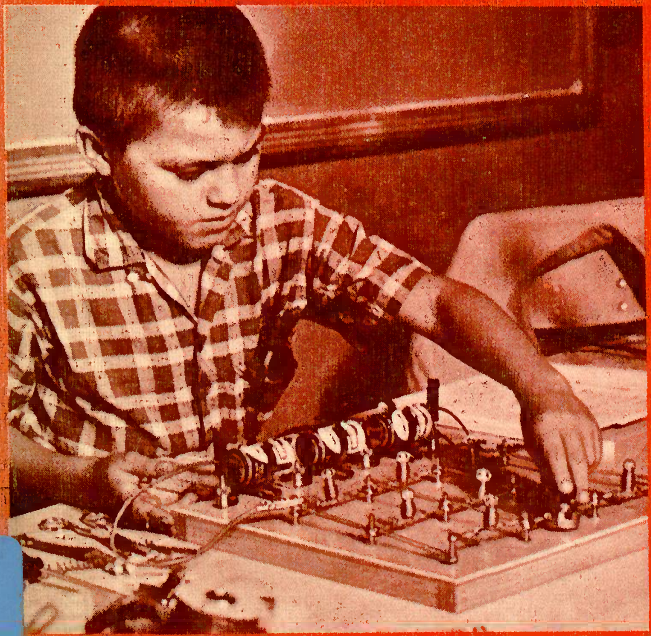
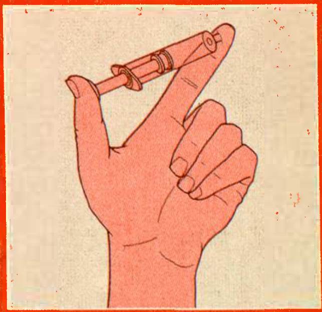
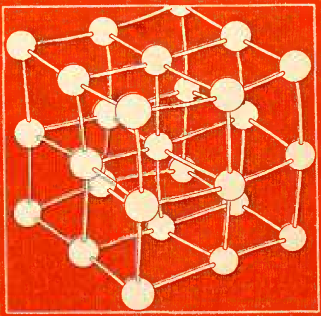
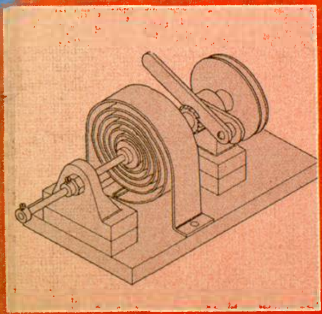
PHYSICS

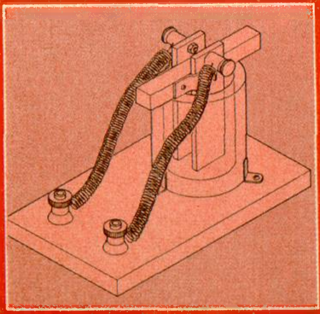
Guide to experiments II

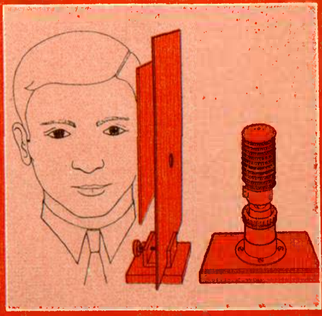












Nuffield Physics Guide to Experiments 2

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Nuffield Physics
Guide to Experiments
2

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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 whom 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 who 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 second year of the 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 *Nuffield Guide to Physics Apparatus*.

Experiments in Year II

Forces

1	*Class Experiment*	– Investigation of elastic materials.
2	*Demonstration*	– Example of a constant (moving) force.
3a	*Class Experiment*	– Use of lever to illustrate turning effect of forces.
3b	*Class Experiment*	– Use of lever to illustrate turning effect of forces.
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14	*Class Experiment*	– Introduction to the current balance.
15	*Class Experiment*	– Circuits from circuit diagrams.
16	*Class Experiment*	– Currents and conductors.
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18	*Class Experiment*	– Using an ammeter to find whether the current in a circuit is the same all round.
19	*Demonstration*	– Demonstration of water circuit.
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21	*Class Experiment*	– Temperature effect and fusing.
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22c	*Optional Class Experiment (buffer)*	– Investigating circuits.
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23	*Class Experiment*	– Introduction to a voltmeter as a cell counter.

Electric Currents

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26	*Class Experiment*	– Copper plating various objects.
27	*Demonstration*	– Lead tree.
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29	*Class Experiment*	– Wet paper demonstration of electrolysis.
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51	*Class Experiment*	– The use of a spring balance marked in newtons.
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53	*Pupil Demonstration*	– To feel the inertia of a 'pound of stuff'.

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55	*Demonstration*	– Transfer of energy in lifting loads.

56 *Demonstration* – Transfer of energy in lifting loads using pulleys.

57 *Demonstration* – Transfer of potential energy to kinetic energy to heat.

58 *Demonstration* – Transfer of kinetic energy to potential energy – 1.

59 *Demonstration* – Transfer of kinetic energy to potential energy – 2.

60 *Demonstration* – Further demonstrations of energy transfers between kinetic and potential energy.

61 *Demonstration* – Examples of energy transfers.

62 *Demonstration* – Radiation energy.

63 *Class Experiment* – Energy transferred in climbing stairs.

64 *Demonstration* – Energy transfer from electric supply.

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65 *Class Experiment* – Measuring heat.

66 *Class Experiment* – Experiment leading to the idea of specific heat and a rough estimate of its value for aluminium.

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68 *Demonstration* – Demonstration of levers and pulleys to show machines do not multiply energy.

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70 *Class Experiment* – Two-dimensional kinetic model.

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72 *Class Experiment* – Expanding liquids.

73 *Demonstration and*
74 *Class Experiment* – Cracking glass.

75 *Class Experiment* – Examining melting.

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80 *Class Experiment* – Pressure change of gases when heated at constant volume.

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82 *Class Experiment* – Models for kinetic picture of liquids and gases.

83 *Demonstration* – Model of gas molecules in motion.

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84 *Class Experiment* – Investigation of conductivities.

85 *Optional Demonstration* – Ingen-Hausz apparatus for conductivity.

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87 *Class Experiment* – Convection in a test-tube.

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90 *Class Experiment* – Passage of heat radiation through glass – 1.

91 *Class Experiment* – Passage of heat radiation through glass – 2.

92 *Optional Additional Experiment* – Absorption of radiation by slab of rocksalt.

93 *Class Experiment* – Comparison of the emission of radiation from a dull black and a shiny surface.

94 *Class Experiment* – Emission of radiation from Bunsen flames.

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97 *Demonstration* – Spectrum demonstration.

Appendix – Operating instructions for the demonstration oscilloscope.

1 *Class experiment*

Investigation of elastic materials

Apparatus

Elastic materials kit – item 2
100 expendable steel springs
16 soft erasers for twisting
8 wide steel springs ($4\frac{1}{2}$ in $\times$ 3 in diameter)
8 soft latex foam blocks
16 lengths of elastic cord

Foamed plastic
Ordinary rubber bands

As the foamed plastic will be destroyed, fresh pieces will be necessary for each class.

Procedure

The pupils are given an assortment of materials from the elastic materials kit for them to see and feel the forces involved in some elastic changes.

2 *Demonstration*

Example of a constant (moving) force

Apparatus

1 bag of sand or block of wood (about $\frac{1}{2}$ kg)	
1 single pulley on clamp	– item 40
1 spring balance (1 kg)	– item 43
3 retort stands	– items 503–504
3 bosses	– item 505
cord	– item 10A

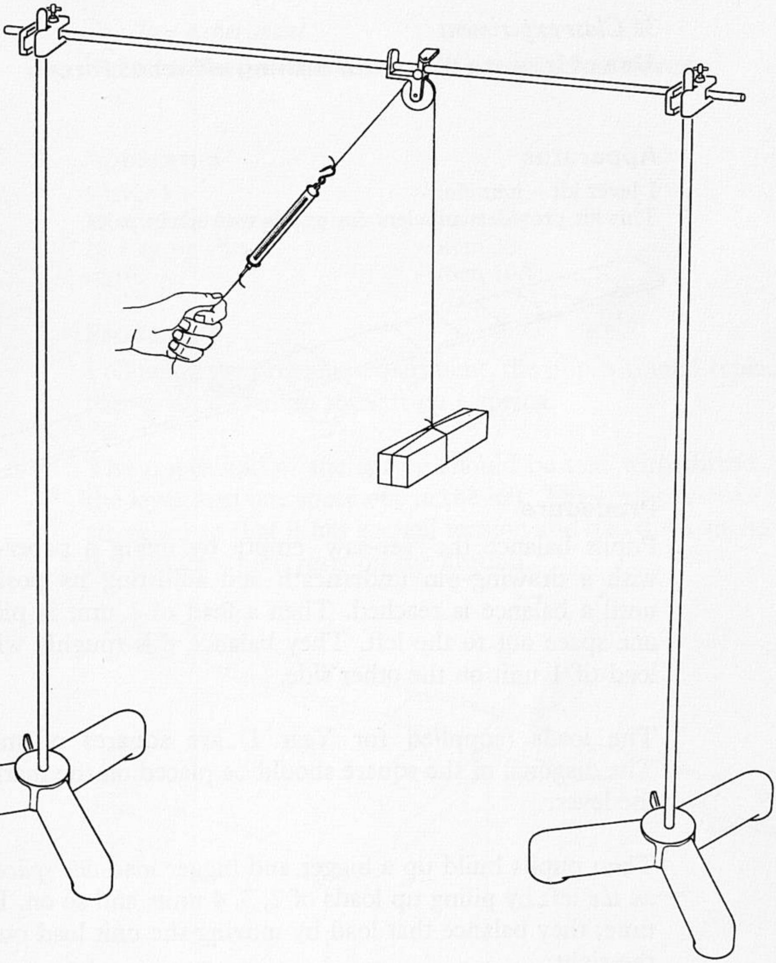
Procedure

a. On the demonstration bench raise a small bag of sand or block of wood with a cord which goes up and over a pulley. Let pupils pull it and feel for themselves whether the force is the same however far the cord is pulled.

b. Offer any unbeliever a spring balance to pull the cord with.

Note

A pulley fixed to a wooden beam on the ceiling of the laboratory would be ideal if there is such a beam available. If so, it will pay to store the rope on the pulley, tying it back to a hook on the wall, because it will be used again later.

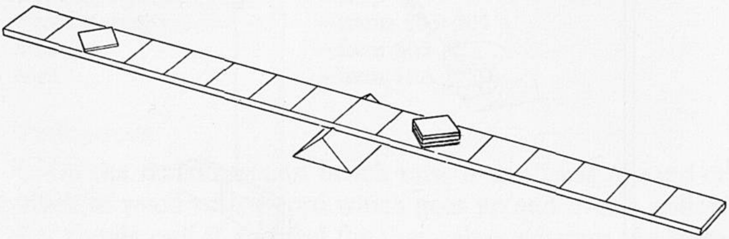


3a *Class experiment*

Use of lever to illustrate turning effect of forces

Apparatus

1 lever kit – item 5
This kit provides sufficient for pupils to work in pairs



Procedure

Pupils balance the 'see-saw' empty by fixing a paper-clip with a drawing-pin underneath and adjusting its position until a balance is reached. Then a load of 1 unit is placed one space out to the left. They balance this roughly with a load of 1 unit on the other side.

The loads (supplied for Year I) are squares of metal. The diagonal of the square should be placed on the mark on the lever.

Then pupils build up a bigger and bigger load *one space out on the* left by piling up loads of 2, 3, 4 units and so on. Each time, they balance that load by moving the unit load out on the right.

Note

An *exact* balance is not needed in this experiment.

3b *Class experiment*

Use of lever to illustrate turning effect of forces

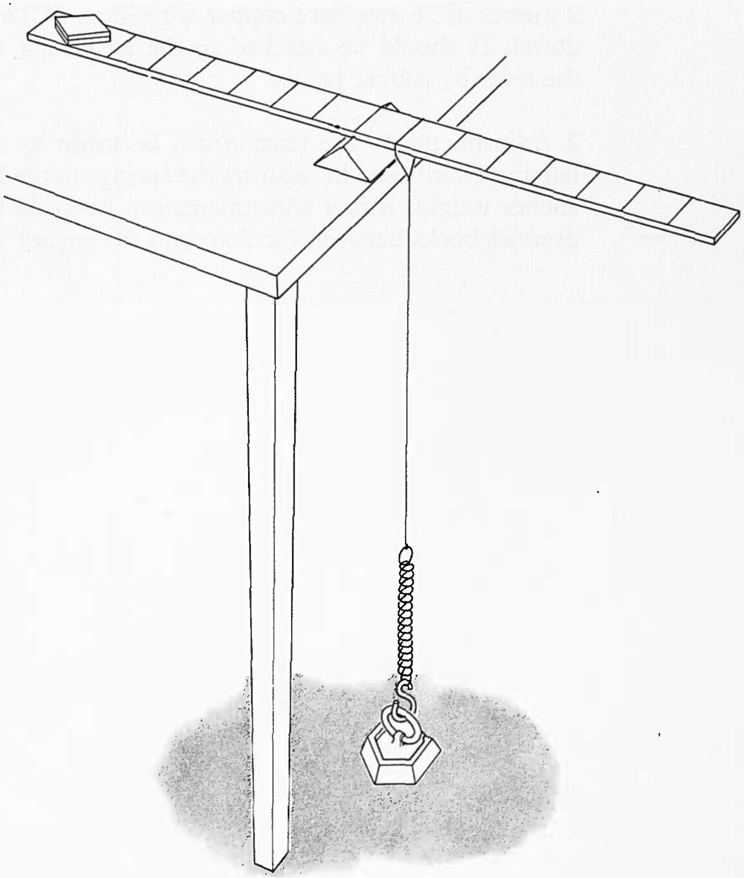
Apparatus

1 lever kit	– item 5
16 expendable steel springs	– item 2A
16 1 kg weights	– item 32
cord	– item 10A

Procedure

Following the previous experiment, the pupils should replace the variable load on the left by a spring.

The upper end of the spring should be tied with thread to the lever arm one space out to the left. The spring should be stretched so that it has a small tension and tied to an anchoring weight which rests on the ground.



For this, pupils must move the see-saw to the edge of the table so that the left-hand arm overhangs the edge. The spring must exert a weak pull that can be balanced by moving the unit load on the right out to a suitable distance. If the lever is only a short distance above the table, it can only tilt a little, and the pull of the spring will be practically constant. To ensure such constancy, the stretch of the spring must be large compared with the change when the lever tilts; therefore a weak spring is needed.

The teacher should show the pupils how to arrange this and ask them to 'measure' the pull of the spring at this stretch by moving it along the right-hand side of the lever until it balances.

Notes

1. As an alternative to the steel springs from the elastic materials kit, a suitable spring can be made by winding about 2 metres of 26 swg bare copper wire (item 2C) around $\frac{1}{4}$ in dowel. It should be attached to the anchoring weight and the lever by rubber bands.

2. Adjustments to the tension can be made by altering the length of cord used in securing the springs to the lever or the anchor weight. Minor adjustments can be made by slipping exercise books between the floor and the anchor weight.

4 *Demonstration*

Turning effect of forces

Apparatus

Door of classroom

Procedure

To illustrate the turning effect of a force, demonstrate with the classroom door (or alternatively, a cupboard door or hinged window).

Try pushing it at the edge, then close to the hinge, then at intermediate positions. Compare the effects.

The teacher might push near the hinge while a pupil pushes (from the other side) farther out.

5 *Optional demonstration*

Screw jack

Apparatus

Either a screw jack, as used by builders to raise girders or a rotating chair (music stool) with spiral thread can be used.

Procedure

Let a pupil sit on the screw jack and raise himself by pushing the arm of the screw jack with one finger.

6 *Demonstration*

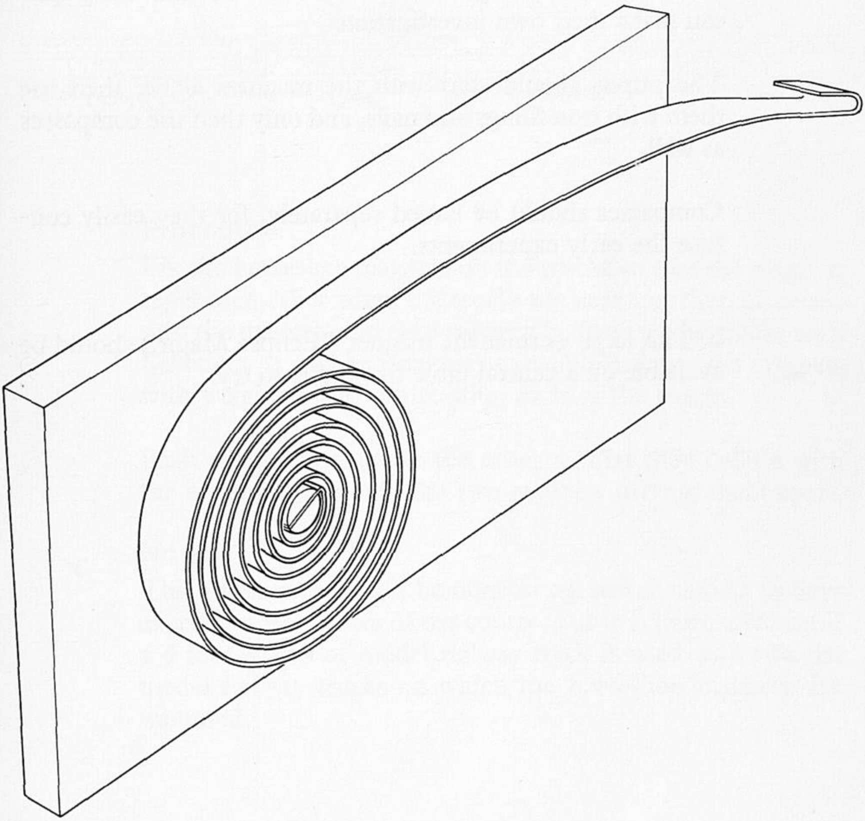
Giant clock-spring to show turning effect of forces

Apparatus

1 large clock-spring	– item 57A
1 retort stand, boss, and clamp	– items 503–506

Procedure

The giant clock-spring provided in the Year II general kit is already mounted on a board with the centre of the spring fixed to it. The board can be clamped vertically to a retort stand for convenience of demonstration.



The open arm of the spring can carry a load at different positions along it and the twisting effect will be seen. It may be necessary to prevent the weight from slipping – small pieces of modelling wax are sufficient.

7 Class experiment

Experiments with magnets

Apparatus

32 pairs cylindrical magnets	– item 50/1
2 horseshoe magnets	– item 50/2
1 'Eclipse Major' magnet	– item 50/3
iron filings	– item 555
nails	
compasses	– item 556
sheets of paper	

Procedure

a. Distribute the magnets around the class so that the pupils can make their own investigations.

The pupils should start with the magnets alone, then use them with iron filings and nails, and only then use compasses as well.

Compasses should be issued separately, for they easily confuse the early experiments.

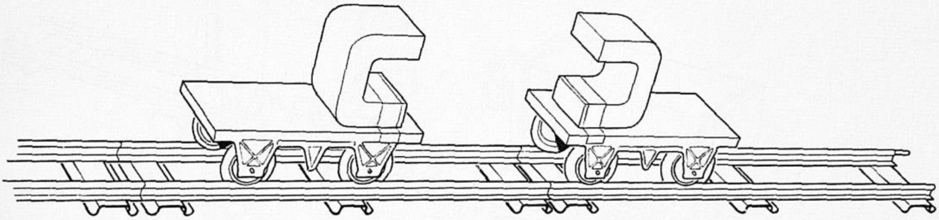
b. The large permanent magnet ('Eclipse Major') should be available on a central table for pupils to try.

8 *Demonstration*

Repulsion of two trucks with horseshoe magnets on them

Apparatus

5 lengths railway track	– item 10R
2 flat trucks	– item 10S
2 horseshoe magnets	– item 50/2



Procedure

Fix the horseshoe magnets on the trucks so that the magnets repel each other when the trucks are near together. If necessary the magnets can conveniently be fixed to the trucks with Sellotape. It may be necessary to counterbalance the magnets with weights taped to the other ends of the trucks.

Push one truck towards the other so that they collide with the repulsion between the two magnets driving them apart.

Notes

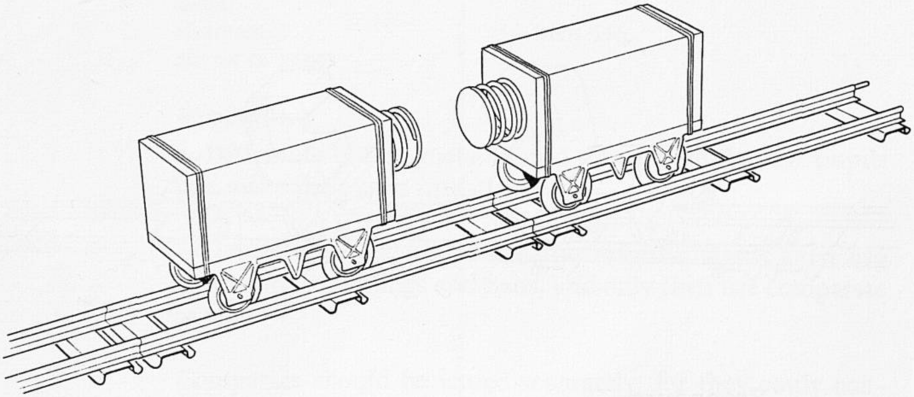
This experiment could be done using two dynamics trolleys as used in later years of the course, but it is more effective if a 4 foot length of model railway track is used with two flat model railway trucks on which the horseshoe magnets are mounted.

9 Demonstration

Repulsion of trucks with buffer springs

Apparatus

5 lengths railway track	– item 10R
2 flat trucks	– item 10S
2 wooden blocks with buffers	– item 10T



Procedure

As a continuation of the previous experiment, replace each magnet by the buffer springs, so that when the trucks are pushed together, the springs collide and the trucks rebound as they did with the horseshoe magnets.

The buffer springs are mounted on blocks of wood which can be fixed to the trucks with Sellotape or elastic bands.

Note

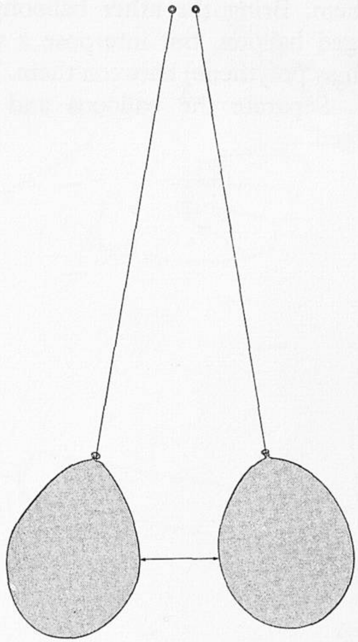
An entertaining variant of these two demonstrations (8 and 9) is to conceal the second truck behind a large card and then to push the first truck towards it, the second truck being first of all free to move and subsequently fixed.

10 *Demonstration*

Introduction to electrostatic forces

Apparatus

4 balloons – item 57C
1 reel nylon thread – item 57K



Procedure

Hang up two inflated balloons by long, nylon threads. The balloons must be far from any metal supports.

Charge them with like charges. This is done by rubbing each balloon successively against one's jacket or pullover.

Having shown repulsion, take two more balloons and rub them together. It will be found that in practice this produces unlike charges on the two balloons, though often unequal in magnitude. With these oppositely charged balloons, show attraction.

Alternative method of charging balloons

The balloons can be made conducting by painting with graphite, by spraying with some aluminium sprays or by dipping into a strong detergent solution which is allowed to dry.

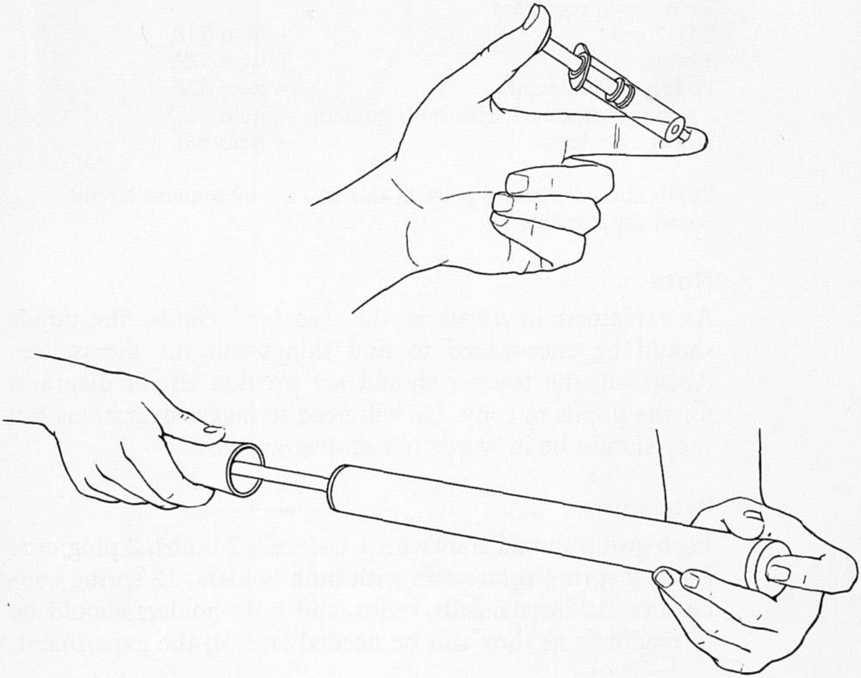
Hang the two balloons up by insulating threads. Charge one of them. Bring the other balloon, uncharged, near to the charged balloon, but interpose a very thin sheet of plastic (such as polythene) between them. Touch the *un*charged balloon. Separate the balloons and they will be oppositely charged.

11 *Demonstration or class experiment*

Gas pressure: forces due to bombardment

Apparatus

bicycle pumps or syringes



Procedure

First drive in the piston of a bicycle pump with the outlet open and repeat with a finger placed over the outlet.

Note

This is, of course, better as a class experiment, if it can be done quickly. If possible, pumps should be borrowed to enable pupils to do it themselves. Alternatively the syringes in the Bristol pressure kit (item 6D) can be used.

12 *Class experiment*

Simple electric circuits

Apparatus

16 Worcester circuit boards	– item 52C
Each group requires:	
3 U-2 cells	– item 52B
3 bulbs	– item 52A
12 spring connectors	– item 52E
3 spring connectors with bulb holders	– item 52D
2 plug/croc leads	– item 52I

Pupils should work in pairs in this and all subsequent circuit board experiments.

Note

As explained in detail in the *Teachers' Guide*, the pupils should be encouraged to find things out for themselves. Above all, the teacher should *not* provide circuit diagrams for the pupils to copy. He will need to make suggestions but they should be in words not in diagram form.

Procedure

Each group should start with 1 U-2 cell, 2 bulbs, 2 plug/croc leads, 2 spring connectors with bulb holders, 12 spring connectors. Additional cells, bulbs, and bulb holders should be in readiness as they will be needed later in the experiment.

The following may be tried by the pupils:

1. Connect a battery to a lamp to make it light.

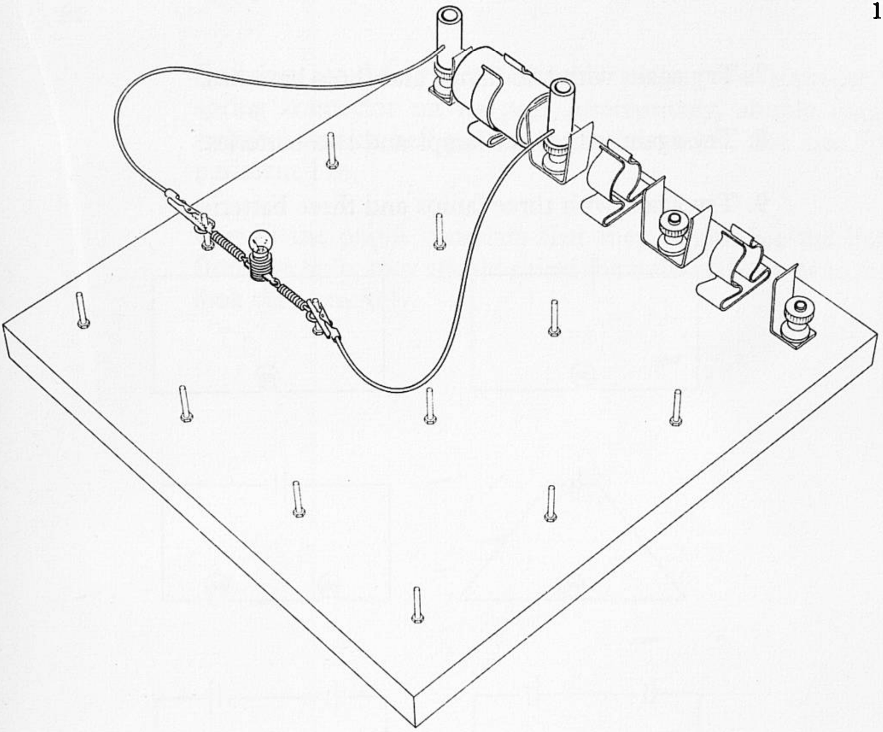
2. Try the battery the other way round.

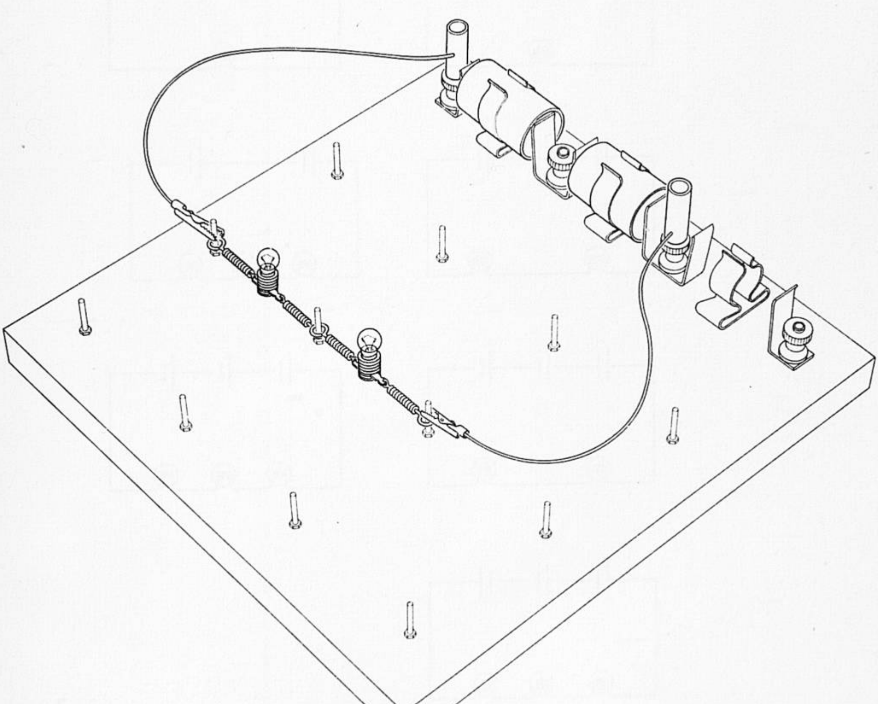
3. Try the circuit with a different shape.

4. Try the battery with two lamps.

5. Repeat everything done already with one lamp but using an extra battery, both with the batteries facing the same way and facing opposite ways.

6. Repeat everything with two lamps and two batteries.

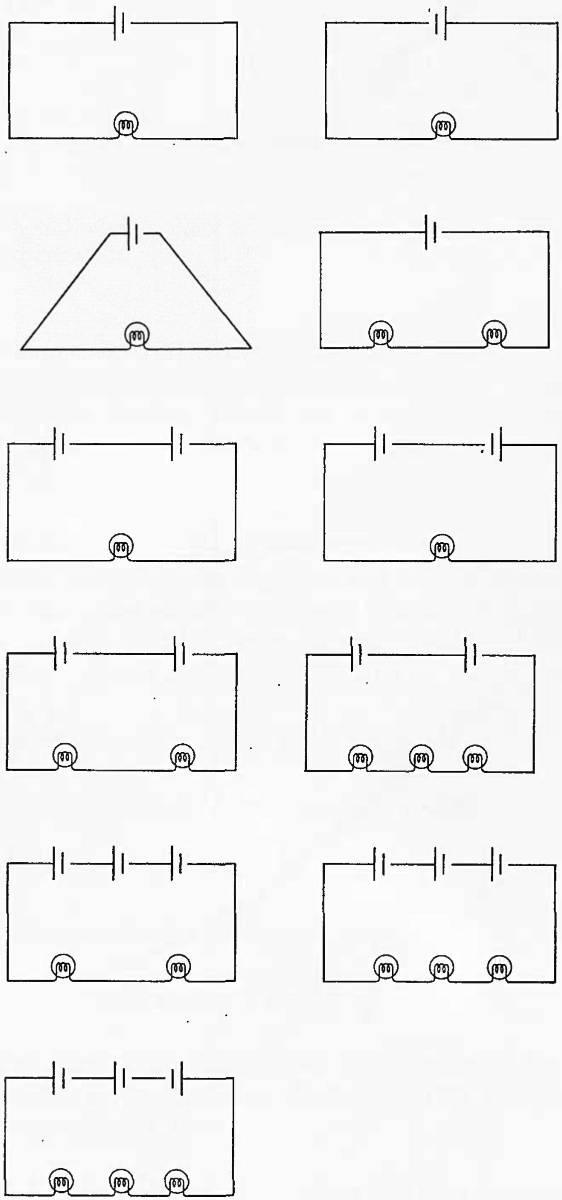




7. Try again with two lamps and three batteries.

8. Try again with three lamps and two batteries.

9. Try again with three lamps and three batteries.



Switches can be improvised by swivelling the appropriate spring connector on its peg. Alternatively, simple toggle switches and/or bell pushes can be provided. See also Experiment 17b.

Should the pupils complain that they cannot see the light from the bulb, they should shield the bulb with the hand and look very carefully.

13a *Class experiment*

Heating effect of a current

Apparatus

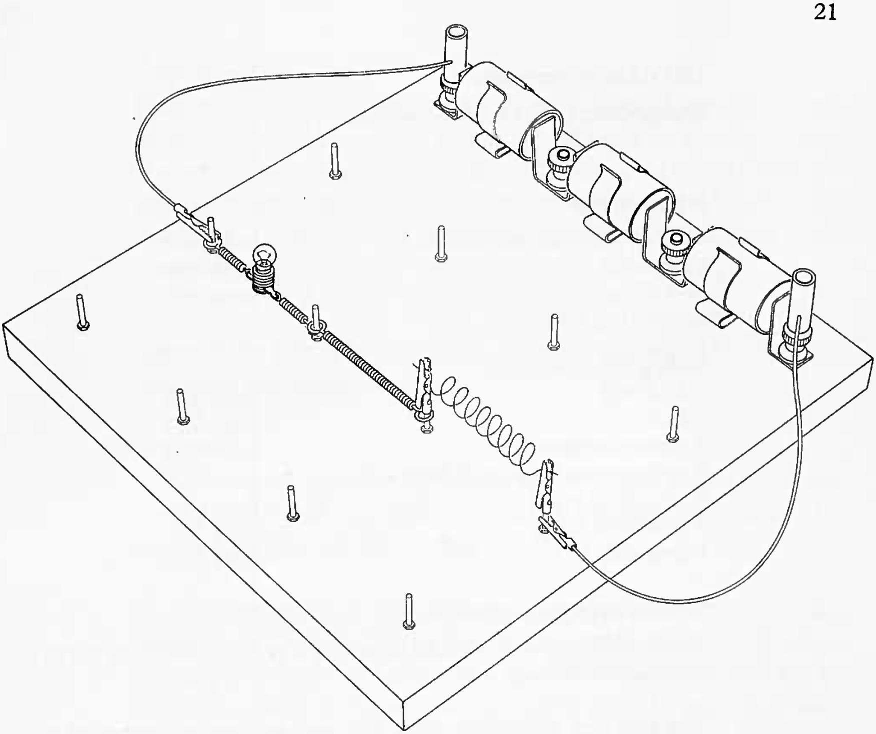
16 Worcester circuit boards	– item 52C
1 4 oz reel bare Eureka wire 34 swg	– item 52P

Each group requires:

3 U-2 cells	– item 52B
1 bulb	– item 52A
2 crocodile clips	– item 52K
4 spring connectors	– item 52E
1 spring connector with bulb holder	– item 52D
2 plug/croc leads	– item 52I

Procedure

Wind a 5 in length of bare Eureka wire into a coil (perhaps on a pencil). Slip the shanks of two crocodile clips over adjacent pillars and use the clips to support the coil. Thus introduce the coil into a series circuit of three cells and a lamp.



13b *Class experiment*

Magnetic effect of a current

Apparatus

16 Worcester circuit boards	– item 52C
compasses	– item 556
iron filings	– item 555
connecting wire	

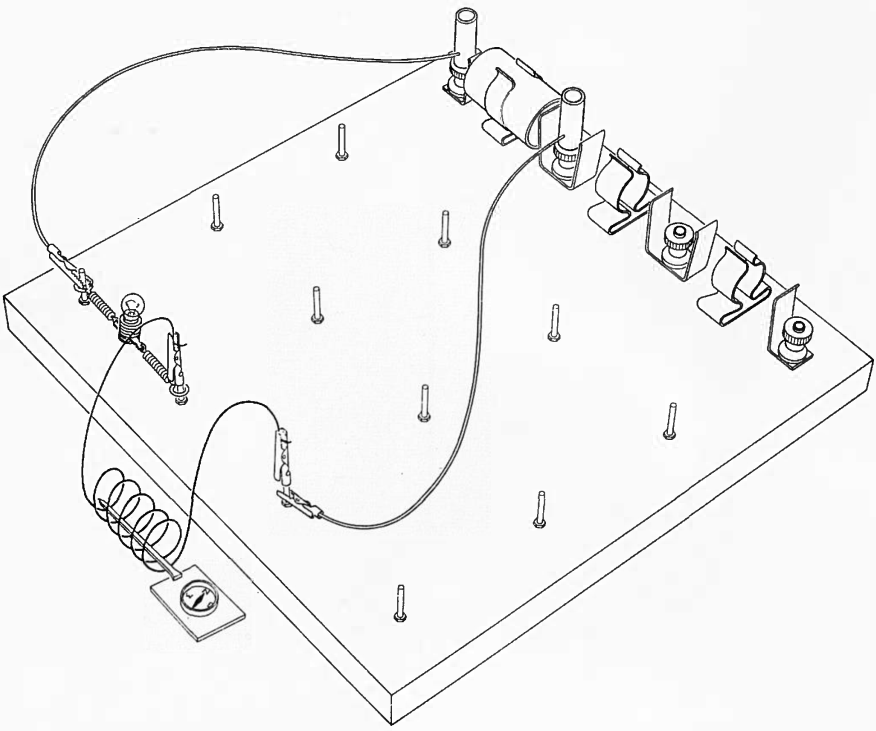
Each group requires:

1 U-2 cell	– item 52B
1 bulb	– item 52A
4 spring connectors	– item 52E
1 spring connector with bulb holder	– item 52D
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J
1 iron nail	– item 52M

Notes on apparatus

The connecting wire should be about a yard of insulated copper wire, about 26 swg.

The iron nail should be about 2 in or 3 in long and made of soft iron. Such nails are included in the circuit board kit (item 52).



Procedure

Pupils should wind the length of wire into a long, tight coil, on a pencil or dowel, into which the nail can easily slip. Using the croc/croc leads, connect the coil into a circuit of one cell and one lamp so that it is conveniently near the plotting compass. Try the nail first on iron filings and then with compass.

Should the effect be too small, it can be increased by dispensing with the lamp in series.

Notes

1. Many nails are weakly magnetized before the experiment commences and any that are should be weeded out or demagnetized before the pupils get them.

2. To demagnetize the nail at least 500 ampere-turns are needed. A Unilab 250-turn coil on 6 volt a.c. takes 3 amps (giving 750 ampere-turns) and a Unilab 500-turn coil on 12 volt a.c. takes 2 amps (giving 1,000 ampere-turns). These are both suitable for demagnetizing nails, but should not be left on for long as the coils get hot (about 18 and 24 watt respectively). The nail is put inside the coil which is connected to an a.c. low voltage supply at 6 or 12 volts as stated above. The nail is slowly removed from the coil – any motion except a sudden jerk will be slow enough. Alternatively the alternating voltage supply may be steadily reduced to zero and the nail will be demagnetized.

14 *Class experiment*

Introduction to the current balance

Apparatus

16 Worcester circuit boards	– item 52C
1 Worcester current balance kit	– item 53
Sellotape	– item 53I
1 reel 26 swg bare copper wire	– item 2C

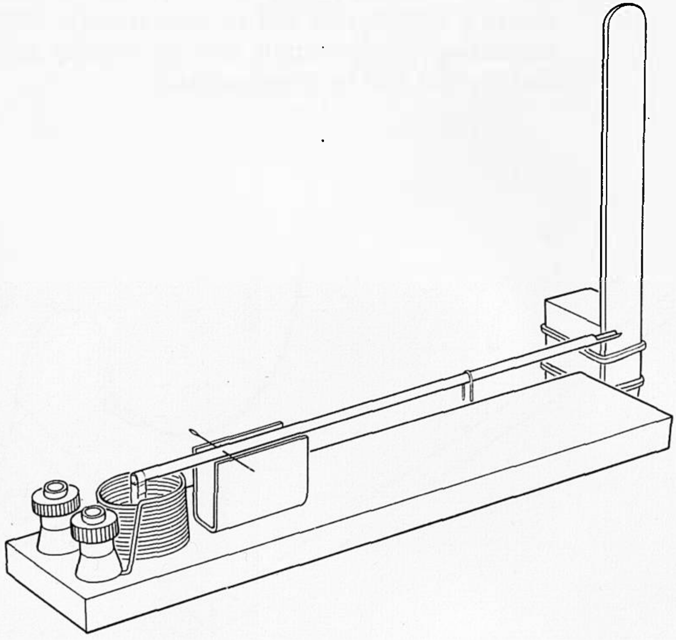
Each group requires:

3 U-2 cells	– item 52B
3 bulbs	– item 52A
spring connectors	– item 52E
3 spring connectors with bulb holder	– item 52D
4 plug/croc leads	– item 52I

Details of current balance:

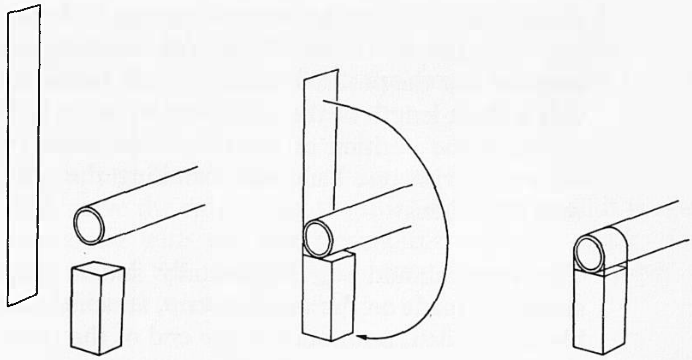
base assembly with coil	– item 53C
$\frac{1}{2}$ in Alcomax magnet	– item 53B
drinking straw	– item 53A
sewing needle	– item 53D
rider of tinned copper wire	– item 53H
wooden strip (6 in × $\frac{3}{4}$ in)	– item 53F
wooden block ($1\frac{1}{2}$ in × $1\frac{1}{2}$ in × $\frac{3}{4}$ in)	– item 53E

The current balance kit (item 53) includes sufficient for sixteen current balances enabling pupils to work in pairs.



Assembly of current balance

1. The pupils should fasten the $\frac{1}{2}$ in magnet near to the end of the drinking straw with about $1\frac{1}{4}$ in of Sellotape. Perhaps the easiest way is to cut the Sellotape, attach it to the magnet and fix the drinking straw as shown below.



2. Balance the straw *on* the needle to find the centre of gravity of the straw with the magnet attached. Stick the needle through the straw a very little farther away from the magnet (not more than 1 mm from the centre of gravity of the combined straw and magnet). Only as a remedy in the face of disappointment should pupils be given these details as instructions. Instead, the teacher should give extra straws and encouragement.

Then with the magnet near the centre of the coil, the needle is about $\frac{1}{4}$ in from the end of the metal channel. The straw should be horizontal when the magnet is vertical.

3. The rider is made by wrapping 2·5 cm of 26 or 28 swg copper wire round a pencil and is slipped over the straw. The rider should balance the straw horizontally when it is not more than 5 cm from the needle. If it has to be nearer the free end of the straw, the range of the current balance will be reduced (though not the sensitivity). For the more clumsy pupils it may be better to use up to 5 cm of 26 or 28 swg wire for the riders. This will make the balance less sensitive but the position of the pin will be less critical. Provide a short length of the same wire to use as a 'lifter' when adjusting the position of the rider (best done by steadying the straw with one hand and handling the wire and rider with the other).

The straw should rest horizontally and a reference mark should be made on the wooden strip, attached to the wooden block provided, positioned at the end of the straw.

4. Check that the coil does not obstruct the free motion of the straw.

Notes on use

1. The leads with a 4 mm plug on one end and crocodile clips on the other end are the most convenient for connecting the balance in the circuit. These are provided in the circuit board kit.

2. If the straws give trouble by slewing round, cut a shallow groove accurately in the vertical rails with a file to localize the straw.

3. Beware of draughts. (Warn pupils not to wait for the straw to come to rest.)

4. The balance is best placed to one side of the board.

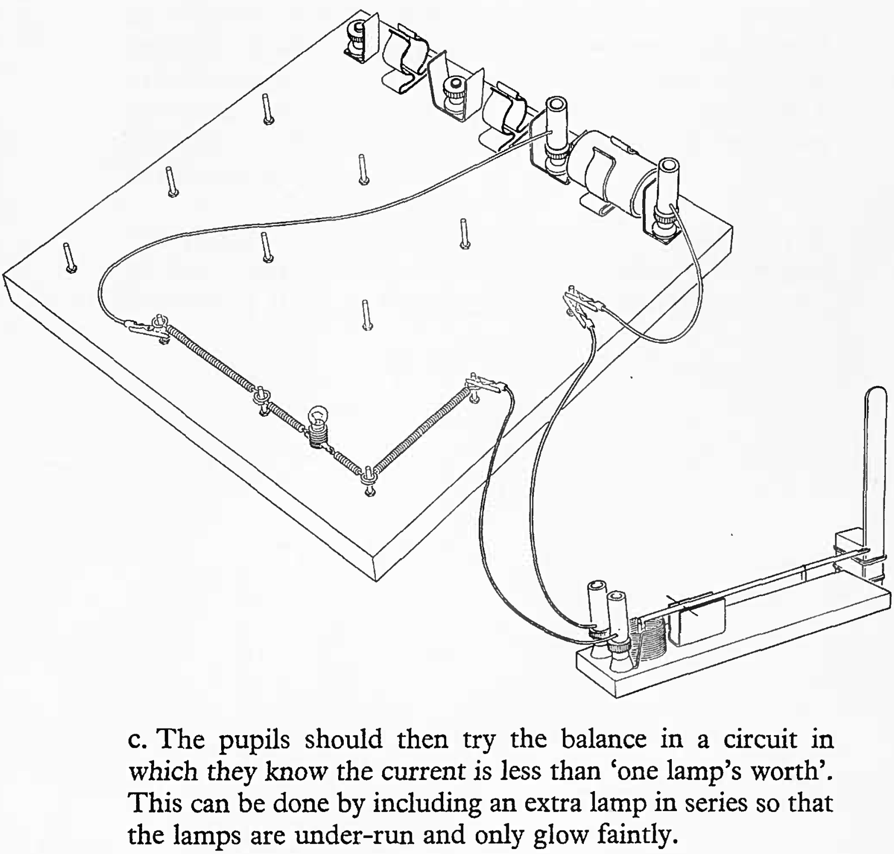
5. The magnet/straw assemblies are quite fragile and care should be taken to preserve them between lessons.

Procedure

a. Pupils assemble their own balances, working in pairs.
b. Pupils connect the balance into a circuit of one lamp and one cell in order to weigh 'one lamp's worth' of current.

After trying the balance in the circuit, the pupils should be asked to reverse the connections to the balance and see what happens. Then onwards they will need to choose the direction so that when a current flows the magnet is drawn into the coil.

When 'one lamp's worth' of current is flowing through the coil, move the rider along the drinking straw until it is again horizontal with the end against the reference mark. This position of the rider will represent 'one lamp's worth' of current and can be marked.



c. The pupils should then try the balance in a circuit in which they know the current is less than 'one lamp's worth'. This can be done by including an extra lamp in series so that the lamps are under-run and only glow faintly.

They should then try the balance when the current is greater than ‘one lamp’s worth’. This can be done using only one lamp but two cells in the circuit so that the lamp is over-run.

d. The pupils should try the balance in a circuit with several lamps in parallel. They should start with a circuit of one cell and one lamp, in which the current through the balance is ‘one lamp’s worth’. Then a second lamp is added in parallel with the first so that the current becomes ‘two lamp’s worth’ and the rider of the balance has to be moved appropriately to restore the balance. Lastly a third lamp is added in parallel with the other two.

15 *Class experiment*

Circuits from circuit diagrams

Apparatus

16 Worcester circuit boards	– item 52C

Each group requires:

3 U-2 cells	– item 52B
3 bulbs	– item 52A
spring connectors	– item 52E
3 spring connectors with bulb holders	– item 52D
2 plug/croc leads	– item 52I

Spare bulbs are included in the Worcester circuit board kit and may be necessary in this experiment.

Procedure

As discussed in the *Teachers' Guide*, no recording in notebooks should have taken place in the earlier experiments with circuit boards. Now, however, when some skill and some knowledge have been acquired, the teacher should give a blackboard talk on how to draw circuits neatly and what symbols to use.

The pupils should then repeat some of the experiments in 12, first drawing the circuit diagrams in their notebooks and then setting them up from their drawings and trying them.

16 *Class experiment*

Currents and conductors

Apparatus

16 Worcester circuit boards	– item 52C

Each group requires:

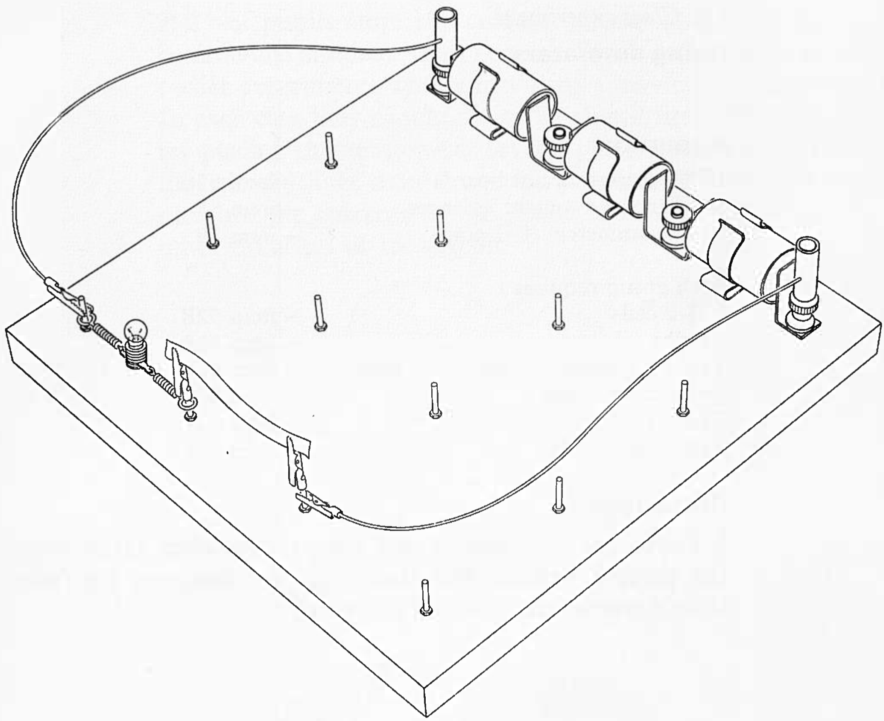
1 U-2 cell	– item 52B
1 bulb	– item 52A
2 crocodile clips	– item 52K
spring connectors	– item 52E
1 spring connector with bulb holder	– item 52D
2 plug/croc leads	– item 52I

Miscellaneous materials such as:
stick of wood
strip of paper
strip of copper
thread of nylon
aluminium foil
pencil lead (preferably a soft grade)
bits and pieces from pupils' pockets

Procedure

Pupils should insert various samples of materials in a circuit to see if they will carry currents.

Crocodile clips with their shanks slipped over adjacent pegs on the circuit board make a very convenient method for holding the samples in the circuit.



17a *Class experiment*

Using ammeters

Apparatus

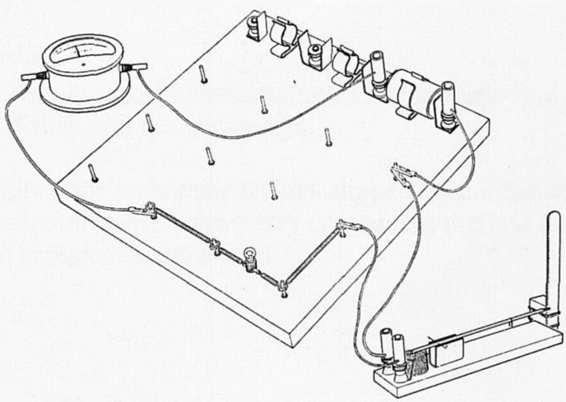
16 Worcester circuit boards	– item 52C
16 Worcester current balances	– item 53
16 d.c. ammeters (0–1 amp)	– item 79

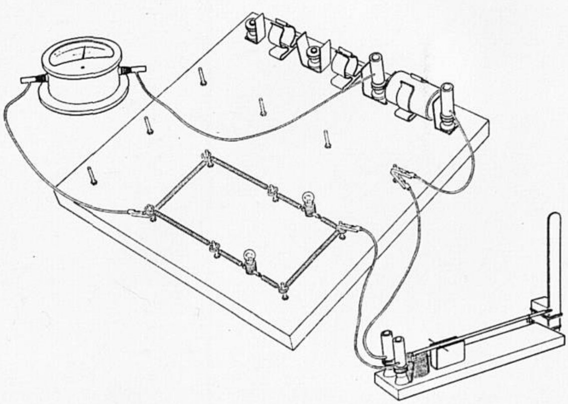
Each group requires:

2 U-2 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

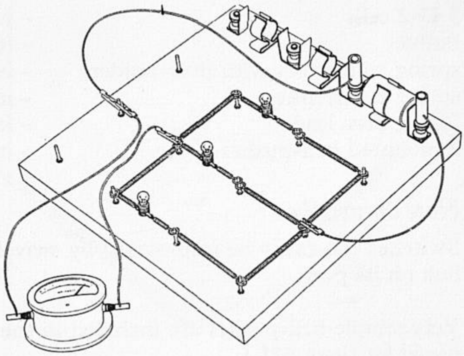
Procedure

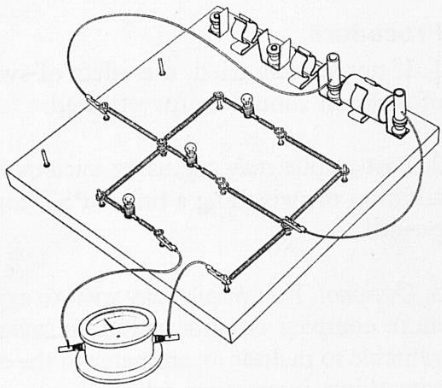
1. Pupils set up a circuit and compare readings taken with the current balance and then with the ammeter for 'one lamp's worth' and 'two lamps' worth'.





2. Then pupils store the current balance away and use the commercial ammeter from now on. Pupils repeat some of the earlier experiments with lamps using a moving coil ammeter. In each case they should draw the circuit first. They should try placing the ammeter at several places in a circuit. Then they should light three lamps (in parallel) with one cell and measure the currents at the points indicated below and in other branches of the circuit.





17b *Class experiment*

Experiments with switches

(These experiments should be done now if they have not been done earlier.)

Apparatus

16 Worcester circuit boards	– item 52C

Each group requires:

3 U-2 cells	– item 52B
bulbs	– item 52A
spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 plug/croc leads	– item 52I
2 mounted bell-pushes	– item 52L

Note on switches

Switches can easily be improvised by swivelling the appropriate link on its peg.

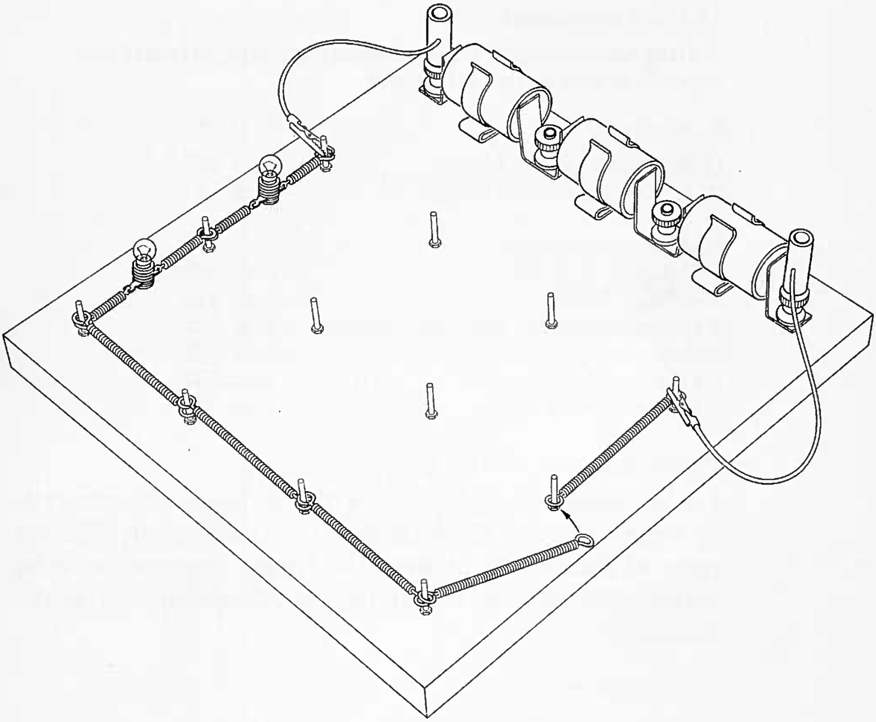
Very simple bell-pushes are included in the Worcester circuit board kit (item 52L).

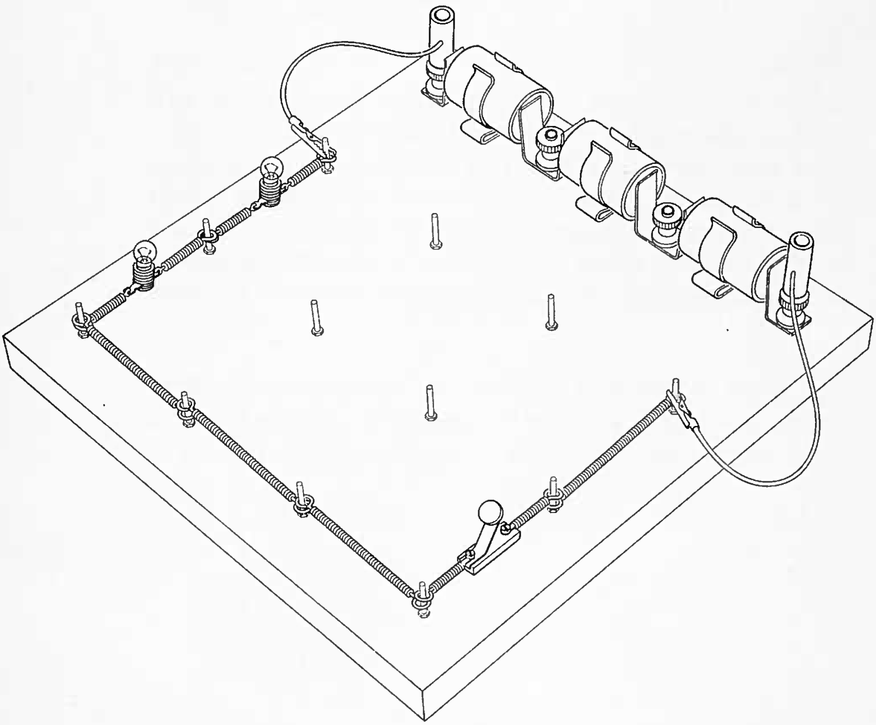
Procedure

1. If not already tried, the effect of switches in various parts of a circuit should be investigated.

2. Fast pupils may try using various kinds of switch and in addition to swivelling a link, SPST toggle switches and bell-pushes.

3. *Optional.* Fast pupils may wish to explore at this stage some more complex circuits including several switches. It is also valuable to include an ammeter in the circuit which may show something interesting when there are branches of several lamps or sets of lamps in a circuit with a switch in each branch. See the additional optional experiments (22).





18 *Class experiment*

Using an ammeter to find whether the current in a circuit is the same all round

Apparatus

16 Worcester circuit boards	– item 52C
16 d.c. ammeters (0–1 amp)	– item 79

Each group requires:

2 U-2 cells	– item 52B
2 bulbs	– item 52A
2 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J

Procedure

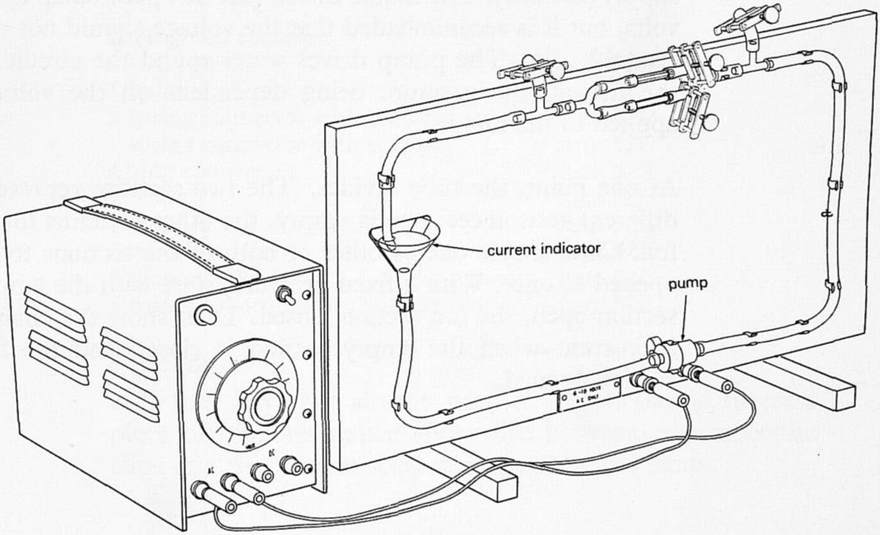
Let the pupils set up a circuit with two lamps and two cells in series. Then let them connect the ammeters in different parts of the circuit: between the lamps, between the cells, between the cells and the lamps, and see each time what the current is.

19 *Demonstration*

Demonstration of water circuit

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 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 illustration. (At this stage, the pressure gauge should *not* be used.) The two tubes which lead through the back can be used to help overcome difficulties with remaining air bubbles.

Sufficient water should be used just to cover the outlet tube of the 'flowmeter' which should be inclined so that the water in the funnel will swirl round when the water current flows.

A small piece of polystyrene (about $\frac{1}{4}$ in cube) is put in the water in the funnel. The speed at which it swirls round is an indication of the strength of the current.

The electric motor – which acts as the water pump – should be connected to the a.c. terminals of the L.T. variable voltage supply (*not d.c.*). The motor can in fact be operated up to 18 volts, but it is recommended that the voltage should not exceed 12 volts. The pump drives water round the circuit of the tubing, the pressure being dependent on the voltage applied to the motor.

At one point, the tube divides. The two sections represent different resistances: one is empty, the other contains metal foil. Clips enable one or other or both of the sections to be opened at once. With a fixed pressure, start with the empty section open, the foil section closed. Then show the change in current when the empty section is closed and the foil section opened.

20 *Class experiment*

Circuit with extra resistance

Apparatus

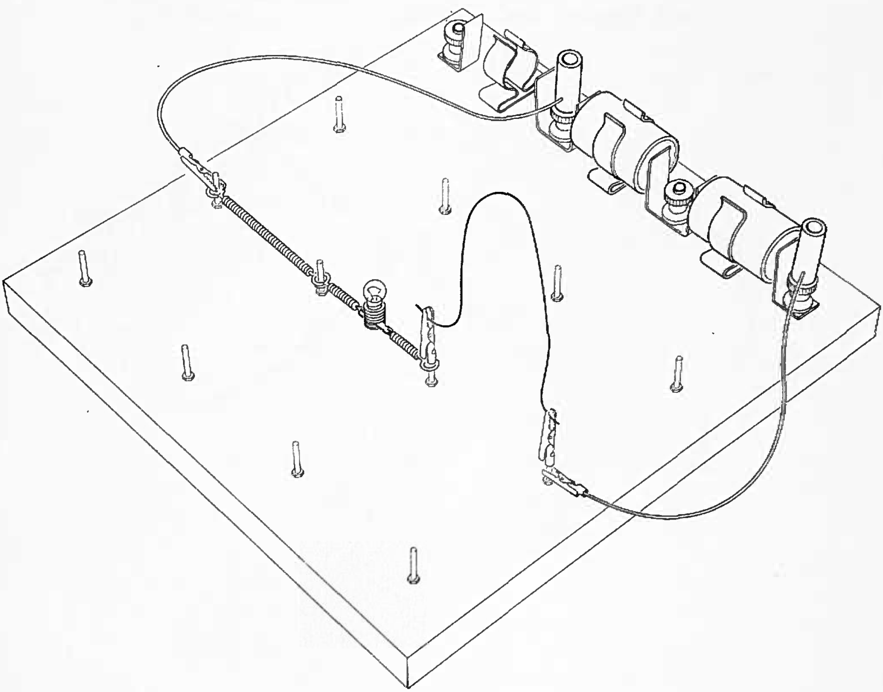
16 Worcester circuit boards	– item 52C
16 d.c. ammeters (0–1 amp)	– item 79

Each group requires:

2 U-2 cells	– item 52B
1 bulb	– item 52A
1 spring connector with bulb holder	– item 52D
1 spring connector with rheostat	– item 52F
spring connectors	– item 52E
1 resistor	– item 52H
1 rectifier	– item 52G
2 crocodile clips	– item 52K
2 plug/croc leads	– item 52I
1 length (30 in) Eureka wire 34 swg	– item 52P

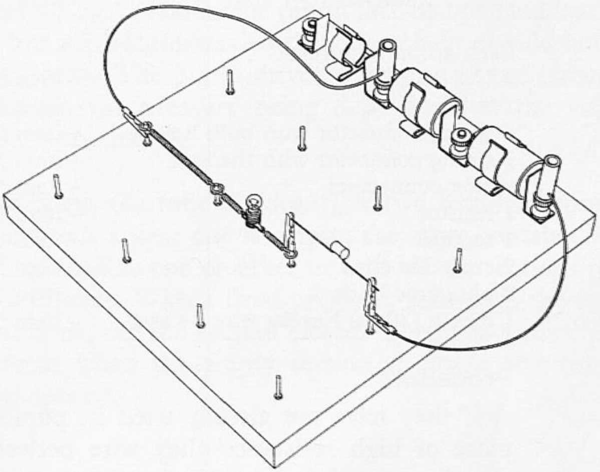
Procedure

a. If they have not already tried it, pupils should insert a piece of high resistance alloy wire between two crocodile clips in a circuit consisting of two cells and a lamp.

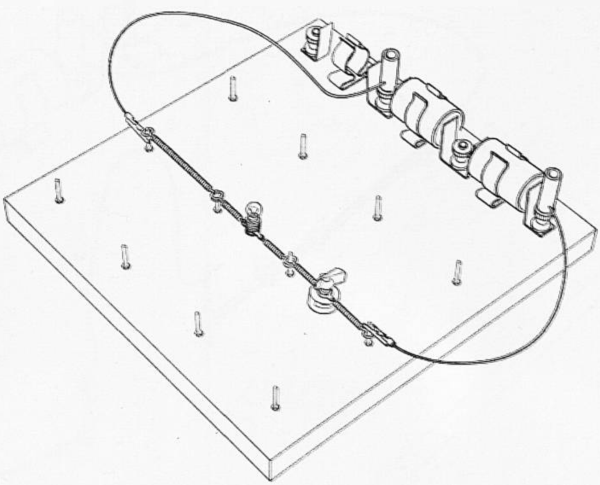


b. They then change the length of wire between the clips and observe the effect on the lamp.

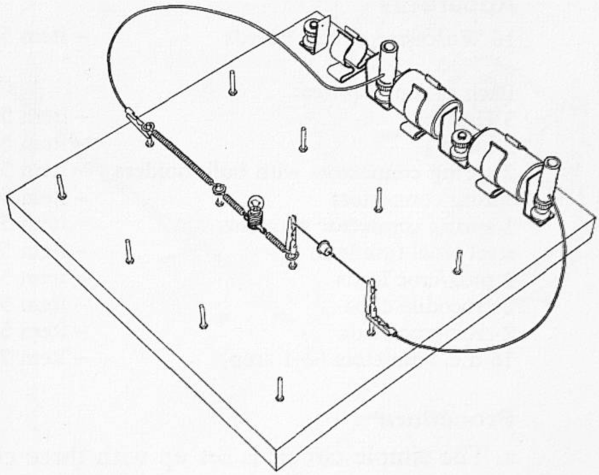
c. They should now put first the fixed resistor and then the variable resistor in their circuit in place of the high resistance wire.



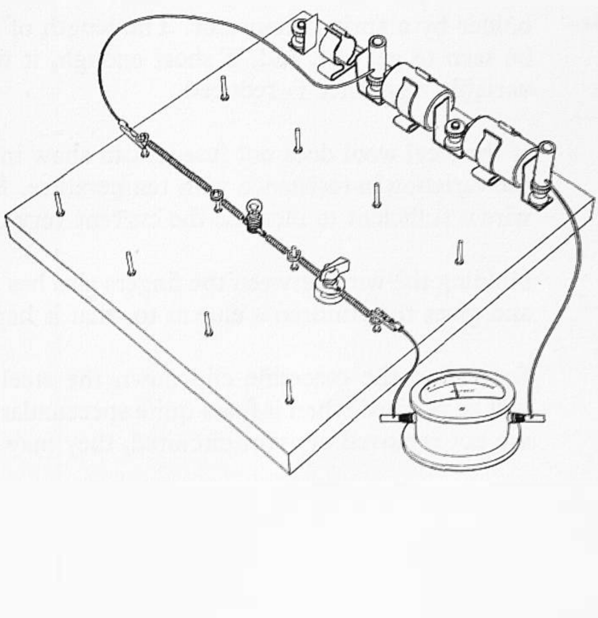
d. With the variable resistor they should try making the lamp both brighter and dimmer.



e. They should also try putting the rectifier in a circuit of lamps and cells. The rectifier is conveniently held between two crocodile clips. They should try the rectifier round both ways.



They may repeat all the experiments with the ammeter in the circuit and observe how it steadily changes as the resistances are altered.



21 *Class experiment*

Temperature effect and fusing

Apparatus

16 Worcester circuit boards	– item 52C
Each group requires:	
3 U-2 cells	– item 52B
2 bulbs	– item 52A
2 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
1 spring connector with rheostat	– item 52F
steel wool (grade 2)	– item 52U
2 plug/croc leads	– item 52I
2 crocodile clips	– item 52K
2 croc/croc leads	– item 52J
16 d.c. ammeters (0–1 amp)	– item 79

Procedure

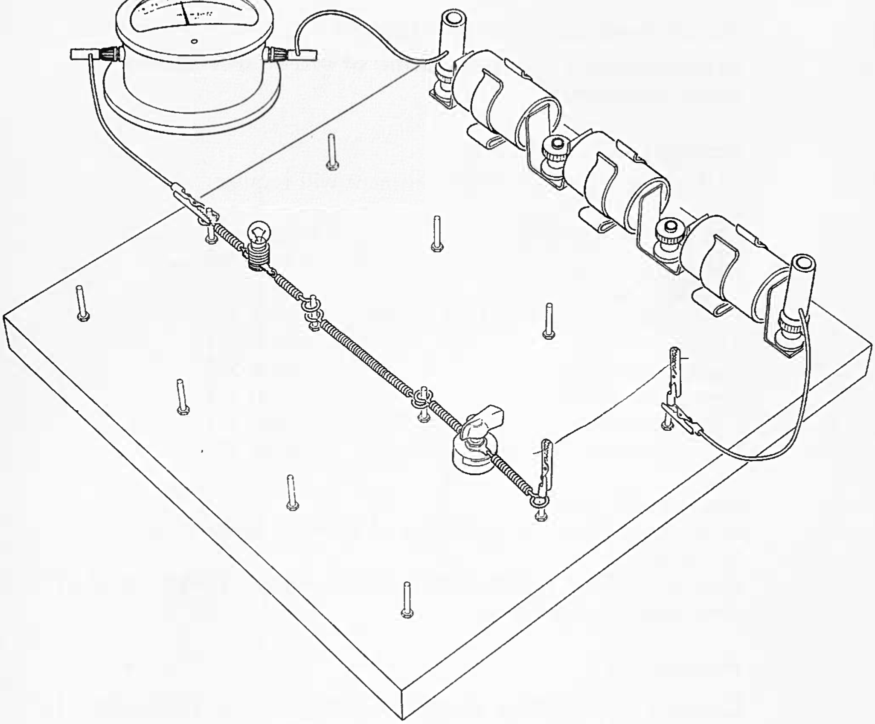
a. The simple circuit is set up with three cells, a lamp, and rheostat in series with the crocodile clips slipped over pillars to carry a 2 in or 3 in length of the steel wool. An ammeter also is included in the circuit, using the croc/croc leads.

b. The bulb can be short-circuited by replacing the bulb holder by a spring connector. The length of steel wool will be seen to get hot, and, if short enough, it will fuse as the variable resistance is reduced.

If the steel wool does not fuse, it can show in a graphic way the variation in resistance with temperature. Blowing on the wire is sufficient to increase the current very considerably.

Holding the wire between the fingers also has the same effect and gives the children a clue as to what is happening.

By sliding the crocodile clip down the steel wool, a point will be reached when it fuses quite spectacularly. If the bulbs are not removed or short circuited, they may fuse first!



22a *Optional class experiment (buffer)*

Investigating the resistance of wires of various sizes and kinds

Apparatus

Each group that does this experiment will require:

1 Worcester circuit board	– item 52C
2 U-2 cells	– item 52B
1 bulb	– item 52A
1 spring connector with bulb holder	– item 52D
2 crocodile clips	– item 52K
spring connectors	– item 52E
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J
1 d.c. ammeter (0–1 amp)	– item 79

Available for class use:
Selection of reels of Eureka wire of different gauges, e.g. 22, 26, 30, 34 swg.
Selection of reels of different wires (e.g. copper, Eureka, iron) of same gauge (e.g. 34 swg).

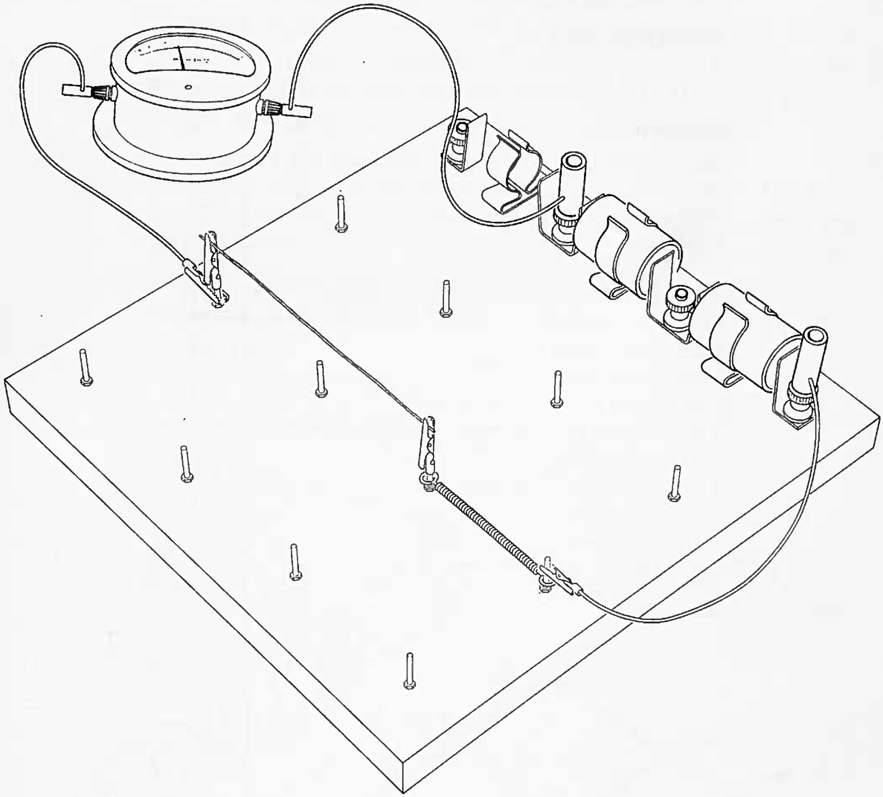
Procedure

Connect up a series circuit of two cells, a lamp and the ammeter, with a 1 ft length of one of the wires closing a gap between two crocodile clips. Note the reading and then replace the specimen of wire with another of the same length but different gauge or material.

If coils of copper wire and of Eureka wire of the same gauge can be prepared, so that they have equal resistances, the effect is very striking. However, as a *prepared* experiment, this may lose the point of being an open extension for faster pupils.

Note

Some may prefer to dispense with the lamp in the circuit to make the effect more easily observable.



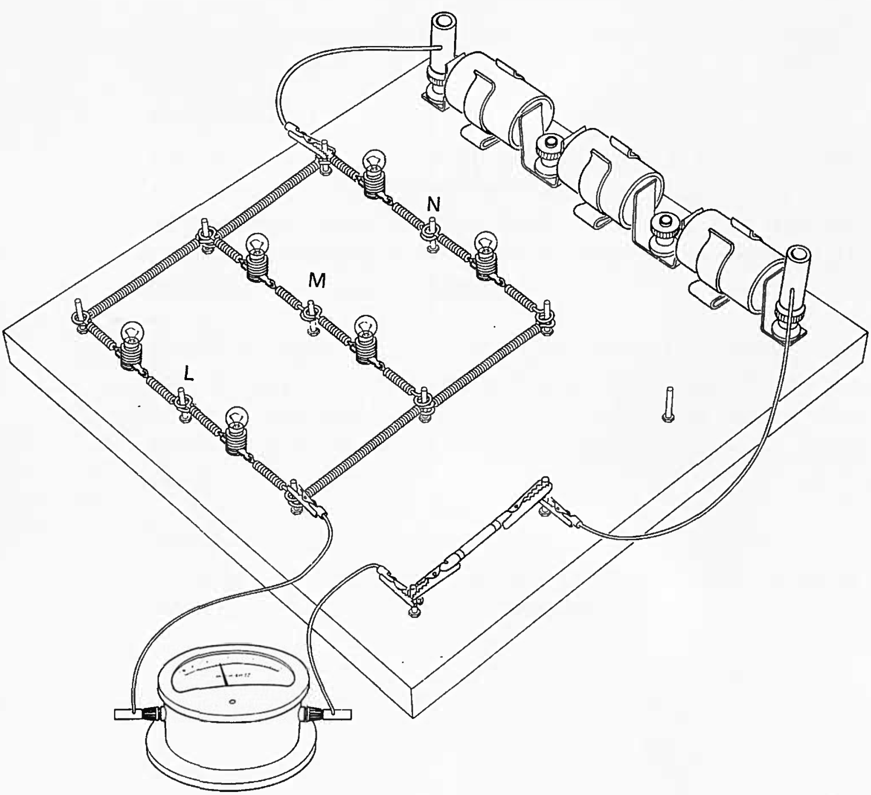
22b *Optional class experiment* (*buffer*)

Testing fuses

Apparatus

Each group that does this experiment will require:

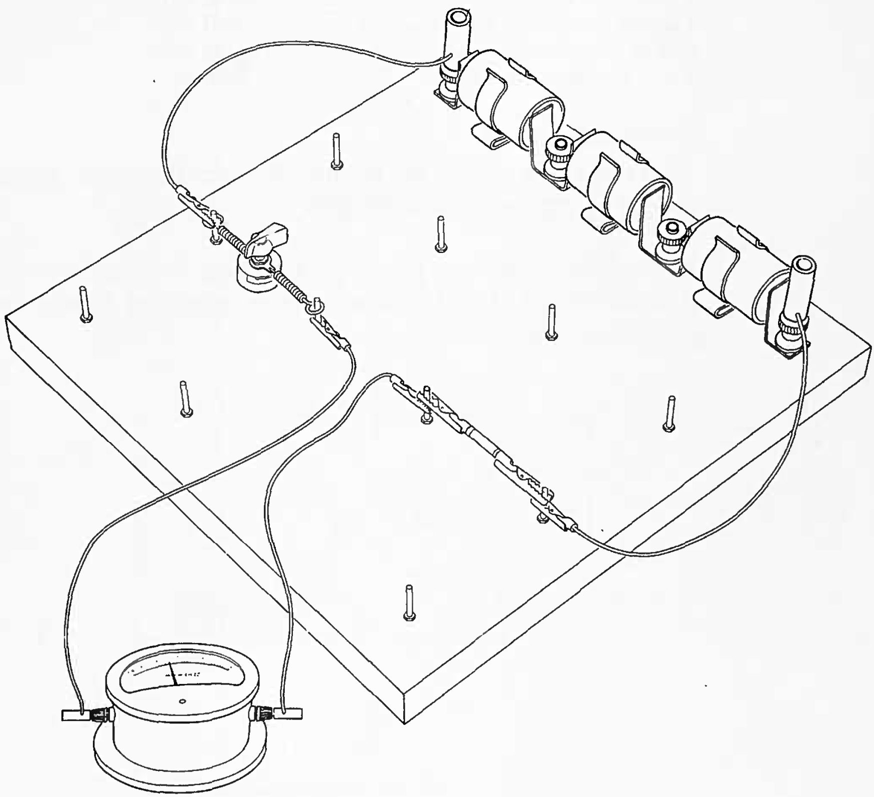
1 Worcester circuit board	– item 52C
6 bulbs	– item 52A
3 U-2 cells	– item 52B
6 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 croc/croc leads	– item 52J
2 plug/croc leads	– item 52I
1 crocodile clip	– item 52K
2 fuse links (Radiospares $\frac{3}{4}$ in type rated at $\frac{1}{4}$ ampere) (1 + 1 spare)	
1 d.c. ammeter (0–1 amp)	– item 79



Procedure

Connect up the circuit shown, but with only the two lamps marked L in circuit diagram. Note the current. Add the two lamps marked M and note the current. Add the third pair of lamps and again note the current.

Alternatively, connect the three cells in series with the fuse link, the ammeter and the variable resistance (rheostat) included in the circuit board kit. Gradually decrease the resistance in the circuit watching the current reading in the ammeter until the fuse blows.



22c *Optional class experiment* (*buffer*)

Investigating circuits

Apparatus

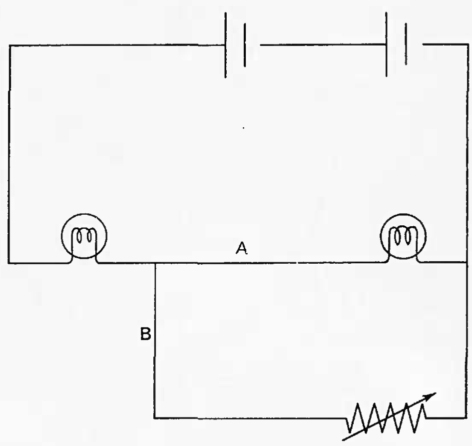
Each group that does this experiment will require:

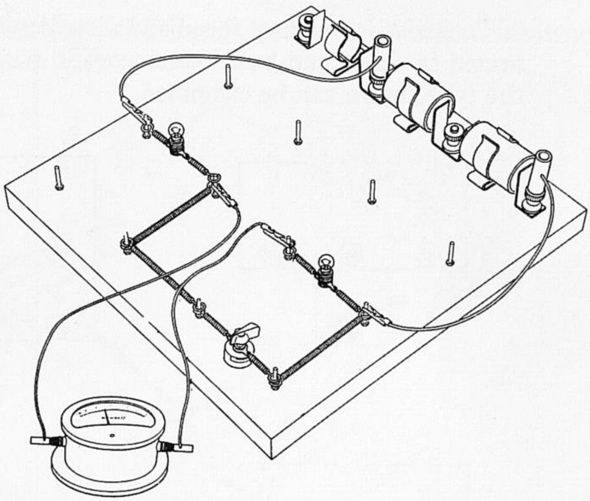
1 Worcester circuit board	– item 52C
3 U-2 cells	– item 52B
5 bulbs	– item 52A
5 spring connectors with bulb holders	– item 52D
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J
1 spring connector with rheostat	– item 52F
spring connectors	– item 52E
1 d.c. ammeter (0–1 amp)	– item 79

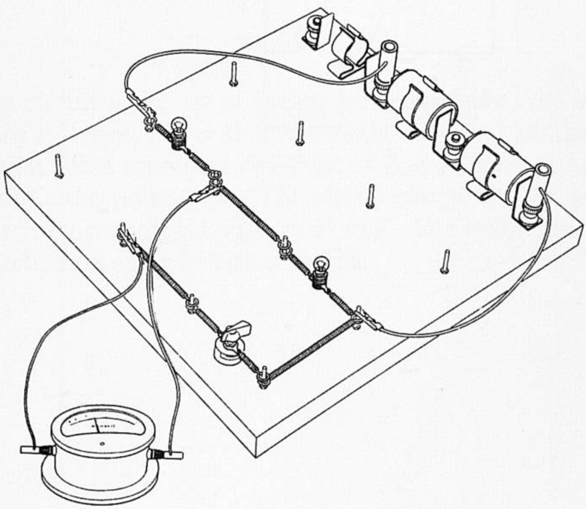
Procedure

There are a number of additional circuits which faster groups of pupils might investigate.

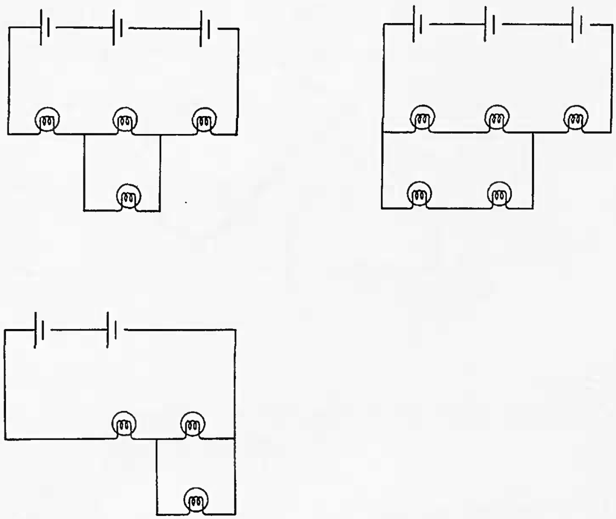
1. First, an ammeter is placed at A and the resistance of the rheostat varied. The ammeter is then moved to B and the experiment repeated.



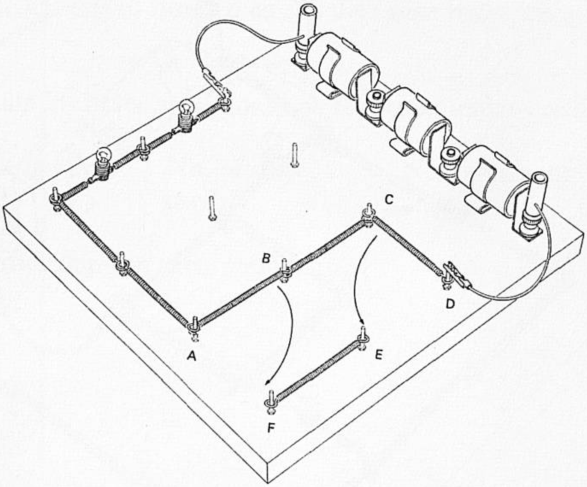




2. To assist in making the distinction between bulbs connected in series and bulbs connected in parallel, circuits of the type shown can be examined:

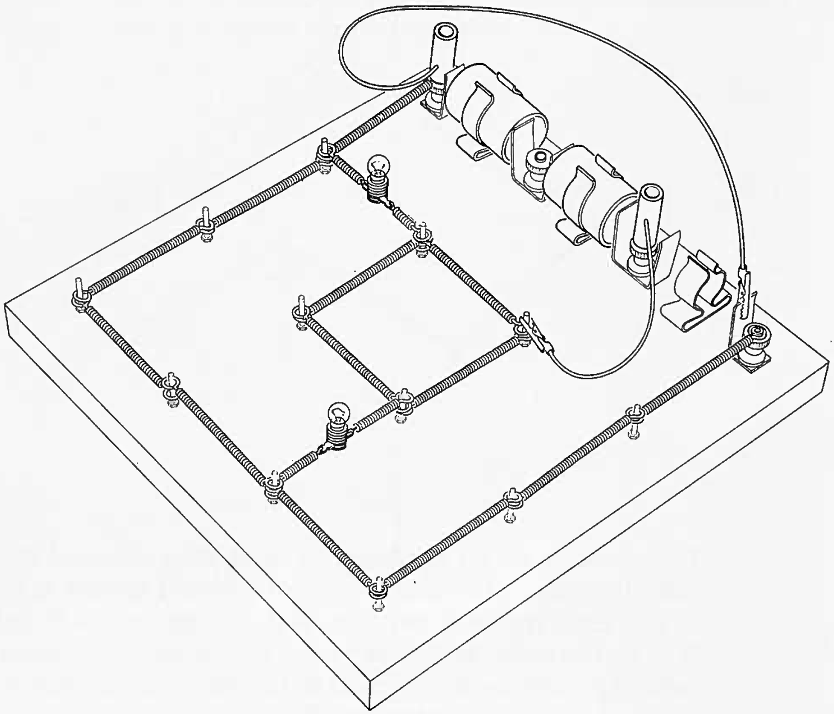


3. Two-way switching using two loose links as switches can be investigated.



The circuit is set up as illustrated using three cells and two bulbs in series. A free link is attached to A and another at D, so that these represent switches. If A is connected to B and D to C, the bulbs light. The circuit can be broken at either switch by changing A to F or D to E. The bulbs can then be switched on again at either switch.

4. The ring-main can be investigated as follows:



5. Problem circuits can be suggested such as using two cells to light four and then six bulbs fully. This can be followed by the lighting of three, then six, then nine bulbs using three cells.

(Results in these cases should be tabulated under headings:

No. of lamps fully lit	No. of cells used	No. of current units

A relationship can then be sought.)

22d *Optional class experiment (buffer)*

Problem circuit

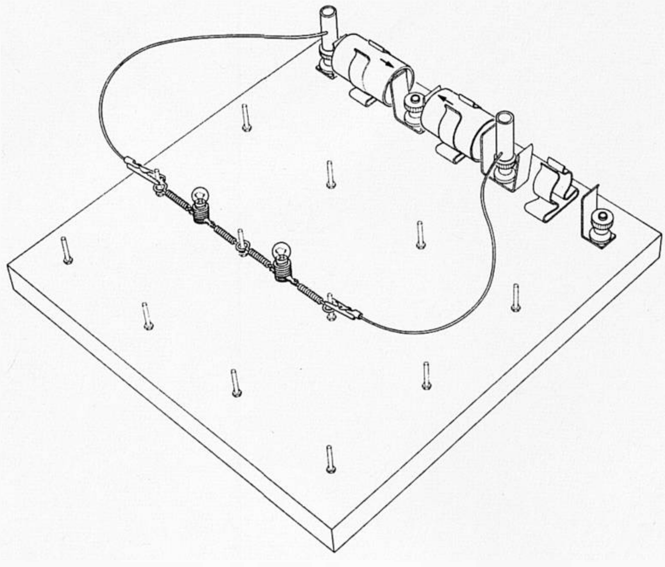
Apparatus

Each group that does this experiment will require:

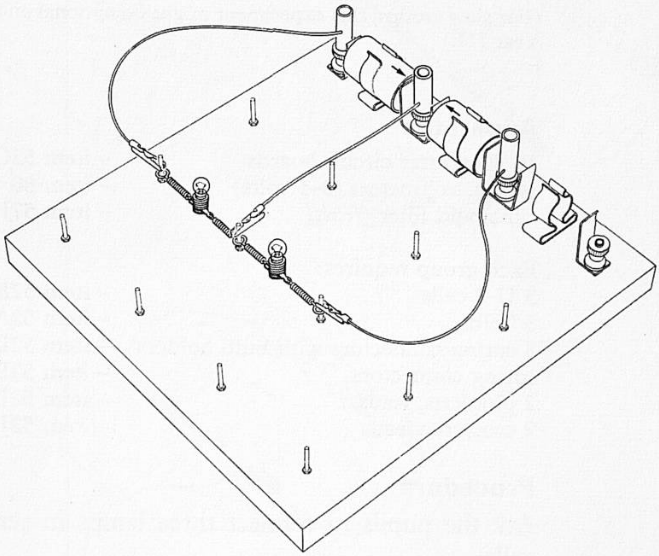
1 Worcester circuit board	– item 52C
2 U-2 cells	– item 52B
2 bulbs	– item 52A
2 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 plug/croc leads	– item 52I
1 croc/croc lead	– item 52J

Procedure

Set up the circuit shown. Why do not the lamps light?



What will happen if an additional link is added as shown below?



23 Class experiment

Introduction to a voltmeter as a cell counter

(For slow groups, this experiment might be optional and postponed until Year III.)

Apparatus

16 Worcester circuit boards	– item 52C
16 d.c. voltmeters (0–5 volts)	– item 80
Cinemoid filter (frost)	– item 57J

Each group requires:

3 U-2 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

Procedure

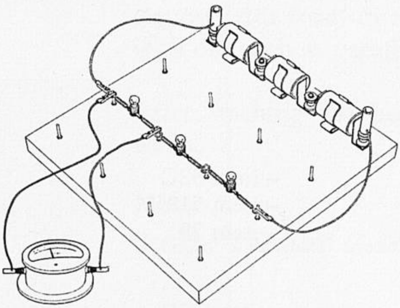
Ask the pupils to connect three lamps in series with three cells.

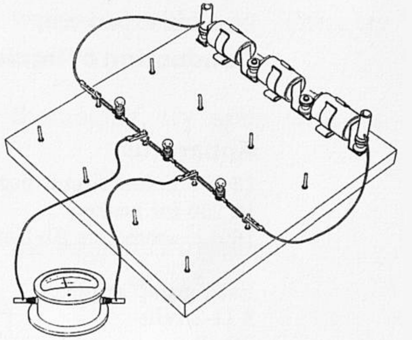
Then put the voltmeter provided across one of the lamps. Then across another. Then across the third. Ask what happens if the leads are connected the wrong way round.

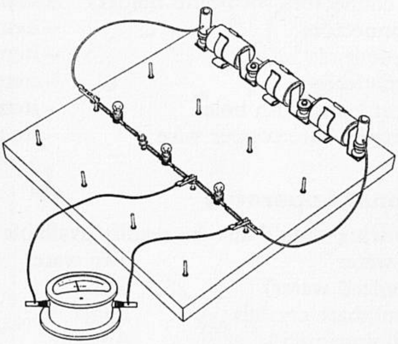
Then put the meter across two of the lamps. Then across three.

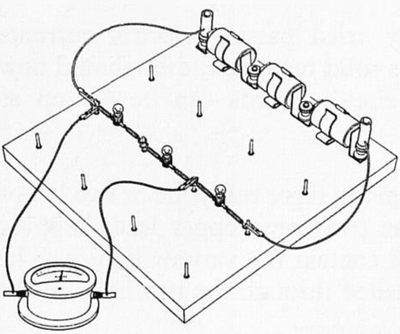
The pupils should begin to get the idea of this new instrument as a 'cell counter'. How many cells are needed to run one lamp? How many for two lamps together? How many for three?

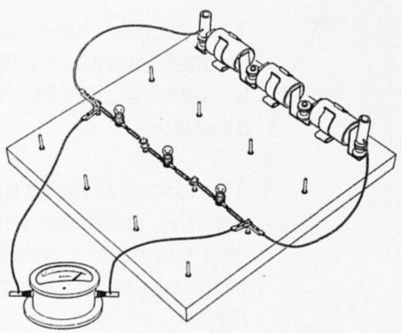
Now arrange two lamps in series with one cell. What does the 'cell counter' read across one lamp? Across two lamps? Let the pupils find it still counts cells (half cells, whole cells, two cells, etc.) however many lamps there are in the circuit.











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.

24 Class experiment

Conduction of liquids

Apparatus

16 Worcester circuit boards	– item 52C
16 250 ml beakers	– item 512/1
16 d.c. ammeters (0–1 amp)	– item 79

Each group requires:

3 U-2 cells	– item 52B
2 bulbs	– item 52A
2 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J
1 hardboard disc with holes	– item 52R
2 6 in lengths bare copper wire	– item 52N

Additional Apparatus

The following should also be readily available:

distilled water	Tap water
(or de-ionized water)	Salt
copper sulphate crystals	Sugar
dilute sulphuric acid	Any oil

Procedure

The pupils have already tried passing electric currents through samples of various solid materials; they should now be offered liquids. The circuit boards can be set up as illustrated:

The circuit is made up from the three cells, one or two lamps and the ammeter with the two bare copper leads dipping into the beaker which will contain the various liquids. The bare copper leads are threaded through the two holes in the lid.

First try distilled water. Then add a few crystals of common salt and stir carefully. Salt will dissolve more readily than copper sulphate crystals, though these can be tried in place of salt.

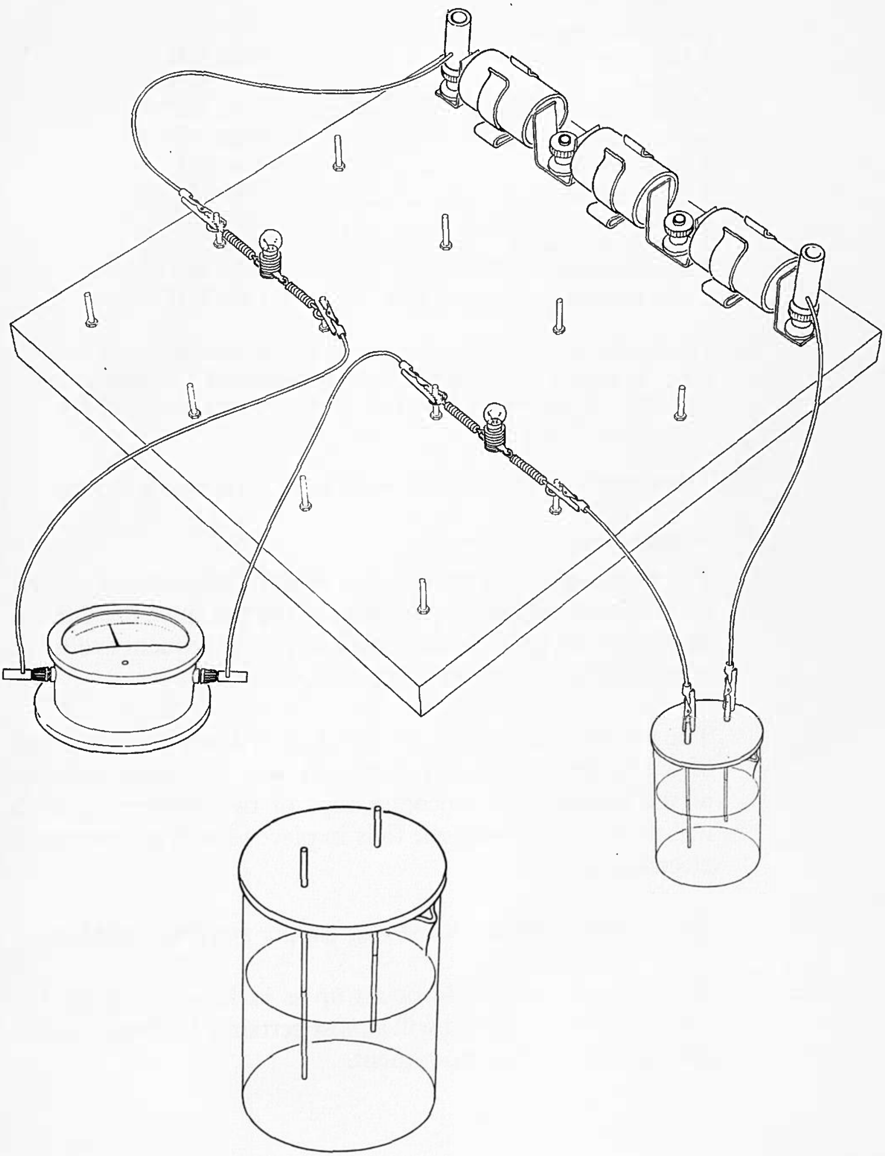
Replace the liquid with fresh distilled water, having washed the beaker carefully. Add several drops of dilute sulphuric acid. Observe what happens to the current.

Repeat with fresh distilled water and add sugar. Then try with oil, such as paraffin.

After washing the beaker thoroughly, try again with tap water.

Note

See the *Teachers' Guide* for the suggested treatment.



25 Class experiment

Introduction to copper plating

Apparatus

16 Worcester circuit boards	– item 52C
16 250 ml beakers	– item 512/1
16 d.c. ammeters (0–1 amp)	– item 79
copper sulphate solution	– see below

Each group requires:

3 U-2 cells	– item 52B
2 bulbs	– item 52A
2 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 plug/croc leads	– item 52I
2 croc/croc leads	– item 52J
2 strips copper foil	– item 52T
2 carbon electrodes	– item 52S
1 hardboard disc with holes	– item 52R
2 6 in lengths bare copper wire	– item 52N

The copper foil is supplied in the Worcester circuit board kit in sheet. It should be cut into strips $\frac{1}{4}$ in wide and $\frac{1}{2}$ in longer than the depth of the beaker. One pair of these strips is needed for each circuit board.

The copper sulphate solution needs to be fairly strong (0·5 N).

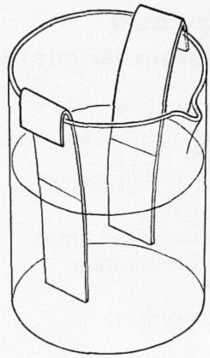
Procedure

The bare copper wire electrodes used in the previous experiment are not satisfactory for copper plating since the current density would be likely to be high with a consequent evolution of oxygen which would affect the current.

The two strips of copper foil are slipped down the inside wall of the beaker and the top half-inch bent back over the edge of the beaker. The crocodile clips of two connecting leads will then serve to keep the foils in place as well as make good electrical contact.

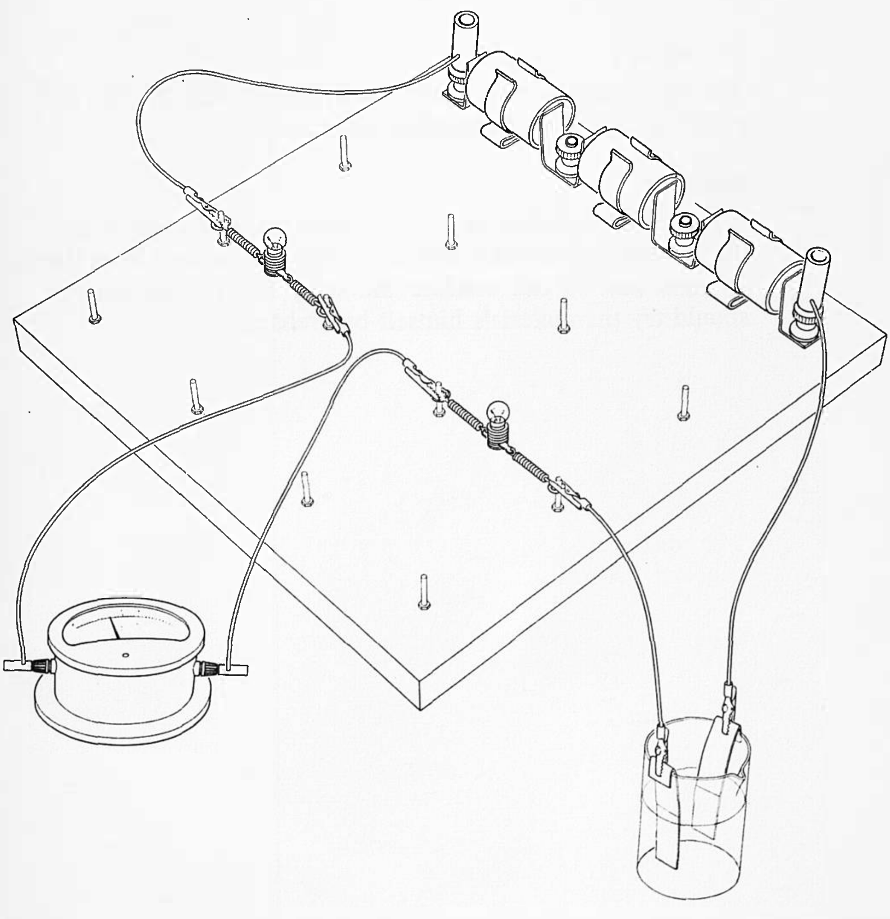
The beaker is filled with strong copper sulphate solution.

The same circuit should be set up as in Experiment 24, but two lamps in the circuit will almost certainly be found preferable to one, in this experiment.



Let the current run for some minutes and then look at the strips to see if there is any difference.

Repeat using the pencil carbons as electrodes. These leads will slip through the holes drilled in the beaker lids and can be kept in place with the crocodile clips of the two leads.



26 *Class experiment*

Copper plating various objects

Apparatus

16 Worcester circuit boards	– item 52C
16 250 ml beakers	– item 512/1
16 d.c. ammeters (0–1 amp)	– item 79
copper sulphate solution	

Each group requires:

3 U-2 cells	– item 52B
2 bulbs	– item 52A
2 spring connectors with bulb holders	– item 52D
spring connectors	– item 52E
2 croc/croc leads	– item 52J
2 plug/croc leads	– item 52I
2 strips copper foil	– item 52T

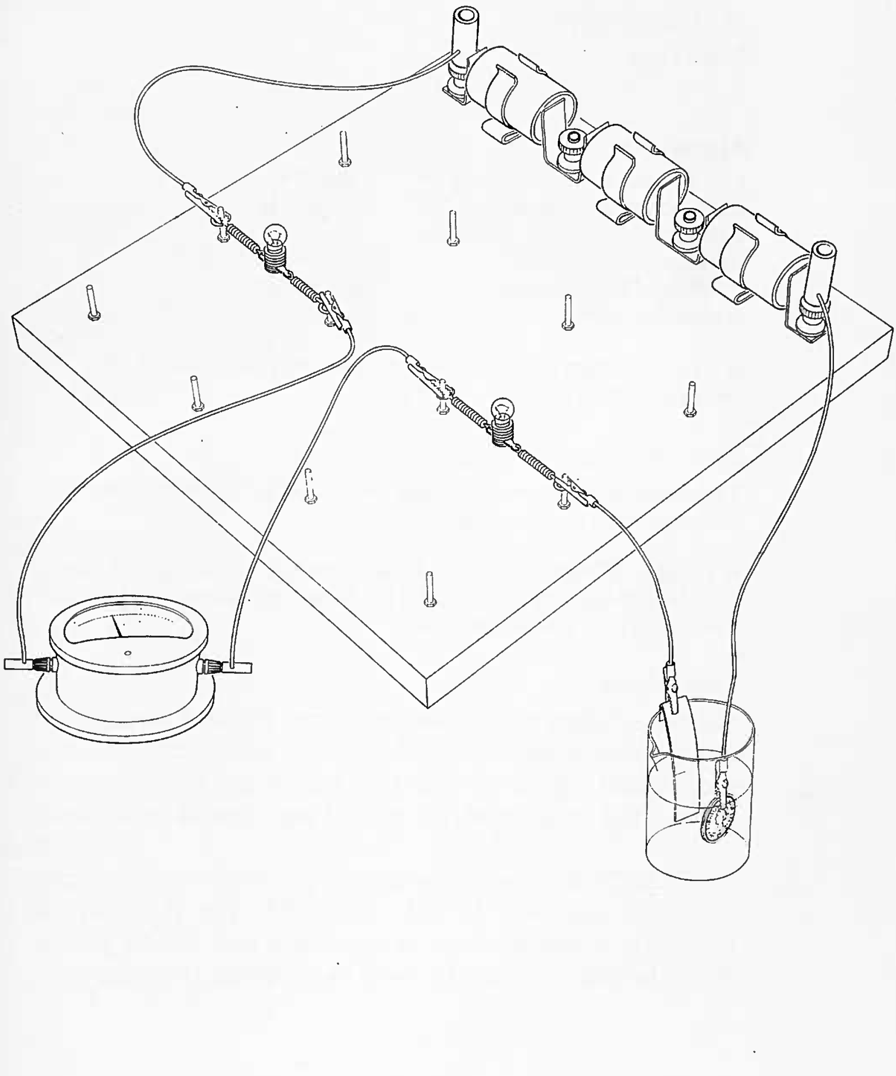
For details of the strips of copper foil, see previous experiment (25).

Procedure

The equipment is used exactly as in Experiment 25, but the pupils should now electroplate other articles.

Note

Care should be taken to avoid objects made of zinc or iron for these metals displace copper of their own accord from the solution and so can confuse the story badly. The teacher should try the materials himself beforehand.



27 Demonstration

Lead tree

Apparatus

1 L.T. variable voltage supply	– item 59
1 cell to contain liquid	– item 57B
1 projection lantern	
suitable electrodes	– see below
solution of lead acetate	– see below
connecting wire	

A 12 volt battery (item 176) can be used in place of the L.T. variable voltage supply.

Notes on apparatus

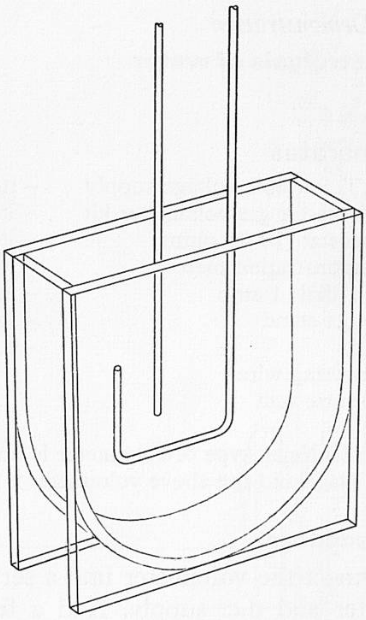
The electrodes can be of carbon (for example, 2 pencil leads) but platinum wire is to be preferred.

A suitable strength is 30 gm of lead acetate to 100 gm of water. Should difficulty be experienced in dissolving the lead acetate, add a few drops of glacial acetic acid.

Procedure

Put the solution of lead acetate in the cell and arrange the two electrodes suitably. In the case of wire electrodes, one wire should run down one side and round the bottom as shown. The other wire, the central one, should be cathode.

Place the cell in a projection lantern and pass a small current, preferably less than 50 mA. About 10 volts d.c. may be necessary. A beautiful tree of crystalline lead will be grown. It can be made to dwindle away by reversing the current.



28 Demonstration

Electrolysis of water

Apparatus

1 L.T. variable voltage supply	– item 59
1 Worcester gas voltameter kit	– item 54
1 rheostat (10–15 ohms)	– item 541
1 demonstration meter	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 retort stand	– items 503–504
1 boss	– item 505
connecting wire	
sulphuric acid	

The Hoffman type of voltameter is not considered suitable at this stage and the above voltameter is recommended.

Procedure

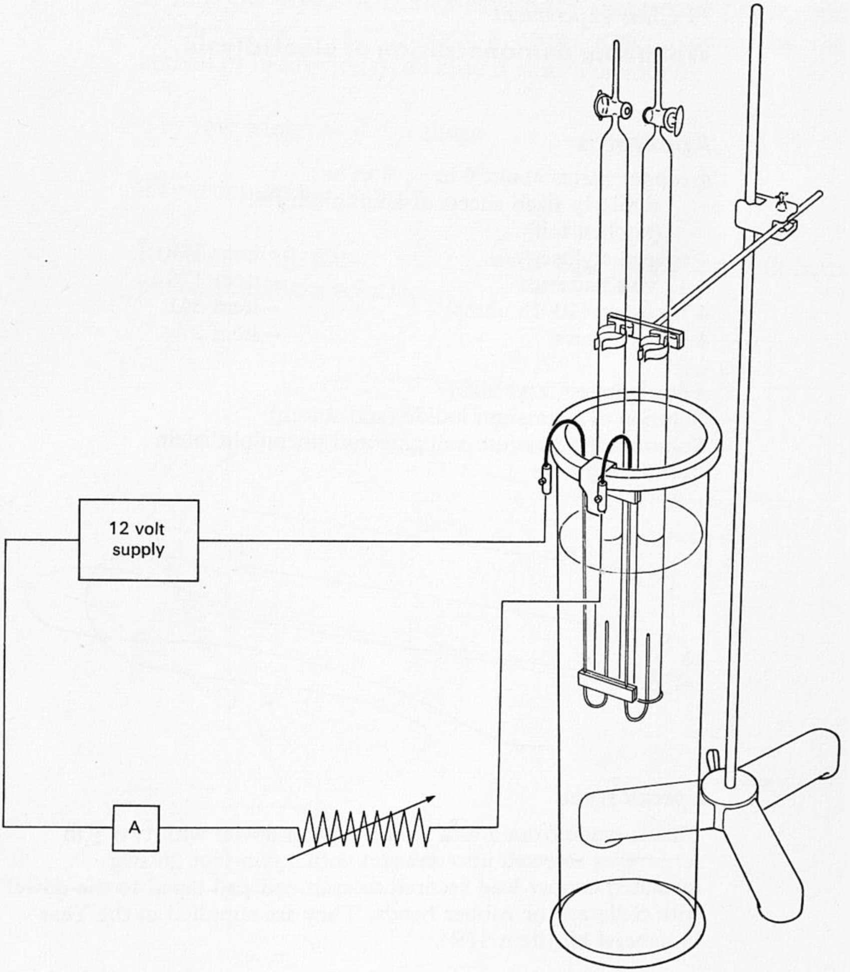
Connect the voltameter into a series circuit of rheostat, ammeter and d.c. supply. Add a few drops of concentrated sulphuric acid and stir well before switching on. A current will now flow and the rheostat can be adjusted to give a suitable current of about 0·5 amp. Bubbles will be seen at both electrodes and gas can be collected in the inverted burettes.

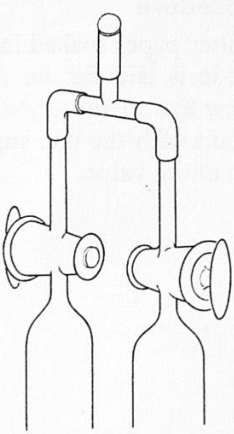
The relatively high solubility of oxygen in water makes it preferable to run the equipment for some time before the demonstration if acceptable volumes of oxygen are to be obtained.

If the current is too low, the inverted burettes should be raised a little.

Note

With a Y-piece and thin rubber tubing, the two gases can be mixed in a soap bubble. (To help form the bubble, the burette taps are opened and the burettes lowered in the voltameter so that the gases are forced out.) If the bubble is exploded, the energy transfer will be apparent.


12 volt
supply
A



29 *Class experiment*

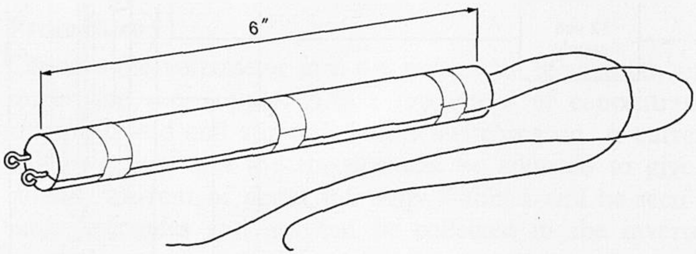
Wet paper demonstration of electrolysis

Apparatus

4 copper plates about 6 in × 8 in or
similarly sized sheets of aluminium foil
(kitchen foil)

4 special styluses	– item 57R
4 12 volt batteries	– item 176
4 rheostats (10–15 ohms)	– item 541
4 transformers	– item 27

Filter papers (large size)
Solution of potassium iodide (and starch)
Solution of potassium sulphate and phenolphthalein
Connecting wire



Special stylus

This is made from a 6 in length of $\frac{1}{2}$ in dowel with two $\frac{1}{4}$ in screw eyes screwed into one end with a two-foot 26 swg insulated copper lead secured to each end and taped to the dowel with Sellotape or rubber bands. They are supplied in the Year II general kit (item 57R).

Procedure

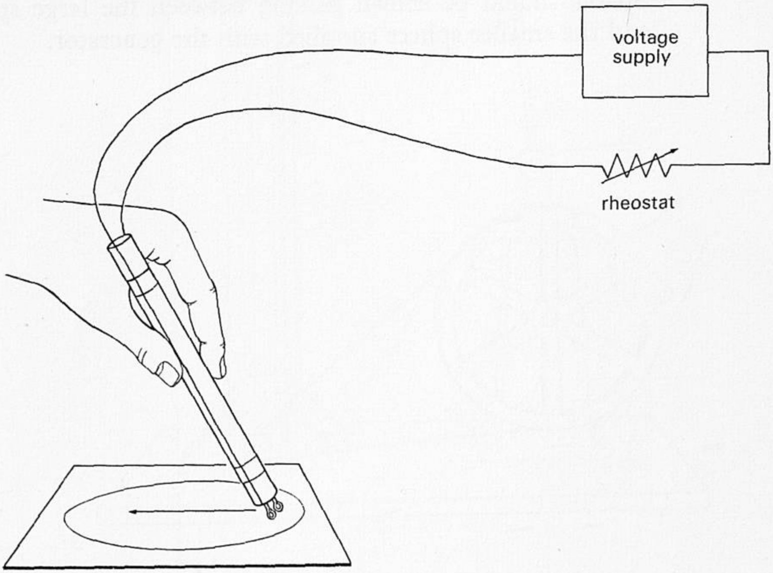
A filter paper soaked in the solution of starch and potassium iodide is laid flat on the metal sheet. The leads from the screw eye in the stylus are connected into a simple series circuit with the d.c. supply and a rheostat, set initially at its maximum value.

If now the stylus is drawn across the dampened paper, one of the screw eyes will leave a brown trace (caused by the arrival of iodine ions), or blue if starch is added.

Try reversing the d.c. voltage.

Try using an a.c. supply.

Repeat using paper soaked with the potassium sulphate phenolphthalein solution.



30 *Demonstration*

To show that a spark can pass through air

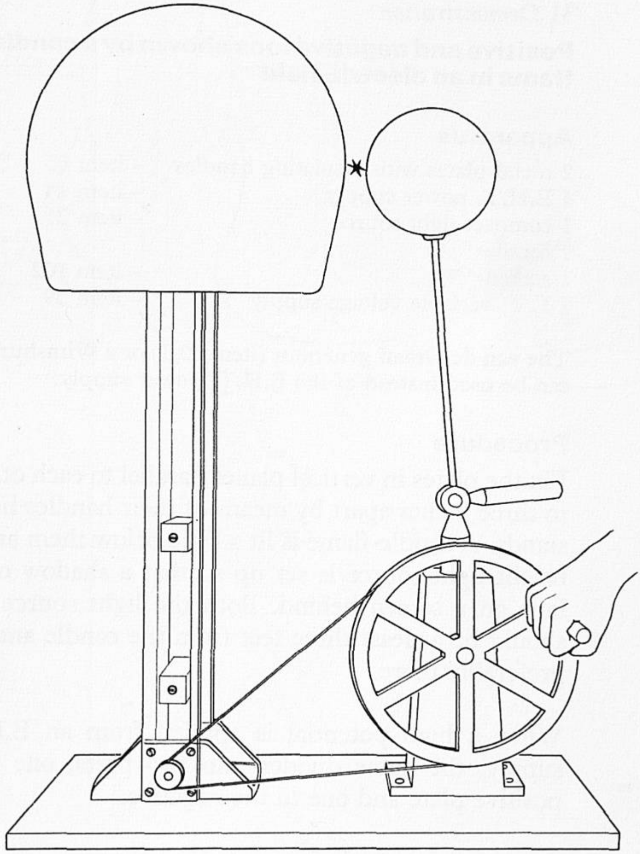
Apparatus

1 van de Graaff generator – item 60/1

Procedure

The makers' instructions should be followed for the care and use of the van de Graaff generator.

Sparks should be shown passing between the large sphere and the smaller sphere supplied with the generator.



31 *Demonstration*

Positive and negative ions shown by a candle-flame in an electric field

Apparatus

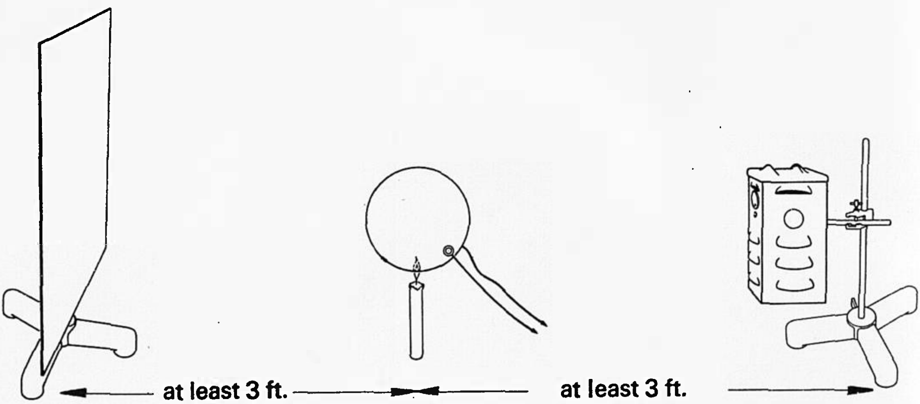
2 metal plates with insulating handles	– item 65
1 E.H.T. power supply	– item 14
1 compact light source	– item 21
1 candle	
1 screen	– item 102
1 L.T. variable voltage supply	– item 59

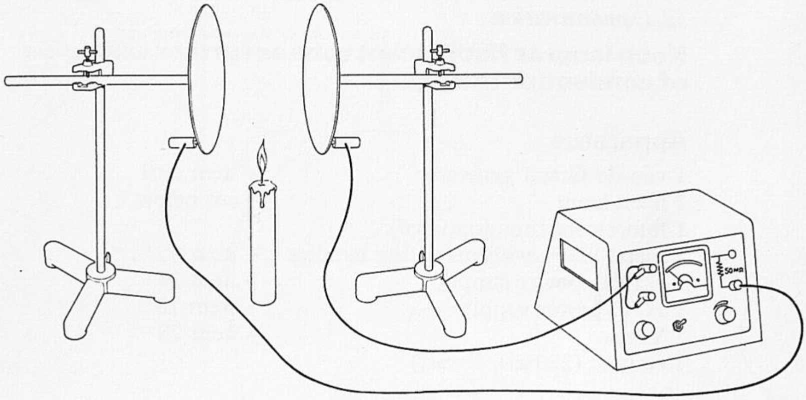
The van de Graaff generator (item 60/1) or a Wimshurst machine can be used instead of the E.H.T. power supply.

Procedure

Fix the plates in vertical planes parallel to each other and two to three inches apart by means of their handles held in retort stands. A candle-flame is lit a little below them and the small bright light source is set up so that a shadow of the plates falls on a screen behind. Both the light source and screen should be at least three feet from the candle and the source preferably more.

When a high potential is applied from an E.H.T. power supply, the flame divides into two parts, one towards the positive plate and one to the negative.





32 Demonstration

Neon lamp or fluorescent tube as further examples of conduction in a gas

Apparatus

1 van de Graaff generator	– item 60/1
1 neon lamp	– see below
1 fluorescent tube (optional)	
2 metal plates with insulating handles	– item 65
1 E.H.T. power supply	– item 14
1 H.T. power supply	– item 13
1 Variac	– item 78
1 resistor (220 kΩ, 1 watt)	

A miniature neon lamp, for example the Radiospares type, works satisfactorily and should be supplied with the accessories for the van de Graaff generator (item 60/1).

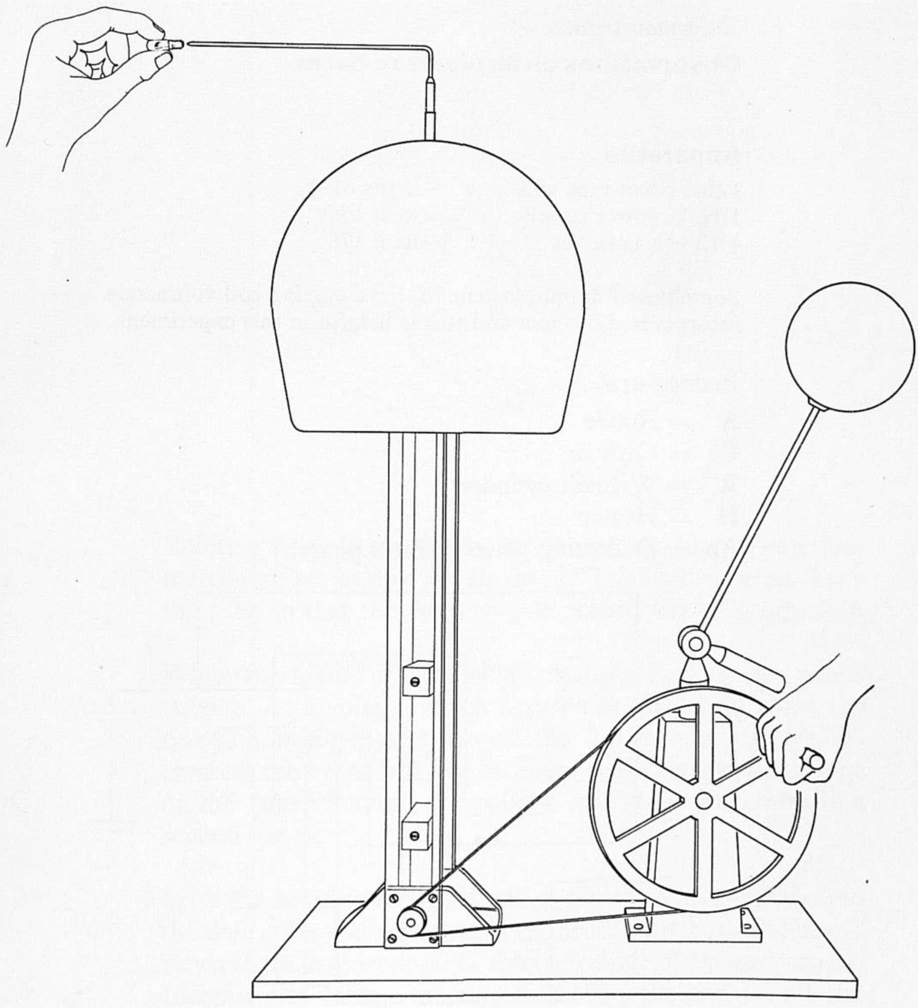
Procedure

a. The tube or lamp is held near to the large sphere of the van de Graaff generator and the glow observed. A convenient arrangement is illustrated below.

Alternatively, the neon tube can be put in a holder with leads attached. One lead from the holder can be plugged into the van de Graaff generator while the lead from the other end of the holder dangles. On bringing up an earthed body (such as finger) near the dangling end, the lamp glows.

To show that an 'electric current' supply does the same thing, the positive terminal of the E.H.T. supply can be connected to one of the metal plates with insulated handles (item 65), while the earthed negative terminal of the supply is connected to the other metal plate. The two plates are set up parallel to each other and, say, six inches apart. The neon lamp is then brought up between the plates.

b. It should then be shown that the neon lamp can be lit using the H.T. power supply giving a d.c. voltage of, say, 200 volts – 4 mm leads and crocodile clips are used to connect to the neon lamp. It is essential to have a safety resistance (220 kΩ, 1 watt) in series with the lamp.



c. Finally it should be demonstrated that the neon lamp can also be lit using a.c. voltages. Great care must be taken if the mains are used, a Variac is a convenient source of voltage. It is essential to have a safety resistance (220 kΩ, 1 watt) in series with the lamp.

33 Demonstration

Observations on an electron beam

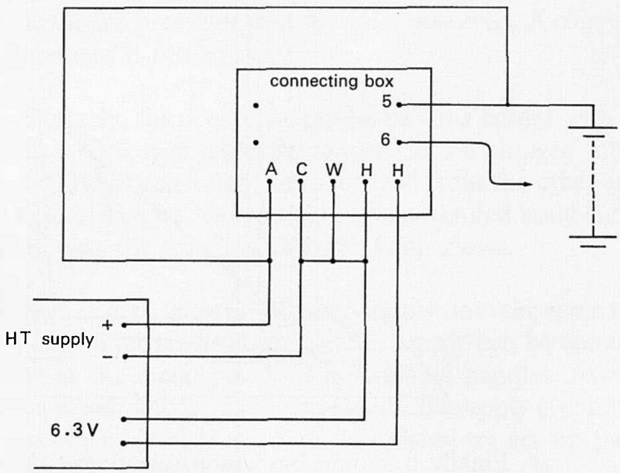
Apparatus

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.

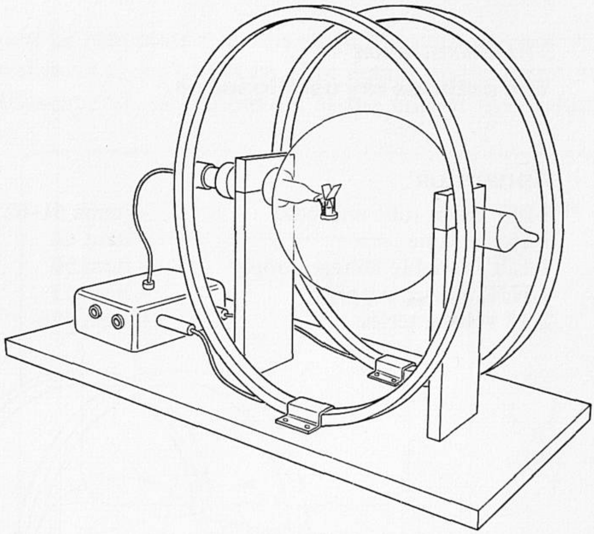
Procedure

A = Anode
C = Cathode
W = Wehnelt cylinder
H = Heater
Ab = Deflecting plates (Ablenkplatten)



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 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 volts, the fine blue beam should be seen. 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 and repeat. 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. (See comment in *Teachers' Guide.*)

2. Always reduce the anode voltage to zero when not actually observing the beam.

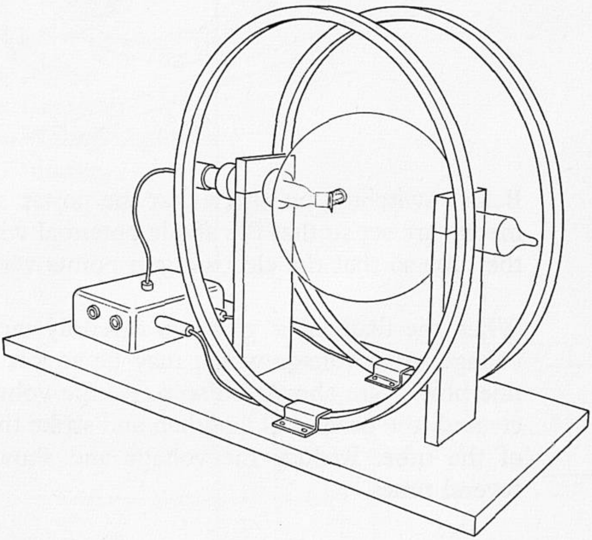
3. Should the beam appear very diffuse at all voltages between 150 and 250, apply up to + 6 V to the Wehnelt cylinder – this may sharpen the beam. Should the trouble continue, return the tube to the makers. It is not doing them justice.

34 *Demonstration*

The cathode ray oscilloscope

Apparatus

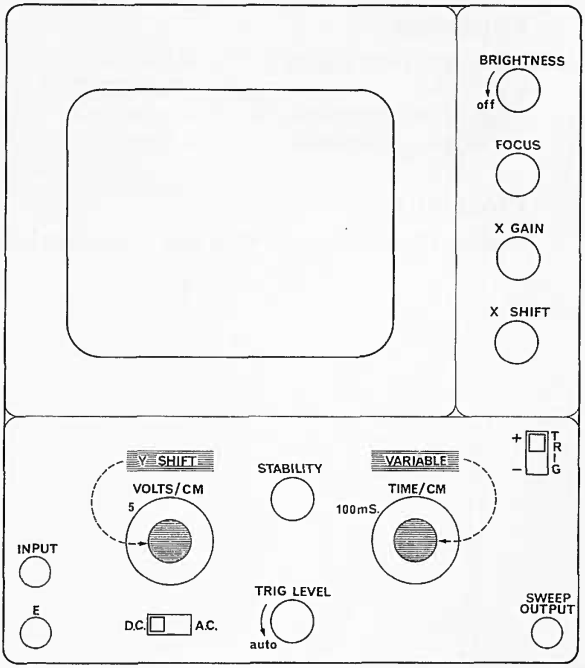
1 fine beam tube and base	– items 61–62
1 oscilloscope	– item 64
1 L.T. variable voltage supply	– item 59
1 H.T. power supply	– item 15
2 12 volt batteries	– item 176



Procedure

a. Turn the fine beam tube used in the last demonstration so that the beam is directed towards the class. The application of a potential difference between the deflecting plates will cause the 'spot' to move in a horizontal direction.

b. Then show the C.R.O. and, after the initial comparison (see *Teachers' Guide*), switch on the heater, having previously made sure that the spot will be central and stationary (at low brilliance), and that the controls are set so that direct connection can be made to both X and Y plates. The time-base should be inoperative at this stage but with its controls set to give slowest speed of sweep. (For details on the demonstration oscilloscope see the appendix at the end of this volume.)



Now connect one battery to the Y plates. Simulate the drawing of a graph by using X-shift control.

Disconnect the battery and switch on the time-base which has already been adjusted to give the slowest rate of sweep.

As it does this, reconnect the battery to the Y plates: switch it on and off a number of times.

Switch off the time-base (or reduce its amplitude to zero), and replace the battery connected to the Y plates by the 12 v a.c. supply from the transformer.

Switch off the a.c. supply whilst the time-base is switched on again and then carefully increase the speed of sweep to display the trace clearly – remembering that it is plotting a graph.

35 *Demonstration*

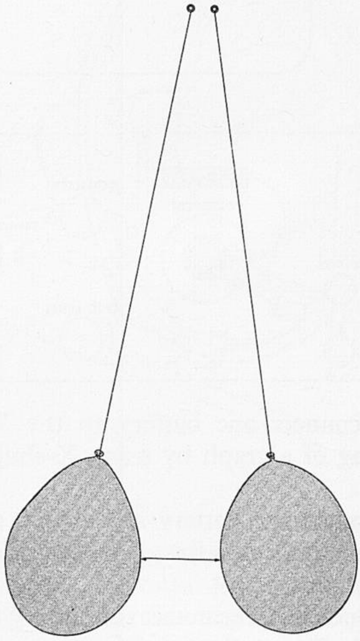
Forces due to electric charges

Apparatus

1 E.H.T. power supply	– item 14
4 balloons	– item 57C
2 light conducting spheres	– item 51D
1 reel nylon suspension	– item 51E

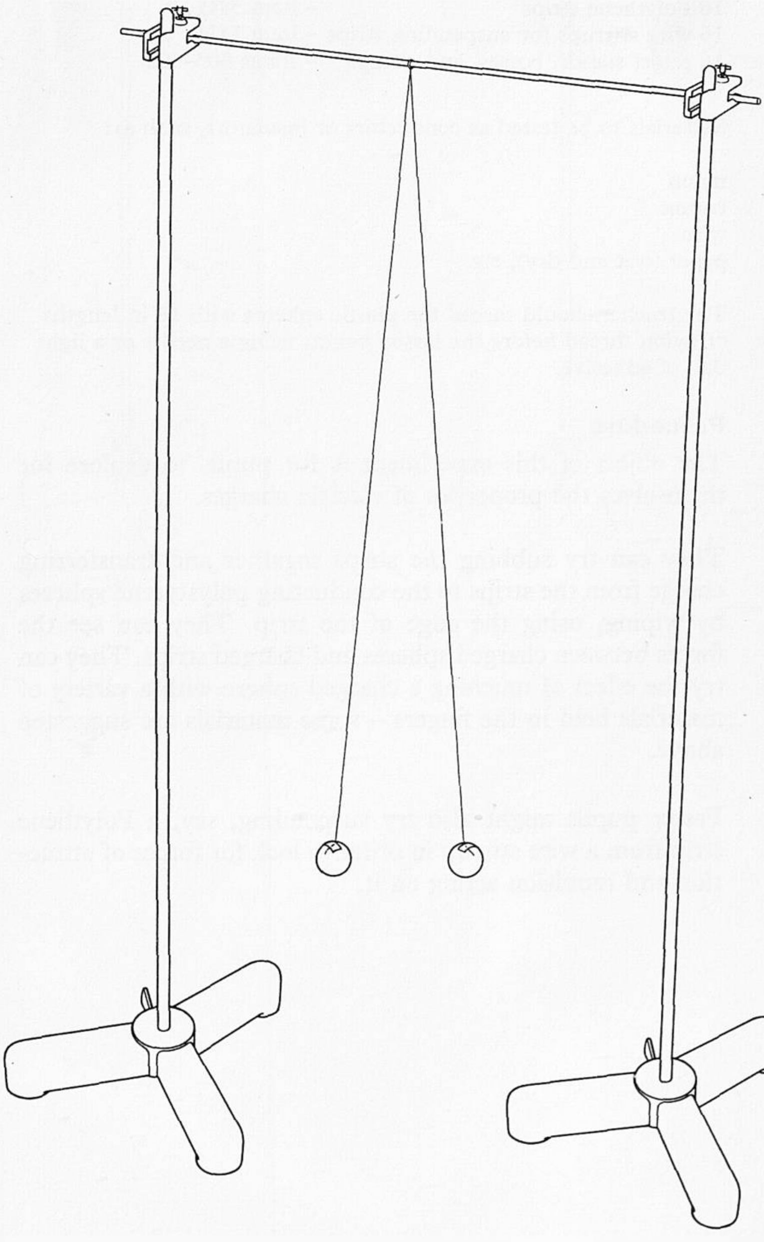
Procedure

Repeat Experiment 10 with two suspended charged balloons.



Then use the E.H.T. power supply – with safety resistor – to charge two very light conducting spheres, suspended by *very* long threads, preferably from the ceiling, or from very high retort stands.

The spheres should first be charged with opposite charges as shown, then with like charges.



36 *Class experiment*

Exploring the properties of charges

Apparatus

32 conducting spheres	– item 51D
reels of nylon	– item 51E
16 cellulose acetate strips	– item 51F
16 Polythene strips	– item 51G
16 wire stirrups for suspending strips	– item 51H
16 retort stands, bosses, and clamps	– items 503–506

Materials to be tested as conductors or insulators, such as:

nylon
cotton
wire
paper (wet and dry), etc.

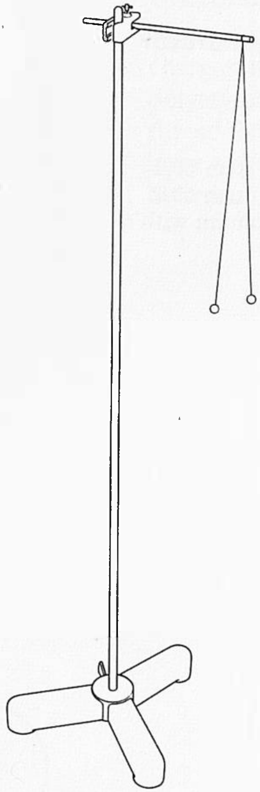
The teacher should thread the plastic spheres with 18 in lengths of nylon thread before the lesson begins using a needle or a light dab of adhesive.

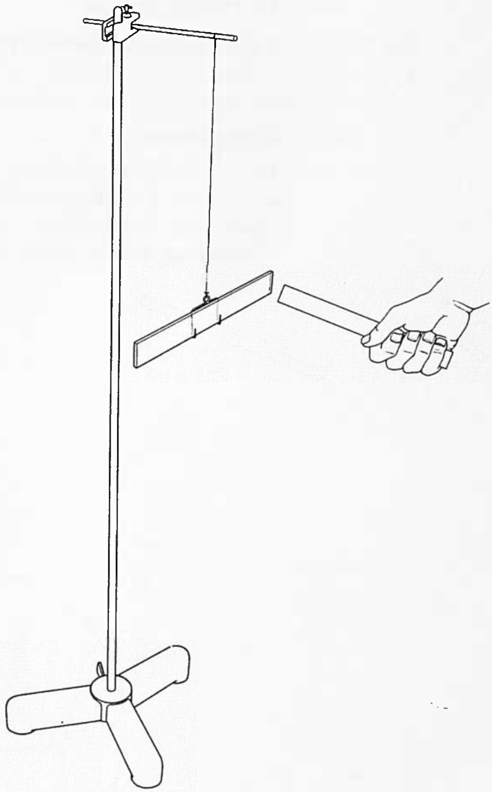
Procedure

The object of this experiment is for pupils to explore for themselves the properties of electric charges.

They can try rubbing the strips together and transferring charge from the strips to the conducting polystyrene spheres by wiping, using the edge of the strip. They can see the forces between charged spheres and charged strips. They can try the effect of touching a charged sphere with a variety of materials held in the fingers – some materials are suggested above.

Faster pupils might also try suspending, say, a Polythene strip from a wire stirrup in order to look for forces of attraction and repulsion acting on it.



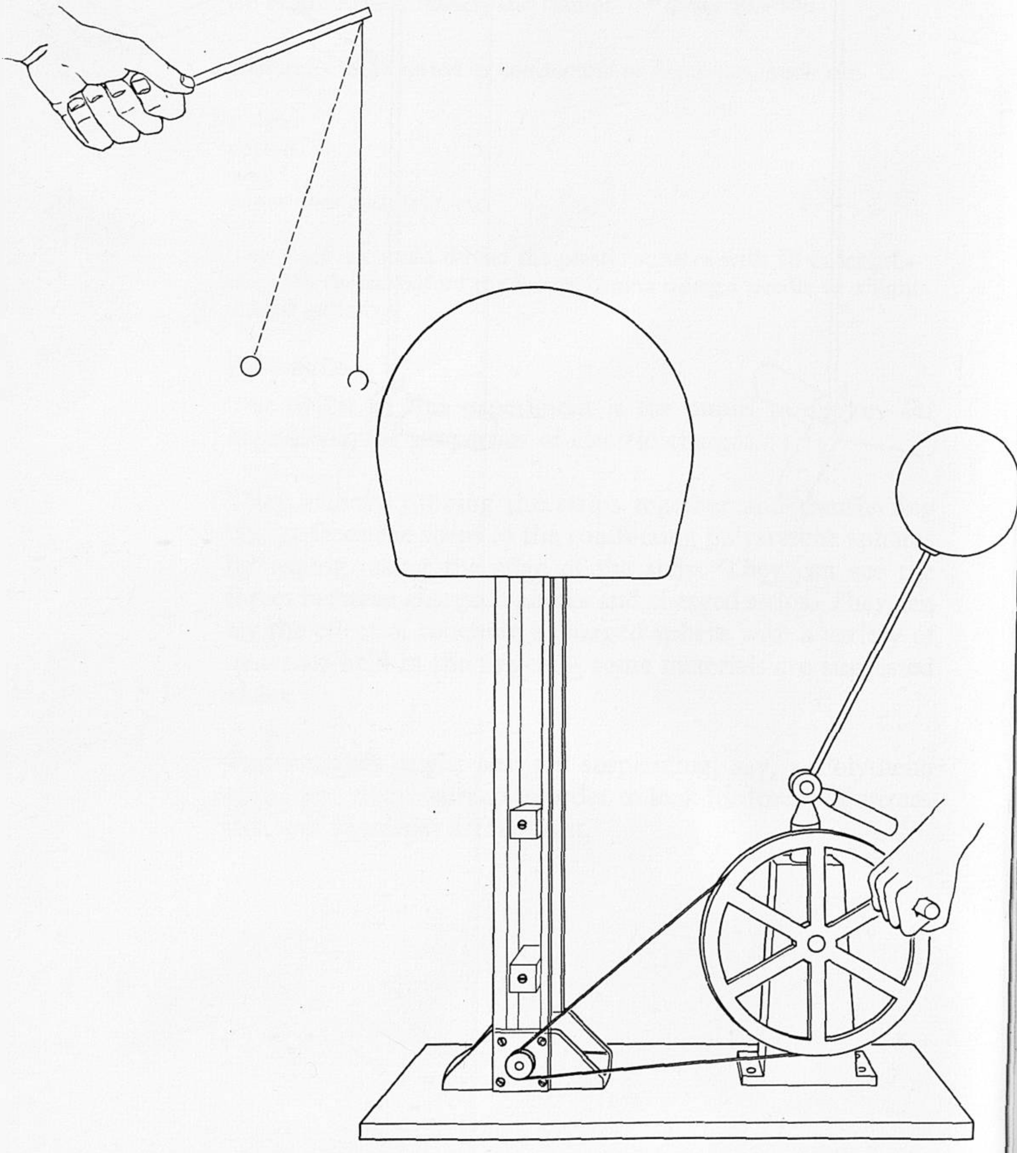


37 Demonstration

Experiments with an electrostatic generator

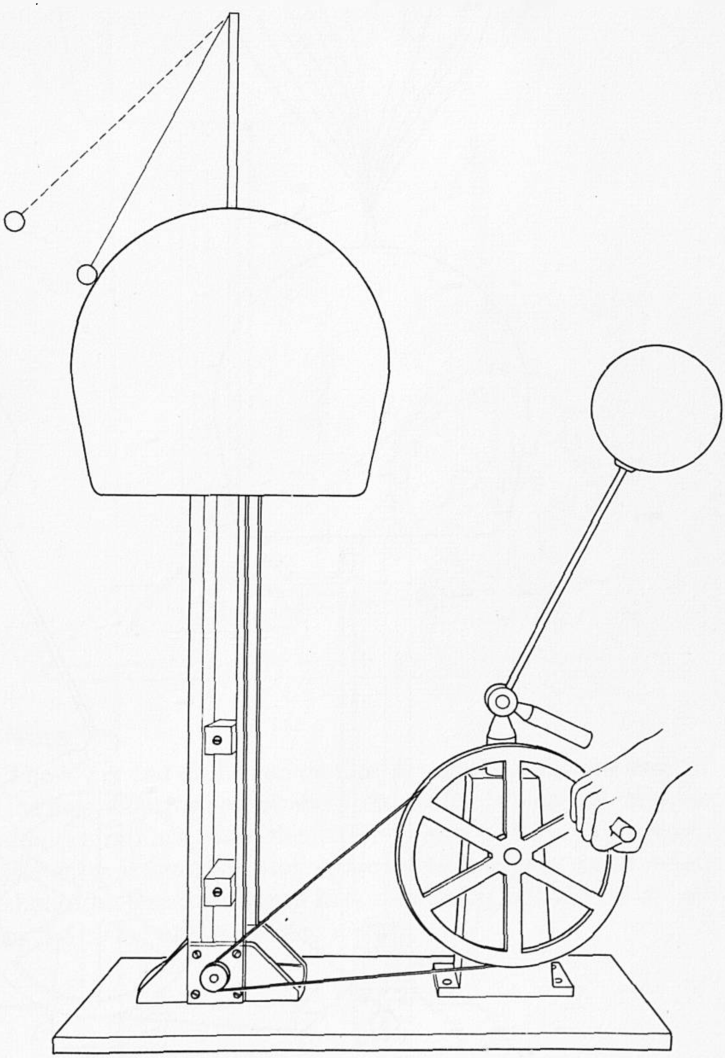
Apparatus

1 van de Graaff generator – item 60/1
accessories for van de Graaff generator – item 60/2
(including 'head of hair' and an insulated column with a conducting sphere suspended from the top)

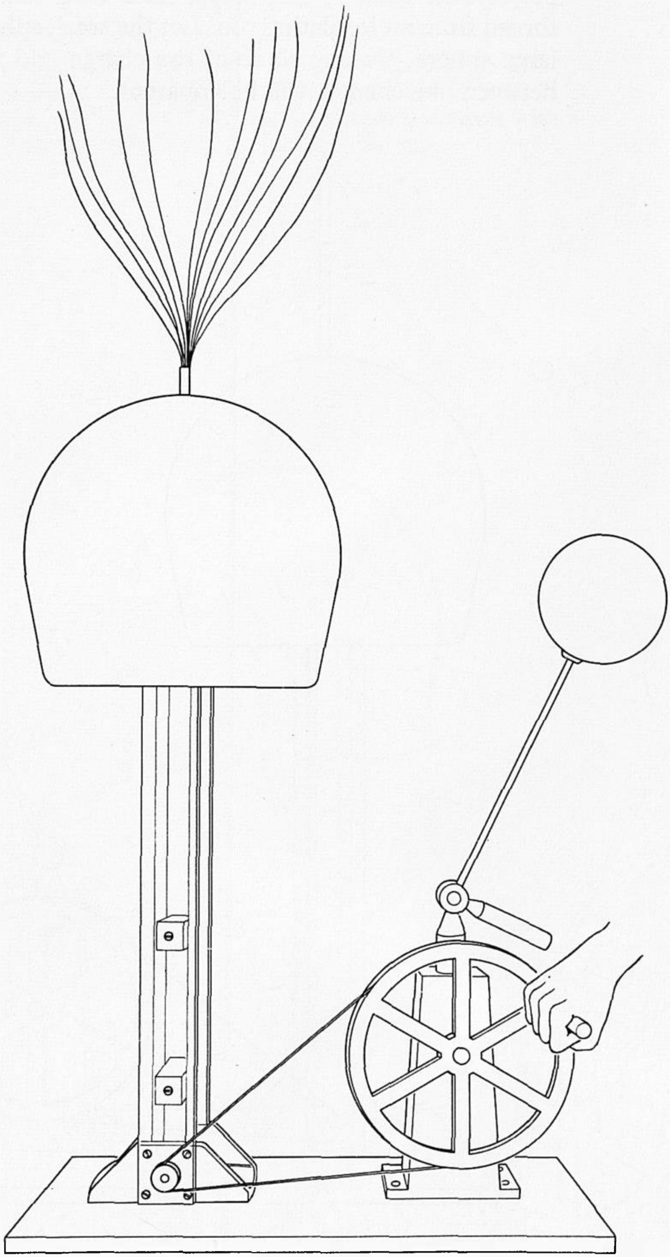


Procedure

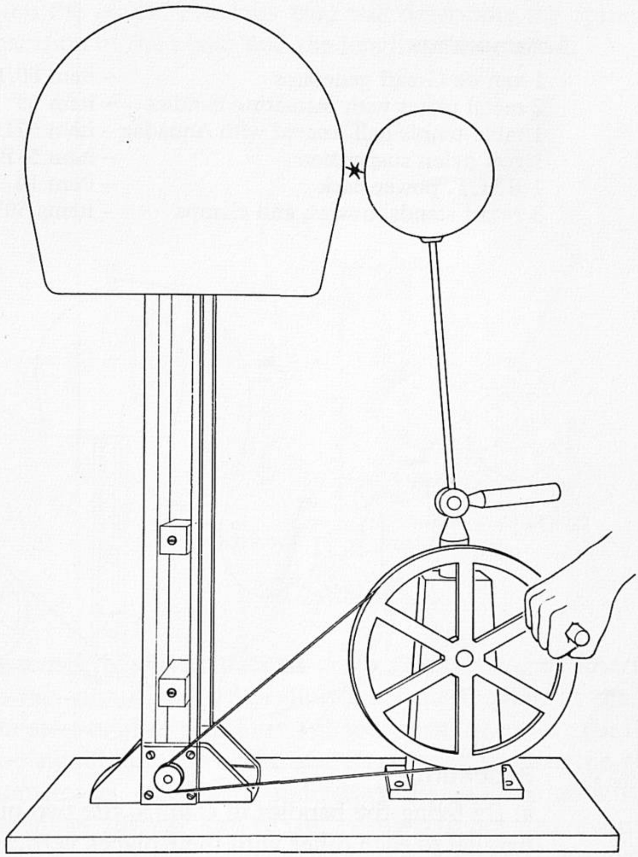
Show the van de Graaff generator as a machine hauling up charges to its large sphere. Bring up the light conducting polystyrene sphere, suspended on a long insulating nylon thread from an insulating rod. Let the small sphere touch the large sphere, sharing some of the charge and the repulsion between like charges will be apparent.



The insulating rod can be fixed in the top of the generator. The 'head of hair' can alternatively be put on the top, again showing repulsion.



Finally, allow the sphere to spark first to a neighbouring earthed sphere and also direct to earth by a wire.



Note

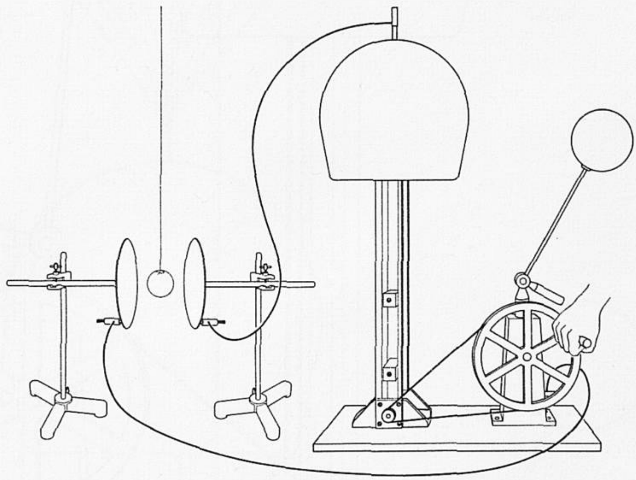
The lower end of the van de Graaff generator and the base of the neighbouring sphere should be earthed effectively in these demonstrations. Since the discharge will give a sudden pulse, the earth connection (for example, to a nearby water pipe) should be free from sharp bends or kinks, and should *not* go to the casing of any electric mains.

38 *Demonstration*

Moving charge and current

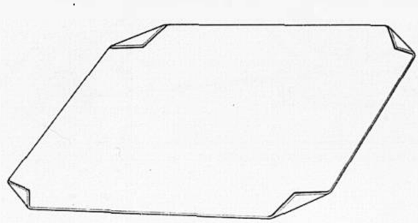
Apparatus

1 van de Graaff generator	– item 60/1
2 metal plates with insulating handles	– item 65
1 table-tennis ball, coated with Aquadag	– item 57L
1 reel nylon suspension	– item 51E
1 E.H.T. power pack	– item 14
3 retort stands, bosses, and clamps	– items 503–506

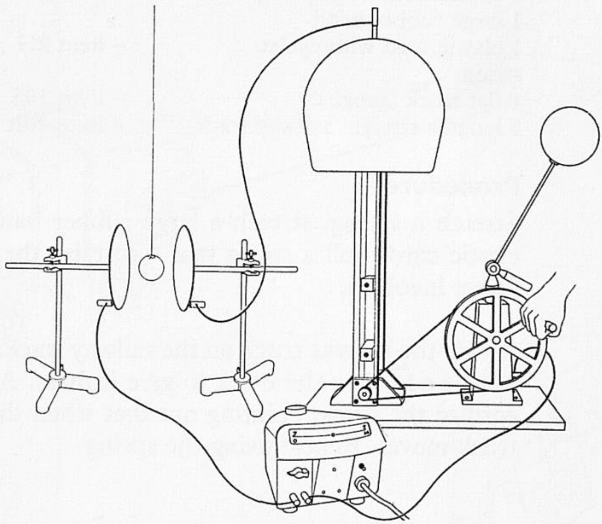


Procedure

a. By fixing the handles in clamps, the two plates are set up parallel to each other with their planes vertical. They should be three or four inches apart. One of the plates is connected to the generator, the other is earthed, as is the lower end of the van de Graaff machine. The plates recommended have a small peg at the back to which a crocodile clip can be attached. This avoids having to connect the clip to the plate itself. Alternatively, a pair of copper plates bent as shown and placed upright on a dry bench will serve.



The table-tennis ball, coated with Aquadag, is hung from a suitable length of nylon thread between the two plates. When the generator is switched on, the ball transfers charges between the plates. Previous trial will determine the optimum separation of the plates and the length of the thread.



If a sensitive galvanometer is available it should be inserted into this circuit and will indicate that the transfer of charge from plate to plate will cause a deflection of the meter. For this to be significant, it will be necessary to show that the galvanometer is capable of indicating the passage of a tiny momentary current derived from a dry cell. For that, connect a dry cell to the instrument through a pupil who completes the circuit momentarily by a brief touch on one terminal.

b. Disconnect the van de Graaff generator and temporarily earth all the equipment. Then connect the positive terminal of the E.H.T. power pack (with the 50 megohm safety resistor in circuit) to the first plate and repeat the experiment, again showing charge transferred.

If it is available, connect the sensitive galvanometer between the second plate and the earth connection. Observe the current.

39 *Demonstration*

Demonstration of forces

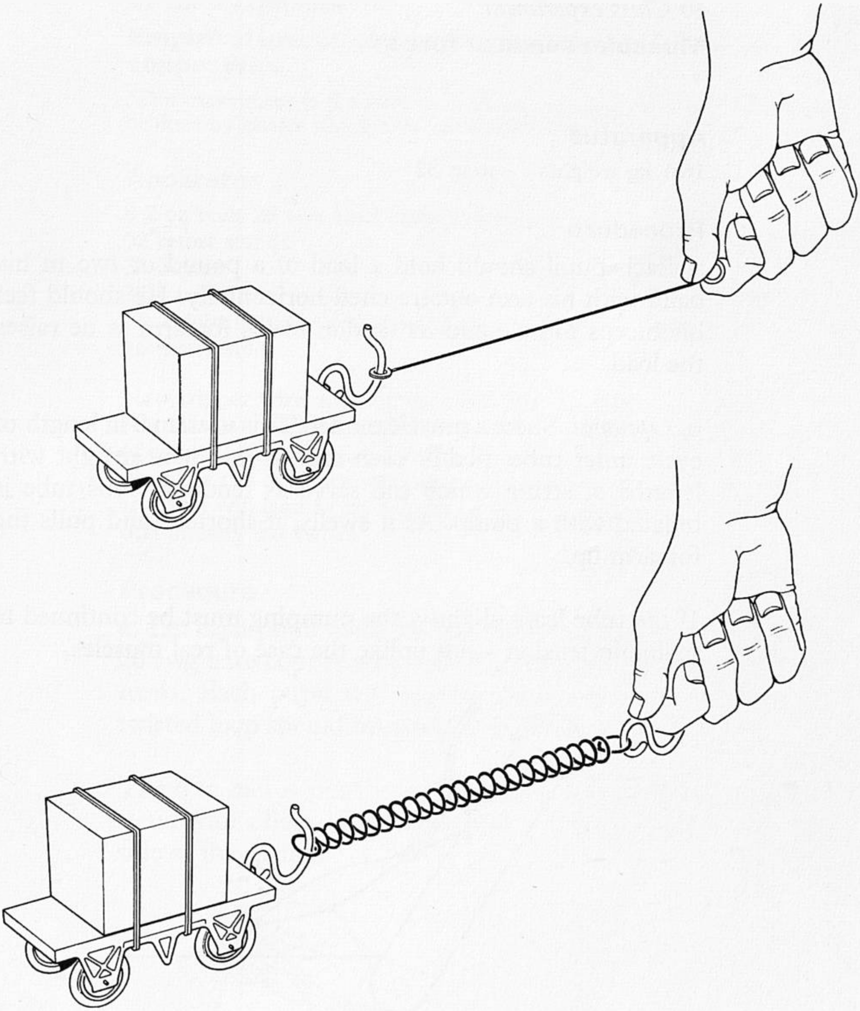
Apparatus

1 expendable steel spring	– item 2A
1 large rubber band	
1 elastic cord with eyelet	– item 2G
string	
1 flat truck (gauge 0)	– item 10S
5 lengths straight railway track	– item 10R

Procedure

Stretch a spring, stretch a large rubber band, stretch some elastic cord, pull a string taut – to raise the question of the forces involved.

Set up the railway truck on the railway track. Blocks of wood can be added to the truck to give it mass. Attach the elastic cord to the truck, pointing out that when there is a pull the truck moves. Repeat using the spring.



40 *Class experiment*

Muscular sense of force

Apparatus

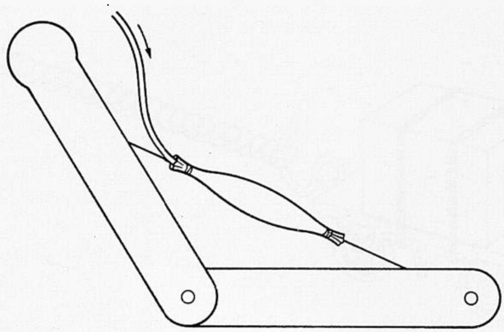
16 1 kg weights – item 32

Procedure

a. Each pupil should hold a load of a pound or two in his hand with his arm outstretched horizontally. He should feel his biceps muscle and its tendon to his forearm as he raises the load.

b. *Optional.* Show a muscle model. This uses an 8 in length of cycle inner tube, tied at each end so that it is airtight with lengths of string which can serve as tendons. This tube is inflated with a pump. As it swells, it shortens and pulls the forearm up.

If the tube leaks slightly, the pumping must be continued to maintain tension – not unlike the case of real muscles.



41 *Class experiment*

Empirical investigation of home-made springs of copper wire

(This experiment is the same as Experiment 33 (a) in Year I and should be done by classes which have not already done it.)

Apparatus

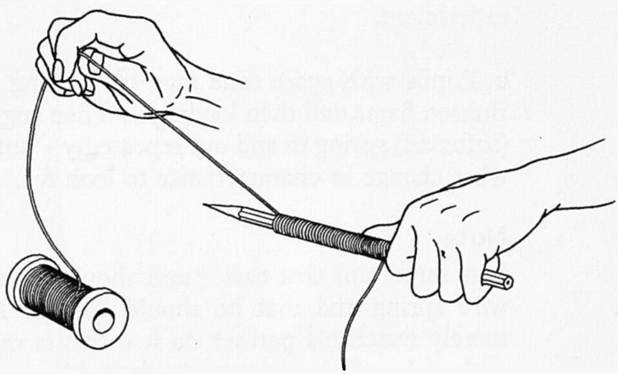
8 2 oz reels 26 swg bare copper wire	– item 2C
32 retort stands	– items 503–504
32 bosses	– item 505
32 6 in nails	– item 10H
16 weight hangers with slotted weights (10 gm)	– item 31/1
16 metre rules	

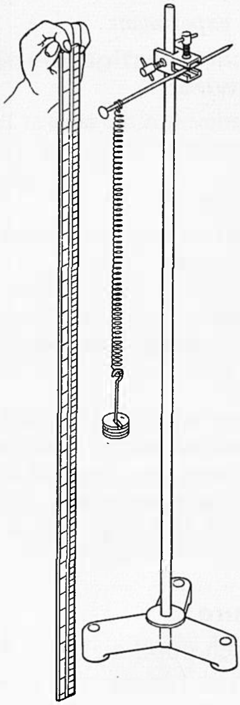
New copper wire must be used for this experiment for two reasons: (*a*) old wire is often uneven in its hardness as the using of copper wire work-hardens it; (*b*) when winding wire on a pencil in the ordinary way, an extra twist is put in at every turn and that will lead to an uneven spring if it is done with old wire that already has twists.

Procedure

a. Let each pupil make his own spiral spring by winding the 26 swg bare copper wire round and round a pencil for 25-30 turns. Each pupil will require about 80-90 cm of wire. A twisted loop should be made at the ends.

The 6 in nail is put through the loop and fixed to the retort stand with a boss. The rule is held in a vertical position at the side of the spring.





The weight hanger should be attached to the springs and a series of equal loads (10 gm) added to stretch the spring, noting the change in length.

See the *Teachers' Guide* for a discussion of the scope of this experiment.

b. Pupils with spare time may try heating their spring in a Bunsen flame and then loading it. Then suggest pushing that (softened) spring in and out repeatedly – but do not tell them what change in characteristics to look for.

Note

It is important that each pupil should have his own copper wire spring and that he should damage his own and not merely watch his partner do it – that is merely frustrating. Although sufficient retort stands and bosses are available for each pupil to have his own (and of course he can wind his own copper spiral), there will have to be some sharing of the weight hangers, though some teachers may care to improvise so that even this sharing is not necessary.

42 Class experiment

Forces with elastic materials

Apparatus

1 elastic materials kit – item 2
plastic foam

If Experiment 1 was omitted earlier in Year II, it should be done now.

Procedure

Let the class try compressing things including latex foam, weak wide springs and plastic foam.

43 Class experiment

Forces in soap films

Apparatus

16 three-sided rectangular wire frames 4 in to 6 in by 2 in, made from stout bare copper wire. A loose thread attached as shown with additional short length added centrally.

Solution of soap or detergent in open dish.

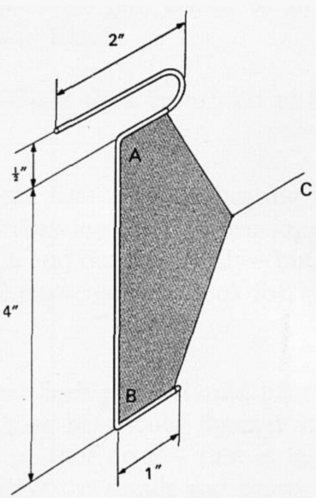
The solution can be made with a few drops of a liquid detergent such as Teepol in a beaker of water. The addition of a little glycerine will make the film last longer.

Procedure

As a demonstration of another kind of force, a soap film formed on the wire frame should be investigated.

1. Immerse the frame in the soap solution in a tray (for example, a developing dish), then hold it up and try pulling the thread C.

2. Hold the frame with A B horizontal, C hanging down. Weight C with a small paper-clip (less than $\frac{1}{4}$ gm).



Note

The film can be broken very easily if a piece of blackboard chalk is used.

44 Demonstration

Frictional forces (solids)

Apparatus

1 friction kit – item 55
1 demonstration spring balance (5 kg) – item 85

The friction kit includes:

1 smooth plank with screw eye (30 in × 6 in × $\frac{3}{4}$ in)
1 smooth block with screw eye (9 in × $4\frac{1}{2}$ in × $\frac{3}{4}$ in)
3 extra blocks without screw eye (9 in × $4\frac{1}{2}$ in × $\frac{3}{4}$ in)
10 rollers of $\frac{1}{2}$ in stainless steel (smooth-ground) rod, 8 in long
1 crank assembly

Procedure

a. In the usual method, the plank is placed on the bench-top and the block of wood dragged along it with the spring balance, the force being recorded by the spring balance.

If the friction force does not show clearly on the spring balance change to another of lower range, for example the 1 kg spring balance (item 43).

That technique makes it difficult to get consistent results, so we suggest method 2.

b. Place the plank on rollers as illustrated.

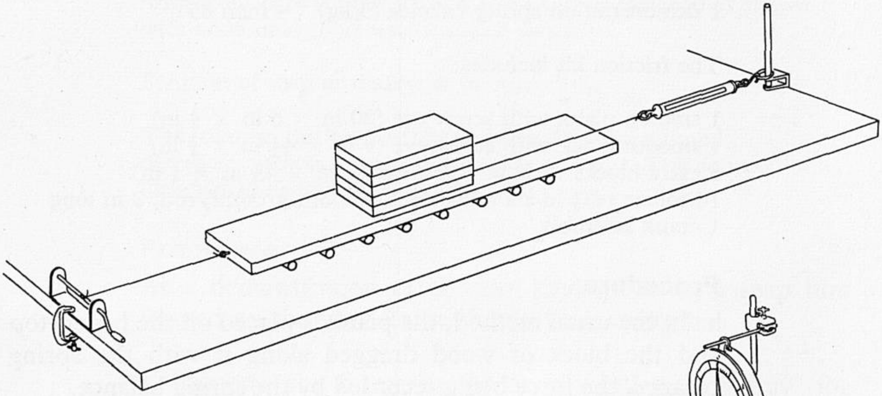
Pull the plank along at constant speed by the string and crank as shown. The block is held at rest by the spring balance whilst the plank moves under it. This will give much steadier readings.

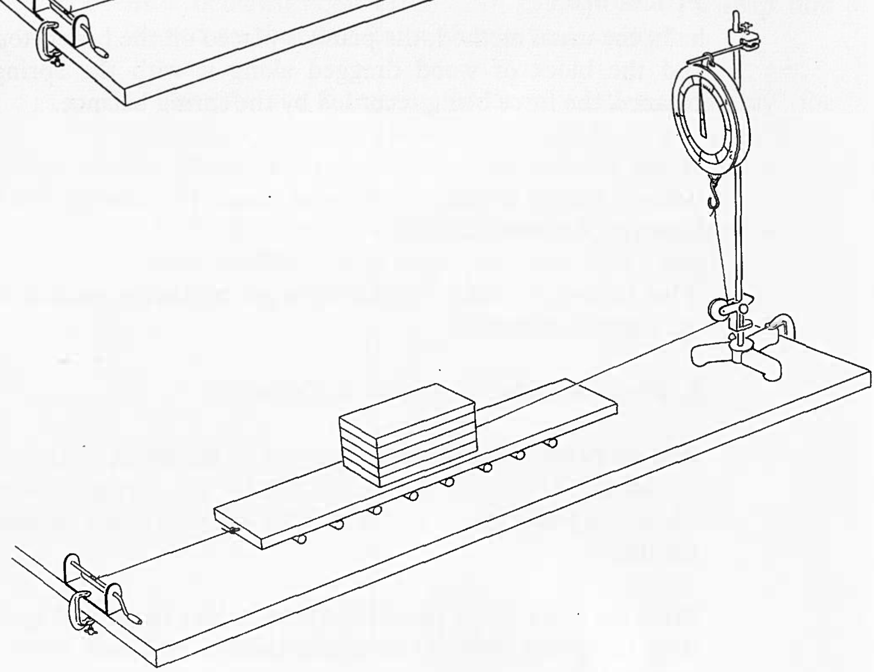
Press the block down against the plank with a finger and again drag the plank along. The spring balance will now show a greater force.

Add an equal block on top of the first so that the force pushing the block on to the plank is doubled. Measure the frictional force. Increase the load with two, three or four blocks and see how the frictional force increases.

Then try again using the plain block but with different speeds.

Finally, turn the block on to its side. See what effect the change of area makes.





45 *Demonstration*

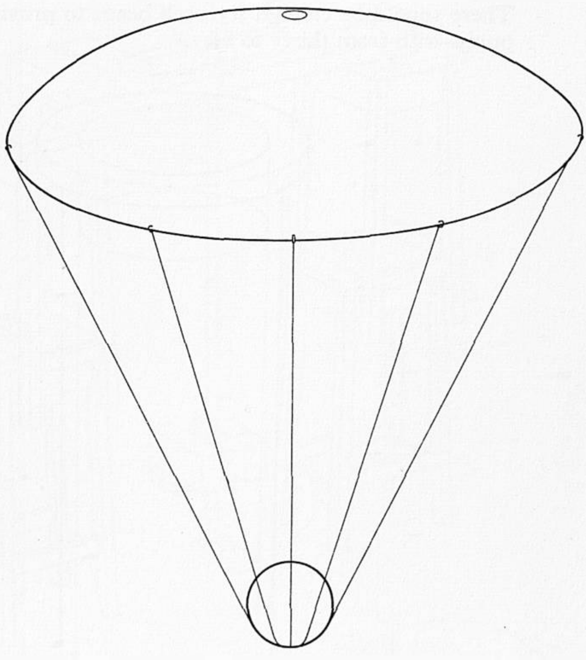
Free fall with parachute

Apparatus

1 table-tennis ball – item 57M
1 improvised paper or cloth parachute

Procedure

The ball is dropped, first by itself and then with the simple parachute attached. A handkerchief is suitable for this – the ball being attached with the help of Sellotape and thread.



46 *Class experiment*

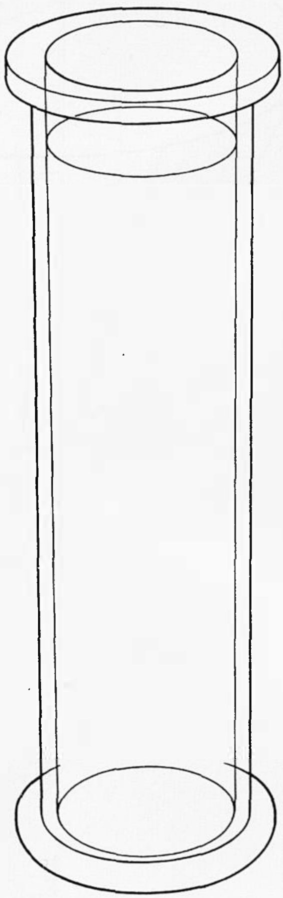
Fluid friction

Apparatus

16 gas jars	– item 514
16 chinagraph pencils	– item 543
1 heavy pendulum	– item 10F
styrocell beads	– item 57E

The heavy pendulum should be the seconds pendulum made with a broomstick and bricks and used in Year I. (See Year I, Experiment 30b.)

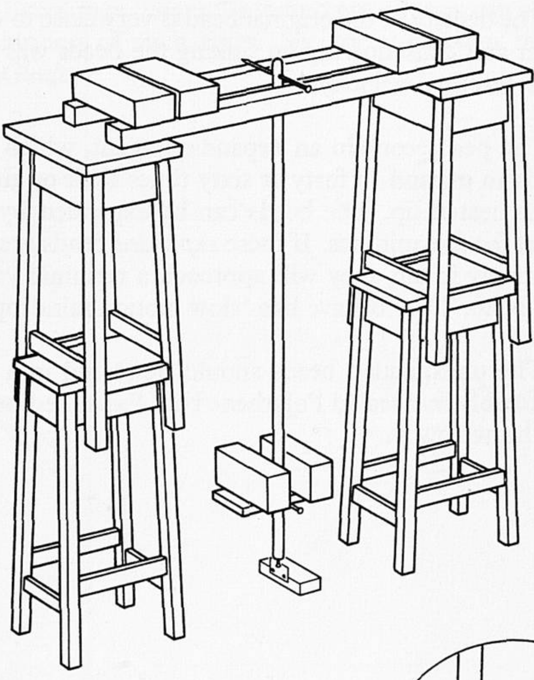
There should be enough styrocell beads to provide each pair of pupils with from thirty to fifty.

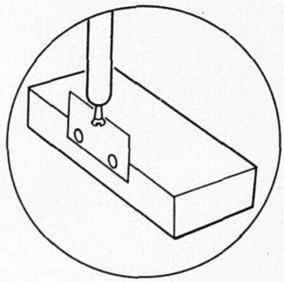


Procedure

Pupils should be asked to find out what they can about the motion when the styrocell beads are released in a large gas jar filled with water.

As suggested in the *Teachers' Guide*, a stop-watch or stop-clock is likely to prolong this first look at fluid friction and a broomstick pendulum ticking loudly once a second is satisfactory. (If the background noise of the class is too great for the signals to be heard clearly, the teacher should give signals by pencil taps or hand claps.)





Pupils can mark rings on the gas jars to help observations. With evenly spaced rings pupils can do the timing 'in their head' with no pendulum or clock, just by making a tap with a pencil as the bead passes each mark.

A drop of a wetting agent in the water will help to prevent beads from clinging to the surface.

Notes

1. Styrocell beads are the raw material from which expanded polystyrene is derived.

2. The density of the original bead is very close to that of cold water and consequently on sinking the beads will soon reach their terminal velocity.

3. The beads contain an expanding agent, which causes the beads to expand to forty or sixty times their original volume when heated up. The beads can be expanded by boiling in water for five minutes. If these *expanded* beads are allowed to fall freely in air, they will approach a terminal velocity in a foot or so. They behave like 'slow motion raindrops'.

4. The unexpanded beads should be stored in a cool place, preferably in a sealed Polythene bag. Expanded beads should be thrown away.

47 Class experiment

Air resistance

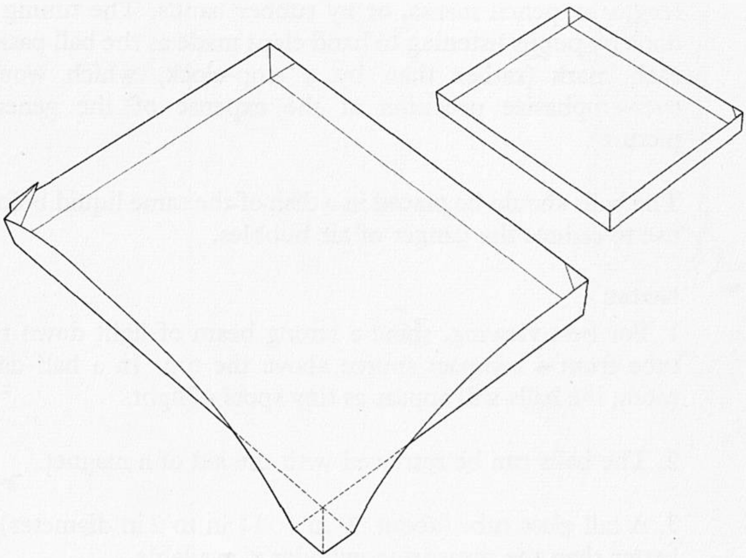
Apparatus

Sheets of paper (say, 8 in × 10 in)

Procedure

The pupils should be shown how to 'stream-line' a sheet of paper by bending the edges to make a tray with sides about $\frac{1}{2}$ in high.

Encourage the pupils to find out all they can about the falling motion of such trays. See the discussion in the *Teachers' Guide*.



48 *Demonstration*

Fluid friction in a viscous medium

Apparatus

1 1000 ml measuring cylinder	– item 518/2
glycerine or heavy oil	
24 ball-bearings ($\frac{1}{8}$ in)	– item 57N
24 ball-bearings ($\frac{1}{16}$ in)	– item 57P
1 chinagraph pencil	– item 543

Procedure

The ball-bearings are allowed to fall freely through the liquid by gently releasing them just above the liquid surface.

The tube is marked off in four or more equal divisions of length by pencil marks, or by rubber bands. The timing is done by pupils listening to hand claps made as the ball passes each mark (rather than by a stop-clock, which would over-emphasize precision at the expense of the general picture).

The balls should be placed in a dish of the same liquid before use to reduce the danger of air bubbles.

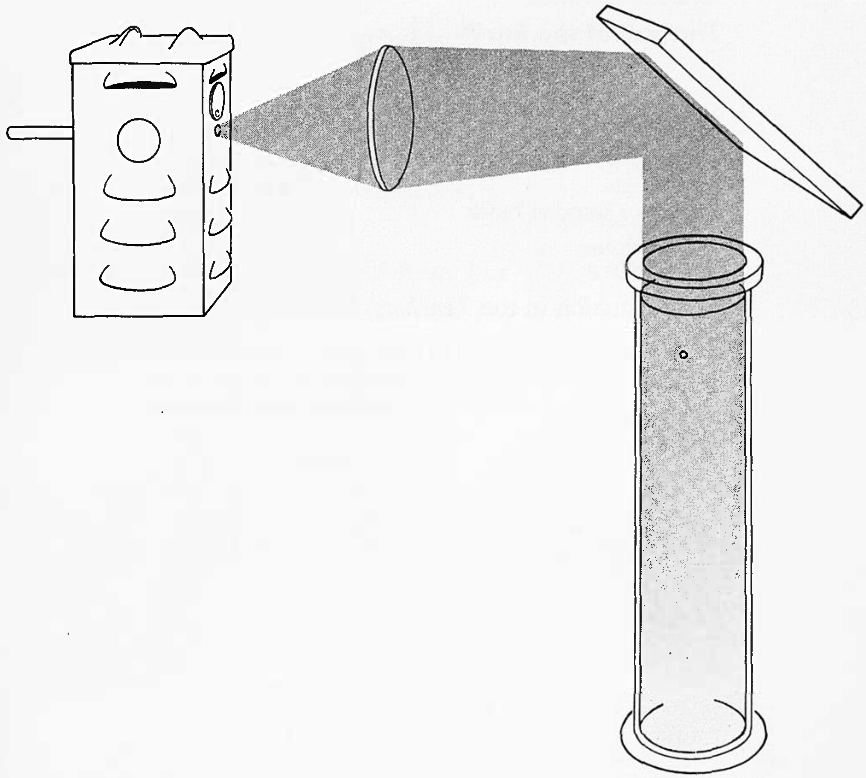
Notes

1. For best viewing, shine a strong beam of light down the tube from a compact source above the top. In a half-dark room, the balls will appear as tiny spots of light.

2. The balls can be retrieved with the aid of a magnet.

3. A tall glass tube (about 30 in × $1\frac{1}{2}$ in to 2 in diameter) is better than the measuring cylinder if available.

4. The teacher might also try polystyrene or glass beads, if these are available.



49 *Demonstration*

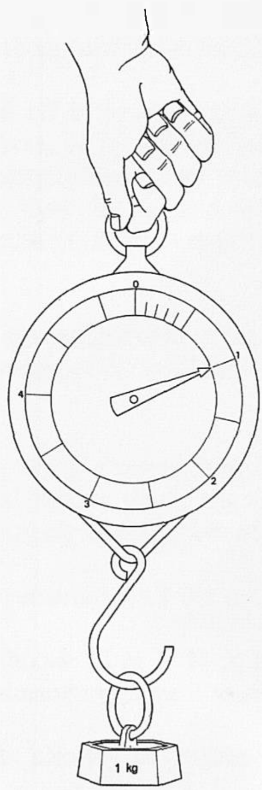
The pull of the Earth

Apparatus

1 demonstration spring balance (5 kg)	– item 85
1 kg weight	– item 32
1 brick or wooden block	

Procedure

See discussion in the *Teachers' Guide.*



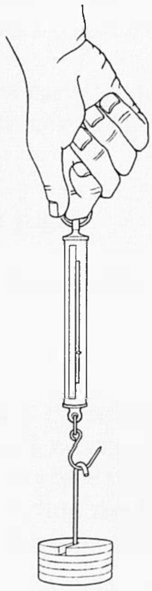
50 *Class experiment*

Marking a spring balance for use

Apparatus

16 spring balances	– item 43
16 weight hangers with slotted weights (100 gm)	– item 31/2
32 $\frac{1}{2}$ lb weights	– item 83
16 unknown masses of about $\frac{3}{4}$ kg	
'write on' Sellotape	– item 57I

The spring balances need to be blank and this can conveniently be arranged by covering the scale of the calibrated spring balances with 'write on' Sellotape strip.



Procedure

a. The pupils are asked to calibrate the balance by hanging 1, 2, 3 . . . equal masses on it. Some should be given equal masses which are 100 gm hangers and 100 gm slotted weights to fit those hangers, others should have $\frac{1}{2}$ lb masses.

b. When the spring balances have been calibrated, the pupils should be given an unknown mass and asked to find out how much the Earth pulls on it in what ever units have been used for calibrating the balances.

51 *Class experiment*

The use of a spring balance marked in newtons

Apparatus

8 newton spring balances (10 n) – item 81

Procedure

The teacher should show the spring balances and let the pupils pull on them and feel a force of several newtons. Use it to 'weigh' a kilogram and a pound. This will be a *very* quick class experiment.

52 Pupil demonstration
Sizes of various forces

Apparatus
1 forces demonstration box – item 63

Details of the demonstration box
This box is made from a framework about 4 ft high, 18 in wide and 4 in deep, with a projecting wooden bar at the back, which can be G-clamped to a laboratory bench. Three freely running pulleys are mounted at the top of the framework. Strings running over these pulleys link three curtain rings (outside) to masses of 1 lb, 1 kg and 102 gm (inside). These masses can move vertically through distances which are set at 1 metre, 1 metre and 1 foot respectively.

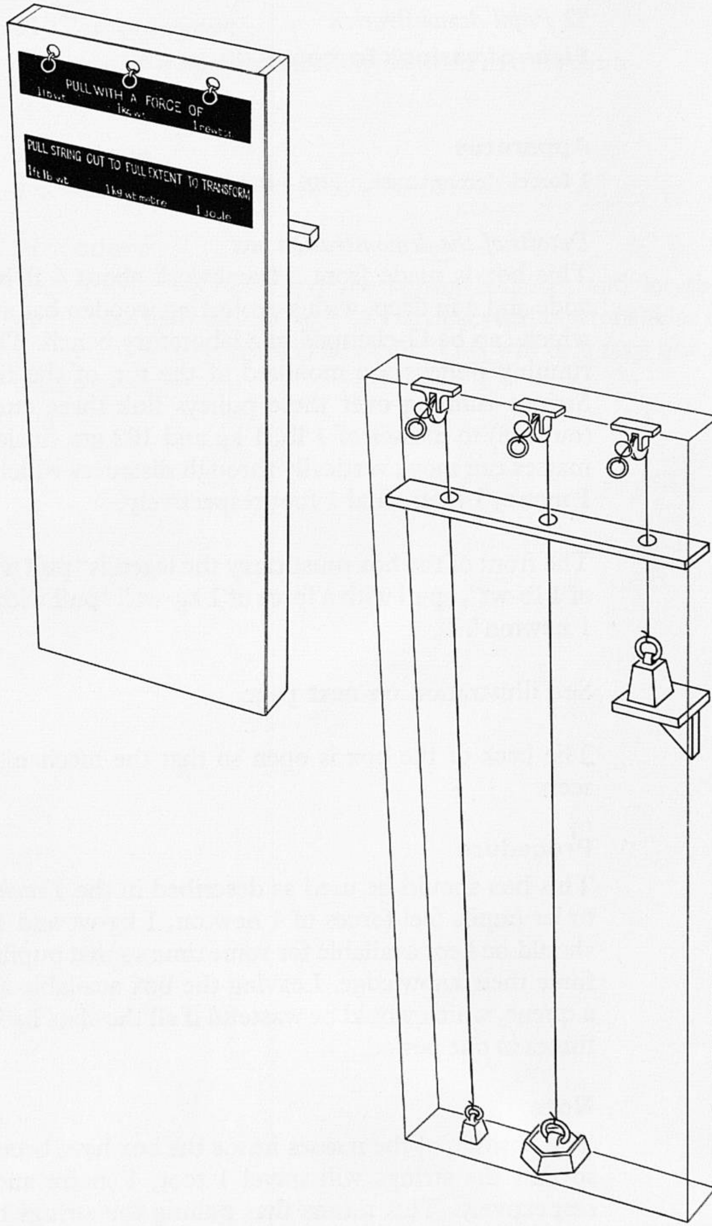
The front of the box must carry the legends 'pull with a force of 1 lb-wt', 'pull with a force of 1 kg-wt', 'pull with a force of 1 newton'.

See illustration on next page.

The back of the box is open so that the mechanism can be seen.

Procedure
This box should be used as described in the *Teachers' Guide* to let pupils feel forces of 1 newton, 1 kg-wt and 1 lb-wt. It should be kept available for some time so that pupils can reinforce their knowledge. Leaving the box available also avoids a queue, which would be wasteful if all the class had to try the forces in one period.

Note
The position of the masses inside the box have been arranged so that the strings will travel 1 foot, 1 metre and 1 metre respectively. This means that pulling the strings to the full extent will transform 1 ft lb-wt, 1 kg-wt metre and 1 joule respectively. This will be used in Year IV of the programme.


PULL WITH A FORCE OF
1lb wt
1kg wt
1 newton
PULL STRING OUT TO FULL EXTENT TO TRANSFORM
1ft lb wt
1kg wt metre
1 joule

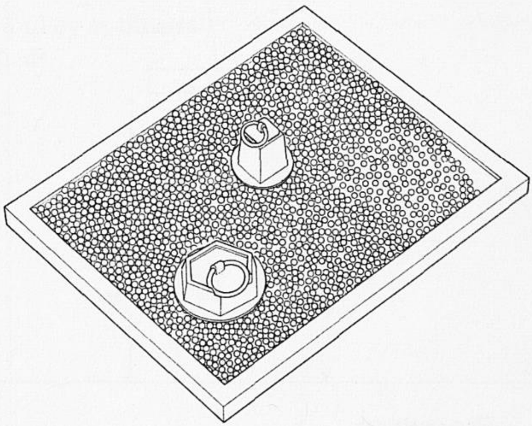
53 *Pupil demonstration*

To feel the inertia of a 'pound of stuff'

Apparatus

1 mounted glass plate	– item 86
1 1 lb weight	– item 36
1 1 kg weight	– item 32
2,000 steel ball-bearing balls ($\frac{1}{16}$ in diameter)	– item 57P

The polystyrene beads can be used in place of the ball-bearing balls.



Procedure

The 1 lb mass with a smooth base rests on the layer of ball-bearing balls which are spread thinly over the glass plate. This reduces friction to small proportions. The mass can then be pushed from side to side to get the feel of getting a mass of one pound moving.

As with certain other experiments, throughout the year, this tray should be left at the side of the laboratory for pupils to try on their own in order to increase their acquaintance with the concept of inertia.

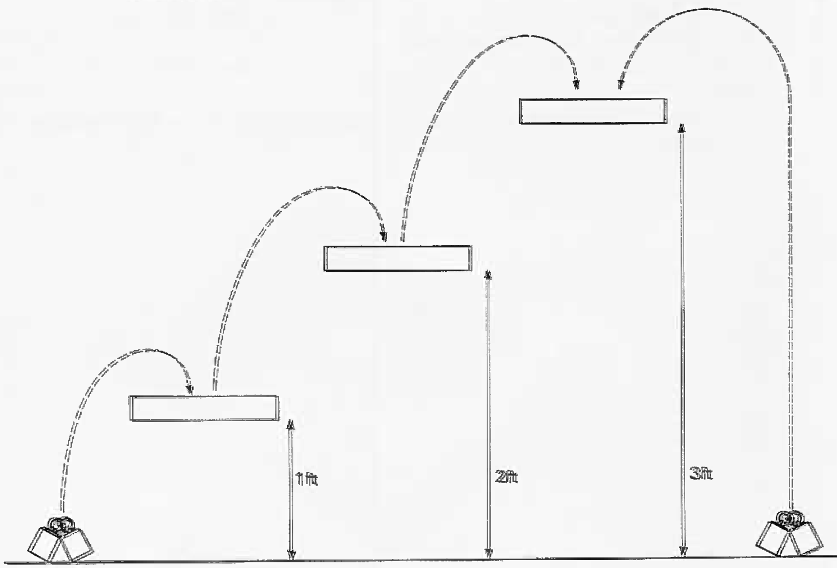
A 1 kg mass should also be put on the glass plate so that the pupils can get the feel of that.

54 *Demonstration*

Transfer of energy between loads

Apparatus

4 1 lb weights – item 36
3 shelves



Procedure

Set up three shelves on the demonstration bench so that they are 1 ft, 2 ft and 3 ft above the bench-top.

The 1 lb loads are lifted through the various distances in the course of the discussion, suggested in the *Teachers' Guide*, of work as energy transfer.

55 Demonstration

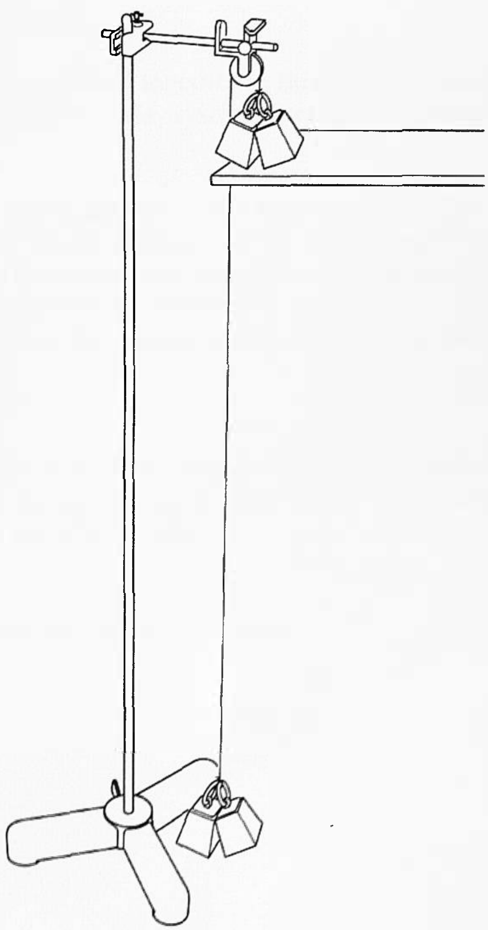
Transfer of energy in lifting loads

Apparatus

4 1 lb weights	– item 36
1 retort stand	– items 503–504
1 single pulley on clamp	– item 40
1 shelf	

Procedure

When on the top (3 ft level) shelf of Experiment 54, two 1 lb loads tied together are attached to a string which runs over a single pulley as illustrated, and connected to a second pair of 1 lb loads.



The shelf is removed so that the 2 lb load is released. It will be necessary to supplement the top load with a tiny additional load to provide 'a little extra energy to pay for friction'. A piece of Plasticine is suitable for this, or one or two gram weights. It falls slowly and raises up the other load.

56 *Demonstration*

Transfer of energy in lifting loads using pulleys

Apparatus

8 1 lb weights	– item 36
1 single pulley	– item 38
1 double pulley	– item 39
1 shelf at height of 3 ft	
1 retort stand rod (4 ft)	– item 503
1 retort stand base	– item 504
1 boss	– item 505
1 6 in nail	– item 10H
cord	– item 10A

Procedure

The retort stand must be supported so that the clamp is 4 ft above the bench.

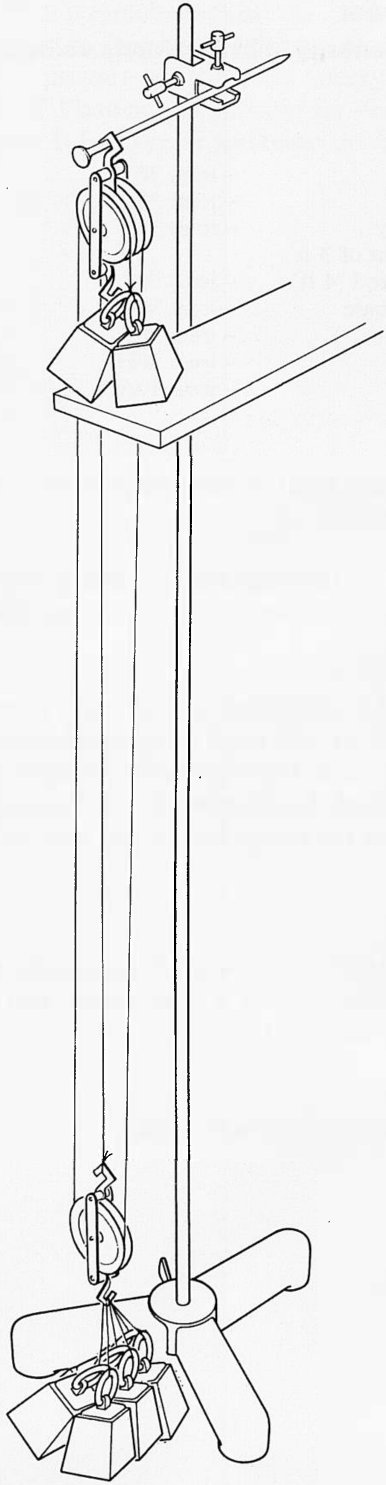
The weights are tied together in bunches to provide loads of 2 lb and 6 lb. The pulley system is set up as shown on the next page.

The 2 lb load is allowed to fall through 3 ft and, at the same time, lift 6 lb. It will need to be supplemented by a small additional load as in Experiment 55. Measure the distance the 6 lb load is raised. As described in the *Teachers' Guide*, this is used to discuss the energy lost by one load and gained by the other.

Note

The weight of the lower pulley is necessarily included in the load. We should choose a light pulley and heavy load to minimize the effect of this.

See illustration on the next page.



57 Demonstration

Transfer of potential energy to kinetic energy to heat

Apparatus

2 1 lb weights – item 36

Procedure

After raising 2 lb 3 ft above the bench, let it drop to the bench. A mat should be placed on the bench to protect it from damage.

58 *Demonstration*

Transfer of kinetic energy to potential energy – 1

This experiment is suggested in the *Teachers' Guide* as a thought experiment, but it can be shown as a demonstration. One possible arrangement using readily available apparatus is suggested below.

Procedure

An 8 ft length of hardboard, about 12 in wide, is arranged on the bench with one end clamped to the bench-top and the other raised about 2 ft 6 in and resting on two 4 ft lengths of angle iron (Handy Angle or Dexion). The board should also be clamped to the bench-top about half-way along just before the start of the gradient. It is necessary to make sure this is secure.

A vertical slit, not more than $\frac{1}{2}$ in wide, is cut in the middle of the board. A string passes through the slit without touching the hardboard and, remaining parallel to the bench-top, passes over a pulley secured to the edge of the bench. A loop (about 18 in long) is tied in the end of the string that goes through the slit, the other end over the pulley is fastened to a 2 lb weight. The loop is hung loosely over two bent posts as illustrated, the part of the loop that is not suspended between the posts is made to lie flat on the board (so that the trolley can pass over it).

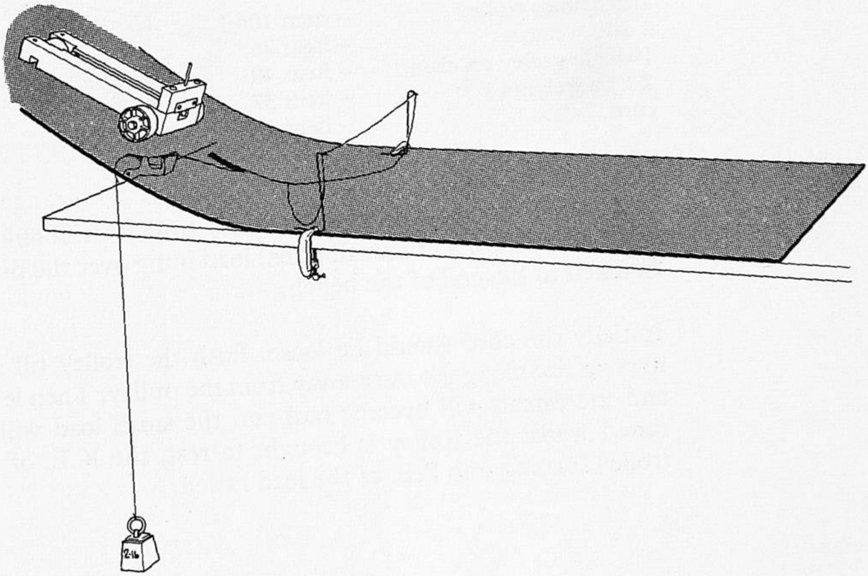
A dynamics trolley with a single peg in the top of it is released from the top of the ramp with the two wheel end leading and the single peg at the back. The peg engages the loop after the trolley has run over those parts of the loop that are on the board. The trolley is brought to rest, raising the 2 lb mass.

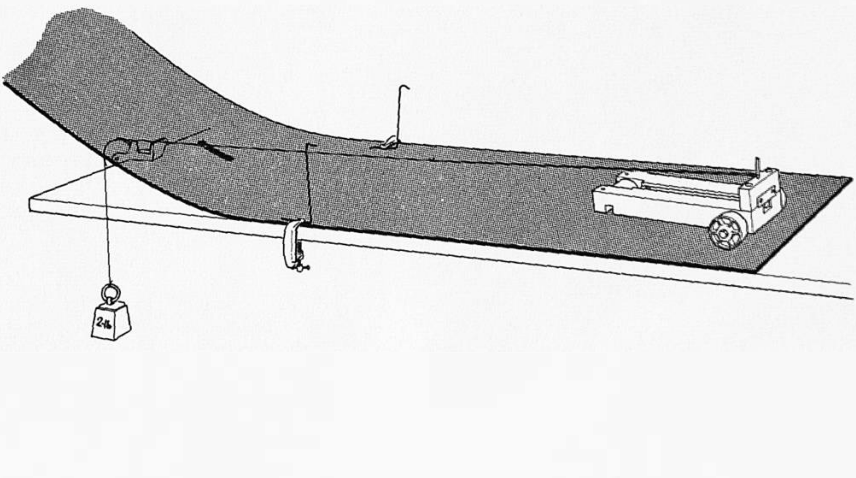
Notes

1. Before the trolley is released, it is important to check that the leading end of it will pass under the raised part of the loop so that the loop may be engaged by the peg.

2. It is best to arrange for a minimum of slack string between the slit and the weight so that the latter starts to rise as soon as the loop is engaged.

3. In a typical experiment, a $2\frac{1}{2}$ lb trolley released from 2 ft above the bench caused the 2 lb mass to rise 1·2 ft. This means that about 50 per cent of the original potential energy was not recovered and was lost in other ways.





59 *Demonstration*

Transfer of kinetic energy to potential energy – 2

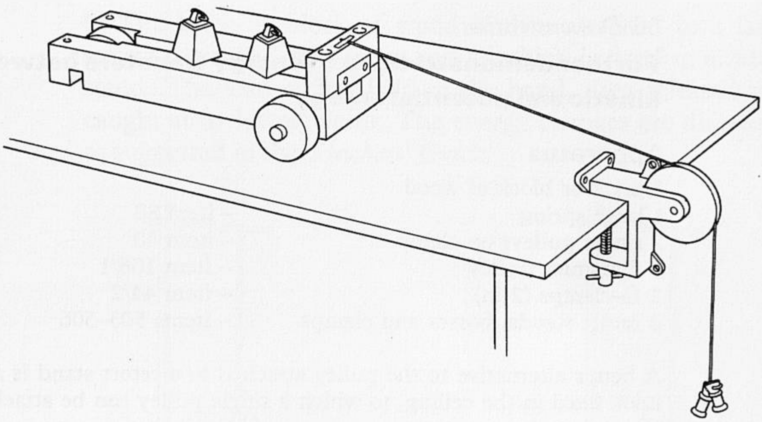
Apparatus

1 dynamics trolley	– item 106/1
2 1 lb weights	– item 36
1 single pulley on clamp	– item 40
2 1 oz weights	– item 37
cord	– item 10A

Procedure

Place the 2 lb loads on the dynamics trolley. It should be attached by a cord to a small (2 oz) load hung over the pulley fastened to the end of the bench.

Initially the cord should be loose. Push the trolley till it is moving fast along the track away from the pulley. Then let go and the thread will become taut and the small load will be raised whilst the trolley is brought to rest, the K.E. of the trolley turning into P.E. of the load raised.



60 *Demonstration*

Further demonstrations of energy transfers between kinetic and potential energy

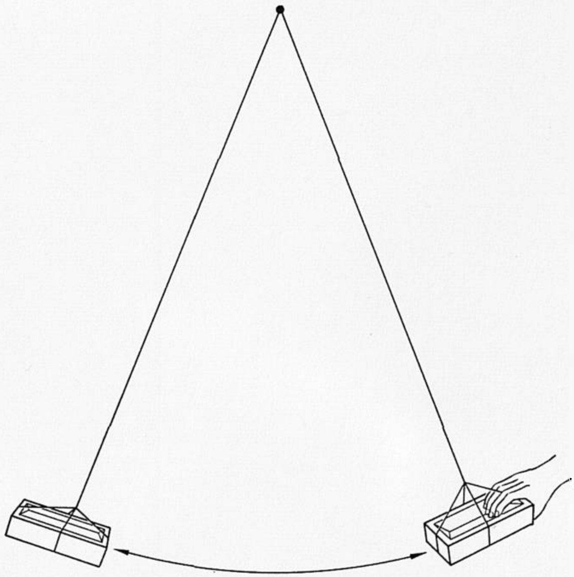
Apparatus

1 brick or block of wood	
1 large spring	– item 88
2 single pulleys on clamp	– item 40
1 dynamics trolley	– item 106/1
2 G-clamps (2 in)	– item 44/2
2 retort stands, bosses and clamps	– items 503–506

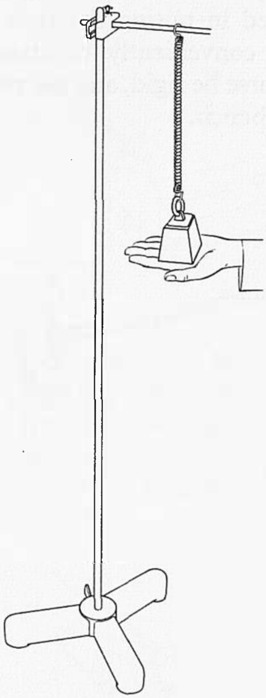
A better alternative to the pulley attached to a retort stand is a hook fixed in the ceiling, to which a single pulley can be attached.

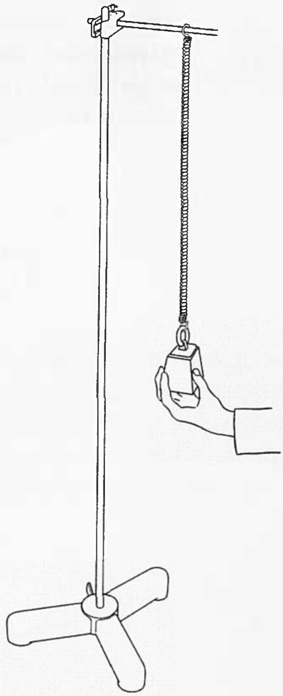
Procedure

a. A brick or block of wood is suspended as a pendulum by as long a string as possible (preferably from ceiling). The load is allowed to swing like a simple pendulum to illustrate a discussion of energy changes from potential to kinetic to potential energy again.

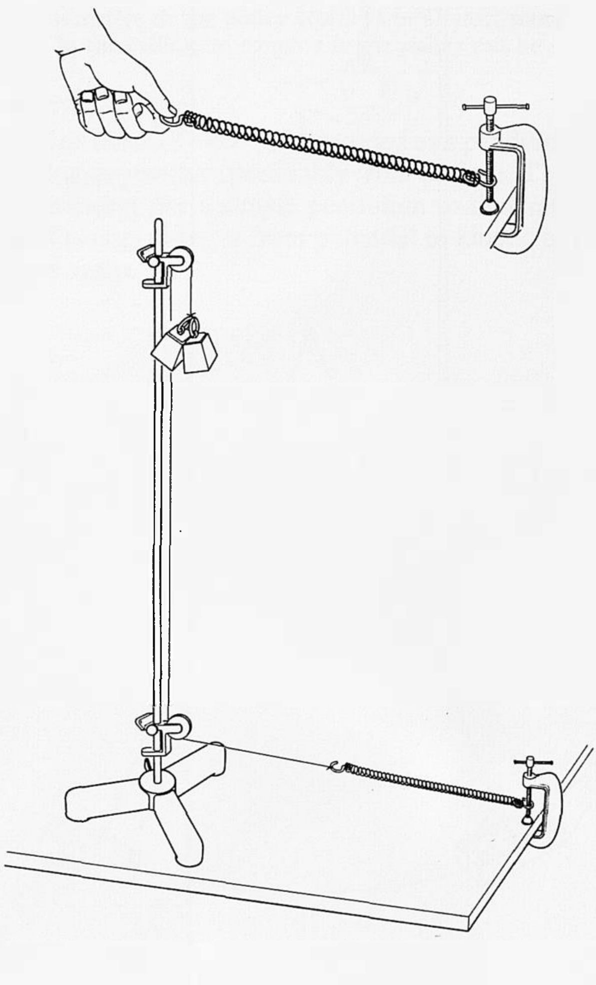


b. The brick or block of wood is then attached to a large spring (item 88), the upper end of which is fixed to a retort stand. The load is first held in the hand, then released and caught at its lowest point. The energy changes are discussed as suggested in the *Teachers' Guide*.

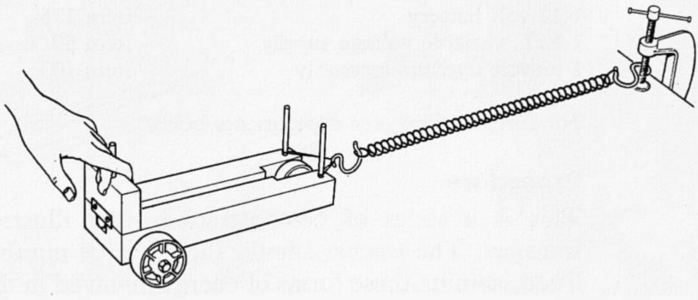




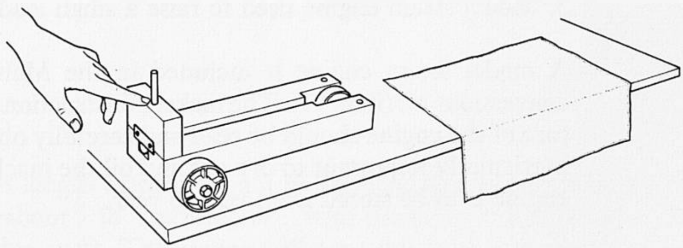
c. One end of a horizontal spring (item 88) is clamped to the end of the table with a G-clamp. The other end is held, then it is pulled so that the spring is stretched and held, while the energy change is discussed; then the free end of the spring is hooked to a cord which runs round two pulleys as shown, ending with the brick or block of wood. The spring is released and the stored energy is used in raising the load. For this experiment the pulleys can conveniently be attached to a retort stand: they must of course be rigid, and the retort stand should be G-clamped to the bench.



d. One end of the spring is anchored as before. The other end is attached to a dynamics trolley. The spring is stretched and the trolley held still. The trolley is released so that the stored energy is this time transferred to kinetic energy.



e. The trolley is given a push so that it has kinetic energy and then allowed to run over a rough patch so that it is brought to rest. Such a rough patch can be made by fixing a length of cloth to the bench-top. This provides an example for the discussion of kinetic energy being transferred to heat energy.



61 *Demonstration*

Examples of energy transfers

Apparatus

1 Malvern energy conversions kit	– item 9
1 12 volt battery	– item 176
1 L.T. variable voltage supply	– item 59
1 bicycle dynamo assembly	– item 103

For further items, see experiments below.

Procedure

This is a series of demonstrations that illustrate energy transfers. The teacher should show a large number of those listed, naming those forms of energy involved in the transfer. Some teachers will wish to set up the experiments as a 'circus' with small groups of pupils moving from experiment to experiment which they operate themselves.

1. Light a match.

2. Run a Bunsen burner.

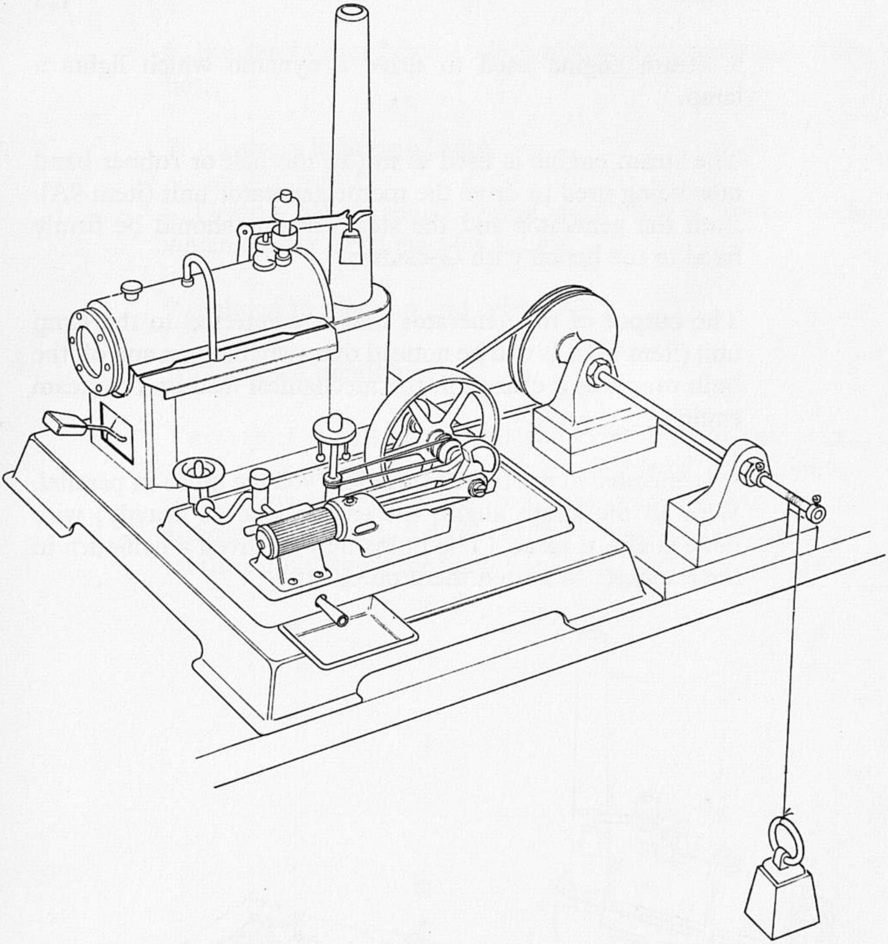
3. Model steam engine used to raise a small load.

A model steam engine is included in the Malvern energy conversions kit (item 9I). The makers' instructions for use and care of the engine should be read and carefully observed. It is particularly important to dry out and oil the machinery if the engine is to be stored from year to year.

The steam engine can be operated using solid fuel or the laboratory gas supply. Methylated spirit burners can also be used, but they are not always as effective.

When the steam pressure is up, turn the steam engine by hand until the condensed steam has been expelled. The engine will now run freely.

The engine should be clamped to the bench with a G-clamp and likewise the line shaft (item 9F) next to it. The small pulley on the engine should drive the large pulley on the line shaft by means of a belt or rubber band.



A length of cord should be attached to a weight on the floor (about 1 lb is satisfactory) with the other end attached to the line shaft. The engine will raise this load, giving it potential energy which is drawn from the chemical energy of the gas supply or solid fuel.

4. Model steam engine accelerating.

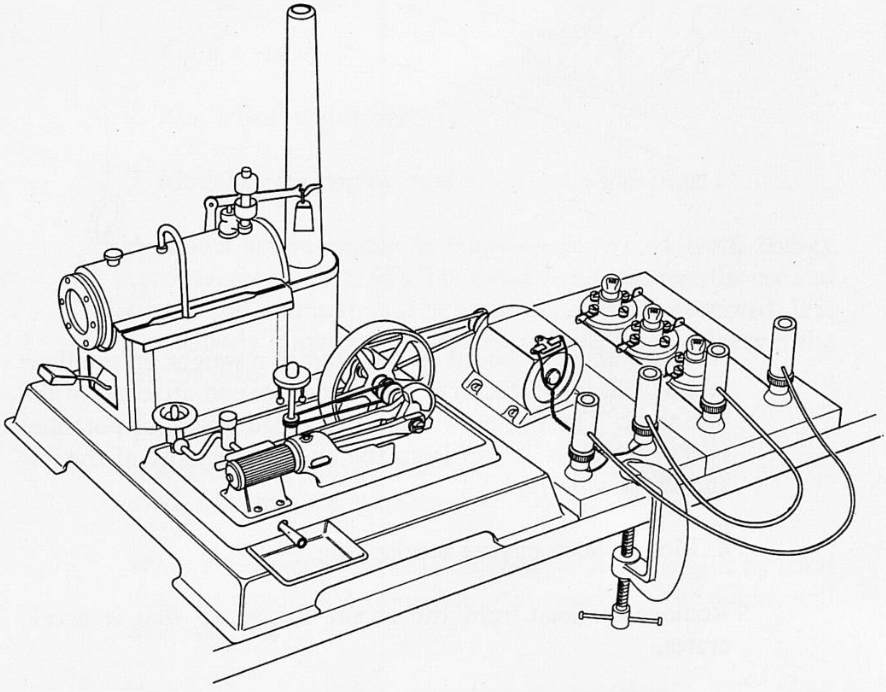
Remove the load from the steam engine so that it accelerates.

5. Steam engine used to drive a dynamo which lights a lamp.

The steam engine is used as in (3), the belt or rubber band now being used to drive the motor/generator unit (item 9A). Both the generator and the steam engine should be firmly fixed to the bench with G-clamps.

The output of the generator unit is connected to the lamp unit (item 9D). It will be noticed that switching on and off the bulb produces a change in the mechanical load on the steam engine.

It is effective to use two or three low voltage bulbs in parallel. With all the lamps alight, the engine labours heavily; with none alight, it races. (The bulbs may be given a half-turn in their sockets to switch them on or off.)



6. Bunsen burner heats a piece of platinum until it is white hot.

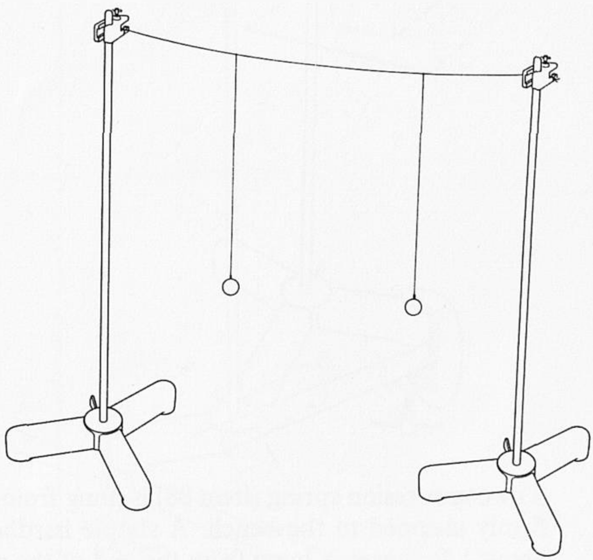
7. A battery lighting a lamp.

8. Grind a handle round against some form of friction brake which clearly develops a lot of heat.

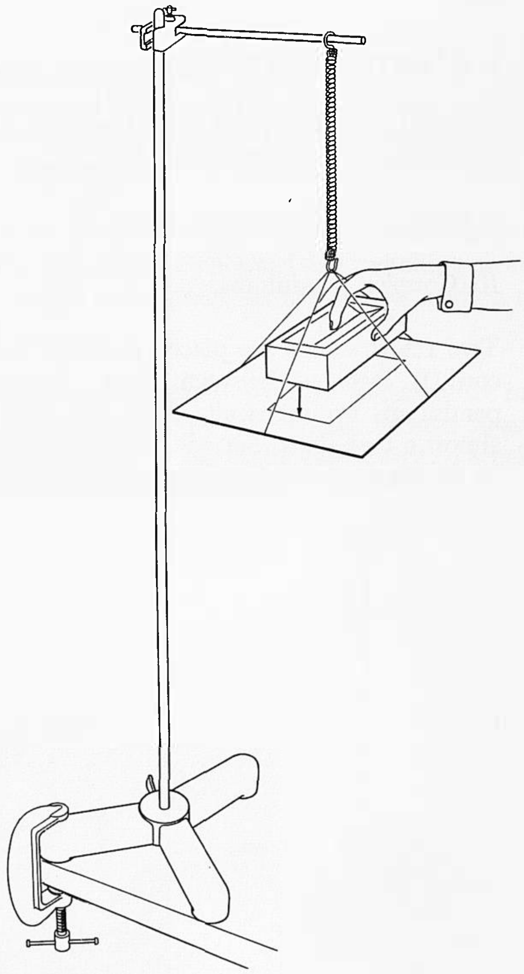
9. Balloon to blow up and release.

10. Coupled pendulums.

Two retort stands are placed about 30 in apart and a light cord is fastened between them. Suspend two identical pendulums symmetrically from this cord so that they are almost a foot apart. Set one of the pendulums swinging and let the pupils watch the energy transfer from one to the other.



11. Weight released on spring.

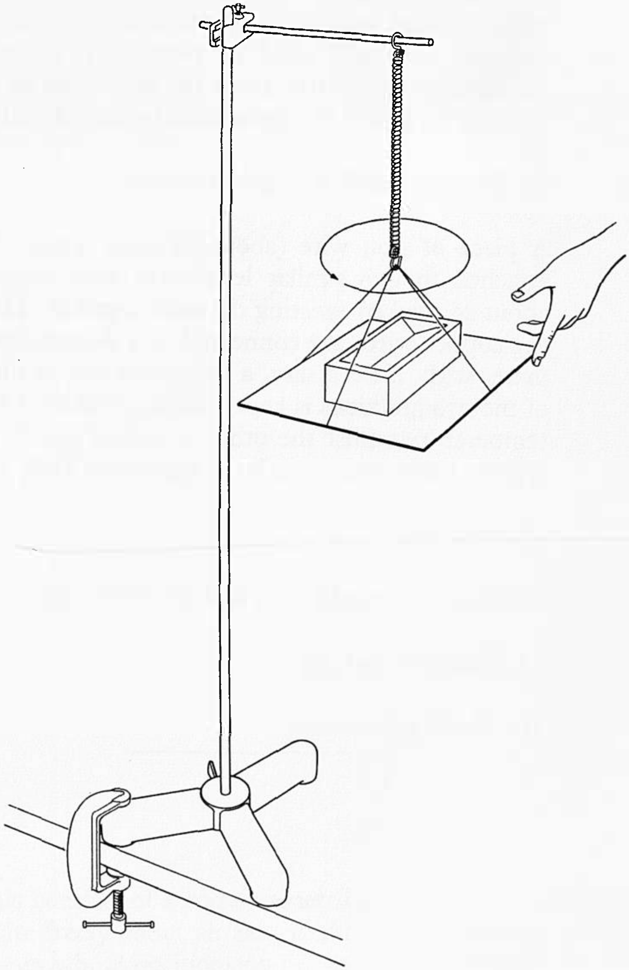


The compression spring (item 88) is hung from a retort stand firmly clamped to the bench. A simple hardboard platform about 1 ft square is hung from the end of the spring by four strings so that it is horizontal.

A load such as a brick is held just over the platform and released suddenly. The changes in energy are observed. Alternatively the weight is hung on the string and held by hand with the string unstretched, then released.

12. Torsional pendulum.

The arrangement used in (11) can be used as a torsional pendulum. The vertical motion is stopped and the platform given a twist.



13. Wilberforce pendulum (*optional: for faster groups*).

This consists of a long helical spring hung vertically from a rigid support and carrying a weight. The moment of inertia of this weight about a vertical axis is such that the period of torsional vibration is equal to that of vertical oscillation. So, when vertical oscillation is started, the consequent slight torsional twist will build up rotation of the bob: energy is periodically transferred from the spin form to the combination of P.E. and K.E. appropriate to the vertical oscillation.

14. Thermocouple and galvanometer.

A piece of iron wire (about 24 swg) about 75 cm long is attached to two similar lengths of bare copper wire (also about 24 swg) by twisting the ends together. The free ends of the copper wires are connected to a demonstration galvanometer with, if necessary, a resistance box in the circuit. One of the two junctions is kept cool in a beaker of water at room temperature whilst the other is heated gently with a flame. (About 1,500 microvolts is the maximum likely to be reached.)

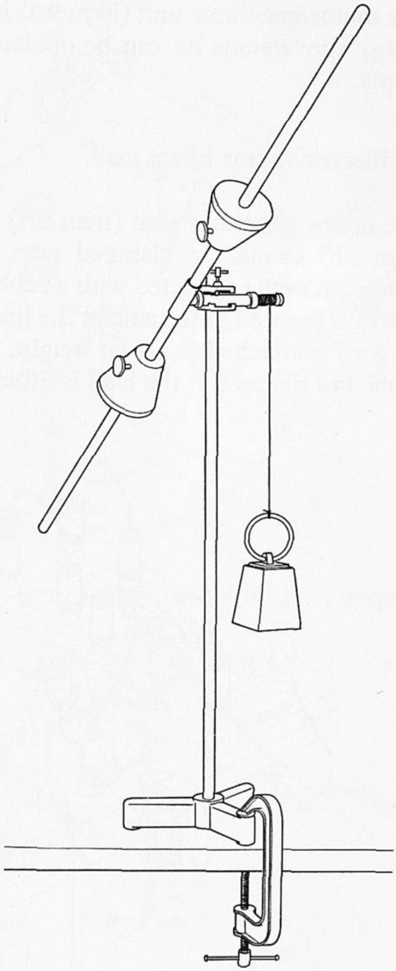
15. Fuel cell.

16. Inertia operated toys, and clockwork toys.

17. Hammer and nails.

18. Model pile driver.

19. *Flywheel of variable inertia.*



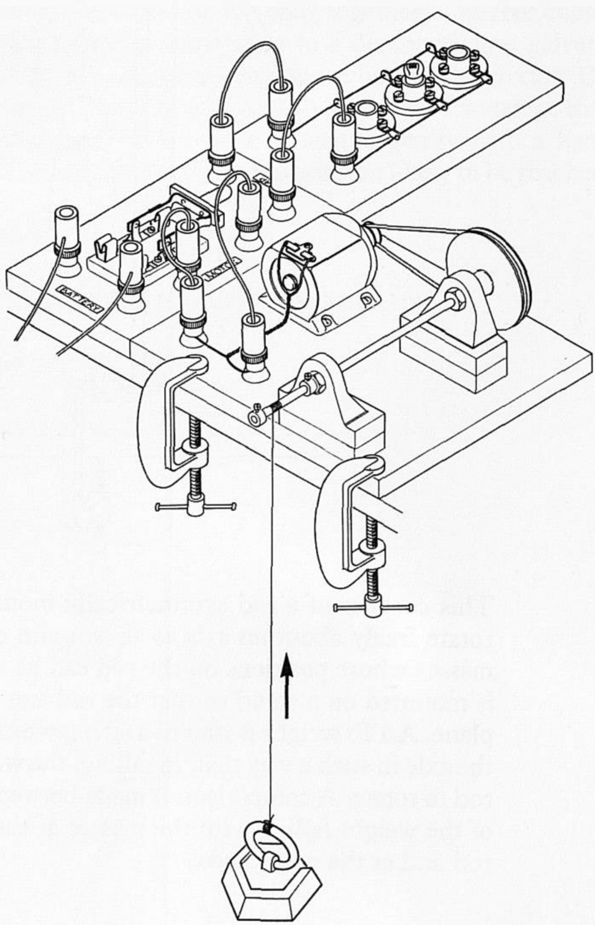
This consists of a rod symmetrically mounted so that it can rotate freely about an axis as shown and carrying two equal masses whose positions on the rod can be altered. The whole is mounted on a stand so that the rod can rotate in a vertical plane. A 1 lb weight is tied to a string which is wound around the axle in such a way that, in falling, the weight will cause the rod to rotate. A comparison is made between the consequence of the weight falling with the masses at the inner ends of the rod and at the outer ends.

20. Battery drives an electric motor.

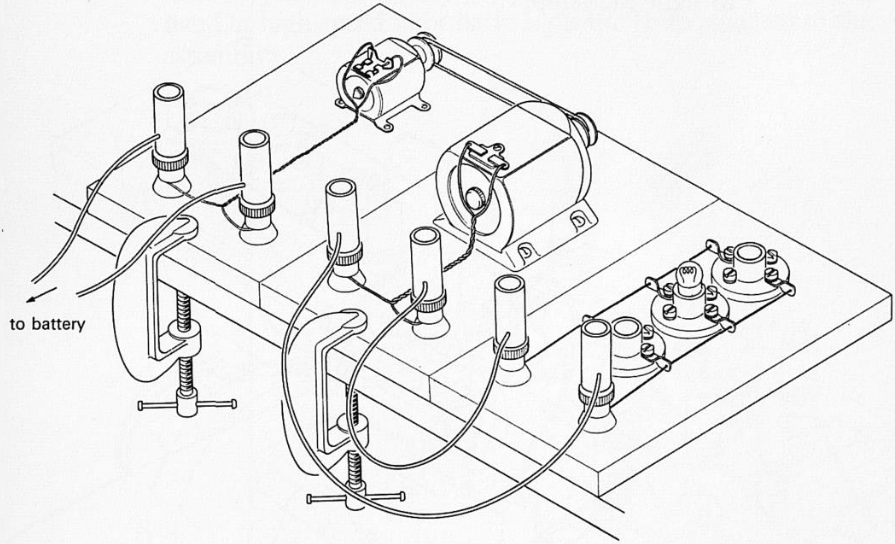
The motor/generator unit (item 9A) included in the Malvern energy conversions kit can be operated from a 4–6 volt d.c. supply.

21. Electric motor lifts a load.

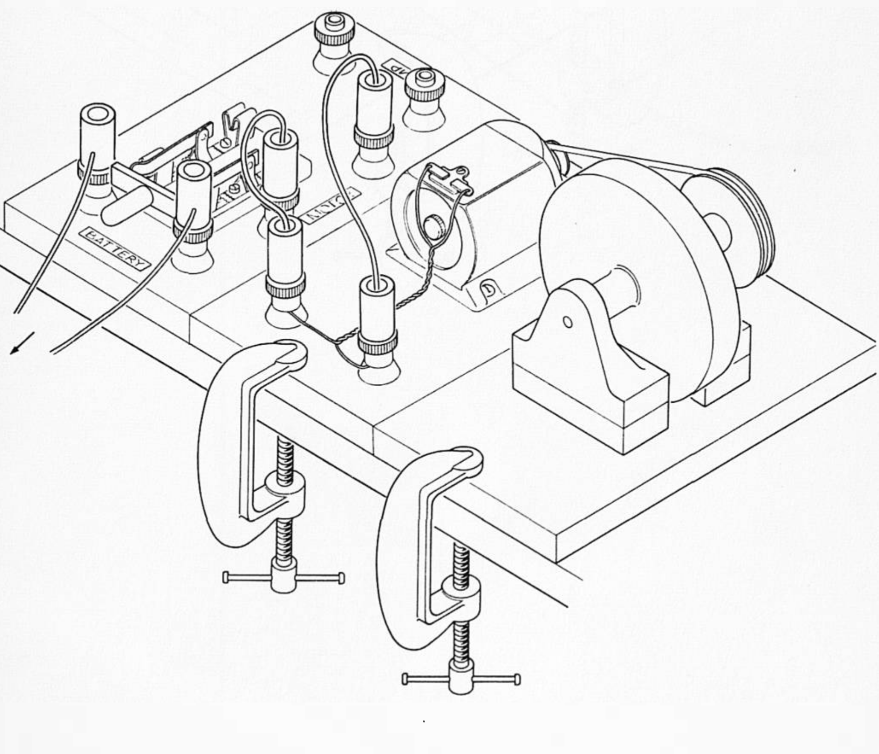
The motor/generator unit (item 9A) and the line shaft unit (item 9F) should be clamped next to each other and the pulleys on each connected with a rubber band or driving belt. A cord is secured to the axle of the line shaft, the lower end of the cord is attached to a 1 kg weight. When 4–6 volts d.c. are applied to the motor, the load is lifted.



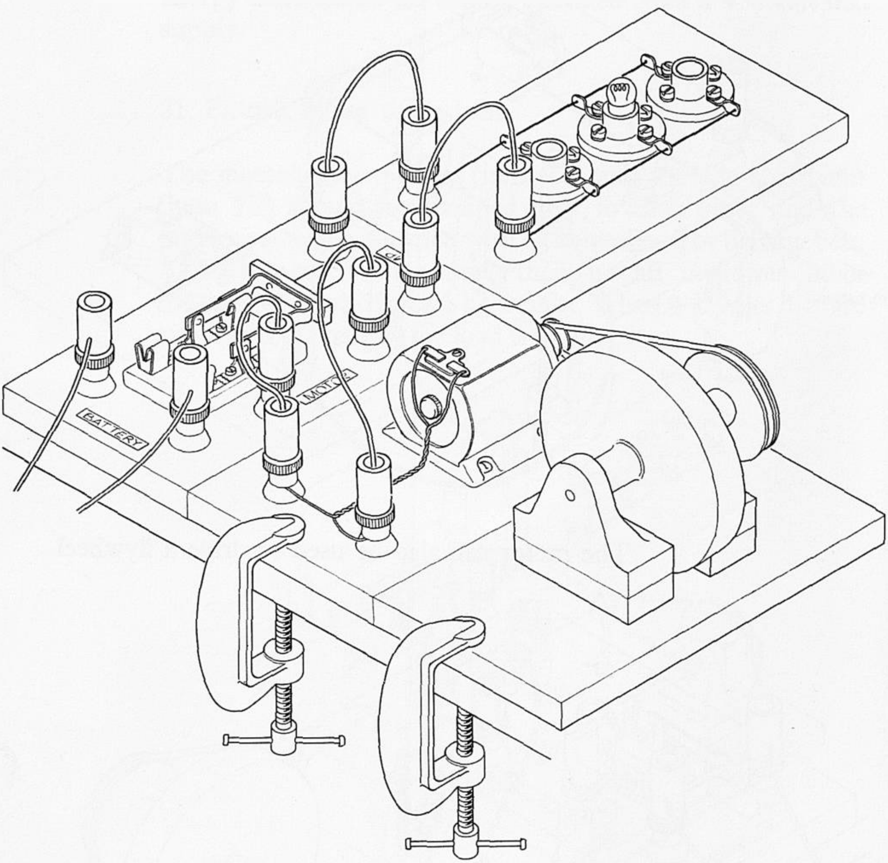
The motor can then be used to drive a generator, which in turn can light a lamp.



The motor can also be used to drive a flywheel.

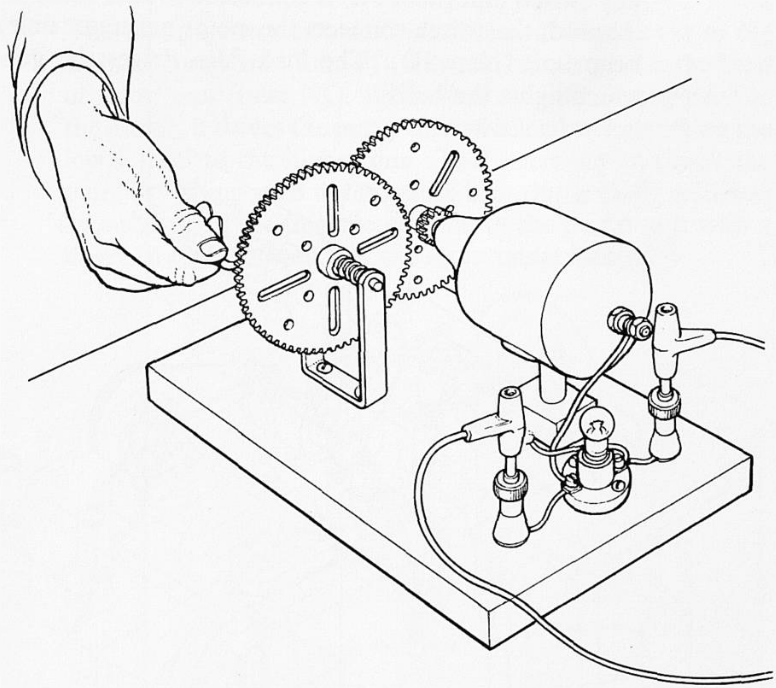


In this last arrangement, if the switch is thrown, the energy stored in the flywheel can be used to drive the generator to light the lamp.



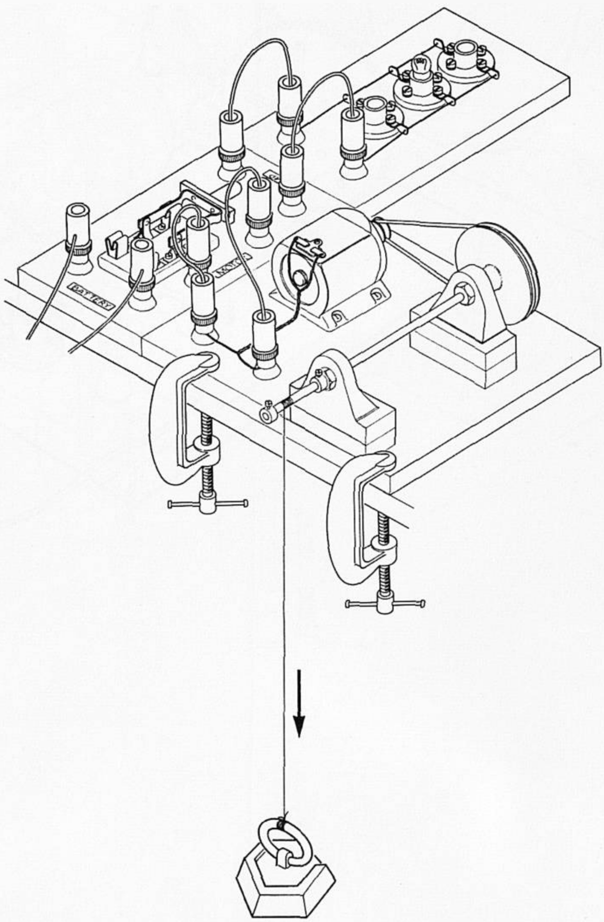
22. Dynamo driven by hand lights a lamp.

The bicycle dynamo assembly (item 103) can be driven by hand at high speed in order to light the lamp attached to the assembly.



23. Falling weight drives a dynamo which lights a lamp.

The motor/generator unit (item 9A) and the line shaft unit (item 9F) are clamped next to each other as in (21) above. A 1 kg load is lifted as described in that experiment. A two way switch unit (item 9C) is connected so that when the load is raised, the switch connects the motor/generator unit to the lamp unit (item 9D). The load falls, drives the generator which lights the bulbs.

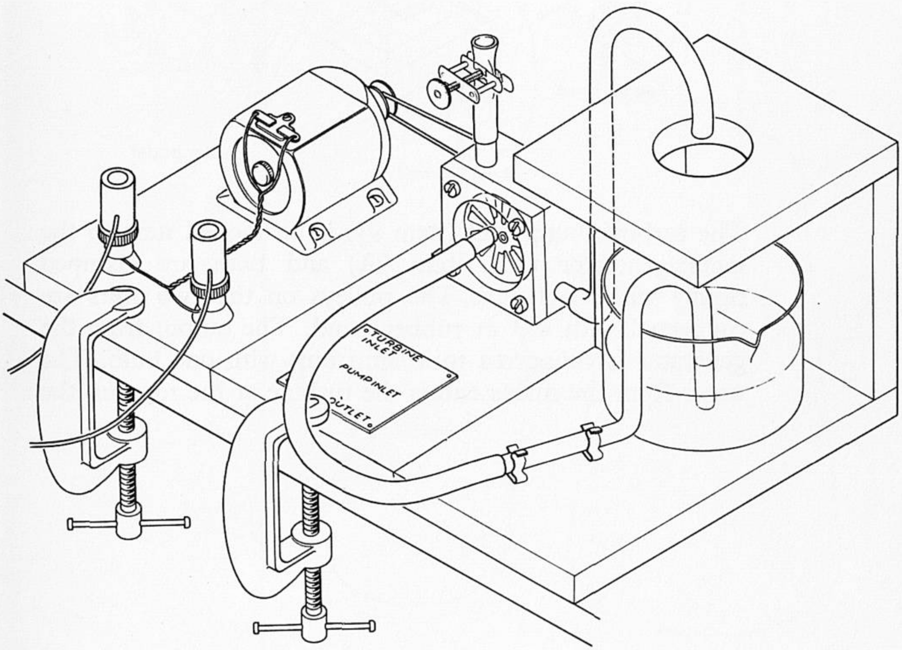


24. Spring gun firing a ball.

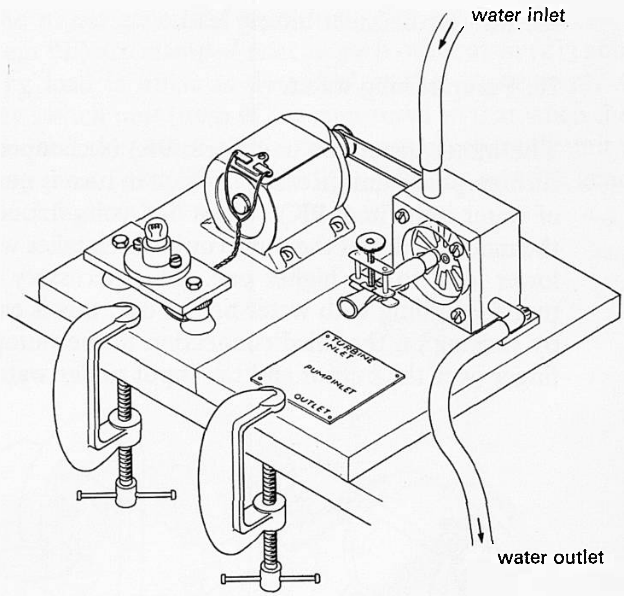
25. Moving hammer hitting lead.

26. Pump raising water.

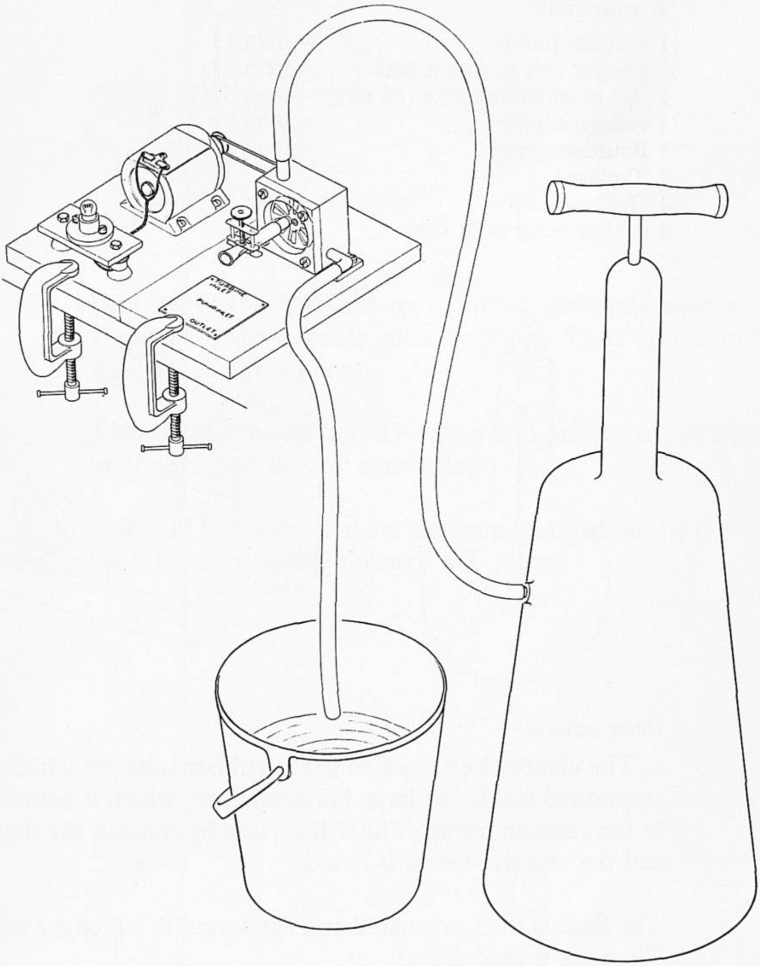
The motor/generator unit (item 9A) is clamped next to the turbine/pump unit (item 9J), which in turn is next to the head of water unit (item 9K). When 4–6 volts d.c. are applied to the motor, it drives the pump unit which takes water from the lower level to the higher one. (It is necessary to prime the pump by filling with water before use: this is easily achieved by sucking on the third connection to the pump unit with a finger over the output and the input under water.)



27. Water turbine driving a dynamo, which lights a lamp.



The turbine/pump unit (item 9J) is positioned next to the motor/generator unit (item 9A) and both are clamped rigidly with G-clamps. The pulleys on the two units are connected with a 3 in rubber band. The output from the generator is connected to a lamp unit with one bulb. The water from the mains enters the turbine at the top and the pressure drives round the turbine blades, which in turn drives the generator. If the water pressure is not very great, some form of force pump will be necessary to increase the pressure.



28. Acid added to alkali produces heat.

29. Photographic exposure meter in which light produces an electric current.

Note

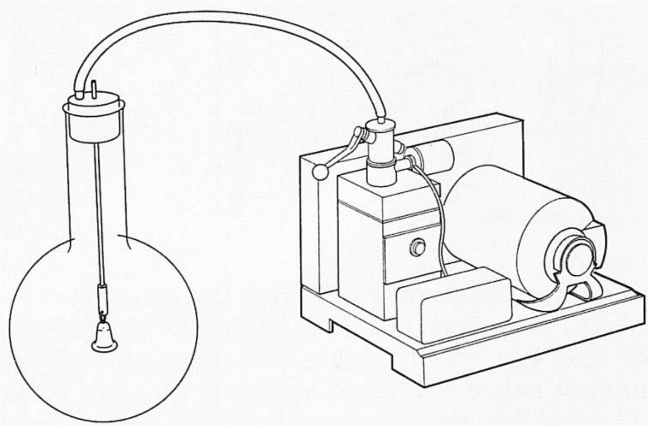
Details of these experiments can be seen in the Esso-Nuffield film for science teachers *Kinetic Energy: Introductory Experiments.*

62 *Demonstration*

Radiation energy

Apparatus

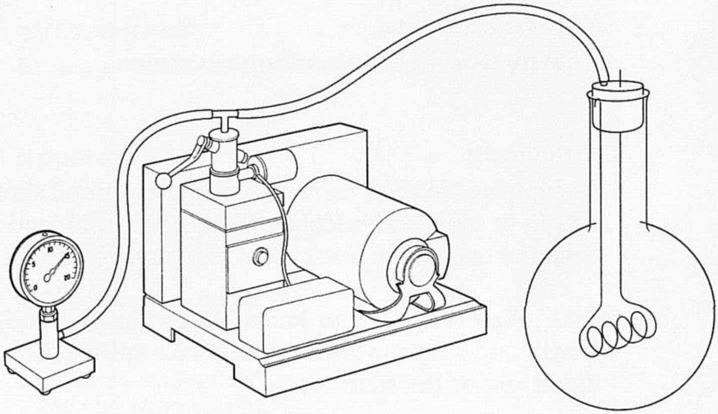
1 vacuum pump	– item 13
1 clapper bell in round flask	– item 87
1 reel of nichrome wire (26 swg)	– item 57G
1 voltage supply	– item 59
1 Bourdon gauge	– item 67
1 T-piece	
1 Hoffman clip	– item 10V
1 rubber bung to fit flask	



Procedure

a. The clapper bell is wired to the rubber tube, by which it is suspended inside the large bolthead flask, which is connected to the vacuum pump. The bell is rung by shaking the flask to and fro and the sound is heard.

The flask is then evacuated and the sound is no longer heard. Then air is readmitted.



b. Remove the bell and fix a coil of nichrome wire inside. Connect to the variable voltage supply. Turn up the voltage until the filament glows.

Then pump the air out. The glow will be brighter as there is no longer heat loss by convection.

It should be shown that air has been pumped out by connecting a Bourdon gauge through a T-piece.

63 *Class experiment*

Energy transferred in climbing stairs

Procedure

As explained in the *Teachers' Guide*, every pupil should climb a flight of stairs and calculate his transfer from food energy to potential energy for that climb, just making a rough estimate.

Each pupil will need to know his or her own weight in kg weight and a tape measure should be available for estimating the height of the stairs.

Each pupil calculates his energy transfer *from* chemical energy (muscles) *to* potential energy that could be useful.

Note

Since we are not at this stage calculating *power*, no timing is involved in this experiment.

64 *Demonstration*

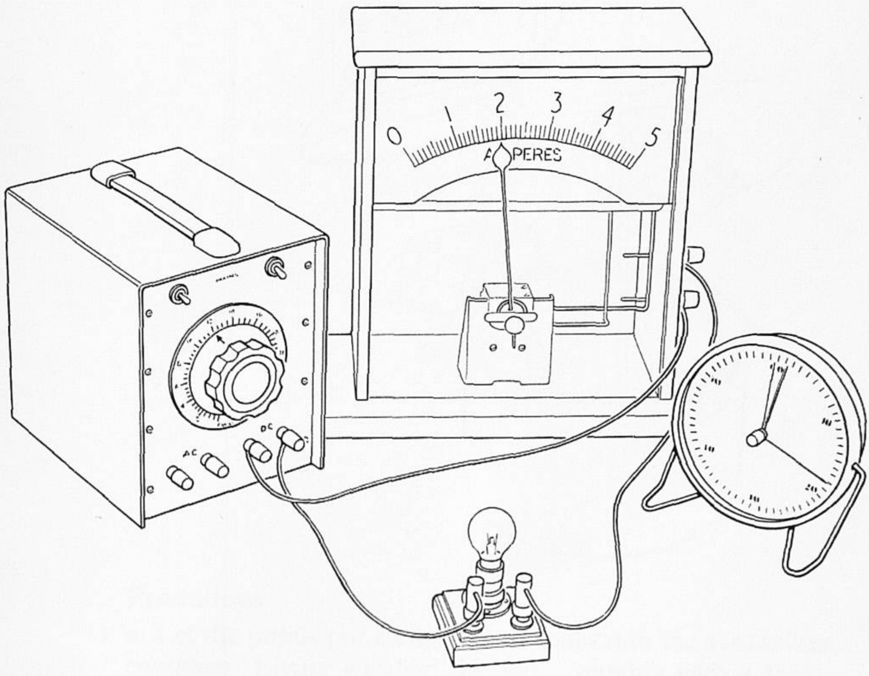
Energy transfer from electric supply

Apparatus

1 12 volt 24 watt lamp	– item 72
1 12 volt 36 watt lamp	– item 73
1 lampholder on base (S B C)	– item 74
1 12 volt battery	– item 176
1 demonstration meter	– item 70
1 d.c. dial: 5 amp	– item 71/2
1 a.c. dial: 5 amp	– item 71/7
1 mounted lampholder (B C)	– item 91D
1 240 volt 60 watt lamp	
1 transformer	– item 27
1 stop-clock	– item 507

Procedure

Connect a simple series circuit of a 12 volt 24 watt lamp and demonstration meter to 12 volt battery. Switch on for 15 seconds. Discuss the energy transfer from the battery to heat and radiation from the lamp.



Repeat using the 12 volt 36 watt lamp.

If an a.c. dial (item 71/7) is available, repeat the above using the 12 volt terminals of the transformer (item 27).

Finally connect the 240 volt 60 watt lamp to the mains with the meter and a.c. dial (if available) in series with the lamp.

Note

The clock is essential because we discuss energy transfer, not power, in this experiment.

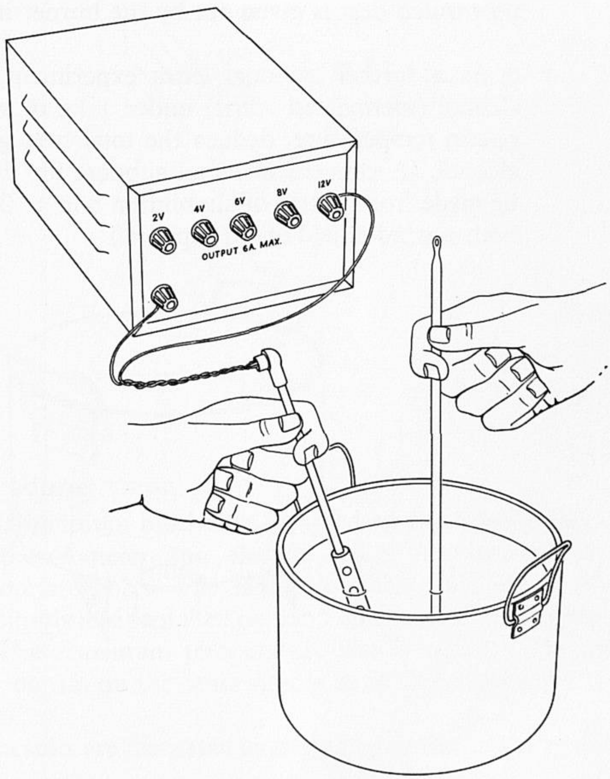
65 *Class experiment*

Measuring heat

Apparatus

8 immersion heaters	– item 75
8 aluminium containers	– item 76
8 lever-arm balances	– item 42
8 thermometers (−10° to 110°C.)	– item 542
8 stop-clocks or stop-watches	– item 507
8 transformers	– item 27

The immersion heaters (item 75) are 12 volt 60 watt. They therefore require 5 amps and this can be supplied from the transformers (item 27).



Procedure

a. Let the pupils put a kilogram of water into the aluminium container, having weighed the water roughly with a lever-arm balance. Measure the temperature of the water with the thermometer. Place the immersion heater in the water and connect it to the 12 V supply. Switch on and start the clock at the same moment.

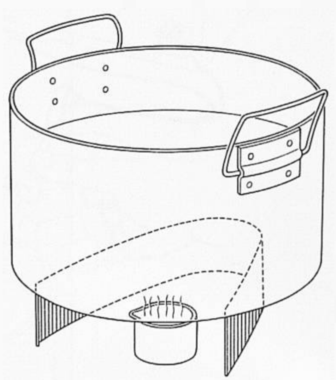
The water should be stirred constantly: this is essential for good results.

Let the supply run for five minutes. Switch off, *continue* stirring and take the highest temperature reached.

b. Repeat the experiment using $\frac{1}{2}$ kg of water.

c. As an optional extra experiment, put a Bunsen burner under 1 kg of water. From the rise in temperature, deduce how much heat is given out by the burner in one minute.

d. As a further optional extra experiment, burn 1 ml of alcohol (methylated spirit) under 1 kg of water. From the rise in temperature, deduce the total heat given out by the alcohol. (A convenient metal support for the container can be made from a strip of aluminium 8 in $\times$ 3 in bent to form both a wind-shield and a support.)

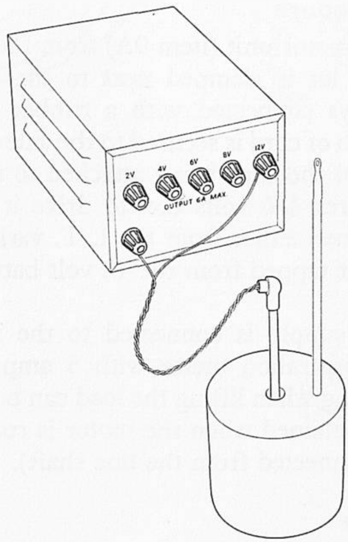


66 *Class experiment*

Experiment leading to the idea of specific heat and a rough estimate of its value for aluminium

Apparatus

8 immersion heaters – item 75
8 aluminium blocks – item 77
8 thermometers ($-10°$ to $110°$C.) – item 542
1 lever-arm balance – item 42
8 stop-clocks or stop-watches – item 507
8 transformers – item 27



Procedure

The aluminium blocks are weighed on the balance and then the thermometer and electric heater are inserted in the appropriate holes. The heater is then connected to the 12 volt supply and switched on for 5 minutes as in Experiment 65. The maximum temperature rise is noted. (The heater must be run on the same supply as in Experiment 65.)

The results are discussed as suggested in the *Teachers' Guide*.

Note

Oil in the thermometer hole in the aluminium blocks will help thermal transfer. It is not necessary to put oil with the immersion heater.

67 Demonstration

Energy and an electric motor

Apparatus

1 motor unit	– item 9A
1 demonstration meter	– item 70
1 d.c. dial: 5 amp	– item 71/2
1 kg weight	– item 32
1 line shaft unit	– item 9F
1 L.T. variable voltage supply	– item 59
cord	– item 10A

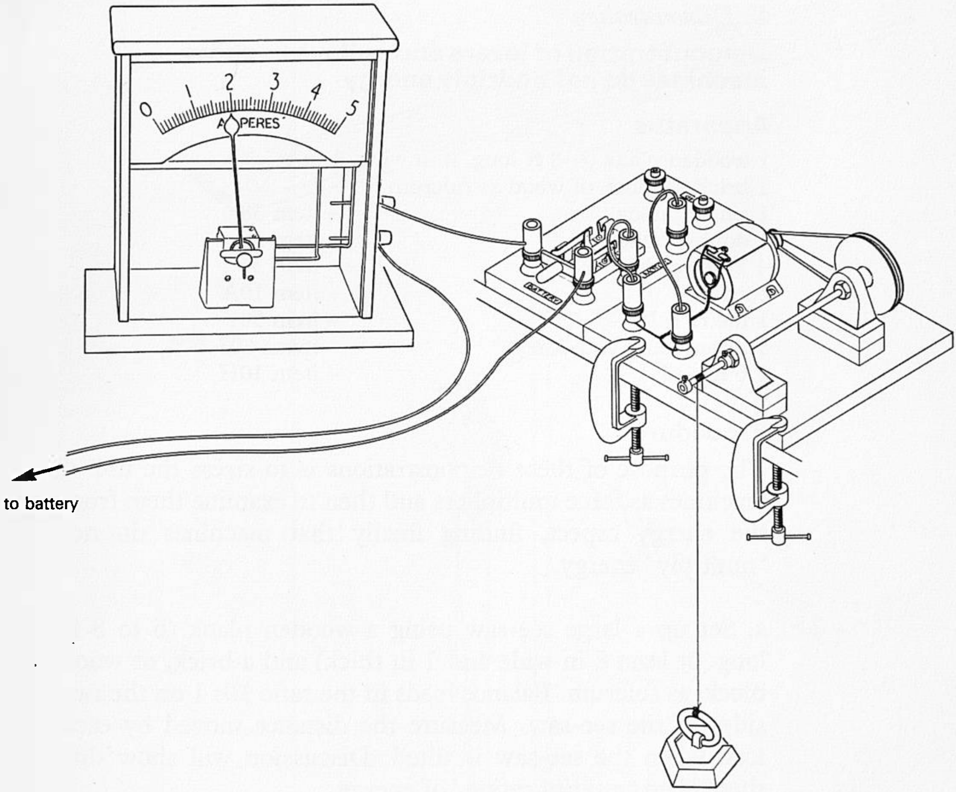
Procedure

The motor unit (item 9A) from the Malvern energy conversions kit is clamped next to the line shaft unit and their pulleys connected with a rubber band or driving belt. A length of cord is secured to the axle of the line shaft, the other end of the cord being attached to the 1 kg load. The motor requires 4–6 volts d.c. to drive it and this is conveniently obtained either from the L.T. variable voltage supply (item 59) or tapped from the 12 volt battery (item 176).

The supply is connected to the motor in series with the demonstration meter with 5 amp d.c. dial. The ammeter reading when lifting the load can be compared with the reading obtained when the motor is running light (that is, when disconnected from the line shaft).

Note

Alternatively teachers can use the fractional horse-power motor (item 150) and lift a substantially heavier load.


0 1 2 3 4 5
AMPERES
to battery

68 *Demonstration*

Demonstration of levers and pulleys to show machines do not multiply energy

Apparatus

1 wooden plank (6–8 ft long, 8 in wide, 1 in thick)	
1 brick or block of wood as fulcrum	
1 single pulley	– item 38
1 double pulley	– item 39
4 1 lb weights	– item 36
cord	– item 10A
1 metre rule	– item 501
1 retort stand and boss	– items 503–505
1 6 in nail	– item 10H

Procedure

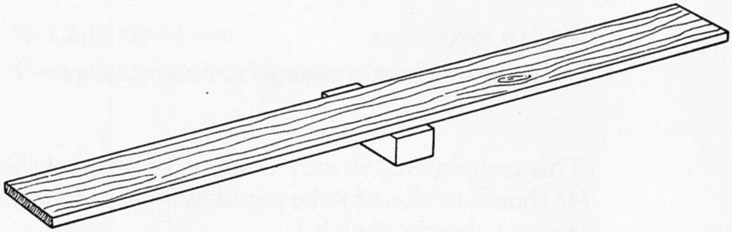
The purpose of these demonstrations is to stress the use of machines as force multipliers and then to examine them from the energy aspect, finding finally that machines do not 'multiply' energy.

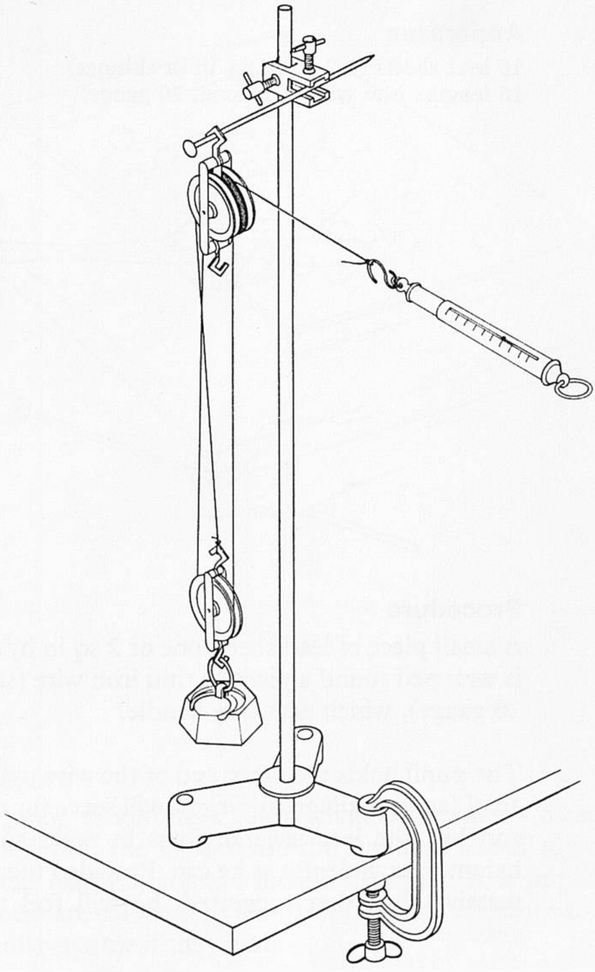
a. Set up a large see-saw using a wooden plank (6 to 8 ft long, at least 8 in wide and 1 in thick) and a brick, or wood block, as fulcrum. Balance loads in the ratio 10: 1 on the two sides of the see-saw. Measure the distance moved by each load when the see-saw is tilted. Discussion will show that there is no 'multiplication' of energy.

b. Set up a pulley system as illustrated. Show that the transfer of energy from one load to the other is about equal even though the loads themselves are different: again show there is no 'multiplication' of energy.

Note

In both cases the see-saw and pulley experiments are used as a basis for discussion and not for precise measurements.





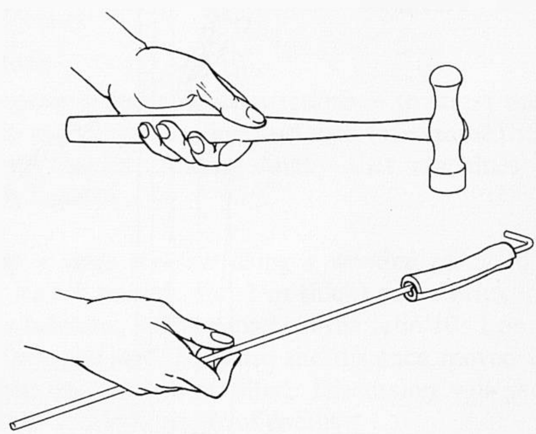
69 *Class experiment*

Transfer of kinetic energy to heat energy

(This experiment, already described in Year 1, Experiment 74c should be done by the pupils as a class experiment if they have not already done it.)

Apparatus

16 lead sheets (1-2 sq in, $\frac{1}{16}$ in or thinner)
16 lengths iron wire (1 ft long, 20 gauge)



Procedure

A small piece of lead sheet, one or 2 sq in by $\frac{1}{16}$ in or thinner, is wrapped round a piece of thin iron wire (say, 1 ft long and 20 gauge), which acts as a handle.

The pupil holds the other end of the wire with the lead on an anvil (an iron kilogram weight will serve for this) on the floor and hits the lead several times in rapid succession with a hammer, as violently as he can. Provided the lead is not more massive than that suggested, he will feel the temperature rise.

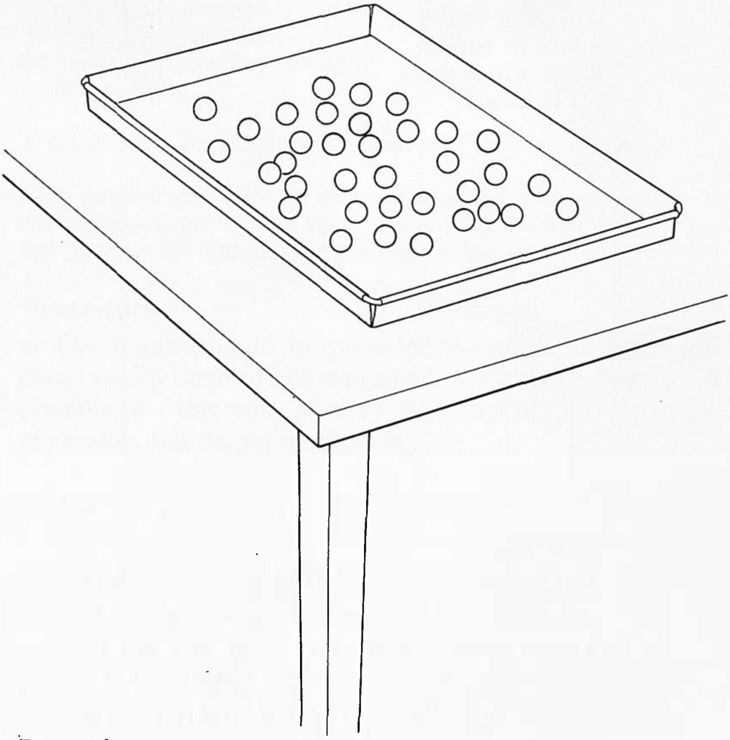
70 *Class experiment*

Two-dimensional kinetic model

Apparatus

Two-dimensional kinetic model kit – item 12

The kit contains 16 metal trays enabling pupils to work in pairs.



Procedure

Each group should have 20–24 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 marble *if* they wish.

Pupils keep the tray in random shaking motion sliding it on the table.

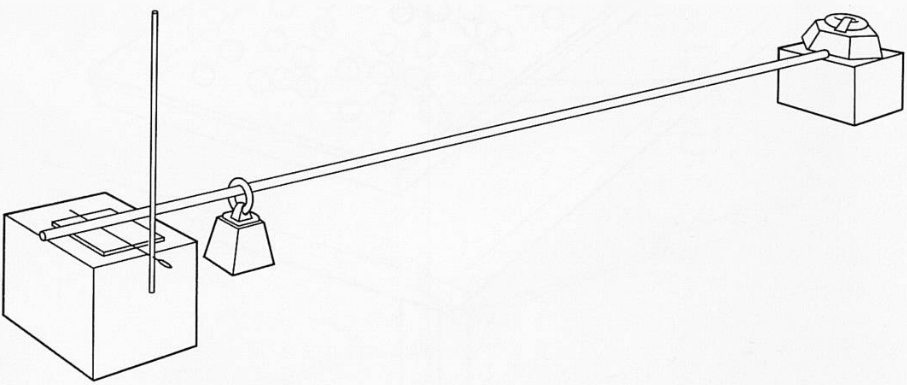
This is an extension of Experiment 49 in Year I. On this occasion, they should also agitate the tray more vigorously to illustrate the relationship between faster motion and change in pressure.

71 *Class experiment*

Expanding solids

Apparatus

8 iron rods (2 ft long, $\frac{1}{4}$ in diameter)	– item 57Q
16 wooden blocks	
8 1 kg weights	– item 32
8 needles	– item 53D
8 drinking straws	– item 53A
8 Bunsen burners	– item 508
8 microscope slides	– item 3G
8 1 lb weights	– item 36



Procedure

The length of rod is supported as shown on the two supports and is prevented from moving at one end by the 1 kilogram weight placed on it. The other end can roll on the needle which rests on a small piece of glass (e.g. a microscope slide) placed on the block. The drinking straw is impaled upon the needle.

When the rod is heated by moving a Bunsen flame along it, the straw will move with the rolling needle.

If the rod slips on the needle, hang a load on it near the needle.

Note

If the straw slips on the needle, run a short piece of fine copper wire through the eye of the needle, and wrap it round the straw.

72 *Class experiment*

Expanding liquids

Apparatus

16 thermometers (−10° to 110° C.)	– item 542
8 aluminium containers	– item 76
8 tripods	– item 511
8 Bunsen burners	– item 508
32 soft glass test-tubes	– item 545
32 Pyrex glass test-tubes	– item 546
32 bungs with capillary tubing to fit test-tubes	– item 547

A suitable size for these tubes would be 75 mm × 12 mm.

Each pupil should have his own test-tube, but they can share thermometers and the hot water baths, which should be kept hot (between 60 and 80°C.) by a Bunsen burner.

Procedure

a. The pupils should be provided with thermometers and asked to dip them in hot water and to watch carefully. (It is possible that they may observe the initial contraction before expansion, but do not mention it.)

b. The soft glass tube is filled with coloured water (a little ink is suitable for this) and the bung inserted so that no air bubbles remain in the tube and the coloured liquid extends to about 1 in or 2 in above the top of the bung.

The tube is then plunged into hot water and the behaviour of the water level in the tube observed. Some will only see the general expansion of the cold water in the test-tube, but some will notice the initial dip downward.

Repeat the experiment using a Pyrex test-tube, telling the pupils it is made of different glass.

73 and 74 Demonstration and class experiment

Cracking glass

Apparatus

1 piece of window glass (say, 4 in square)	
1 tripod	– item 511
32 5 in soft glass tubes	– item 57S
32 5 in Pyrex glass tubes	– item 57T
16 Bunsen burners	– item 508
16 beakers	– item 512/2
2 5 in clear silica tubes	– item 57U

Procedure

1. First there should be a *demonstration* of a piece of window glass cracking when it is heated in a Bunsen flame. The pane is placed on a tripod and heated near one corner with a bare flame. The teacher should ask the pupils why it cracks, but should not give any explanation yet.

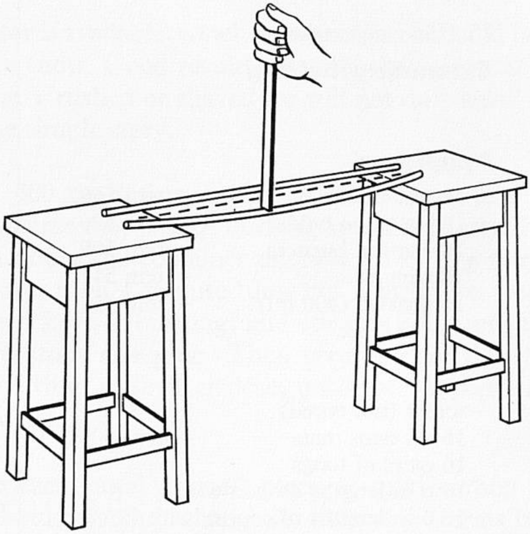
2. Each pupil should be given a short length of *soft* glass tubing which he can heat in a Bunsen flame and then plunge into water.

This experiment should then be repeated with similar lengths of Pyrex tubing.

3. The teacher should then demonstrate using a piece of clear-fused silica tubing.

Notes

1. As outlined in the *Teachers' Guide*, a possible explanation of the difference in cracking between soft glass and Pyrex likely to come up in discussion is that Pyrex is able to stand a greater strain. To demonstrate that this is not the case, put two lengths (say, 3 ft – 4 ft long soft glass and Pyrex of equal size) as a bridge between two stools. The centre of each one is depressed in turn with, say, a half-metre rule and the position noted when each breaks. Since the depression is a measure of the strain, a comparison of maximum depressions will compare strains.



2. An entertaining demonstration – as well as a useful technique – is to half fill a milk bottle with old car-engine oil. Then to heat a large non-electric soldering iron or poker in a Bunsen flame and plunge it into the oil. The bottle will crack cleanly at the oil level.

3. A nichrome wire heated electrically can be used to crack big glass pipes and this might be demonstrated. It is advisable to start the crack with a wheel or diamond, then to wrap the wire over the crack and heat it to red heat.

Safety Screens

Whenever the teacher has to give a demonstration with something made of glass which might shatter and hurt him or the class, it is recommended that a pair of large safety sheets of Perspex be used. The sheet between the teacher and the apparatus should be 36 in high by 24 in wide. This is not so wide that he cannot reach his arms round from behind and manipulate the apparatus, but it is high enough to shield his face. The sheet between the apparatus and the class should be 30 in square.

These sheets (of $\frac{3}{16}$ in Perspex) should on no account be framed for that would spoil the feeling of full transparency. They could well be supported by pairs of slotted bases (item 30).

75 Class experiment

Examining melting

Apparatus

a. 16 test-tubes (Pyrex)	– item 546
16 test-tube holders	– item 526
16 Bunsen burners	– item 508
16 tripods	– item 511
16 beakers (400 ml)	– item 512/2
naphthalene	
b. lead	
solder (not cored)	
16 asbestos mats	– item 509
16 pairs of tongs	
16 6 in lengths of iron wire	
16 6 in lengths of copper wire	
c. snow (if available)	
16 thermometers (−10° to 110°C.)	– item 542
d. small polythene bags	
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2

Procedure

a. A small quantity of naphthalene is put into the test-tube to a depth of about 1 in. Water is heated in the beaker over the Bunsen burner and the test-tube is held in it with the test-tube holder. Observations should be carried out on the melting and solidifying of the naphthalene.

The object of this is to let pupils see the phenomenon, rather than make measurements. So a thermometer need not be used.

(The naphthalene must be in a test-tube heated in a water bath. In the open, it may catch fire.)

b. If they did not do the experiments in Year I, pupils should also try heating a few grams of lead in a tin lid or crucible, heating a few inches of solder (*not* cored) held in tongs over an asbestos mat, heating pieces of iron wire and pieces of copper wire in a Bunsen flame.

c. If snow is available, a melting experiment should be carried out with snow. Good results are unlikely unless the snow is very fine. Crushed or shaved ice will not do – small icebergs spoil the simple story.

Heat a 400 cc beaker, crammed with snow, over a *small* Bunsen flame that is kept burning at a steady rate. Hold the Bunsen under the container of snow for only $\frac{1}{4}$ minute at a time. After each $\frac{1}{4}$ minute 'dose' of heat, move the Bunsen away (but keep it burning) and stir carefully until the temperature stops changing. Then give another dose of heat. Continue thus, dose after dose, until the temperature is 30° C. or higher.

d. Give each pupil a small piece of solid carbon dioxide. They should watch it change its state as it warms up in the room. They should not be allowed to handle it with their bare hands. They should put a small piece in a Polythene bag with the air squashed out and seal the bag, so that they can see the bag expanding as the carbon dioxide evaporates.

Note

The carbon dioxide 'snow' is prepared by opening the valve of the cylinder so that the gas escapes into a bag of closely woven material held over the jet of the dry ice attachment. A 5 or 10 second 'burst' is sufficient: the solid CO_2 can be peeled off the inside of the bag. It may be necessary to invert the cylinder if it is the type without a siphon tube. The CO_2 in the cylinder is liquid at room temperature and it is latent heat of vaporization that is responsible for the cooling to freeze a little to solid.

See also the note in Section C of the *Nuffield Guide to Physics Apparatus* for details on how to obtain solid CO_2 in block form.

76 *Class experiment*

Examination of boiling

Apparatus

16 Pyrex beakers (400 ml)	– item 512/2
16 Bunsen burners	– item 508
16 tripods	– item 511

Procedure

The pupils should half fill the beaker with water and then bring it gently to the boil. They should watch the process carefully, observing the formation of bubbles.

Except with a very able group it is better to let pupils carry out the experiment the first time without a thermometer in the water.

77 Demonstration

Change of volume: water to steam

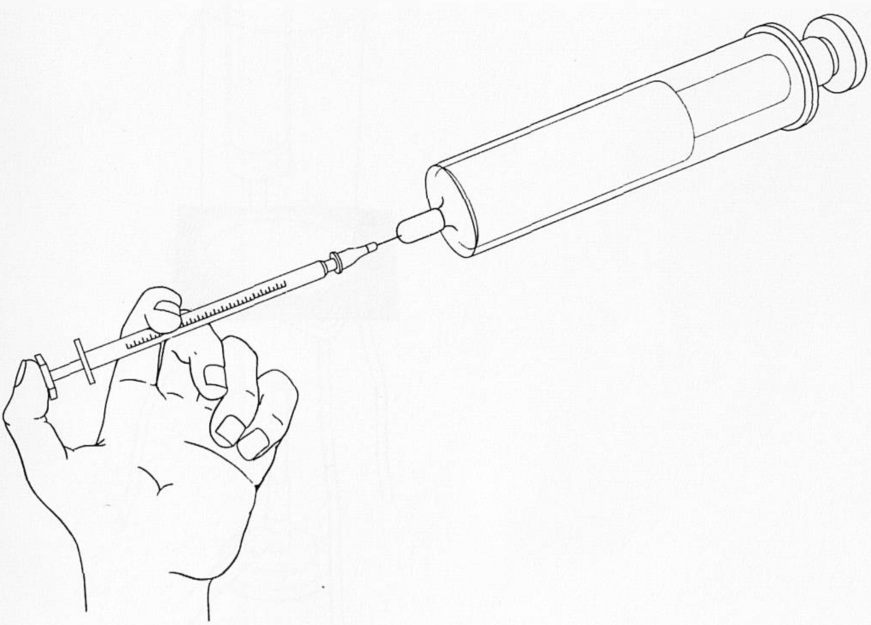
Apparatus

1 syringe kit	– item 148
2 Bunsen burners	– item 508
2 deep beakers	– item 513
2 tripods	– item 511
brine	

Procedure

As it takes time to heat the syringe, it is recommended that the syringe be pre-heated before the arrival of the class.

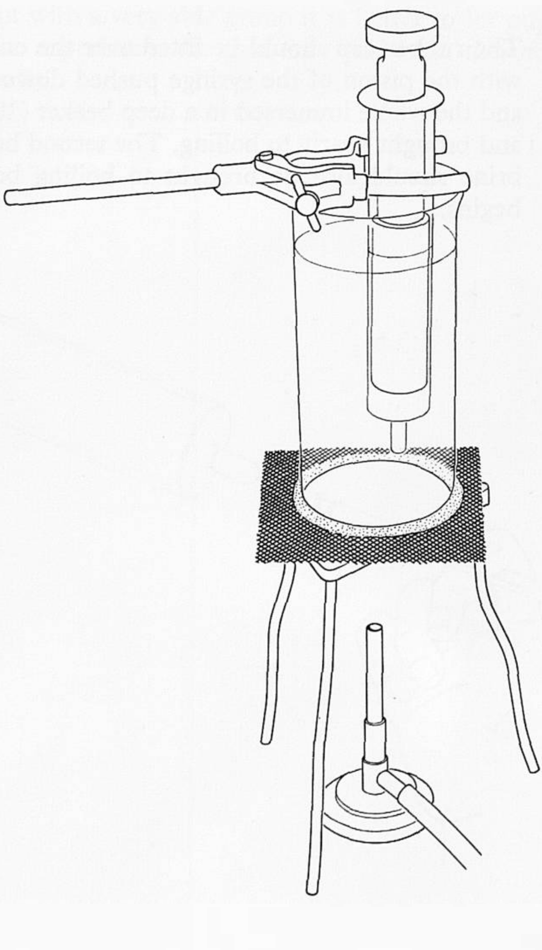
The rubber cap should be fitted over the end of the syringe with the piston of the syringe pushed down to zero volume and the whole immersed in a deep beaker (1000 ml) of water and brought nearly to boiling. The second beaker containing brine should also be brought to boiling before the lesson begins.



For the demonstration, partially fill the hypodermic with water. Remove the large syringe from the hot water. If necessary, hold in a clamp attached to a retort stand. Invert the hypodermic and eject any air in it and then inject $\frac{1}{10}$ ml of water through the rubber cap into the syringe. The cap 'seals' up on removing the needle.

Immerse the large syringe in the boiling brine. The water will turn to steam and the volume change will be observed.

After the water has all turned to steam, the syringe should be removed so that the steam condenses back to water and the decrease in volume will be seen.



Notes

1. It is essential that the syringe be internally dry before use.

2. Twisting the piston as the volume changes may be helpful, though pupils will doubtless call this cheating unless the decrease in volume on condensation is also shown.

3. The caps provided are tight fitting: this is essential as otherwise they can be blown off.

4. Precise results will not be obtained from this experiment. The accuracy of the experiment will show an order of magnitude: 0/1 ml of water becoming at least 100 ml of steam. (The recognized value is a change of 1 to 1,600.)

78 *Optional demonstration*

Expansion of water on freezing

Apparatus

1 iron flask for freezing	– item 82
freezing mixture of ice and salt	
1 bucket	– item 533

Procedure

The special iron flask is filled with water previously boiled to make it air-free. All air bubbles are removed and the plug is screwed in. The bottle is then buried in freezing mixture and covered with a cloth.

(If solid carbon dioxide is available, the iron flask can be embedded in that.)

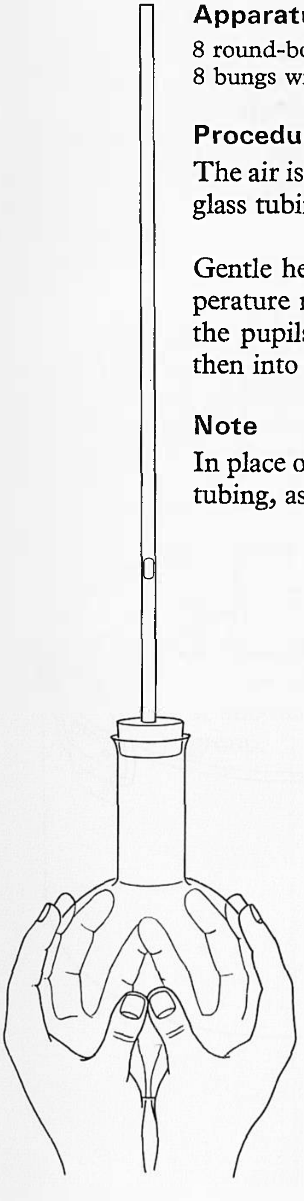
The breaking of the flask will be clearly heard.

Note

To avoid a long wait and uncertain timing, cool the flask in ice-water beforehand.

79 *Class experiment*

Qualitative examination of expansion of gases



Apparatus

8 round-bottomed flasks	– item 548
8 bungs with narrow bore tubing to fit	– item 549/2

Procedure

The air is entrapped in the flask with a small bead of oil in the glass tubing.

Gentle heating with the hand will produce a sufficient temperature rise for the oil index to move up the tubing. Then the pupils should try plunging the flask first into cold and then into warm (not hot) water.

Note

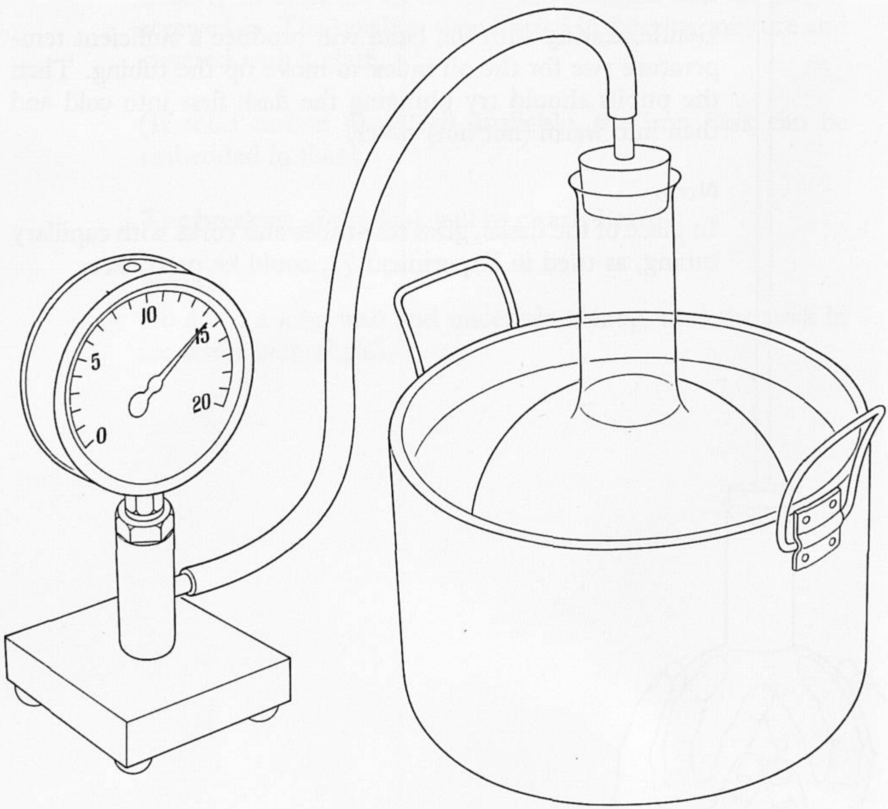
In place of the flasks, glass test-tubes and corks with capillary tubing, as used in Experiment 72, could be used here.

80 *Class experiment*

Pressure change of gases when heated at constant volume

Apparatus

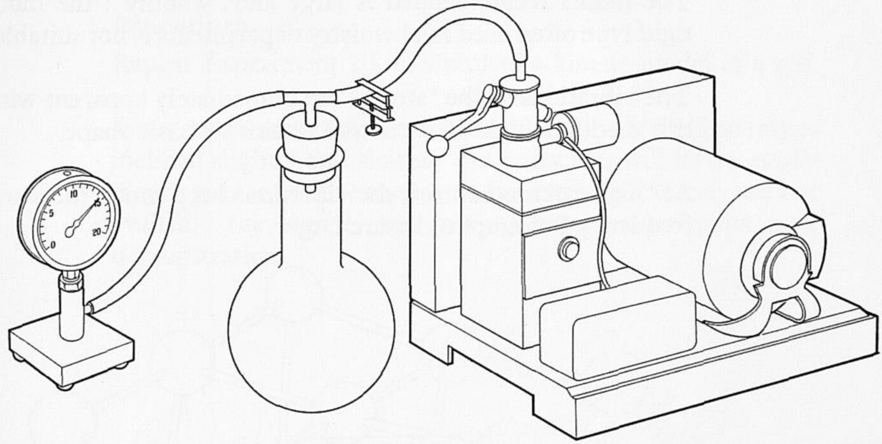
8 Bourdon gauges	– item 67
8 250 ml round-bottomed flasks	– item 548
8 rubber bungs and tubing	– item 549/2
8 aluminium containers	– item 76
8 tripods	– item 511
8 Bunsen burners	– item 508



Procedure

The Bourdon gauge is connected to the flask. It is observed first with the flask in the cold water (preferably at or near the freezing point) and then with the flask in hot water (preferably at or near the boiling point).

The pressure change from atmospheric at freezing point to that at boiling point is of the order of 5·3 lb per sq in.



Note

By using a T-piece and tap or clip, the teacher can pump out, say, two-thirds of the air so that the experiment can be tried at another density. This might be done with a specially fast group.

81 *Demonstration*

Model of vibrating atoms in solids

Apparatus

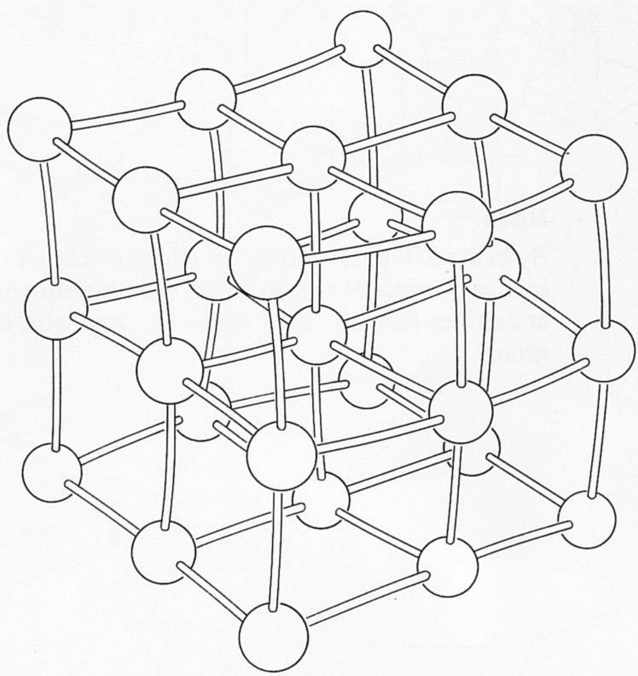
Atom model – item 22

Procedure

The model recommended is large and 'wobbly': the more rigid type often used in chemistry departments is not suitable.

The vibrations of the 'atoms' are immediately apparent with this model though the structure retains its basic shape.

At 'higher temperature', the vibrations keep much the same frequency but amplitudes are larger.



82 *Class experiment*

Models for kinetic picture of liquids and gases

Apparatus

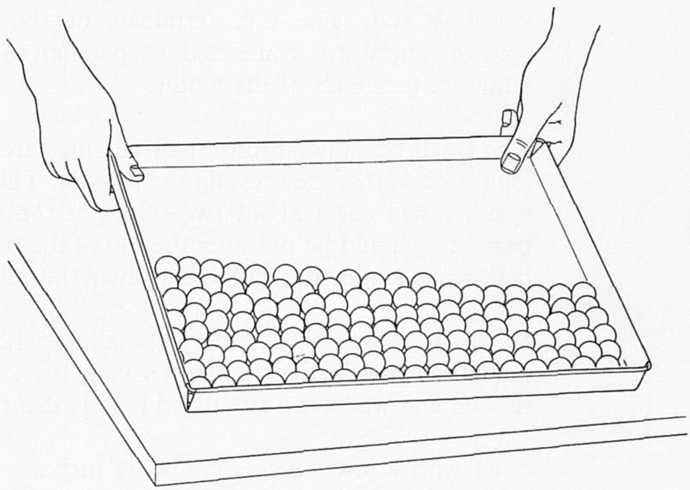
Two-dimensional kinetic model kit – item 12

The kit contains 16 metal trays enabling pupils to work in pairs.

Procedure

Repeat Experiment 70, to simulate a kinetic model of a gas.

For a model of a liquid, more marbles are added. The tray is inclined slightly and shaken. More marbles will be necessary if each pair is to have their own liquid model. If they are not available the teacher will have to show this model as a demonstration.



83 *Demonstration*

Model of gas molecules in motion

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

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.

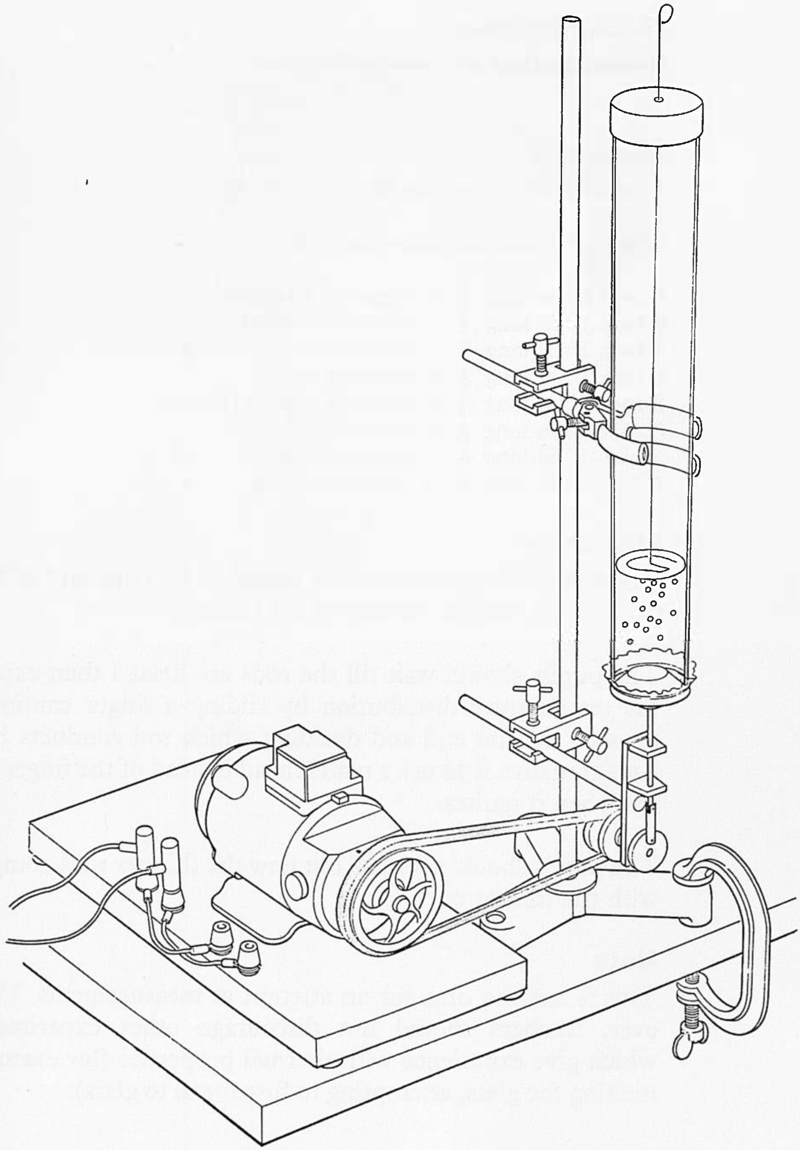
The small phosphor-bronze ball-bearings are put inside the long tube so that they rest on the bottom. The most effective number will cover about two-thirds of the base area. The brass cap should be put over the top of the tube: it prevents balls from coming out and it cuts down the noise.

When the voltage is increased (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.

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.

The 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' up there. Various small cardboard weights can be added on top of the disc.



Note

This experiment, amongst others, can be seen in the Esso-Nuffield film *An Approach to the Kinetic Theory*. This is a film for teachers and not suitable for pupils. It is available on free loan from Esso Petroleum Company, Victoria Street, London, S.W.1.

84 *Class experiment*

Investigation of conductivities

Apparatus

1 conductivity kit – item 56

The kit includes the following rods:

8 rods 10 in long $\frac{1}{8}$ in diameter – copper
8 rods 10 in long $\frac{1}{8}$ in diameter – brass
8 rods 10 in long $\frac{1}{8}$ in diameter – aluminium
8 rods 10 in long $\frac{1}{8}$ in diameter – iron
8 rods 10 in long $\frac{1}{8}$ in diameter – glass (Pyrex)
8 rods 10 in long $\frac{1}{16}$ in diameter – copper
8 rods 10 in long $\frac{1}{16}$ in diameter – brass
8 rods 10 in long $\frac{1}{16}$ in diameter – iron

Procedure

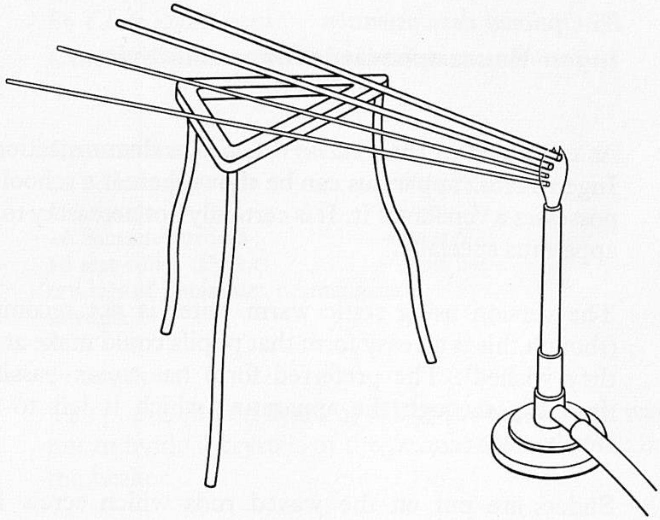
The rods are supported on the tripod so that one end of each projects on into the middle of the flame.

The pupils should wait till the rods are heated then explore the temperature distribution by sliding a finger cautiously towards the hot end and deciding which rod conducts best. An alternative is to use a match head instead of the finger and see when it ignites.

The pupils should also find out how the thinner rods compare with the thicker ones.

Note

This is not the time for an attempt at measurements. However, teachers should not discourage other experiments, which give experience with thermal properties (for example: melting the glass, attempting to fuse metal to glass).



85 *Optional demonstration*

Ingen-Hausz apparatus for conductivity

As explained in the *Teachers' Guide*, a demonstration of the Ingen-Hausz apparatus can be shown here if a school already possesses a version of it. It is certainly not necessary to buy the apparatus specially.

The version using static warm water is not recommended (though this is an easy form that pupils could make at home if they wished). The preferred form has steam passing continuously through the apparatus, which is left to attain a steady state.

Sliders are put on the waxed rods which screw into the steam chamber. As the wax melts, the sliders slip down to the point at which the temperature is that of melting wax. The distances for the steady state indicate conductivities, though not proportionally.

The rods must be coated beforehand with a fairly even, thin layer of wax. Any of the following methods will serve:

1. The rods are unscrewed from the steam box laid in a chilled tin tray containing molten paraffin-wax, removed quickly, held vertically to allow the excess wax to drain off, and screwed into the steam box. The rods are screwed into the steam box with the sliders held on them at the top.

2. The rods are kept in their vertical position, screwed into the steam box; the sliders are held at the top, while each rod in turn is coated with wax by bringing up a very tall Pyrex test-tube of molten wax round it. (This is an easy method if a glass blower is available to make a special tube. The wax in the tube must be heated above melting point.)

3. The rods are kept screwed into the steam box, the sliders are held at the top, and each rod is painted with a paint brush dipped in very heated molten wax. This produces an uneven thick coating of wax, which must then be thinned by blowing a Bunsen flame up and down the rod. (This is the poorest method, only successful in very skilful hands.)

86 *Class experiment*

Convection currents in liquids

Apparatus

16 beakers (600 ml) – item 512/3
16 tripods – item 511
16 Bunsen burners – item 508
16 test-tubes (Pyrex) – item 546
crystals of potassium permanganate
sawdust

Procedure

The pupils should begin by filling the beaker with water, then put individual crystals of the permanganate on the bottom of the beaker.

The water is then *gently* heated over the Bunsen burner and the motion of the dye observed. For clear effect, use a small flame and no gauze between Bunsen and beaker (Pyrex beakers *do* stand this).

The experiment should also be tried in a test-tube. Repetitions of the experiment should always start with a new lot of cold water.

When pupils proceed to boil the water, the motion is more clearly displayed with the sawdust.

Note

Some pupils will want to watch the boiling process. They should not be discouraged from repeating Experiment 76.

87 Class experiment

Convection in a test-tube

Apparatus

32 test-tubes (hard glass)
32 Bunsen burners – item 508
potassium permanganate crystals

Procedure

The pupils should be instructed to fill the hard glass test-tube with cold water. When the water is still, they should drop in a single very small crystal of potassium permanganate so that it falls to the bottom, leaving little colour.

First the test-tube should be held in the bare fingers near the top of the water but not above water level. It should then be heated with a Bunsen flame at the bottom of the tube as long as it can be held with bare fingers. The Bunsen flame should not be too vigorous. Each pupil should watch the dye in his own test-tube.

The test-tube should be emptied, cooled, washed and filled again with cold water. When at rest, a very small crystal of dye is again added without stirring.

This second time the tube is held at the bottom with bare fingers and heated with the Bunsen flame near the top of the tube, just below the water surface. Heating should continue as long as the tube can be held and the pupil observes as before.

See the *Teachers' Guide* for a discussion of the aims of this experiment.

Note

The teacher should remember that some children, whose skin is easily burned, do not notice much pain during the original contact. Therefore, although it is very important for children to feel the temperature changes directly, the teacher should warn them to be careful not to hold the tube when it feels too hot for comfort. Test-tube holders – or their equivalent made from folded pieces of paper – spoil this experiment.

88 *Demonstration*

Convection in a Bunsen flame

Apparatus

1 compact light source	– item 21
1 Bunsen burner	– item 508
1 translucent screen	– item 46/1
1 L.T. variable voltage supply	– item 59

Procedure

The Bunsen is lit and put one to two feet in front on the compact light source and a shadow is cast either on to the wall or on to the translucent screen. The pupils should look at the shadow and discuss what they see with the teacher.

The compact light source needs 12 volts and takes 8 amps. It may be connected to the L.T. variable voltage supply set at 12 volts.

89 *Class experiment*

Transmission of radiation

Radiation 'circus'

The following experiments, 90–96, should be done as a 'circus' by the pupils passing from one experiment to the next. In these we give pupils clear instructions, yet the experiments are 'open' in a different sense: the pupils are asked to extract as many conclusions or inferences as they can from what they observe. See the discussion in the *Teachers' Guide*.

Apparatus

4 heating elements	– item 58C
4 asbestos sheets with holes	– item 58E
4 retort stands, bosses, and clamps	– items 503–506

Method of detection

In the experiments that follow, special detecting instruments such as thermopiles are deliberately avoided. Pupils use their own skin as the detecting device, their cheeks or the backs of their hands.

Source of radiation

Heating elements from bowl fires are used as the source of radiation and are included in the radiation kit. They can be improved by shortening the wire by 10–20 per cent so that the heater runs at a higher temperature.

If the heating element is not available, a 'tree' from a gas fire can be hung by a length of stout iron wire in a Bunsen flame. When fully heated, this will radiate well.

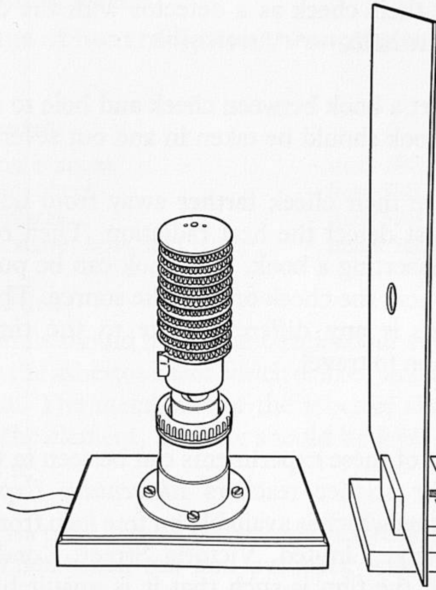
Procedure

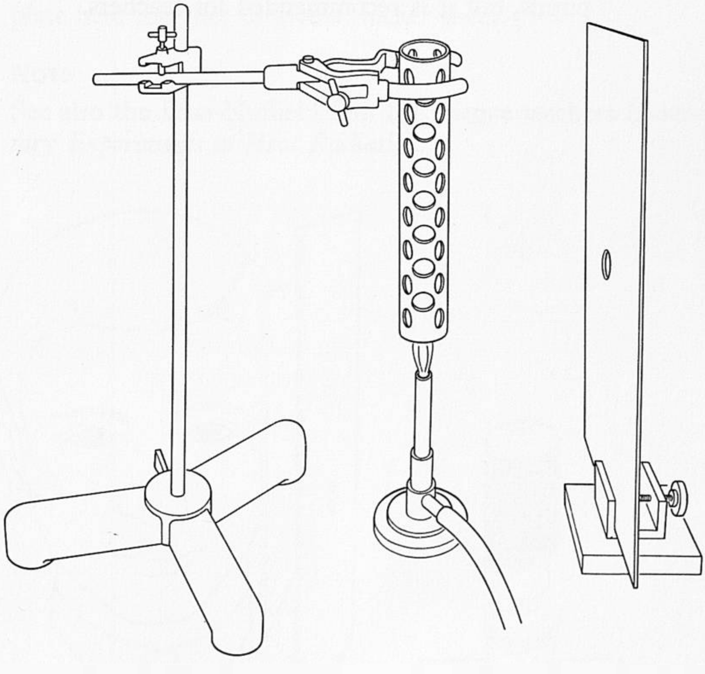
The heater is set up on the bench connected to the a.c. mains. In front of it is fixed the asbestos sheet, held with a retort stand, boss, and clamp so that the metal side is towards the heater and the hole is level with the glowing element.

The pupils should:

1. Look at the element through the hole,

2. Put the back of their hand near the hole to feel the radiation,





3. Use their cheek as a detector with the cheek 10 in away from the hole.

4. Insert a book between cheek and hole to see what happens – the book should be taken in and out several times,

5. Move their cheek farther away from hole until they can only just detect the heat radiation. Then repeat the experiment inserting a book. The book can be put in by a partner either near the cheek or near the source. Then pupils can see if there is any difference due to the time taken for the radiation to travel.

Note

Details of these experiments can be seen in the Esso-Nuffield film for science teachers *Elementary Experiments in Heat Radiation* which is available on free loan from Esso Petroleum Company, Limited, Victoria Street, London, S.W.1. The pace of the film is such that it is unsuitable for showing to pupils, but it is recommended for teachers.

90 *Class experiment*

Passage of heat radiation through glass – 1

Apparatus

1 heating element	– item 58C
1 asbestos sheet	– item 58E
4 glass plates	– item 58F
1 retort stand, boss, and clamp	– items 503–506

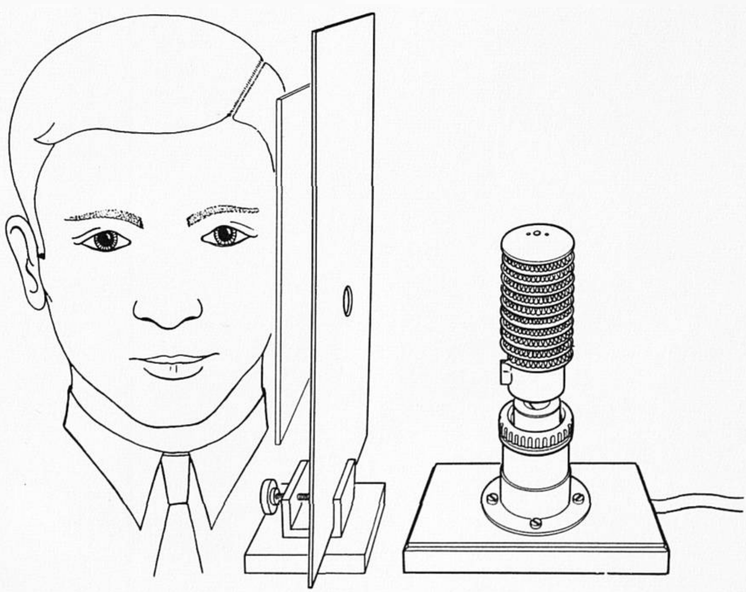
Procedure

The pupils should hold their cheek about 10 in away from the hole in the asbestos sheet which is fixed in front of the heating element. The metal side of the asbestos sheet should be towards the element, the hole should be level with the glowing part of it.

The glass plate should be inserted between the cheek and the hole. Then taken out and put back whilst the pupil notes what he feels. It may be repeated using two sheets of the glass plate held together to give a thicker sheet.

Note

See also the Esso-Nuffield film for science teachers *Elementary Experiments in Heat Radiation.*



91 *Class experiment*

Passage of heat radiation through glass – 2

Apparatus

1 heating element	– item 58C
1 asbestos sheet	– item 58E
4 glass plates	– item 58F
1 retort stand, boss, and clamp	– items 503–506

Procedure

As an addition to the previous experiment, the pupil holds the sheet of glass beside his cheek and moves up very close to the hole in the asbestos sheet in front of the heating element, keeping the glass between the cheek and the hole. Then he takes the glass away.

Note

This is most effective with a thick plate – for example, two thin plates (item 58F) held together.

92 *Optional additional experiment*

Absorption of radiation by slab of rocksalt

Apparatus

1 heating element	– item 58C
1 asbestos sheet	– item 58E
1 retort stand, boss, and clamp	– items 503–506
1 slab of rocksalt	

The rocksalt need not have polished faces.

Procedure

If a slab of rocksalt is available, pupils should repeat the previous two experiments using rocksalt in place of the plate of glass.

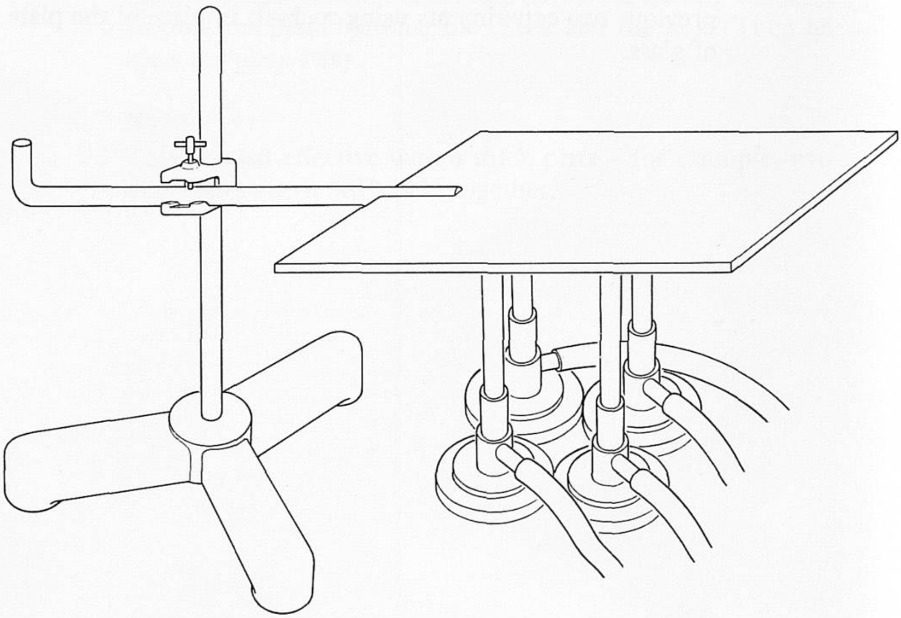
93 *Class experiment*

Comparison of the emission of radiation from a dull black and a shiny surface

Apparatus

1 copper sheet	– item 58D
vegetable black	– item 58B
1 retort stand, boss, and clamp	– items 503–506
4 Bunsen burners	– item 508
methylated spirit	

The mounted copper sheet is made from a sheet of $\frac{3}{16}$ in copper, blackened on one side, with $\frac{1}{2}$ in iron rod handle secured rigidly with two nuts and bolts.



Procedure

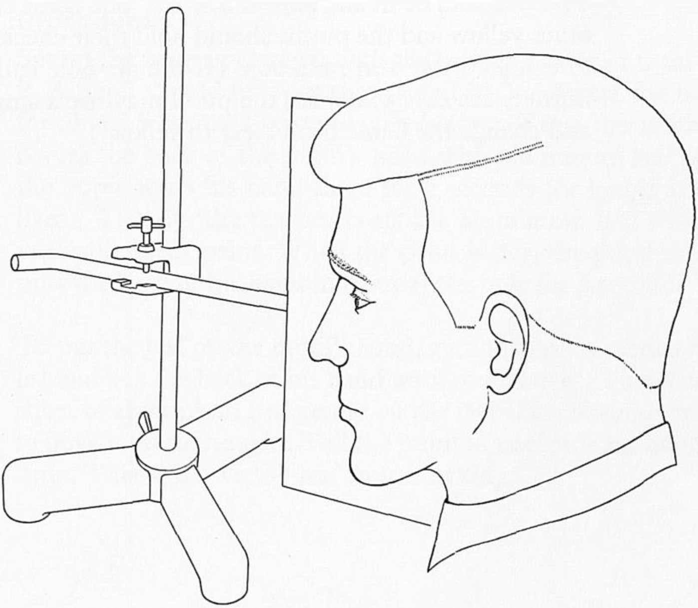
One side of the copper sheet should be given a coat of vegetable black mixed with methylated spirit and allowed to dry so that it has a dull black surface. The other side of the plate should be polished bright, though tarnishing in the flame is inevitable.

The copper sheet is secured rigidly to the retort stand, using a boss, so that the sheet is horizontal with the bright side downwards. It is then heated vigorously with four Bunsen burners underneath until it is as hot as possible.

The Bunsen burners are removed and the plate turned so that it is vertical.

Pupils should successively (and as quickly as possible), hold their cheek first near the bright side then the black side and then back near the bright side.

The plate should be re-heated after every 6–8 pupils have tried it.



Note

It is recommended that teachers should see the Esso-Nuffield film *Elementary Experiments in Heat Radiation* which shows this experiment. It is available on free loan from Esso Petroleum Company, Limited, Victoria Street, London, S.W.1. It is intended for teachers and is not suitable for showing to pupils.

94 *Class experiment*

Emission of radiation from Bunsen flames

Apparatus

16 Bunsen burners – item 508

Procedure

The object of the experiment is to compare the radiation from a clear Bunsen flame and from a yellow flame.

Each group of four pupils requires two Bunsen burners. These should be lit and adjusted so that one flame is clear, the other yellow and the pupils should hold their cheek near each to compare the heat radiation. (If the air-hole collars of the burners are easy to adjust, the pupil may use a single burner and change the flame from clear to yellow.)

95 *Class experiment*

Detection of heat radiation with different surfaces

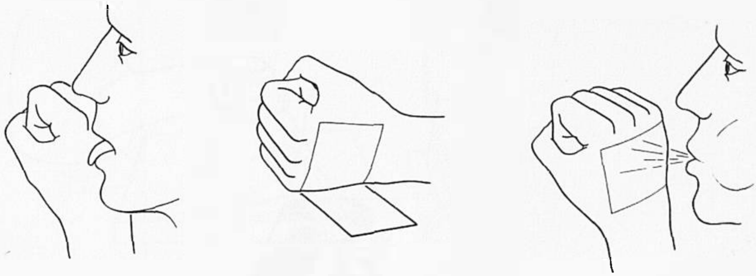
Apparatus

1 heating element	– item 58C
1 asbestos sheet with hole	– item 58E
1 retort stand, boss, and clamp	– items 503–506
aluminium leaf	– item 58A
vegetable black	– item 58B
1 1 in paint brush	
1 crystallizing dish	– item 528
methylated spirit	

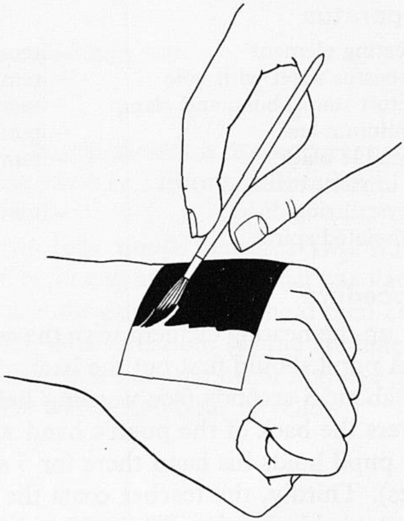
Procedure

Set up the heating element with the asbestos sheet in front of it. A pupil should first put the back of his hand near the hole for about 5 seconds (see warning below). Then the teacher covers the back of the pupil's hand with aluminium leaf and the pupil holds his hand there for 5 seconds (or longer if he likes). Thirdly, the teacher coats the aluminium leaf with a vegetable black paint. When the paint is dry, the pupil again puts the back of his hand in front of the hole for 5 seconds.

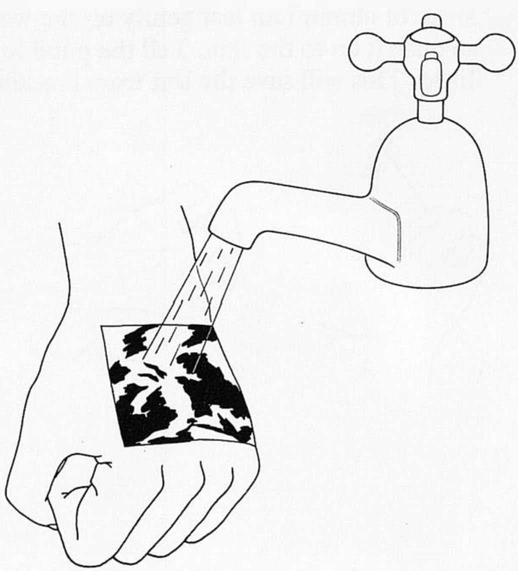
To put the leaf on the pupil's hand, get the pupil to clench his fist and lick the back of his hand until wet all over. Then lay a sheet of aluminium leaf gently on the wet skin, blowing on it to push it on to the skin. Tell the pupil to unclench his hand a little. This will save the leaf from cracking.

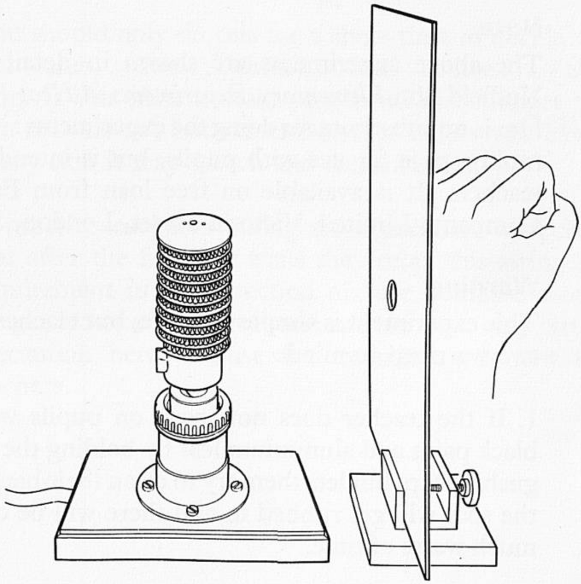


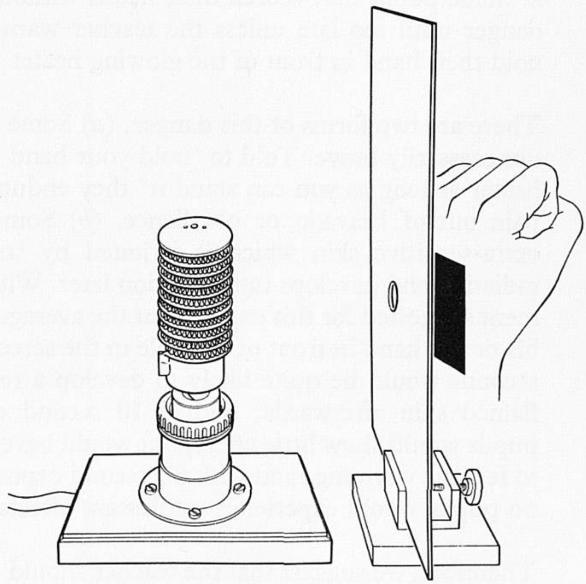
To blacken the aluminium leaf, mix some vegetable black with methylated spirit to the consistency of thick soup. Apply with a 1 in soft paint brush on top of the leaf.



To get rid of the paint and leaf, pupils should hold the hand under a running tap and above all they should not try to rub off the paint or leaf.







Note

The above experiments are shown in detail in the Esso-Nuffield film *Elementary Experiments in Heat Radiation.* The film is no substitute for doing the experiments: it goes at far too rapid a pace for use with pupils, but is intended for science teachers. It is available on free loan from Esso Petroleum Company, Limited, Victoria Street, London, S.W.1.

Warning

This experiment is simple and safe, but teachers need to keep two warnings in mind:

1. If the teacher does not insist on pupils washing off the black paint and aluminium leaf by holding the hands under a gushing tap, but lets them try to clean their hands by rubbing, the soot will get rubbed in and there will be complaints and much waste of time.

2. Some pupils may scorch their hands without realizing the danger until too late unless the teacher warns them not to hold their hand in front of the glowing heater too long.

There are two forms of this danger: (*a*) Some pupils may be unnecessarily brave. Told to 'hold your hand in front of the heater as long as you can stand it' they endure considerable pain out of bravado or obedience. (*b*) Some pupils have extra-sensitive skin which is irritated by strong infra-red radiation and develops inflammation later. With the arrangement suggested for this experiment the average pupil holding his or her hand in front of the hole in the screen for about 20 seconds would be quite likely to develop a red patch of inflamed skin afterwards; with a 10 second exposure most pupils would show little effect, but would have plenty of time to feel the warming; and with a 5 second exposure we believe no pupils would experience unpleasant effects.

Therefore, we suggest that the teacher should use the following form of instructions, for the sake of safety:

'Hold your hand close to the hole in the screen, with the back of your hand towards the red-hot heater. Notice what you feel. Do not hold your hand very long, in case you scorch it.

You should only do this for a short time to decide what you feel – one . . . two . . . three . . . four . . . five . . . – about that long. If you want to hold your hand there longer than that you may do so; but remember that unless you have a very horny skin it may scorch and feel sore later.'

In practice teachers running this experiment with classes find that after the first few trials they relax this stringent safety requirement in the direction of 'use common-sense'. The danger is not a very great one and we have only stressed the precaution here because the experiment is new to many teachers.

Further experiments on radiation

Procedure

a. Set up a pair of metal-surfaced parabolic mirrors 6–10 ft apart. Position one of the heating elements at the focus of one of them. Move the back of the hand or the cheek in front of the other to find the position of maximum intensity.

If mirrors are not available, two electric bowl fires can be used; one should have a heating element in place, the other should be without it.

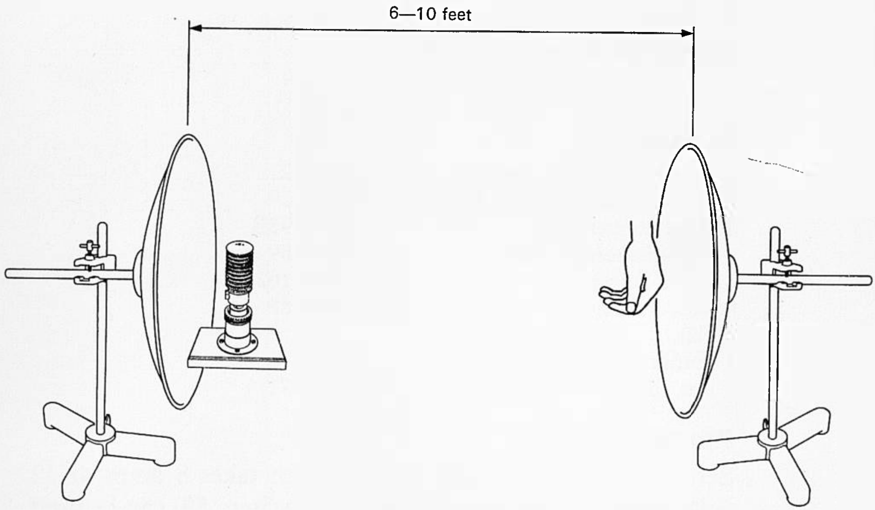
b. Water inside a copper box is kept boiling using an immersion heater. Alternatively the box is kept at 100°C. by passing steam through it. One face is bright; one face is dull black having been coated with vegetable black; one face is covered with white paper pasted on. The back of the hand or the cheek is used to compare the radiation.

c. Experiment 95 can be repeated using white paper on the hand instead of aluminium leaf.

d. A thermometer (0°–100°C.) is put in a metal container filled with boiling water, and the rate of cooling is observed. This should be done first with a well-polished container, secondly with a layer of vegetable black painted on the outside.

e. A 60 watt gas-filled mains lamp and a 60 watt vacuum-filled mains lamp are switched on near each other. The pupils decide, as a detective problem, which of the two has gas inside.

f. Put a cheek near a mains lamp and switch on and off to feel how promptly the radiation reaches the face.


6—10 feet

97 *Demonstration*

Spectrum demonstration

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 large convex lens	– item 93B
1 high-dispersion prism	– item 69
1 white screen	– item 102
1 phototransistor	– item 68
1 cell	
1 demonstration meter	– item 70
1 d.c. dial: 2·5–0–2·5 mA	– item 71/4

Procedure

Set up the compact light source which takes 8 amps at 12 volts. The L.T. variable voltage supply (item 59) can be used for this.

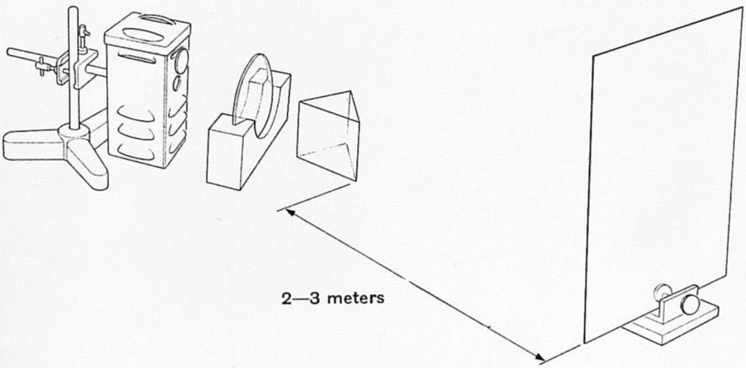
In front of the lamp a fairly wide slit could be put, but in fact this is not necessary with the tungsten-iodine lamp in the compact light source. 20 cm in front of the lamp, position the plano-convex lens with the plane surface towards the source. This will form an image of the hot filament far away. After the lens, and near to it, put the high-dispersion prism and position the white screen so that it is at the image distance from the lens. The spectrum will be seen. The phototransistor is connected in series with a 1·5 volt cell and the demonstration meter with a 2·5–0–2·5 mA scale. The metal cap provided should be placed over the phototransistor, leaving a slit through which the radiation passes.

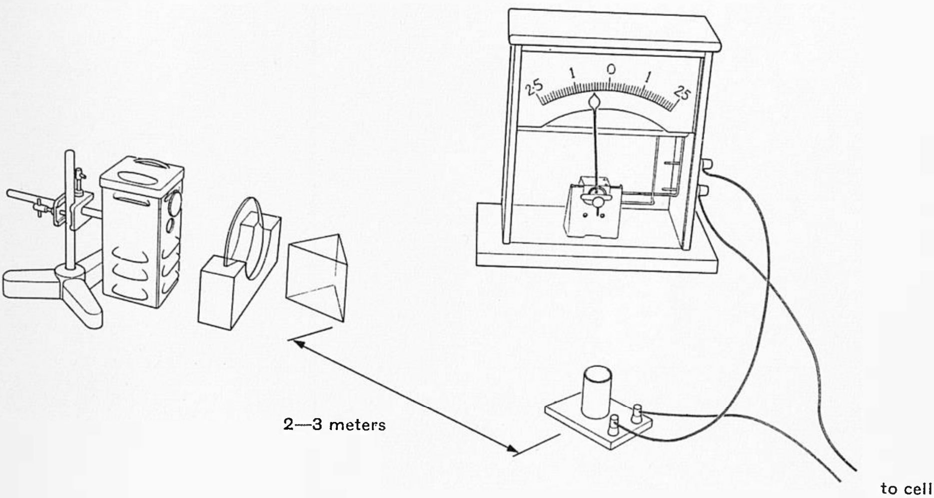
The phototransistor is moved through the visible spectrum showing the response on the galvanometer. It will be clear that there is radiation beyond the visible end of the spectrum.

Notes

1. Because the prism and lens are made of glass, there will be a sharp cut-off in the infra-red.

2. The phototransistor is mounted on a board with a red and a black terminal. The red terminal should be connected to the positive side of the cell.


2—3 meters


2.5
1
0
1
2.5
2—3 meters
to cell

Appendix

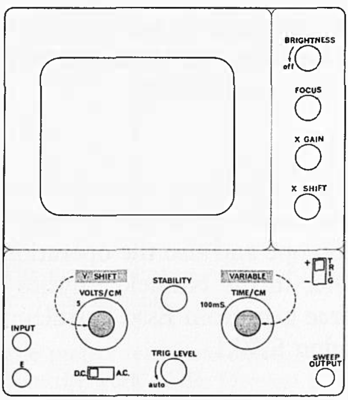
Appendix

Operating instructions for the demonstration oscilloscope

The details and operating instructions given here refer to the Telequipment S51E 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 makers' 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, set the controls as follows:



Brightness to OFF
Focus to the mid-position
X Gain fully anticlockwise
X Shift to the mid-position
Trig to +
Time/cm to 1 ms
Variable fully clockwise
Stability fully clockwise
Trig Level fully clockwise
Volts/cm to ·5
Y Shift to the mid-position
Input Switch to DC

Plug the oscilloscope into the mains supply and 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 by displaying a 50 c/s wave-form and then exploring the action of the various controls (excepting 'Stability' and 'Trig Level' which are set by the above procedure). Details regarding the use of 'Stability' and 'Trig Level' are given in the oscilloscope handbook.

Note: To avoid screen damage, do not use excessive brightness or, with the time-base off, leave the spot in a fixed position for any longer than necessary.

Esso-Nuffield film

Teachers are advised to see the Esso-Nuffield film *Oscilloscopes and slow A.C.* which shows in detail the operation of this demonstration oscilloscope and also the operation of the class oscilloscopes used later in the Nuffield Physics course. The film is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

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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.

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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 III
Guide to experiments IV
Guide to experiments V

Questions book I
Questions book II
Questions book III
Questions book IV
Questions book V