencies because of C and R. This is another reason for not using it except for the purpose indicated above.

Time base

When the time base is switched off the spot is automatically centred and there is no X-shift control.

When the time base is switched on, the *speed* of the spot is determined by the setting of the 'Range' and 'Variable' controls.

However, the *frequency* of repetition of the time base is not much increased at the higher speeds and the time base is often interrupted by slow changes of the input voltages. For these reasons it is better to have the time base off when the oscilloscope is being used as a d.c. voltmeter.

When an alternating voltage is connected to the input, it automatically triggers the time base and gives a very steady trace.

Esso-Nuffield film

This oscilloscope is also discussed in detail in the film *Oscilloscopes and Slow A.C.*

The Nuffield Foundation Science Teaching Project and the organizers are grateful to the following for help and advice:

Dr G. J. Alder
R. Barr
N. D. N. Belham
D. Bryant
J. C. Cain
D. G. Carter
D. Chillingworth
A. Dalziel
G. W. Dorling
J. N. Emery
G. E. Foxcroft
A. Germani
K. M. Grayson
J. T. Jardine
C. W. Kearsey
D. Layton
R. Leigh
W. Llowarch
J. G. Mattock
E. L. Pye
W. Ritchie
D. W. Scott
M. S. Smith
Dr J. R. Spooner
R. Stone
M. Stewart
A. W. Trotter
G. W. Verow
A. F. Vyvyan-Robinson

The Association for Science Education
The Institute of Physics and Physical Society
The Physics Department at Imperial College, London
The Head Master and Council of Malvern College
The Principal and Governors of Worcester College of Education
The Esso Petroleum Company Ltd
Associated Electrical Industries
Loughborough College of Advanced Technology

The many members of the area teams who contributed so much to the early discussions.

The project team acknowledges the initial help and inspiration derived from the work of the Physical Science Study Committee in the U.S.A. and the Scottish Education Department's Physics Project.

NUFFIELD FOUNDATION SCIENCE TEACHING PROJECT PHYSICS SECTION

The physics programme was inaugurated in May 1962 under the leadership of Donald McGill. It suffered a severe setback with his tragic death on the 22nd 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.

Consultative committee

Chairman Professor Sir Nevill Mott, F.R.S.
Professor C. C. Butler, F.R.S.
N. Clarke
Professor J. C. Gunn
Sister Saint Joan of Arc
Professor R. V. Jones, F.R.S.
W. K. Mace
J. M. Osborne
Dr C. W. W. Read
The Rev. R. G. Wickham

Organizer

Professor E. M. Rogers

Associate organizers

J. L. Lewis
E. J. Wenham

Assistant organizer

D. W. Harding

Area co-ordinators

Sister Saint Joan of Arc
Miss D. J. Alexander
Miss A. Lipson
Dr H. F. Boulind
B. R. Chapman
D. C. F. Chaundy
M. J. Elwell
L. Ennever
R. C. Hardwick
R. D. Harrison
V. J. Long
E. W. Tapper
C. L. Williams

Schools collaborating in the trials

The Abbey School, Ramsey
Ashfield County Secondary School

Banbury Grammar School
Baptist Hills School, Bristol
Barnard Castle School
Bartley Green Girls' Grammar School
Batley Grammar School for Boys
Batley High School for Boys
St Brendan's College, Bristol
Bridgnorth Secondary Modern School for Boys
Bromsgrove County High School

Calder High School, Mytholmroyd
Chatham House Grammar School, Ramsgate

Dame Allan's School, Newcastle
The Downs School, Colwall

Elliott School, Putney
Erith County Grammar School

Forest Hill School

The Grammar School for Boys, Cambridge
Godolphin and Latymer School

Harborne Hill School, Birmingham
Hinckley Grammar School
Huddersfield New College
Huntingdon Grammar School

King's College School
Kynaston School, London, N.W.8

Maidstone Grammar School
Malvern College
Manchester Grammar School
March Grammar School
Marsh Hill Boys' Technical School, Birmingham
Mill Mount Grammar School, York
Moseley Grammar School for Boys, Birmingham

Orton Longueville Grammar School

Rainsford County Secondary School, Chelmsford
Redland High School for Girls, Bristol
La Retraite High School, Bristol
Rhodesway Secondary Modern School, Bradford
Rickmansworth Grammar School

Sheldon Heath Comprehensive, Birmingham
Soham Grammar School
Sutton County Grammar School for Boys
Swavesey Village College
Sydenham School

Tottenham County School

Valley Gardens Modern School, Whitley Bay

Welwyn Garden City High School
Westminster School
Whitley Bay County Grammar School
City of Worcester Grammar School for Girls

Organizer Professor E M Rogers
Associate organizers J L Lewis E J Wenham
Assistant organizer D W Harding

Other Nuffield Physics publications

Teachers' guide I
Teachers' guide II
Teachers' guide III
Teachers' guide IV
Teachers' guide V

Guide to experiments I
Guide to experiments II
Guide to experiments IV
Guide to experiments V

Guide to apparatus

Questions book I
Questions book II
Questions book III
Questions book IV
Questions book V