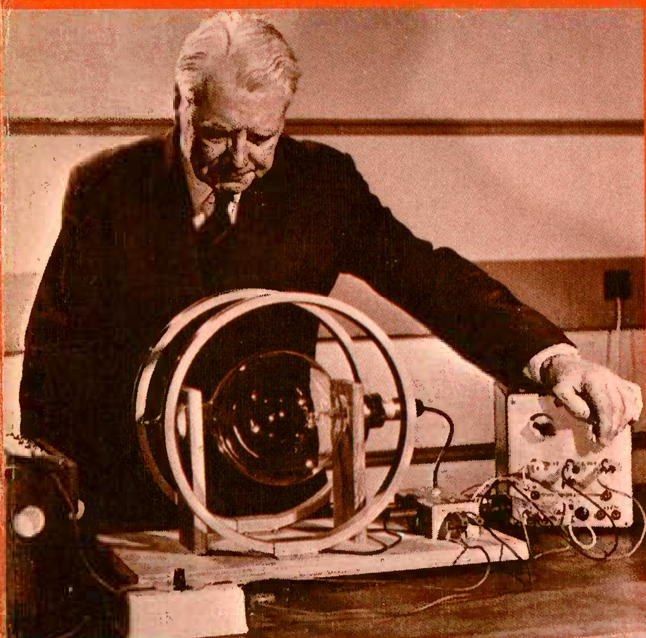
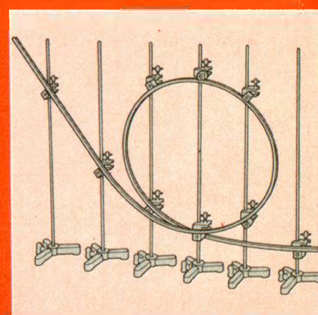
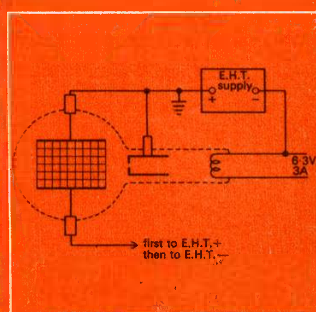
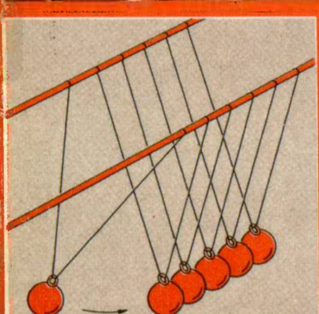
PHYSICS

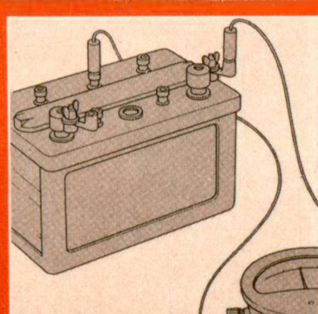
Guide to experiments IV

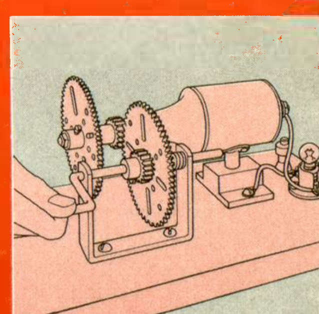












Nuffield Physics Guide to Experiments 4

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Nuffield Physics
Guide to Experiments
4

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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 which the Scottish Education Department and the Association for Science Education, as it now is, were conspicuous) had drawn attention to the need for a renewal of the science curriculum and for a wider study of imaginative ways of teaching scientific subjects. The trustees of the Nuffield Foundation considered that there were great opportunities here. They therefore set up a science teaching project and allocated large resources to its work.

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

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

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

Brian Young
Director of the Nuffield Foundation

Introduction

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

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

Experiments in Year IV

Mechanics

1	*Demonstration*	– Multiflash photographs of free fall.
2	*Demonstration*	– Multiflash photographs of motion down an incline.
3	*Optional Revision Experiment*	– Tickertape technique: investigating motion down an incline.
4	*Class Experiment*	– Constancy of acceleration when a constant resultant force is applied to a mass.
5	*Optional Demonstration or Class Experiment*	– Acceleration which is not constant.
6	*Class Experiment*	– Rough experiments on acceleration.
7	*Class Experiment*	– Quantitative experiments on acceleration.
8	*Demonstration*	– Multiflash photographs of CO_2 pucks being accelerated – I.
9	*Demonstration*	– Estimate of acceleration using a scaler as a millisecond timer.
10	*Optional Demonstration*	– Demonstration trolley to measure velocity and acceleration.
11	*Class Experiment*	– Mass and acceleration. A simple test on the effect of increasing the mass of object accelerated using masses in the ratio 1:2:3 pulled by forces in the ratio 1:2:3.

12	*Optional Class Experiment (Buffer)*	– Acceleration with a fixed force applied to one, two and three trolleys respectively.
13	*Optional Extra Demonstration*	– Multiflash photographs of CO_2 pucks being accelerated – II.
14	*Demonstration*	– Fluid friction and terminal velocity.
15	*Demonstration*	– Frictionless motion: uniform velocity.
16	*Class Experiment*	– Feeling friction.
17a	*Demonstration*	– Illustration of Newton's first law.
17b	*Demonstration*	– Balancing forces without friction.
18	*Demonstration*	– Galileo experiment on a rolling ball.
19	*Class Experiment*	– Rough estimate of g.
20	*Demonstration*	– Measurement of g using a scaler as a timer.
21a	*Optional Demonstration*	– Measuring g with electric stop-clock.
21b	*Optional Demonstration (Buffer)*	– Estimate of g using pulsed water drops with stroboscopic illumination.
22	*Optional Demonstration*	– Measurement of g with multi-flash photographs of free fall.
23	*Demonstration*	– Rockets.
24	*Pupil Demonstration*	– Inertia shown with pendulums.

38	*Class Experiment*	– Bernoulli experiment with sheets of paper.
39	*Demonstration*	– Bernoulli demonstration with water flowing through a tube.
40	*Demonstration*	– Newton's Third Law with a metre rule.
41a	*Class Experiment*	– Elastic collision of trolleys.
41b	*Class Experiment*	– Inelastic collision of trolleys.
42	*Class Experiment*	– Adding mass to a moving system.
43	*Demonstration*	– Multiflash photographs of momentum interchanges.
44	*Optional Demonstration*	– Collision between long pendulums.
45	*Demonstration*	– Collisions between balls.
46	*Class Experiment*	– Explosion of two trolleys.
47	*Class Experiment*	– 'Inverse explosion' with trolleys.
48	*Optional Extra Class Experiment*	– Two dimensional collisions.
49a	*Demonstration*	– Cloud-chamber collisions.
49b	*Demonstration*	– Expansion cloud-chamber.
50	*Optional Home Experiment*	– Collisions with coins.
51	*Optional Demonstration*	– Collisions with electrostatic forces.
52	*Demonstration*	– Head-on collision between trolleys with magnets attached.

Kinetic Theory

101	*Optional Demonstration (Buffer)*	– Photograph of marbles in motion.
102a	*Demonstration*	– Change of volume: liquid air to gas.
102b	*Film*	– Change of volume: liquid air to gas.
103	*Demonstration*	– Simple molecular model.
104	*Chart*	– Chart of molecular data for air.

Universal Conservation of Energy

105	*Demonstration or Class Experiment*	– Converting mechanical energy to heat.
106a	*Demonstration*	– Revision experiment, measuring heat exchanges between hot and cold water.
106b	*Class Experiment*	– Measuring heat.
106c	*Class Experiment*	– Measurement of heat produced on burning 1 ml of alcohol.
106d	*Class Experiment*	– Rough estimate of the specific heat of aluminium.
106e	*Optional Class Experiment*	– Specific heat of aluminium.
107	*Class Experiment*	– Measurement of J.
108	*Demonstration*	– Models.
109	*Demonstration*	– Chart of methods and results of experiments on J.
110	*Demonstration*	– Comparison of the powers of electric motors.

111	*Demonstration*	– Comparison of powers of electric lamps.
112a, b	*Class Experiment*	– Pupils measure their own useful power.
112c	*Wallchart*	– Human energy – food supplies and activity demands.
112d	*Optional Extra Experiment*	– Working against a band brake.
112e	*Optional Home Experiment*	– Output of power cycling up a hill.
113	*Class Experiment*	– The energy transfer box.
114	*Class Experiment*	– The newton balance.

Electricity

115	*Demonstration*	– Series and branching circuits.
116	*Demonstration*	– The water circuit.
117	*Demonstration*	– Electrolysis of copper sulphate solution.
118	*Demonstration*	– Electrolysis of water.
119	*Demonstration*	– Demonstrations with capacitors.
120	*Demonstration*	– Lamp comparison.
121	*Demonstration*	– Comparison of two different electric motors running on the same current.
122	*Demonstration*	– Lamps in parallel.
123	*Demonstration*	– Connecting a voltmeter
124	*Demonstration*	– The water circuit.
125a	*Class Experiment*	– Use of the voltmeter.

136	*Number not used*	
137	*Number not used*	
138	*Demonstration*	– Introduction to voltmeter as a cell counter.
139	*Class Experiment*	– Ohm's Law.
140	*Optional Class Experiment (Buffer)*	– Temperature change and resistance.
141	*Optional Demonstration (Buffer)*	– Relationship between volts and amps for electrolytes.
142	*Demonstration*	– Voltage/current relationship for a gas.
143	*Optional Class Experiment*	– The effect of temperature changes on conductivity.
144	*Optional Demonstration (Buffer)*	– The effect of heat on a thermistor.
145	*Optional Demonstration (Buffer)*	– The effect of heat on common salt and paraffin wax.
146	*Optional Demonstration*	– Current in a heated glass rod.
147	*Optional Demonstration*	– Conductivity of germanium.
148	*Demonstration*	– The transistor.
149a	*Class Experiment*	– Measurement of power transferred with a lamp.
149b	*Class Experiment*	– Measurement of power transferred with a motor.

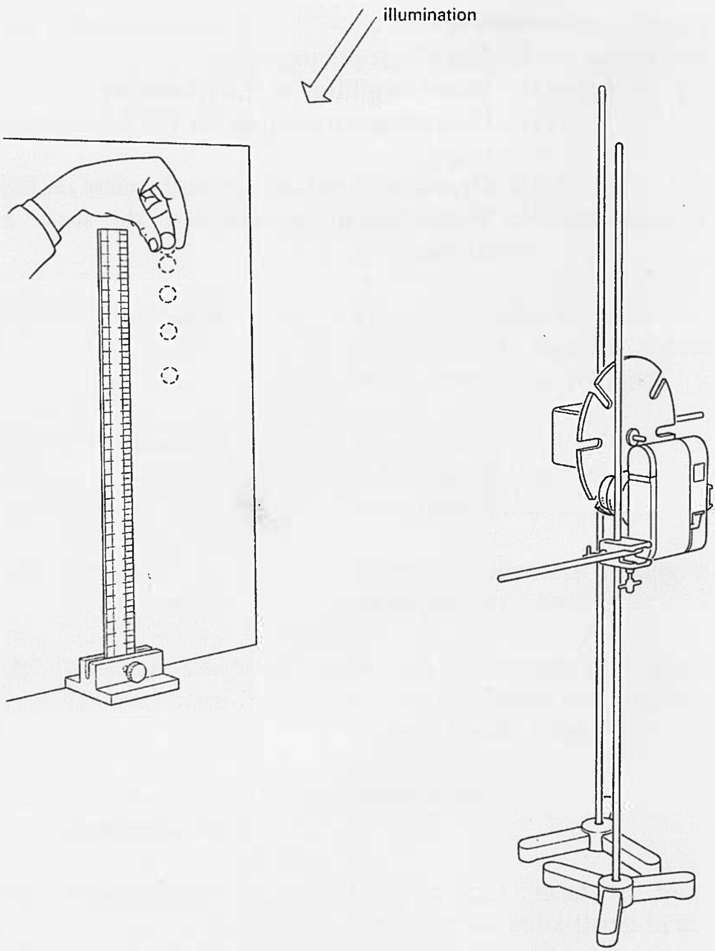
150	*Demonstration*	– Power of a fractional horse-power motor.
151	*Class Experiments and Demonstrations*	– Measuring resistance with a voltmeter and an ammeter.
152	*Optional Class Experiment*	– Fault finding.
153	*Class Experiment with Demonstration*	– Calculation and testing of a resistance to make an arc work from the mains.
154a	*Class Experiment*	– D.C. model power-line.
154b	*Demonstration*	– D.C. model power line at higher voltage.
154c	*Class Experiment with Demonstration*	– Measurement of power in model power-line.
154d	*Class Experiment with Demonstration*	– A.C. power-line.
155	*Optional Additional Class Experiment*	– Electrical measurement of the specific heat of aluminium.
156	*Optional Additional Demonstration*	– Investigation of the light from a lamp.
157	*Optional Demonstration (Buffer)*	– Discussion of power wasted inside a battery.

Electrons

158	*Class Experiment*	– The diode.
159	*Class Experiment*	– The diode as a rectifier shown on the C.R.O.
160	*Demonstration*	– Stream of electrons from a hot filament casting shadows.

161	*Demonstration*	– Stream of electrons first shown striking an inclined screen and then being deflected in an electric field.
162a	*Demonstration*	– Fine-beam tube to show the deflection of electron beam in an electric field.
162b	*Demonstration*	– Fine-beam tube to show the deflection of electron beam using alternating voltages.
163	*Demonstration*	– Fine-beam tube to show the deflection of electron beam in a magnetic field.
164	*Optional Demonstration*	– Stream of electrons hitting a metal plate and heating it.
165	*Optional Additional Demonstration*	– Stream of electrons from a hot filament collected in a cylinder inside a Perrin tube.
166	*Optional Extra Demonstration*	– Positive rays.
167	*Demonstration*	– Positive and negative ions shown by a candle-flame in an electric field.
168	*Demonstration*	– Ions carrying a current through the air.
169	*Demonstration*	– 'Macro-Millikan' apparatus.
170	*Film*	– Millikan's experiment.
171	*Class Experiment*	– Oscilloscopes used to show acoustic wave-forms.
172	*Demonstration*	– The diode as a rectifier shown on a C.R.O.

Appendices


illumination

1 *Demonstration*

Multiflash photographs of free fall

Apparatus

1 steel ball (1 in or $\frac{3}{4}$ in diameter)	– item 131A
1 camera	– item 133
1 motor-driven stroboscope	– item 134/1
1 lamp	
1 metre rule	– item 501

A $2\frac{1}{2}$ in slide projector is suitable for the lamp.

Procedure

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

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

A dry cell to which a pea lamp is attached is an effective substitute for the ball. The cell is dropped as before. Some cushioning on the floor is necessary to prevent breakage of the lamp. Good blackout is advisable for good photographs with this technique.

The picture should include a metre rule so that, later, it may be used in an estimate of '*g*'. The strobe frequency should also be recorded.

Note

See Appendix I at the end of this volume for details of, and methods for, multiflash photography.

2 *Demonstration*

Multiflash photographs of motion down an incline

Apparatus

1 motor-driven stroboscope	– item 134/1
1 lamp	
1 steel ball (1 in or $\frac{3}{4}$ in diameter)	– item 131A
1 camera	– item 133
1 runway	– item 107

A 2 in × 2 in slide projector is suitable for the lamp.

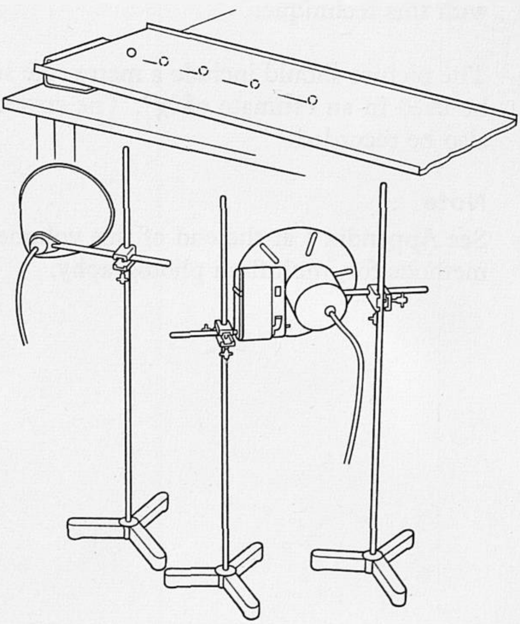
Procedure

Set up a straight inclined plane. Allow the steel ball, which should be well polished, to roll down this incline starting from rest. A fall of about 1 ft in 6 to 8 ft will be found convenient.

Illuminate the ball by the lamp. Three-quarter blackout is needed. Position the camera near to the lamp in such a way that the ball can be conveniently photographed. Start the stroboscope and open the shutter just before the ball is released. Close it when the ball passes out of the field of view.

Note

See Appendix I at the end of this volume for details of, and methods for, multiflash photography.



3 *Optional revision experiment*

Tickertape technique: investigating motion down an incline

Apparatus

16 dynamics trolleys	– item 106/1
16 tickertape vibrators	– item 108/1
16 runways	– item 107

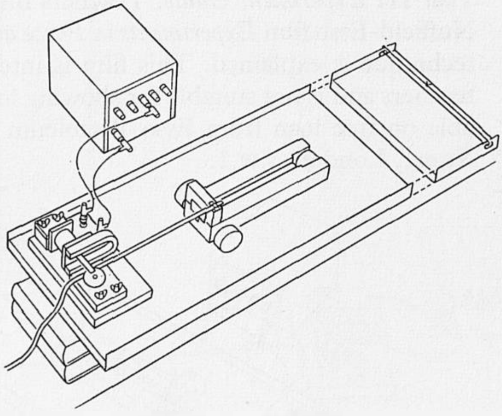
One set for every two pupils.

Procedure

The purpose of this experiment is to remind the pupils of the tickertape technique used in Year III. They should tilt the runway by placing blocks of wood or books under one end to make a slope of about 1 in 10. The trolleys should be allowed to run down the incline starting from rest and a tickertape record obtained.

Each pupil should obtain his own tape and cut it into lengths of ten ticks and paste up a chart (as in the Year III experiments) to revise the earlier work.

See the *Teachers' Guide* for discussion on the choice of a tape chart rather than plotting a graph.



4 *Class experiment*

Constancy of acceleration when a constant resultant force is applied to a mass

Apparatus

16 dynamics trolleys	– item 106/1
16 tickertape vibrators	– item 108/1
16 elastic cords for accelerating trolleys	– item 106/2
16 runways	– item 107

One set for every two pupils.

It is essential to have a plane runway, carefully compensated for friction.

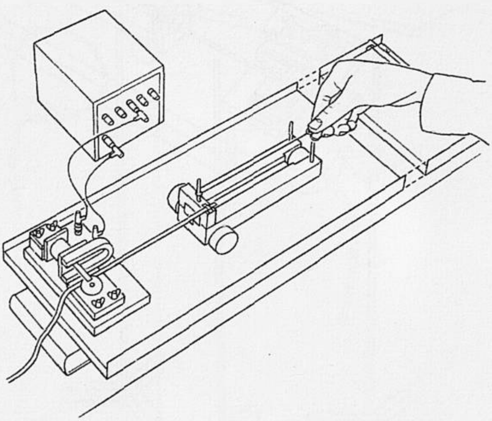
Procedure

This experiment repeats with more care the introductory experiments of Year III on force and acceleration.

With a single piece of stretched elastic used to accelerate a single trolley, a tickertape trace is obtained and the usual tape chart is made.

Film

Details of the use of vibrators and tickertape were given in the Year III *Experiment Guide*. Teachers might also refer to the Nuffield-Esso film *Experiments in Force and Motion* where the technique is explained. This film is intended for the use of teachers and is not suitable for showing to pupils. It is obtainable on free loan from Esso Petroleum Company, Victoria Street, London, s.w.1.



5 *Optional demonstration or class experiment*

Acceleration which is not constant

Apparatus

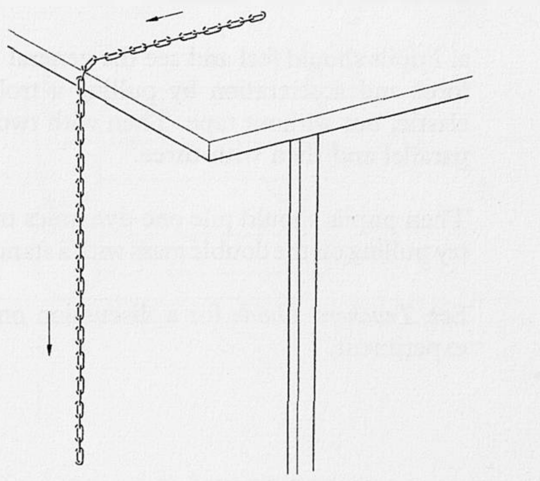
1 or 16 lengths of chain (about 3 ft long)

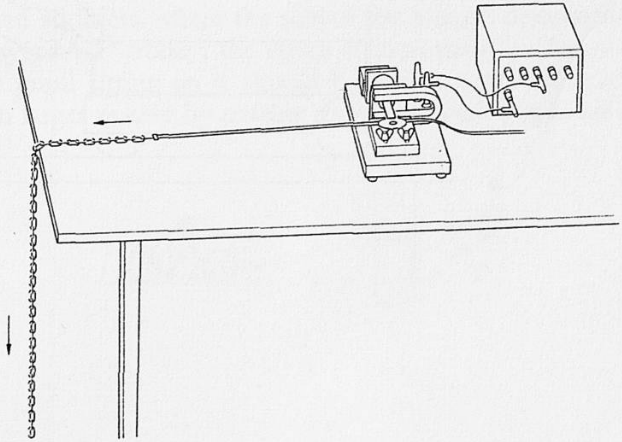
1 or 16 tickertape vibrators – item 108/1

Procedure

The length of chain is placed on a smooth table so that it is at right angles to the edge. The end is then pulled over the edge until, on release, the whole chain slides. Then the hanging portion pulls the rest, with increasing acceleration.

The experiment may then be repeated with a length of tickertape attached to the chain so that a record is obtained.





6 *Class experiment*

Rough experiments on acceleration

Apparatus

a. 32 dynamics trolleys	– item 106/1
48 elastic cords for accelerating trolley	– item 106/2
b. 1 large demonstration trolley	– item 160/1
1 demonstration spring balance (5 kg)	– item 85

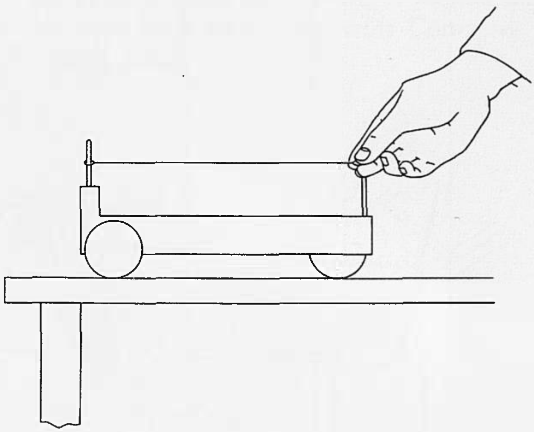
Procedure

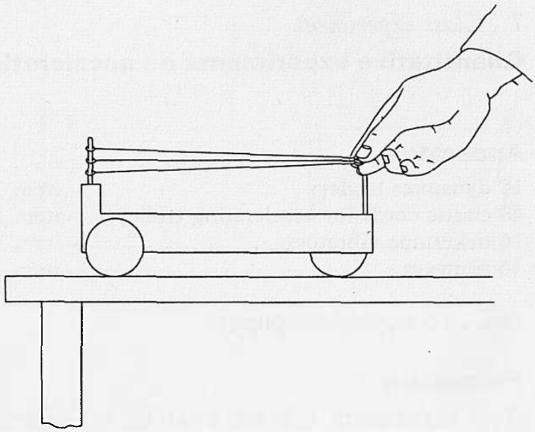
These experiments are intended to be rough preliminary trials done without any measuring instruments. Pupils should acquire their own feeling for the fact that a relatively bigger force gives things greater acceleration. And then with more stuff to be accelerated, either a bigger force has to be used or the acceleration is smaller.

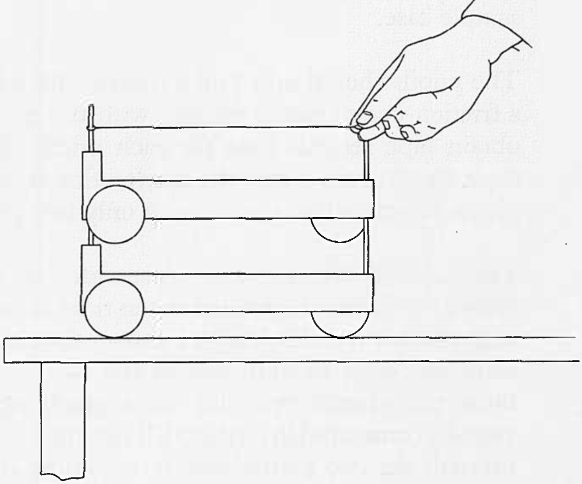
a. Pupils should feel and see the general relationship between force and acceleration by pulling a trolley with a stretched elastic, but without tape. Then with two stretched elastics in parallel and then with three.

Then pupils should pile one dynamics trolley on another and try pulling on the double mass with a standard stretched elastic.

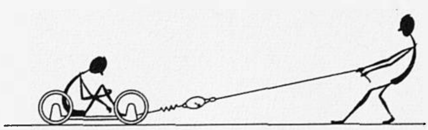
See *Teachers' Guide* for a discussion on the purpose of this experiment.







b. *Additional optional de-luxe experiment.*
As an addition, where the school has a large demonstration 'playground' trolley, the effect of increasing the force with one pupil sitting on it should be shown first. Then repeat with larger masses by putting more and more pupils on it.



7 *Class experiment*

Quantitative experiments on acceleration

Apparatus

16 dynamics trolleys	– item 106/1
48 elastic cords for accelerating trolleys	– item 106/2
16 tickertape vibrators	– item 108/1
16 runways	– item 107

One set for every two pupils.

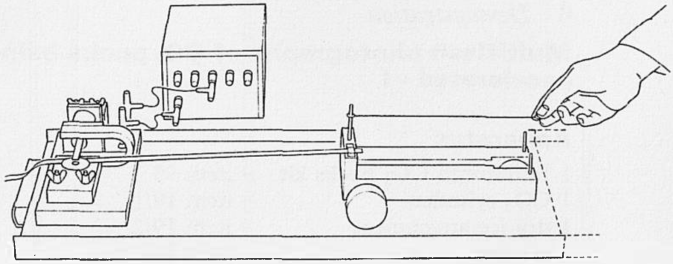
Procedure

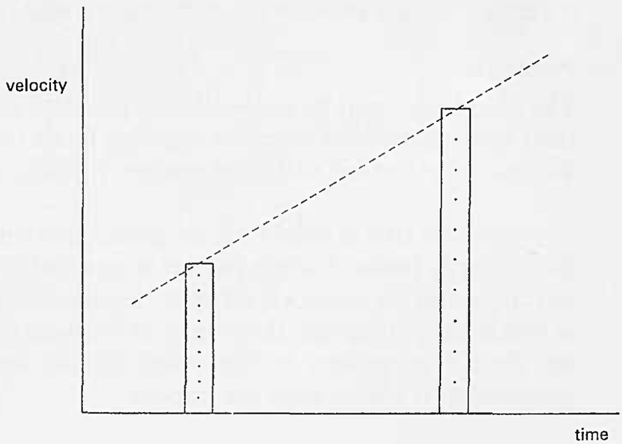
This experiment asks for a careful set of measurements with vibrator and tapes. The tape charts in Experiment 4 should have made clear the *constancy* of the acceleration in one sample case.

The pupils should now pull a trolley with a fixed force along a friction-compensated runway with tickertape attached and obtain tape records (one for each pupil). Since they know from Experiment 4 that the acceleration is constant, they can plot a velocity-time graph using only two points.

They should take a speed, represented by a length of tape giving the distance travelled in ten ticks at an early stage, and then another ten-tick length a known time later, say fifty ticks from mid-time to mid-time of the two samples. They plot these two speeds vertically on a graph against time horizontally (measured in ten ticks). They then draw a straight line through the two plotted points, assuming constant acceleration.

The pupils draw similar graphs when the trolley is pulled by two elastic cords in parallel and, if time permits, also with three.




velocity
time

8 *Demonstration*

Multiflash photographs of CO_2 pucks being accelerated – I

Apparatus

1 Edinburgh CO_2 pucks kit	– item 95
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2
1 camera	– item 133
1 motor-driven stroboscope	– item 134/1
1 lamp	

A 2 in × 2 in slide projector is suitable for the lamp.

Procedure

The glass plate must be very carefully polished using methylated spirit and duster (window-cleaning fluids may be used) and carefully levelled using the wedges supplied with it.

Two or three cm^3 of solid CO_2 are placed underneath one of the magnetic pucks. A white pointer is attached to the puck at its centre, and the camera is set up at the side of the glass plate so that it can photograph the pointer as the puck moves across the plate. The pointer is illuminated by the lamp and the stroboscope is placed near the camera.

The accelerating force in this experiment needs to be very small and the lengths of elastic used with the trolleys are not suitable. Instead a longer length should be used, one end of which is attached to the top of the puck with Sellotape. The stretch on this must be kept uniform. A convenient technique for this is to hold the end against a half-metre rule and ensure that it is always the same distance from the puck. Practice will result in fairly steady forces.

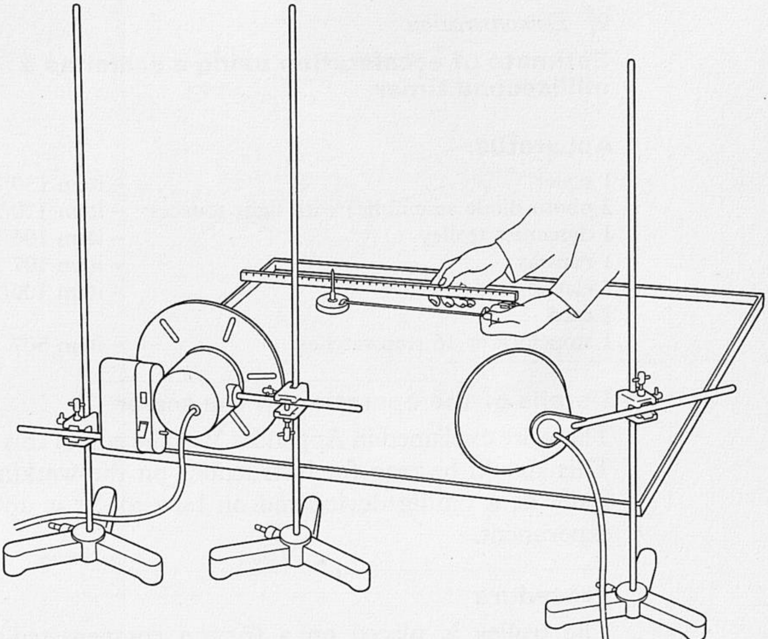
The stroboscope is started. The camera shutter is opened. The puck is released.

Three-quarter blackout is essential for good photographs.

Note

1. See Appendix I at the end of this volume for details of methods for multiflash photography.

2. When using CO_2 cylinders it is necessary to ensure good ventilation.



9 *Demonstration*

Estimate of acceleration using a scaler as a millisecond timer

Apparatus

1 scaler	– item 130/1
2 photo-diode assemblies with light sources	– item 130/2
1 dynamics trolley	– item 106/1
1 runway	– item 107
3 elastic cords	– item 106/2
1 card	
1 stopclock or 16 stopwatches	– item 507

Details of the operation of the scaler

These are explained in Appendix V at the end of this volume. This should be read for instructions on the working of the scaler as a timing device and on how to set it up for this experiment.

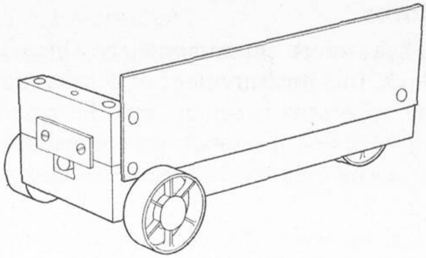
Procedure

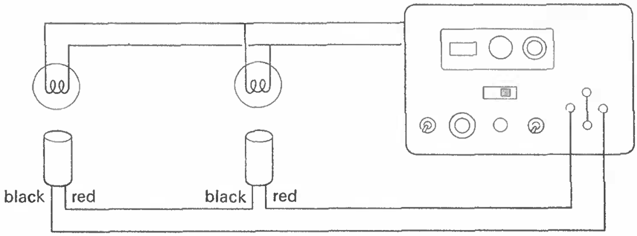
The trolley is placed on a friction compensated runway, released from rest and accelerated by the stretched elastic.

A piece of cardboard either 10 or 20 cm long and 5 or 6 cm high is fixed to the side of the trolley. The time of passage of this card past a 'station' is measured by the scaler, which counts the number of millisecond pulses that elapse while the card is passing an illuminated photo-diode and cutting off the light from it.

Two such stations are set up, one near the beginning of the runway, the other near the end, the separation between them being one metre. At each station there is a small lamp illuminating a photo-diode with a beam of light across the track. The length of the card, when divided by the clock-reading gives a measure of the velocity at which the trolley passes a station. This use of the photo-diode should first be demonstrated.

The two photo-diodes are set up in series and connected to the red terminals of the scaler. They are placed a metre apart and positioned so that card on the trolley will interrupt first the light to one photo-diode, then the light to the other.





Both measurements of the time of passage at each diode can be made in the same run provided there is time to read the scaler between stations. This needs a good observer posted by the scaler.

The overall time which the trolley takes to travel between the two stations should be measured, not with the scaler but with an ordinary clock. A demonstration stopclock can be used or pupils can be given stopwatches for it.

Notes

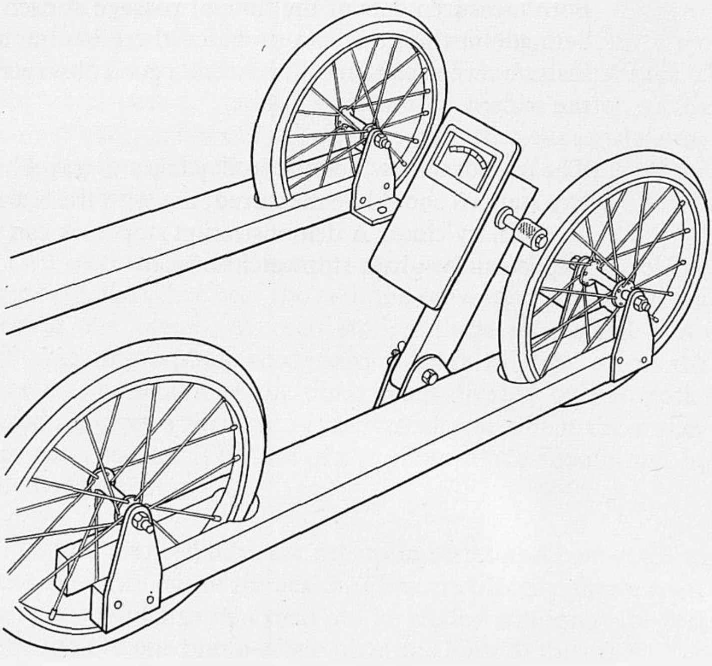
1. Like most experiments in which the scaler is used as a clock, this measurement of acceleration takes little time once the apparatus is set up and the principle is understood. So teachers may prefer to set the experiment up and to let the pupils take their own measurements in groups of two or more.

2. If the scaler does not appear to count correctly when the light is cut off by the cardboard:

(i) try adjusting the relative position of lamp and photo-diode to obtain maximum illumination of the latter;

(ii) try reversing the polarities of the photo-diodes, (*a*) with respect to each other, and (*b*) with respect to the 'make to stop' sockets.

3. A convenient method of attaching the two lamps to the 2–3 V supply on the scaler is to use two short 4 mm stackable plug leads. The photo-diodes can be joined by using one such lead.



10 *Optional demonstration*

Demonstration trolley to measure velocity and acceleration

This is an additional *de luxe* experiment for those who have the apparatus or can make it for themselves.

Apparatus

1 demonstration trolley – item 160/1
1 meter attachment – item 160/2

The meter attachment is a special device, recommended not for general use but for the interest of setting it up and getting it to work.

Procedure

The attachment to the trolley enables one wheel of the trolley to drive a small permanent-magnet d.c. dynamo. The output of the dynamo is fed to a millivoltmeter which will thereby indicate speed. (As an exercise this could be calibrated directly.)

Instead of connecting directly to the millivoltmeter, the output is fed to the primary of a small transformer and the secondary of that transformer is connected to the millivoltmeter. The voltage in the secondary will be roughly proportional to the rate-of-change of the primary current, so that the meter gives a measure of acceleration. (Once again pupils could test whether the meter measures this quantity and can attempt a rough calibration.)

Alternative experiment

An unknown weight, hanging over the edge of the bench, may be used to pull a dynamics trolley with a spring balance installed on the trolley to measure the pull. Such a 'strangmeter' must be well damped and difficulties of construction do not enable the technique to be recommended. By combining the 'strangmeter' with a meter attachment as described above direct readings of speed, acceleration and pull could be obtained.

See diagram opposite.

11 *Class experiment*

Mass and acceleration. A simple test on the effect of increasing the mass of object accelerated using masses in the ratio 1 : 2 : 3 pulled by forces in the ratio 1 : 2 : 3

In this experiment we suggest a special choice of forces and masses, from which we expect to obtain the same acceleration in each case. Therefore, detailed measurements are not necessary: *any* timings that show the acceleration is (approximately) the same in all three cases will suffice.

Apparatus

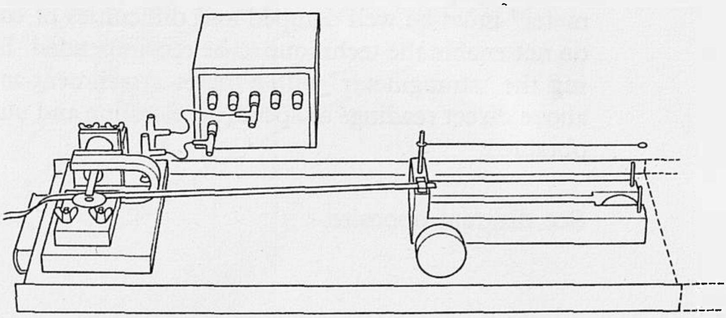
32 dynamics trolleys	– item 106/1
48 elastic cords	– item 106/2
16 runways	– item 107
16 tickertape vibrators	– item 108/1

One set for every two pupils. When each group needs three trolleys, it is suggested they borrow from their neighbours.

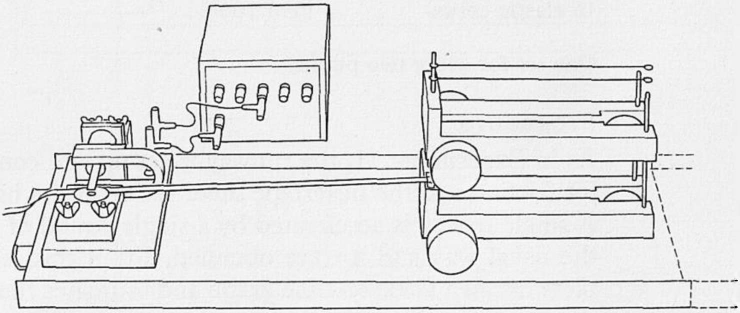
Procedure

For this experiment, pupils find out whether the acceleration is the same in all three cases. Therefore, their analysis of the tape need not be so detailed – in fact, a simple timing of the motion from rest with a stopwatch would suffice, but for the time being very short.

The runway is set up and compensated for friction. The tickertape timer is set up at the higher end. A single trolley is accelerated by a single strand of rubber in the usual way and a trace obtained. From this trace, each pupil makes his own estimate of acceleration. Measurements of two batches of marks would suffice; or a full graph of speed against time may be plotted.



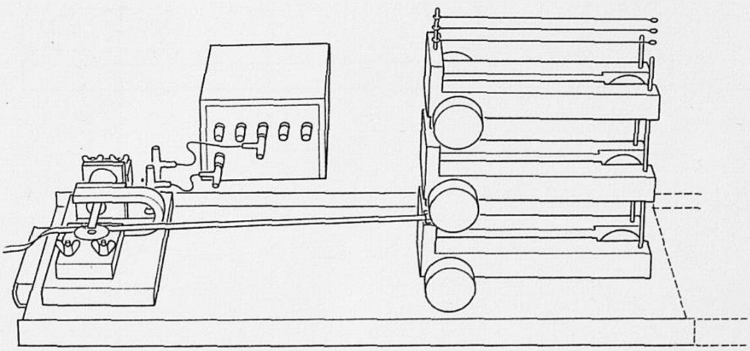
Two trolleys are then stacked on top of each other to serve as a trolley of double mass, twice as much matter. The accelerating force is provided by two identical rubber strands in parallel. The two rubber strands are each kept at the same standard stretch and pupils *assume* that a double force is thus provided. Again, each pupil draws a velocity-time graph and estimates the acceleration.



Then pupils borrow a trolley from neighbours. Three trolleys are stacked on each other and accelerated using three parallel, identical strands of rubber.

It is necessary to arrange the friction compensation with the tape in use and to readjust it anew for each mass. One might expect the proper tilt to be the same for several trolleys as for one; but in practice it often changes and, unless the compensation is made carefully, the experiment does not go well.

For the essential argument in this experiment, see *Teachers' Guide*.



12 *Optional class experiment (buffer)*

Acceleration with a fixed force applied to one, two and three trolleys respectively

Apparatus

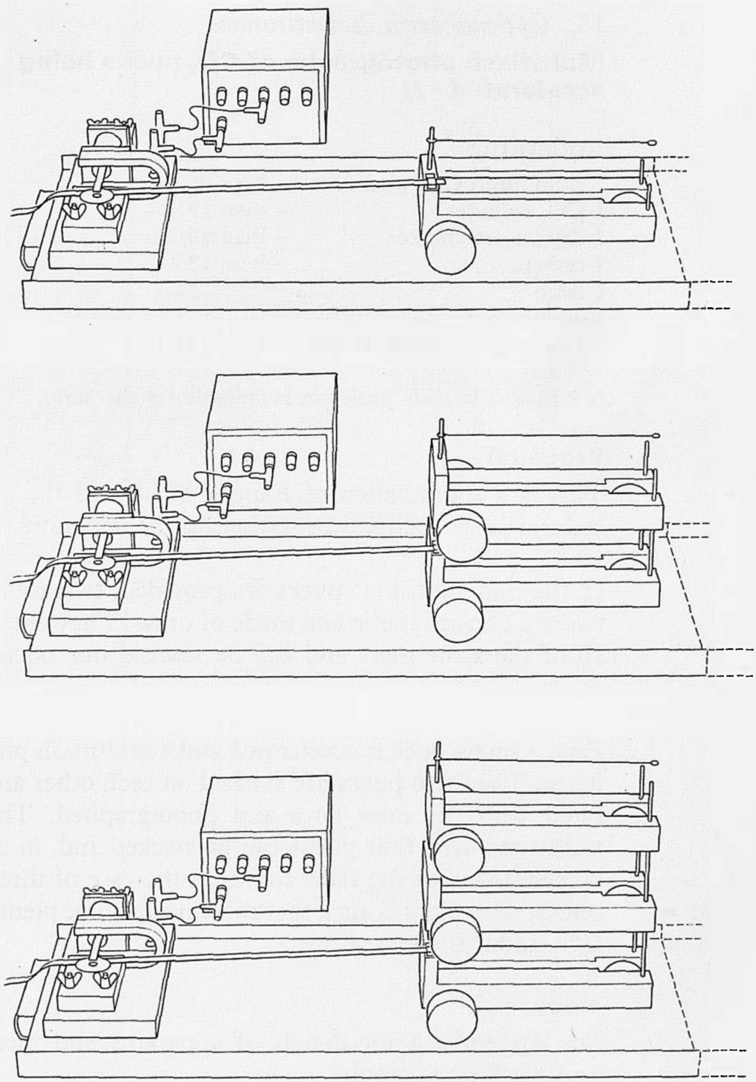
16 dynamics trolleys	– item 106/1
16 runways	– item 107
16 tickertape vibrators	– item 108/1
16 elastic cords	– item 106/2

One set for every two pupils.

Procedure

As in Experiment 11, the runway is set up and compensated for friction and the tickertape timer set up at the higher end. A single trolley is accelerated by a single strand of rubber in the usual way and a trace obtained. From this, each pupil plots his own velocity–time graph and estimates the acceleration.

The *same* force is then used to accelerate two trolleys stacked on each other and then on three trolleys. Each pupil plots graphs and estimates accelerations and compares the results.



13 *Optional extra demonstration*

Multiflash photographs of CO_2 pucks being accelerated – II

Apparatus

1 Edinburgh CO_2 pucks kit	– item 95
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2
1 camera	– item 133
1 lamp	
1 elastic cord	
1 motor-driven stroboscope	– item 134/1

A 2 in × 2 in slide projector is suitable for the lamp.

Procedure

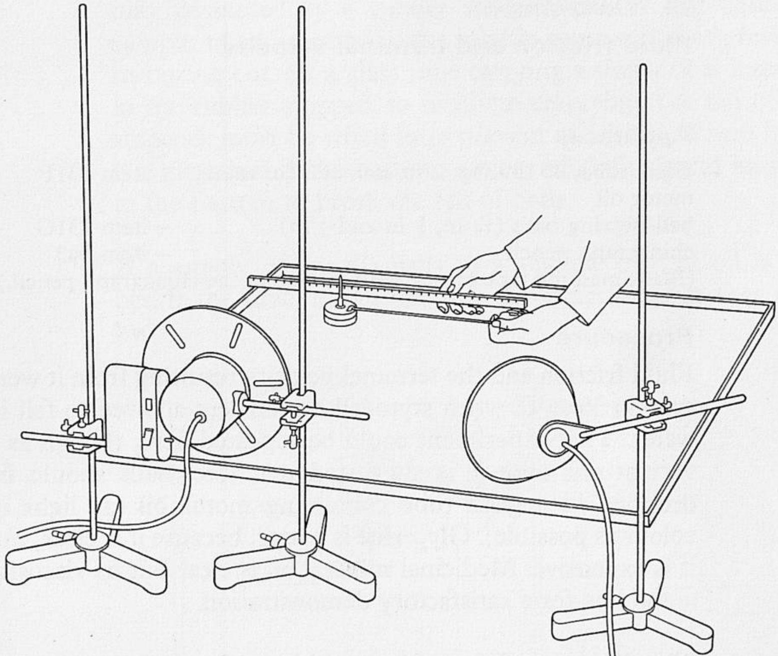
This is a continuation of Experiment 8 and the same procedure should be used in setting up the apparatus.

In the pucks kit, four pucks are provided, two are magnetic, two are non-magnetic and made of brass. They are, however, all of the same mass and can be stacked one on top of the other.

First a single puck is accelerated and a multiflash photograph taken. Then two pucks are stacked on each other and accelerated with the *same force* and photographed. Then three pucks and even four pucks can be stacked and, in each case, accelerated with the same force. In the case of three or four pucks, the weight is such that there needs to be plenty of solid CO_2 under the lowest one.

Note

See Appendix I for details of apparatus and methods for multiflash photography.



14 *Demonstration*

Fluid friction and terminal velocity

Apparatus

Glass tube, 30 in long, 2 in diameter (or more) – item 131F
motor oil
ball-bearing balls ($\frac{1}{16}$ in, $\frac{1}{8}$ in and $\frac{1}{4}$ in) – item 131G
chinagraph pencil – item 543
(Black masking tape can be used instead of the chinagraph pencil.)

Procedure

Fluid friction and the terminal velocity resulting from it were seen in Year II when styrocell beads were allowed to fall in water. That experiment could be repeated here, though as a variant this time it is suggested that steel balls should be dropped in a glass tube containing motor oil (as light in colour as possible). Glycerine is better, because it is clear, but it is expensive. Medicinal mineral oil is clear but its viscosity is too low for a satisfactory demonstration.

The diameter of the tube should be at least 2 in so that the falling balls will not be too near the sides. The balls should be placed in a small dish of oil before use so that each ball is already oily and thus does not carry an air bubble with it.

The outside of the tube is marked at 10 cm intervals with a chinagraph pencil or strips of black masking tape.

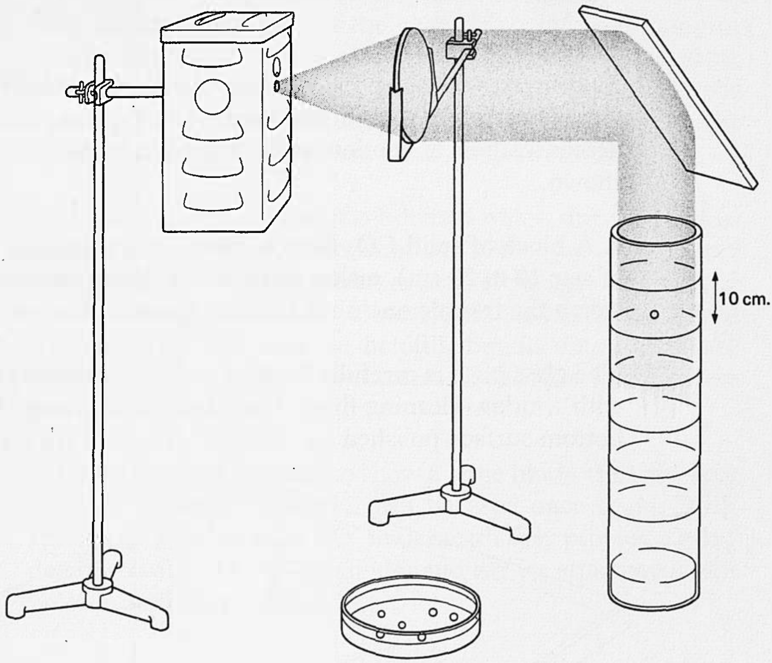
As the falling ball comes level with each mark, the teacher claps his hands or gives some other signal. Stopwatches should not be used. (See *Teachers' Guide*.)

Special illumination is helpful. If the room can be partially darkened, and if the oil is of a light colour so that it does not absorb much light, the best illumination is a beam from a very bright source directed vertically down the tube by a mirror.

Ball bearings of various sizes should be tried. To remove them from the tube, a magnet can be used.

The bottom of the tube should be closed by some arrangement which is not likely to give way under the influence of oil and make a messy flood. The bottom may be a closed glass end, preferably hemispherical, made by a glassblower. Or, it may be closed by a rubber stopper, but in that case the stopper must be wired to the tube in some way that prevents its oozing out. (If a glass tube carrying a stopcock is inserted in the rubber stopper, to facilitate emptying, the tap of the stopcock must be wired in to prevent accident.) Where there is a glass end at the bottom, a piece of cloth should be sunk to the bottom to break the fall of balls.

If a supply of (small) balls in a shallow dish of oil is left beside the tube, pupils may try the experiment as they pass by.



15 *Demonstration*

Frictionless motion: uniform velocity

Apparatus

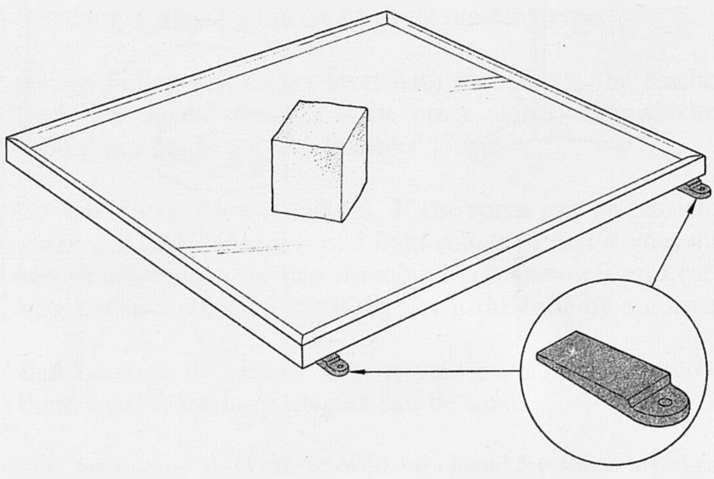
1 glass base plate	– item 95A
4 wedges	– item 95B
a. 1 block of solid CO_2	
b. 2 CO_2 pucks	– item 95C
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2
c. 2 CO_2 pucks	– item 95C
polystyrene beads	– item 10N

Procedure

By contrast with the previous experiment where the frictional force was such that a terminal velocity was reached, a demonstration of motion with negligible friction should be shown.

1. A block of solid CO_2 (which may be very roughly a cube, of size 10 to 20 cm), makes an excellent demonstration and is worth the trouble one must take to obtain it. See note below.

The glass plate is carefully levelled and very carefully cleaned with window-cleaning fluid. The block of CO_2 must have its bottom surface polished by 'ironing' it to and fro on a thick



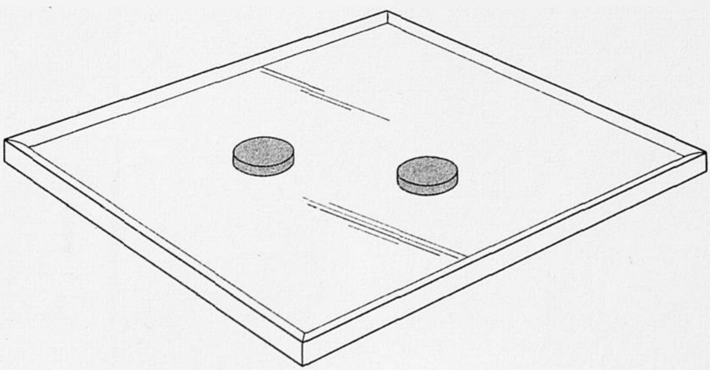
flat sheet of metal. The block will then coast to and fro on the plate almost without friction.

It is essential to level the glass precisely. Motion of a block of CO_2 itself gives a more delicate test of levelling than any ordinary spirit level. So this experiment must be tried out beforehand and the glass levelled by inserting pieces of paper and wedges.

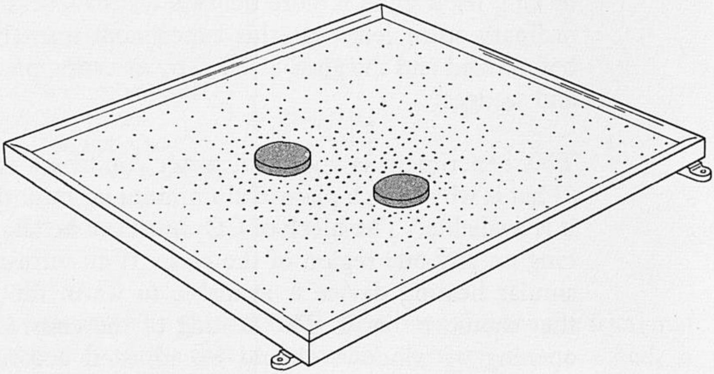
This experiment is spoiled if water condenses on the plate. (That is why a thick plate of aluminium is better than glass, if it is available.) The block of CO_2 must not be allowed to wait long on any one region of the glass. If an infra-red lamp or similar heating device is available to warm the glass plate, that should be used. The heating of the classroom and the opening of windows should be adjusted according to the weather to give as low relative humidity as possible.

In addition to the danger of condensed water, dirt on the glass surface will spoil the demonstration. If the glass is not fresh and clean, it should be given several cleanings with special glass-cleaning fluid. If absolute alcohol is available, a final washing with that may be helpful, but in many cases the alcohol that is available leaves traces on the glass that do more harm than good.

2. Or: If it is not possible to show a large block, then the ring magnets from the pucks kit can be used once again. With about 2 or 3 cm^3 of solid CO_2 underneath they provide a good demonstration. The CO_2 cylinder and dry ice attachment will provide sufficient solid CO_2.



3. Or: If neither of the above is possible, the glass plate should be thinly covered with polystyrene beads. Put the ring magnet pucks on top of them and they will move with very little friction. But these beads make a poor substitute for 1 or 2.



Note on solid CO_2

It is so valuable for pupils to see some experiments with plenty of solid carbon dioxide, particularly the large block coasting on the flat glass sheet, that we urge schools to make every effort to purchase solid carbon dioxide in bulk, from time to time. It is not difficult to obtain the block if notice is given to the suppliers a week or two beforehand. It is sent by rail and the cost is not great. This is not a material that is difficult or expensive to obtain. Details are given in the Nuffield Physics *Guide to Apparatus*.

16 *Class experiment*

Feeling friction

Apparatus

Bricks or books.

Procedure

1. To feel friction for himself, each pupil should put a hand loosely on the table, palm down, and drag it along the table. Then he gets a neighbour to drag it along – that helps to concentrate attention on the forces at the surface.

2. Now using the skin as the table-top, the pupil places his hand, palm up, on the table-top and puts a heavy load such as a brick or a pile of books on his upturned hand. A neighbour drags the load along.

17a *Demonstration*

Illustration of Newton's first law

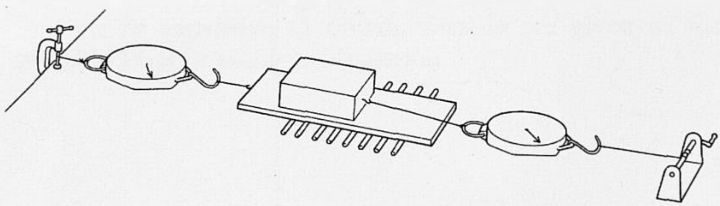
Apparatus

1 large plank	– item 55A
1 crank assembly	– item 55E
10 steel rollers	– item 55D
2 demonstration spring balances	– item 85
1 wooden brick	

Procedure

Put rollers under the plank so that it can move freely on them with very little friction. Keep the plank from moving by attaching it to a G-clamp at the end of the bench with a horizontal string. Insert a spring balance which will measure the force exerted on the plank – the stationary 'floor' – when the brick is dragged along it.

Place the brick on the plank, attach a string to it connected to a second spring balance and thence to a crank assembly. As the brick is dragged along the plank by turning the crank, pupils watch the readings of the two spring balances to see if the two forces are equal.



17b *Demonstration*

Balancing forces without friction

Apparatus

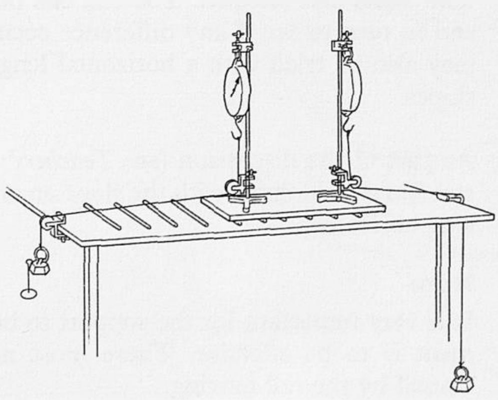
1 smooth plank	– item 55A
10 rollers	– item 55D
2 retort stands	– items 503–504
2 bosses	– item 505
2 clamps	– item 506
2 demonstration spring balances	– item 85
4 single pulleys on clamp	– item 40
2 1-kg weights	– item 32
1 weight hanger with slotted weights (10 gm)	– item 31/1

Procedure

The two retort stands are stood on the plank to form a massive trolley mounted on the rollers. Each stand carries one of the pulleys fixed towards the base and a spring balance. A cord from each balance passes under the pulley and over another pulley clamped firmly to the end of the bench. Each cord supports a 1-kg mass and the positions are adjusted so that when one mass is on the floor, the other is almost at bench height.

An additional mass is then added to the upper mass so that the trolley moves on its rollers, quickly reaching constant velocity. The additional mass should be such that the 'trolley' does not continue to accelerate and 50 gm is usually about the value required.

For discussion see the *Teachers' Guide*.



18 *Demonstration*

Galileo experiment on a rolling ball

Apparatus

1 large ball-bearing ball (or large marble)	– item 131A
1 flexible curtain-rail	– item 119
2 retort stands	– items 503–504
1 boss	– item 505
1 clamp	– item 506
2 G-clamps	– item 44/1

The flexible curtain rail – see Nuffield Physics *Guide to Apparatus* should neither be flimsy, nor unsymmetrical.

Purpose

This demonstration is to remind the pupils of the experiment already seen in Year III (Experiment 53a).

Procedure

The recommended method for supporting the curtain-rail is to glue a 2-ft wooden lath ($\frac{1}{2}$ inch square) to each end of the underside of the curtain-rail. One end is conveniently held with a retort stand and clamp at a height of about 1 ft above the bench. The other end can be held in another retort stand or the teacher may prefer to hold it by hand.

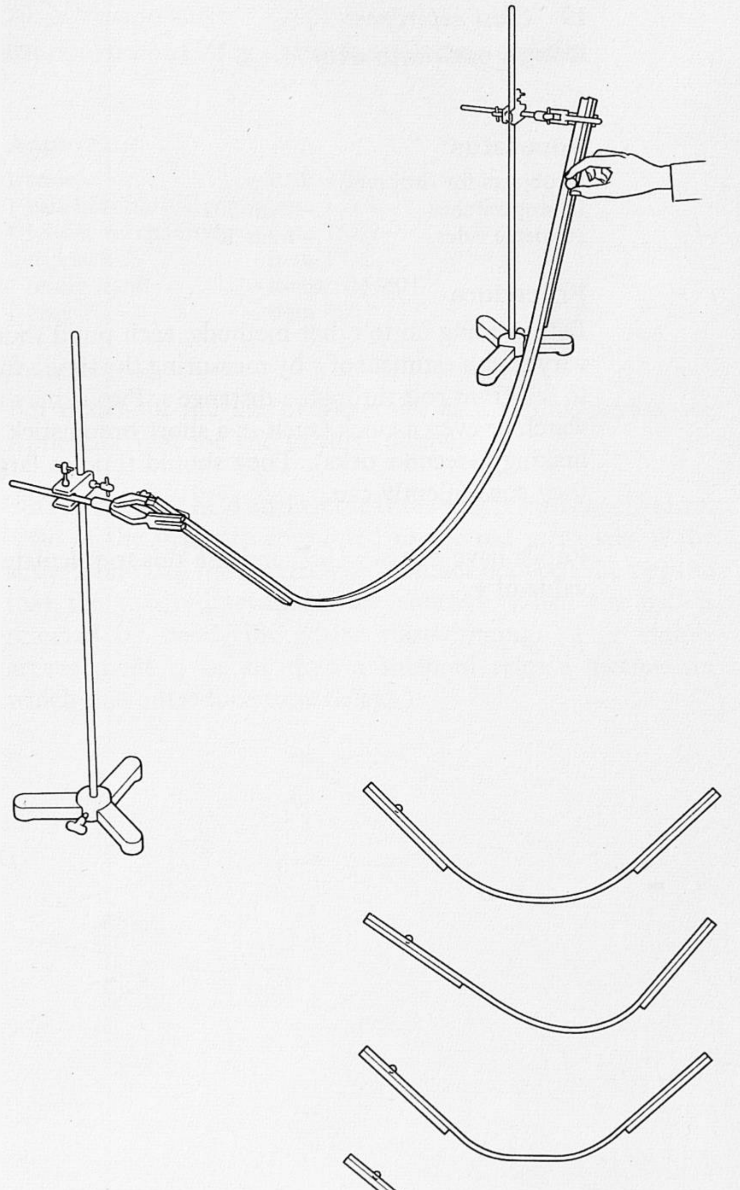
The ball bearing is held at the top of one end of the curtain-rail and released so that it rolls down one side and then up the other.

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

As part of the discussion (see *Teachers' Guide*), the demonstration should finish with the slope on one side and the other side horizontal.

Note

It is very important for the support to be rigid if the experiment is to be effective. There must not be energy losses caused by the rail moving.



19 *Class experiment*

Rough estimate of *g*

Apparatus

16 objects for dropping	
16 stopwatches	– item 507
16 metre rules	– item 501

Procedure

Before going on to other methods, each pupil should make a very rough estimate of g by measuring the time t for an object to fall from rest through a distance s. Pupils may use a stop-watch or even a clock (such as a short broomstick pendulum making $\frac{1}{2}$-second ticks). They should time as large a fall as they conveniently can.

Pupils have met $s = \frac{1}{2}at^2$ and use this to calculate the rough value of g.

20 *Demonstration*

Measurement of *g* using a scaler as a timer

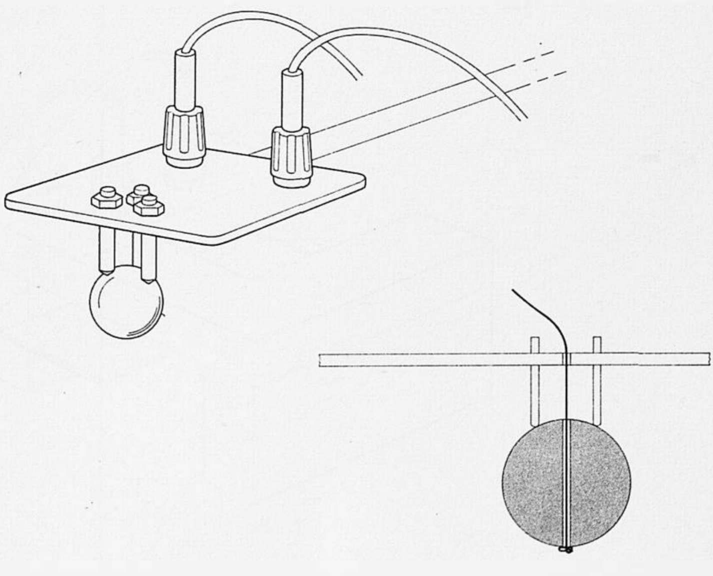
Apparatus

1 scaler	– item 130/1
1 ball-bearing ball	– item 131A
1 release mechanism	– item 131H
1 trip switch	– item 131I
1 retort stand	– items 503–504
1 boss	– item 505

Procedure

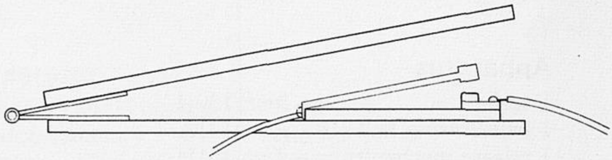
For details of the use of the scaler as a timing device, see Appendix V at the end of this volume.

The steel ball is held against the three-peg release mechanism. Two of the pegs are connected to the red terminals of the scaler. The ball makes electrical contact between the pegs so that the two red terminals are shorted. When the ball is released by hand, the scaler starts timing. (This simple arrangement is better than a solenoid release mechanism which may introduce time delays.)



It may be preferred to have a string release for the ball as shown. This enables the ball to be released from above instead of holding it underneath the three-pin mechanism.

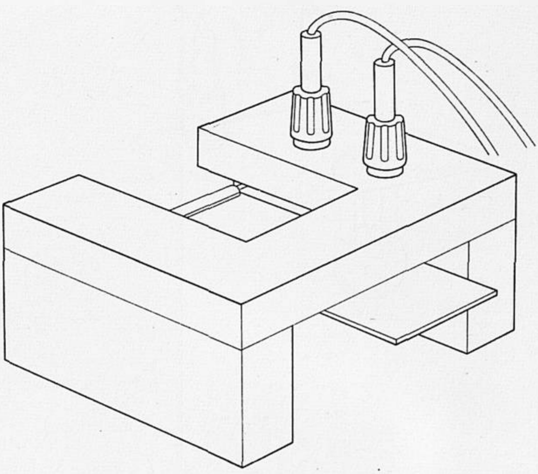
The ball is set up a metre or more above a switch as illustrated.



The terminals are also connected to the red terminals of the scaler. On falling, the ball closes the switch which stops the scaler, thereby giving the time of fall. It is probably easier teaching if the arrival switch works the same way as the release switch: that is, if the clock starts on a break and stops on a make which the above switch provides.

Some may prefer to use a trip-switch as illustrated below, which breaks a circuit when the ball hits it. If this is used the terminals of the trip-switch are connected to the green terminals of the scaler. When the ball strikes the trip-switch, the switch opens and stops the scaler.

The time is read for a measured fall. g can be calculated from $s = \frac{1}{2}at^2$.



21a *Optional demonstration*

Measuring *g* with electric stopclock

If a school has a demonstration electric stopclock this could be arranged so that pupils take it in turns to use it for a measurement of g. Many teachers will also have other ingenious ways of measuring g: these special devices are only recommended where the teacher already has a device of his own.

21b *Optional demonstration (buffer)*

Estimate of *g* using pulsed water drops with stroboscopic illumination

This optional experiment is *not* recommended except for a very fast group.

Apparatus

1 compact light source	– item 21
1 motor-driven stroboscope (with 5-slit disc)	– item 134/1
1 tickertape vibrator	– item 108/1
1 large converging lens (focal length 10 cm, large aperture)	– item 93B
1 screen	– item 102
1 constant-pressure apparatus	– item 166
1 L.T. variable voltage supply	– item 59

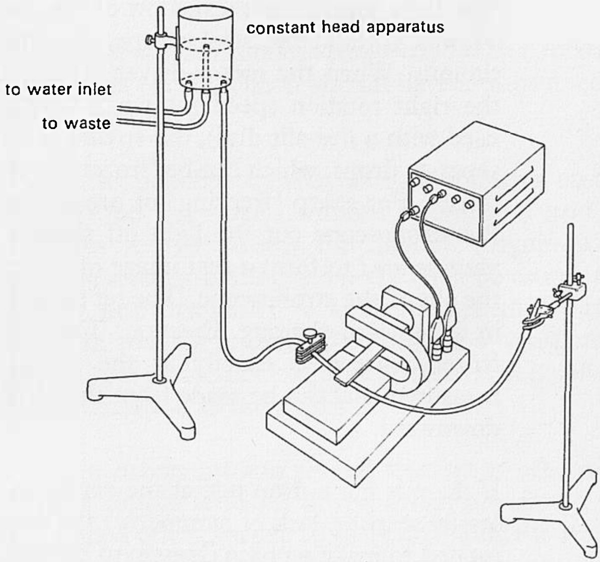
General Note

This shows a stream of water drops following each other at equal intervals of time (1/50 second) in a parabola. The drops are 'frozen' by stroboscopic illuminations as in the pulsed water drops Experiment 67 in Year III.

In this demonstration a grid is added, so that the vertical motion of the drops can be measured and used to obtain a rough estimate of g. Since the pulses, which make the stream emerge as separate drops, are made by an electro-magnet on the a.c. supply, the time interval from drop to drop in the frozen pattern is known.

Procedure

Water from a constant pressure supply flows through a rubber tube controlled by a screw pinch clamp to reduce the flow to a small stream. At the end of the tube there is a short piece of glass tubing drawn out to make a jet. A fairly large stubby jet, up to 2 mm in diameter works well. The height of the constant pressure supply should be 1 to 3 ft above the jet. The pinch clamp is adjusted so that if the stream is directed vertically upward it rises to a height of 6 to 12 in above the jet.



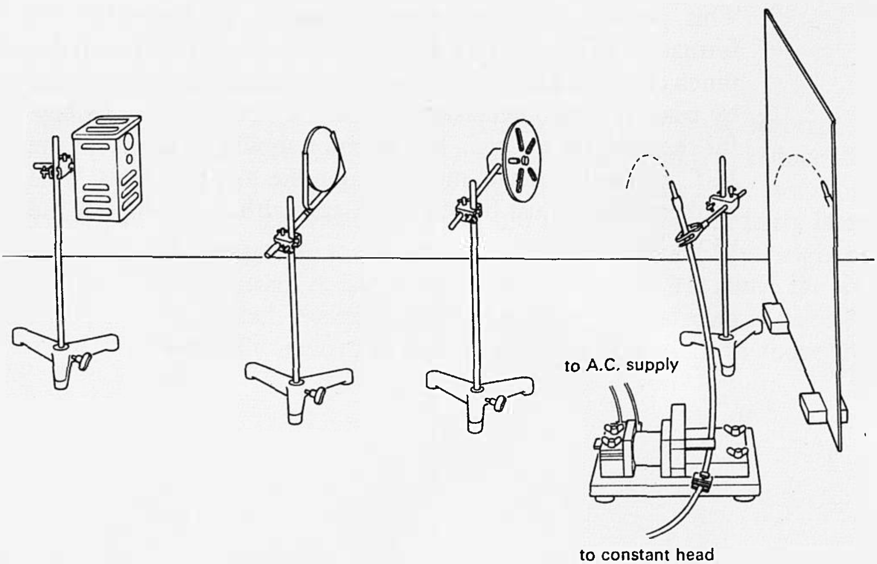
To make the stream break up into a regular series of drops, the rubber tube that runs from supply to glass jet is placed in the vibrator between the blade and the base so that the vibrator squeezes it fifty times a second. The pinch clamp must be located on the rubber tube just *before* the vibrator (so that the pumping action of the vibrator drives water to the jet).

This periodic encouragement is enough to determine the formation of drops. The flow rate must be adjusted with the pinch clamp to a suitable value, the optimum rate being found by trial. It is also necessary to find the optimum a.c. voltage for the vibrator by trial. The vibrator should be run from the L.T. variable voltage supply using the a.c. terminals. The rubber tubing must be of a small size with thin wall, not the usual Bunsen tubing.

The light source casts a shadow of the stream on the screen. Viewed without the stroboscope, the stream will look continuous. When the motor-driven stroboscope is adjusted to the right rotation speed (or when a synchronous motor is used with a *five*-slit disc), the stream is seen to be a series of separate drops, which can be 'frozen' in the shadow cast on a screen. For sharp 'freezing' of drops it is essential to make the stroboscope cut the light off sharply. Therefore *a lens must be used* to form a real image of the compact filament at the slit of the stroboscope. The jet should direct the streams in an upward-slanting direction. Then, if one drop in the frozen pattern is exactly at the vertex of the parabola, measurements can be made from that drop, as starting level, downward.

If there is not a drop just at the vertex in the frozen pattern (easily seen by lack of symmetry) the whole motor must be rotated to make a phase change, to bring a drop to the top of the parabola. (In practice, a change of voltage of the vibrator or a change of voltage applied to the synchronous motor, may suffice to make such a change of phase.)

The vertical distances fallen from the vertex drop to the next below it and the next and the next are then measured and used to estimate g, assuming that the time from drop to drop is 1/50 second.



Notes

1. It is best to use a synchronous stroboscope motor rotating at 300 revolutions per minute. It should have a disc attached to it with *five* slits in it.

2. It is, of course, possible to make the measurements on the shadow-picture on the screen without imposing a grid of horizontal wires near the stream. But then the magnification imposed by the shadow-casting geometry must be estimated. Pupils usually find this easier to understand with a direct measurement in which a grid of wires, or even a transparent centimetre scale, is placed so close to the stream that it suffers the same magnification as the stream itself.

3. If the stream breaks up into several streams or otherwise fails to form a simple series of drops, other jets should be tried, until a good one is found. Also try changing the reservoir height, the pinch clamp and the vibrator voltage.

4. It is essential to support the motor-driven stroboscope quite separately, so that vibrations from it are not transmitted to the screen.

22 Optional demonstration

Measurement of *g* with multiflash photographs of free fall

Apparatus

1 ball-bearing ball (1 in or $\frac{3}{4}$ in diameter)	– item 131A
1 motor-driven stroboscope	– item 134/1
1 camera	– item 133
1 metre rule	– item 501
1 lamp	

A 2 in × 2 in slide projector is suitable for the lamp.

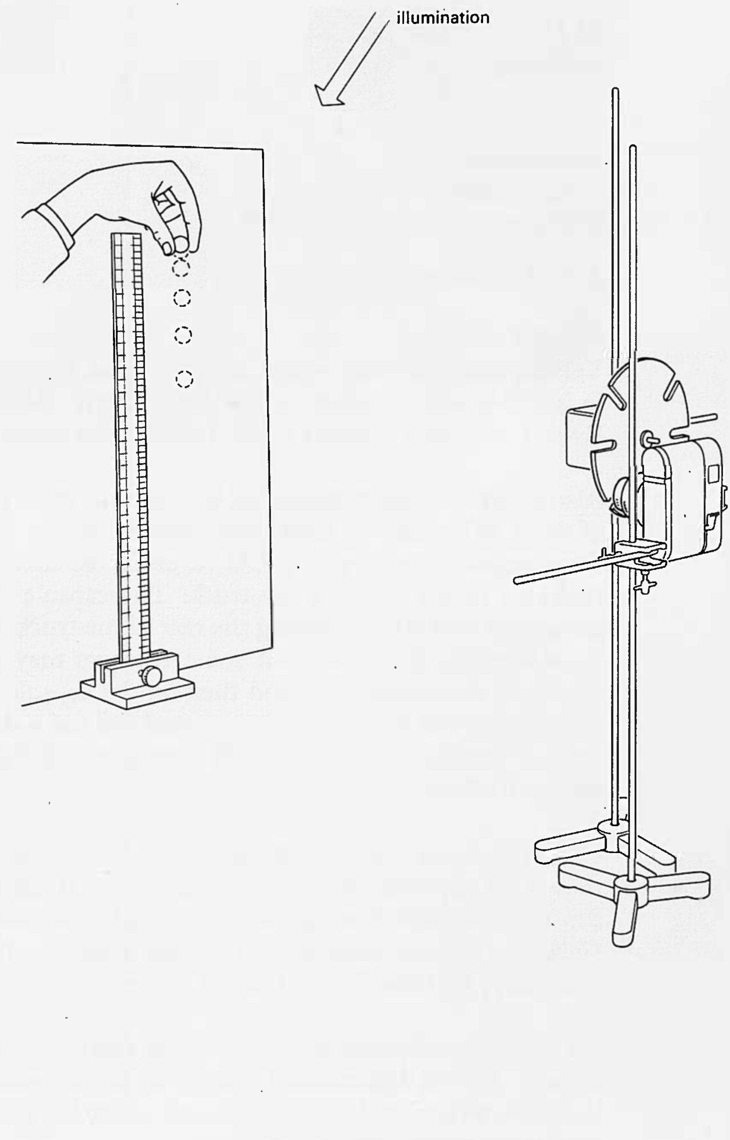
Procedure

This is a repetition of Experiment 1 in which multiflash photographs of free fall are obtained with a scale for measurement. From the photographs a value for g can be deduced.

The synchronous motor-driven stroboscope rotates at 300 rev/min. Either the six-slit or five-slit disc can be used with it. The stroboscope is set up in front of the camera in the usual way. The ball bearing is illuminated by the lamp, placed near to the camera so that direct illumination does not fall on it.

Note

See Appendix I at the end of this volume for details of methods for multiflash photography.


illumination

23 Demonstration

Rockets

Apparatus

1 water rocket	– item 167
1 CO_2 capsule rocket	– item 168

Spare CO_2 capsules will be required.

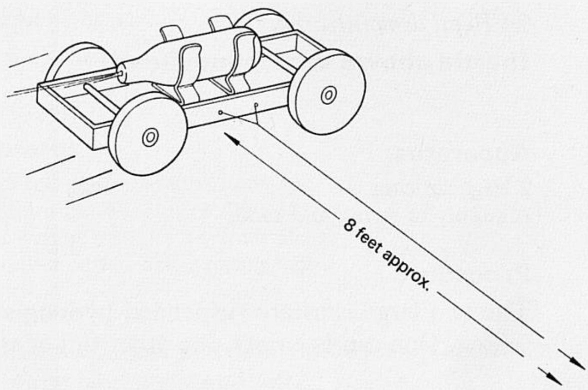
Procedure

Various kinds of water rocket are obtainable from toy shops, (a suitable water rocket is made by Merit: Merit Lunar Rocket, catalogue number 9220). One of these might be fired.

Also available from toyshops are CO_2 capsule rockets and one of these might also be fired if the school has one. A simpler arrangement is to attach a CO_2 capsule (as used for soda syphons) to the top of a toy truck. The capsule should be horizontal with its neck facing the rear of the truck. Sellotape is satisfactory for fixing, but some teachers may prefer to attach an aluminium tube and then fix the capsule inside it. The capsule can be broken with a round nail and a sharp blow from a hammer. The truck will then move at high speed across the floor.

One commercial version of the dynamics trolley will take these CO_2 capsules very conveniently. This is illustrated in the Esso-Nuffield film for science teachers *Momentum and Collision Processes*, available on free loan from Esso Petroleum Company, Victoria Street, London, S.W.1.

Another manufacturer makes a simple truck to take a CO_2 capsule. For an entertaining variant of the experiment, the truck can be attached by an 8-ft length of cord to a fixed pivot so that the truck rotates in a circle.


8 feet approx.

24 Pupil demonstration

Inertia shown with pendulums

Apparatus

2 large tin cans
A supply of string and sand.

Procedure

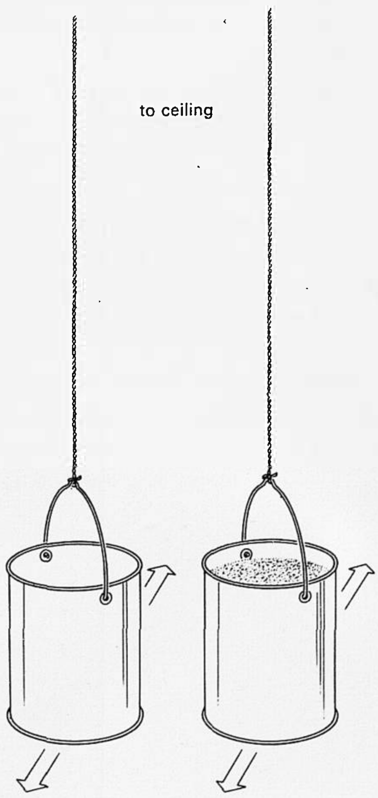
The two large cans are suspended by long strings from the ceiling. One can is empty, the other full of sand.

1. Pupils try pushing each with a short, sharp push to feel how easily or otherwise they can be accelerated.

2. If available, a shooter which fires ping-pong balls or peas can be used to bombard each can in turn.

Note

See also Experiment 56 in Year III.



25 *Pupil demonstration*

Mass exhibit

Apparatus

1 mounted glass plate	– item 86
1 kilogram mass	– item 32
1 1-lb weight	– item 36

A supply of small ball-bearing balls.

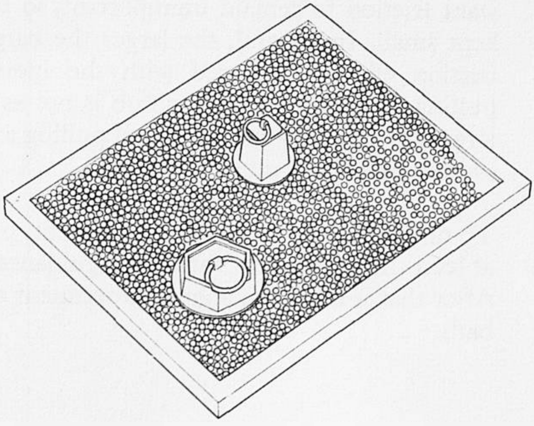
Procedure

The mounted glass plate should be set up horizontally at the side of the laboratory and left, if possible, for a few weeks so that pupils can try this demonstration individually. The plate is partially covered with a layer of small ball-bearing balls (1/16 in or $\frac{1}{8}$ in diameter). A kilogram, clearly labelled, rests on a hardboard disc on the balls on the tray. Pupils are encouraged to push this standard mass with a finger to feel its 'inertia'.

A one-pound mass should also be provided, to replace the kilogram when pupils want to try that.

Note

Polystyrene beads could be used instead of ball-bearing balls; but they are more messy, subject to damage, and in general less satisfactory. Steel balls cost less than 10s. per 1,000. Two thousand will suffice for a glass plate 1 ft square. If teachers fear that pupils will find these small balls too tempting and carry them away as souvenirs, we suggest that giving each pupil one or two of them to take home will meet this difficulty – since balls of this size do not, in fact, make very useful toys.



26 *Optional demonstration*

Inertia: barge in a tank of water

(This optional demonstration is not recommended except where the equipment is already available.)

Apparatus

Toy barge of wood, plastic or metal
blocks of wood or weights
large tank of water

Procedure

The plastic toy barge is put in a large tank of water and towed gently by a finger. Blocks of wood or weights are successively added to the barge and at each stage the barge is towed through the water.

At low speeds, with a massive barge of good shape, the drag of water friction will be only a small fraction of the pulling force, so we may expect constant acceleration for a given force, proportional to the force and inversely proportional to the effective mass. However, this experiment is not recommended for measurements but rather as a qualitative experiment that enables pupils to feel the inertia of the barge as some quality that makes the barge difficult to accelerate.

As speed increases, the drag of fluid friction increases greatly – perhaps roughly as the square of the velocity – and it will become important so that the motion approaches a terminal velocity. Friction also increases when the barge is loaded up and sinks deeper in the water. In the present experiment, we want friction to remain unimportant, so the speed must be kept small. In general, the larger the barge the smaller the friction effects compared with the inertia effects. Thus, pulling a small toy in a washtub is not as good as pulling a larger toy in a full-size bath; and pulling a very large toy in a swimming bath is much better still

To obtain benefit from this experiment, pupils must try it – at least the first time – with some guidance from the teacher. After that it might be a good experiment to try at home in a bath.

A moving ship carries some water along with it; and as the ship moves along, displaced water is transferred from bow to stern of the ship. Therefore, the effective moving mass is not just the mass of the ship but the mass of the ship plus some water. On that account the experiment should remain a rough, qualitative one. Again, the effect of added mass may be less noticeable on a large scale.

27 *Class experiment*

The inertia balance (the 'wig-wag')

Purpose

This is a qualitative experiment with two uses:

a. To aid pupils in learning the nature of mass. The apparatus enables them to see the effect of the same set of forces on different masses, without any interference from gravity.

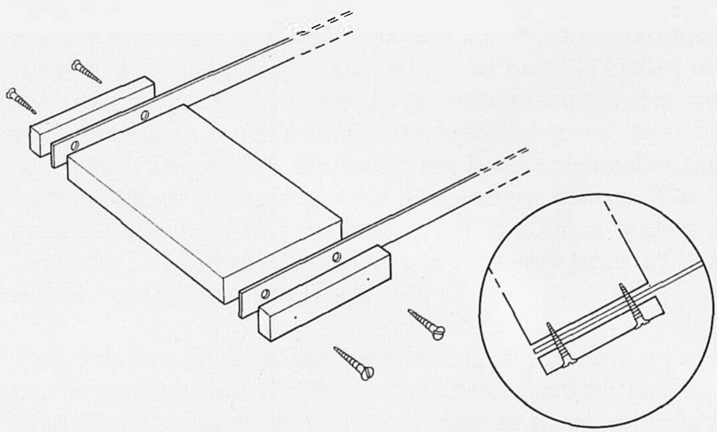
b. For very able pupils, a special extension of the experiment helps to clarify the distinction between mass and weight still further by letting pupils see what happens when they 'take some of the weight off the machine' without changing the mass. This extension, which is a delight to teachers, may well prove too confusing for most pupils; so it should not be allowed to take a prominent place in the experiment.

Apparatus

1 inertia balance kit – item 146

This provides sufficient balances to enable pupils to work in pairs.

Either a professionally made balance or a simple home-made form can be used. There is no essential difference in the two forms except in cost and appearance. Some teachers may feel it wiser to provide pupils with simple rough apparatus.

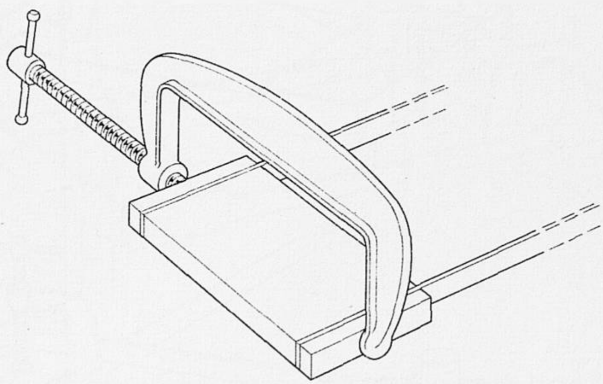


Making a 'wig-wag'

For a home-made wig-wag, use two hack-saw blades or equivalent lengths of metal strip and place a block of wood between them at one end, to serve as anchorage to be fixed to the table. Place another block of wood between them at the other end, to act as the platform to carry the loads.

It would seem simplest to attach the blades to the blocks of wood by driving screws through holes in the blades into the blocks. That would leave some play between the blades and the blocks of wood as the blades bend to and fro, and that would lead to considerable damping. To avoid spoiling the machine's behaviour by damping, it is essential to clamp each blade very firmly on both sides. Where the blade is clamped against a wooden block, another small block of wood or metal should be placed outside the blade, flush with the main block, so that the blade emerges as if from the well-matched jaws of a vice. Then screws may be driven through small block and blade into the big block.

If the machine is to be put together only temporarily, a large G-clamp may be used to clamp small blocks, both blades, and the large block together, in a multiple sandwich with a similar clamp at the other end.



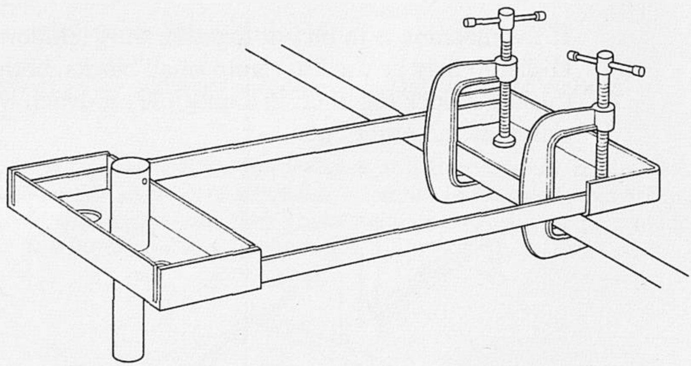
Procedure

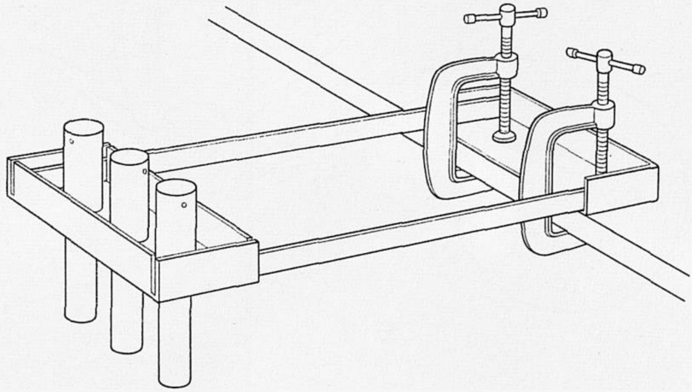
a. *General experiment*

One end of the 'wig-wag' machine is clamped rigidly to the bench with G-clamps so that the blades stick out horizontally. The other end acts as a platform that can vibrate to and fro laterally. Pupils pull the platform to one side, release it and watch it vibrating.

The load is then increased by adding masses to the platform and the pupils will find that the vibrations take longer. (The amount of load to be added depends on the strength of the blades in the actual apparatus; but it should be possible to add enough load to slow the vibrations down to half of the original frequency, or even less.)

It is important that the fixed end of the device should be very rigidly clamped to the table so that energy is not lost unnecessarily. An elastic band round the loads will prevent them from rattling.

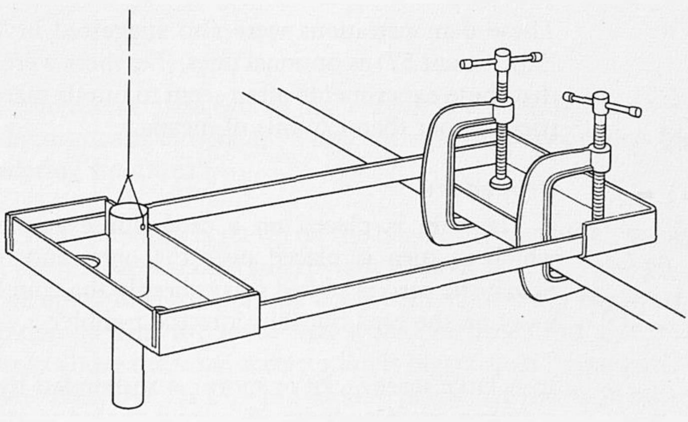




b. *Extension for a fast group*
The blades shove the platform and its load to and fro, and the slowness of the oscillations indicates the mass of the moving system. It does not depend on the pull of the Earth on that mass, its weight. Pupils can make sure of that by 'taking away some of the weight' without changing the mass.

They do that by pulling the added loads upward with a thread, so that most of the weight of the load is borne by the thread and only a little of it supported by the moving platform – and yet the moving platform carries the full mass of the load to and fro with it.

A skilful pupil carries some of the weight simply by pulling it upward with a taut thread and moving his hand to and fro in phase with the motion of the platform to keep the thread vertical. Or the thread can be a long one running up to a support far above the platform. Then, as the platform oscillates, the thread is tilted to and fro but not enough to affect the motion noticeably. Yet it is able to support a fraction of the weight.



Note

In some forms of this device, the platform has large holes drilled in it to receive special loads that slip into the holes and are prevented by a peg from falling right through. This makes it easier to add loads without any danger of slipping on the platform and these special loads can be provided with holes for the thread of Part (b). However, this increases the 'special' nature of the device, while ordinary weights would make it seem more like an experiment put together to conduct a useful test.

28 *Optional demonstration*

Inertia experiments

Apparatus

a. coin
card
tumbler

b. retort stand – item 503
boss – item 505
clamp – item 506
thread
large weight (1 kg or more)
G-clamps

c. pile of books

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

e. 5 wooden blocks (say, 4 in × 3 in × 2 in)
hammer
mallet or hammer

Warning

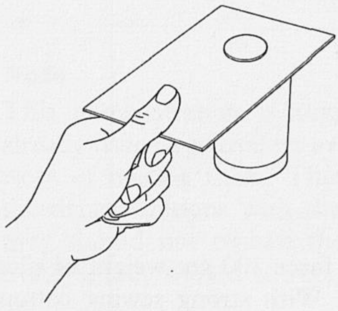
These demonstrations were also suggested in Year III (see Experiment 57) as optional ones. Teachers were warned then that these experiments often seem to pupils merely delightful tricks rather than exhibits of inertia.

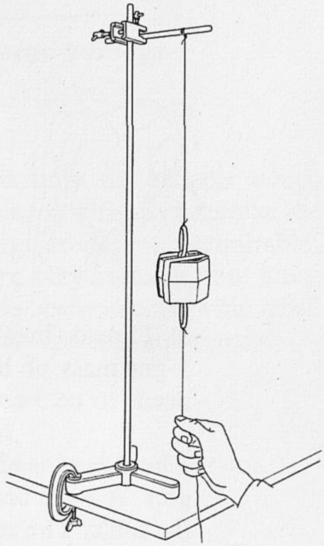
Procedure

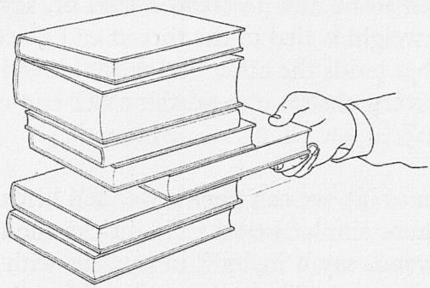
a. The coin is placed on a card (for example a postcard) which in turn is placed over the open end of a tumbler. When the card is pulled away sharply the coin is not carried away on the card but falls into the tumbler.

b. A large mass (1 kg or more) is suspended by thread from a strong, rigid support. A second thread is attached to the underside of the mass. The lower thread is pulled until one thread or the other breaks. It will be found that *if* the pull is a steady one that increases slowly, the upper thread breaks; but if the pull is a sudden jerk, the lower thread breaks.

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

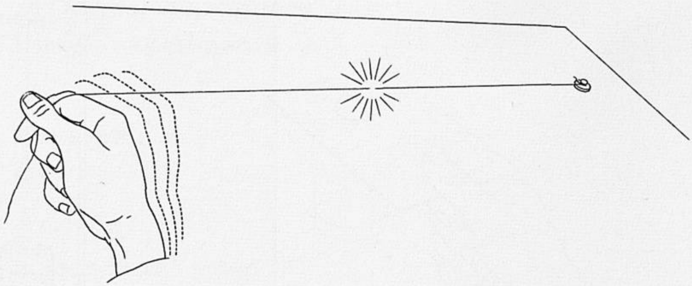






A convenient mass can be made by Sellotaping together two 2 kg masses as illustrated. These provide convenient rings for securing the thread.

c. A pile of books is set up on the bench and one of the books in the middle is pulled smartly out without upsetting the pile. The operator must pull the book with sufficiently big acceleration so that the force that would be needed to give the books above the same acceleration is bigger than limiting friction. Thus there is slipping and the pile above the book being pulled out does not manage to follow the book being pulled out (see *Teachers' Guide*, Year III, for further discussion).



d. Thread (breaking force 100 gm weight or more) tied to a 1-gm mass of brass. With strong sewing cotton, the mass needs to be 5 or even 10 gm for success.

The thread is shown to be able to stand a load of, say, 100 gms. A 1-gm brass weight is tied to the thread and placed on the table. The teacher holds the other end of the thread with the thread slack. A very abrupt jerk on the other end of the thread will break it.

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

29 Optional demonstration

Inertia demonstration with large trolleys

Note

This demonstration is suggested only for schools which already have large trolleys available, or wish to undertake the work of making them. These large trolleys are admirable: the demonstrations with them are very valuable, but since they should not replace the class experiments with small trolleys, they should be regarded as optional equipment.

Apparatus

1 demonstration trolley – item 160/1
1 smaller demonstration trolley to fit on top of the larger one.

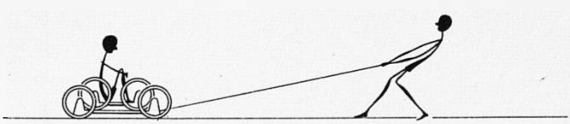
Procedure

The experiments discussed in the Ministry of Education pamphlet No. 38 *Science in Secondary Schools* are as follows:

The large trolley is at rest on the floor. A pupil walks towards it (along its line of movement) and steps on to it and stops walking. Although the walker stops relative to the trolley, he and the trolley together continue to move forward.

Secondly, the pupil walks towards the stationary trolley, walks straight on across the trolley and then on beyond. Practically no motion is given to the trolley.

Then the pupil steps on to the trolley from a standing start by it and then walks off the trolley. The trolley moves backwards and there is very little motion of the walker forward.



If available, a smaller demonstration trolley is placed on top of the larger trolley so that it can move freely along its length. A pupil sits on the floor of this smaller trolley, thus adding mass. (Or, in a luxury version, the small trolley may have a seat rigidly attached to it, on which the pupil can sit.)

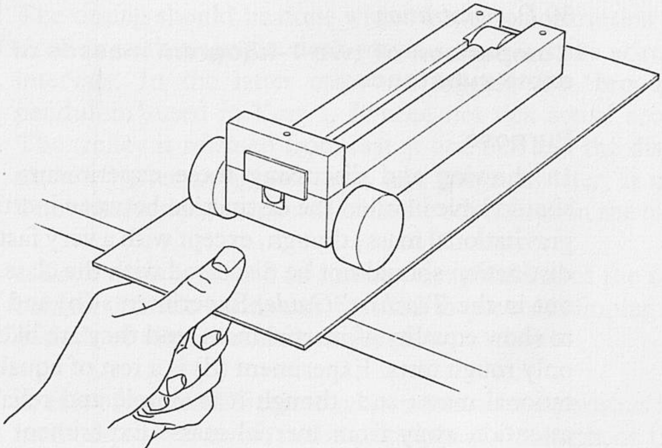
With the pupil in place the lower trolley is pulled. It will be seen that the pupil remains still relative to the ground.

When the large trolley has been pulled out from under the small one, the latter drops to the ground, still in the same place. Therefore the large trolley must be the under-slung type as otherwise the drop would be too great when the small trolley comes off.

Pupils may do the last experiment on a small scale with a class experiment trolley resting on a sheet of hardboard on the table. When the hardboard is suddenly pulled and dragged along under the trolley, the trolley gains very little motion. The hardboard is easier to drag if it is placed on rollers or marbles; but since that is likely to convert the experiment into a demonstration, it may be better to do without that.

Note

The first experiments mentioned above are concerned with momentum and are only relevant later in the course. The experiments with the two trolleys are the ones that might be used at this stage.



30 *Demonstration*

Comparison of two 1-kilogram masses of the same substance

Purpose

In showing and discussing these experiments, the teacher should have in mind the distinction between inertial mass and gravitational mass; though, except with a very fast group, that distinction should not be discussed with the class. As pointed out in the *Teachers' Guide*, Experiments (b) and (c) are tests to show equality of inertial mass, and they are likely to appear only rough tests. Experiment (d) is a test of equality of gravitational mass; and, though it is simple and reliable, it leads attention away from inertial mass. Experiment (a) is just a test of 'counting mass' – here only a very rough test by similarity of appearances; but in principle a fine test if only one could count all the atoms in each body and have some assurance that all those atoms are identical.

Apparatus

2 1-kilogram weights	– item 32
1 dynamics trolley	– item 106/1
1 elastic cord for accelerating trolley	– item 106/2
1 runway	– item 107
1 inertia balance	– item 146A
1 equal-arm balance	
1 stopclock or other timing device	– item 507

The two 1-kilogram masses must be of the same substance and have the same shape. One should be labelled 'standard kilogram mass'.

Procedure

a. Two 1-kilogram masses of the same substance are shown to initiate the discussion suggested in the *Teachers' Guide* on comparison of masses. One of them is labelled the 'standard kilogram mass'. Since they look the same size and are made of the same material, we suggest they are likely to have equal numbers of atoms and have the same mass.

b. The masses are put in turn on to a dynamics trolley and accelerated with a standard force by elastic in the usual way. Since the aim here is to demonstrate equal masses by equal accelerations, it would be unnecessary and even confusing to make detailed timings with tickertape.

The timing should be done with a large demonstration stop-clock or with a simple clock making audible ticks at regular intervals. In the latter case, we suggest the 'broomstick pendulum' used in Year I. It need not tick actual seconds. The trolley is released from rest at one tick and the distance travelled after an agreed time, say, two ticks later, is noted. The observation is repeated with the other load on the trolley.

c. Each mass is placed in turn on the platform of the inertia balance. Elastic bands can be used to prevent slipping. The periods of vibration are compared.

d. It is of course difficult to make accurate comparisons in the methods above, but it is the principle of the methods that is the concern. In spite of the danger of confusion, a final easier method should be shown. The standard kilogram and the other 'kilogram' are put on the two pans of an equal-arm balance to show the Earth pulls on them equally.

Note

See the *Teachers' Guide* for a discussion of the assumptions in (d) above when shifting from inertial mass to gravitational mass.

31 Demonstration

Comparison of two 1-kilogram masses of different substances

Apparatus

1 kilogram mass of brass or lead	
1 kilogram mass of aluminium	
2 dynamics trolleys	– item 106/1
4 elastic cords for accelerating trolleys	– item 106/2
1 stopclock	– item 507
1 tickertape vibrator	– item 108/1
1 inertia balance	– item 146A
1 equal-arm balance	
1 long weak spring or rubber thread	

Procedure

a. A piece of aluminium is adjusted, in front of the class, to balance a kilogram of brass (or lead). These are now two equal *gravitational* masses.

b. It is now to be shown that we have two equal inertial masses. Each mass is placed in turn on the inertia balance ('wig-wag'). Elastic bands can be used to prevent the mass slipping. The periods of vibration are seen to be the same.

c. *Optional.* Or each mass is put in turn on a dynamics trolley and accelerated with a standard force using elastic. The time to travel a measured distance should be shown to be the same in each case.

d. *Optional.* Two equal trolleys are placed far apart on a level runway. A weak spring or a long rubber thread is stretched between them to accelerate them towards each other. One of the kilogram masses is placed on each trolley. The trolleys are held at rest and released. They are seen to travel equal distances to the point of collision; but, if a larger load is placed on one trolley, the distances are unequal.

e. Finally the two masses are allowed to fall from rest, starting simultaneously, showing that they both fall with the same acceleration. Since the balance in (a) showed the Earth's pull on each was the same, this demonstration shows that equal forces produce the same accelerations, so that the masses must be equal.

Pupils often find the reasoning of this puzzling. Since g is the same for all objects, they do not see that this demonstrates equal masses, even though the information from Experiment (a) is necessarily brought in. Therefore, it is helpful to repeat Experiment (a) with unequal masses: the balance tips over, the forces are not equal; therefore, although we see the same acceleration when those two masses fall, we do not infer the masses are equal. (See discussion in *Teachers' Guide*.)

32a *Class experiment*

Feeling a force of 10 newtons by holding a kilogram

Apparatus

16 1-kilogram weights	– item 32
8 newton spring balances (10N)	– item 81

Procedure

Each pupil should hold the kilogram mass and then let it drop. He cannot measure the acceleration, but it is something already measured in the course. He knows that it falls with acceleration 9·8 metres/second per second.

As discussed in the *Teachers' Guide*, the pupil uses $F = ma$ to calculate the force accelerating the kilogram, and arrives at 9·8 newtons.

Finally, the pupil should hang the weight on a newton spring balance and see if the balance is correctly calibrated.

32b *Pupil demonstration*

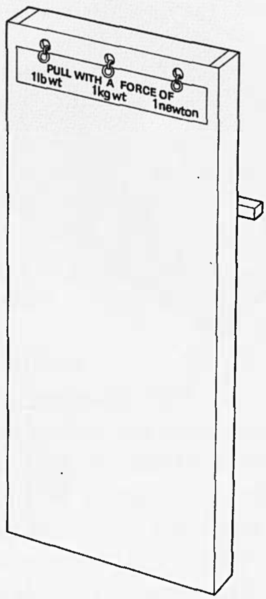
Forces demonstration box

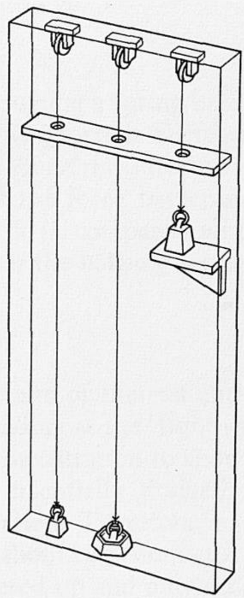
Apparatus

1 forces demonstration box – item 63
(for details of the box see Year II)

Procedure

The forces demonstration box will already have been seen in earlier years of the course, but it should be left in the laboratory throughout the present stage of the course as well, so that pupils can familiarize themselves with a force of 1 newton, and compare it with forces of 1 kilogram-wt and 1 pound-wt. Teachers will find that this box pays very considerable dividends in increasing familiarity.



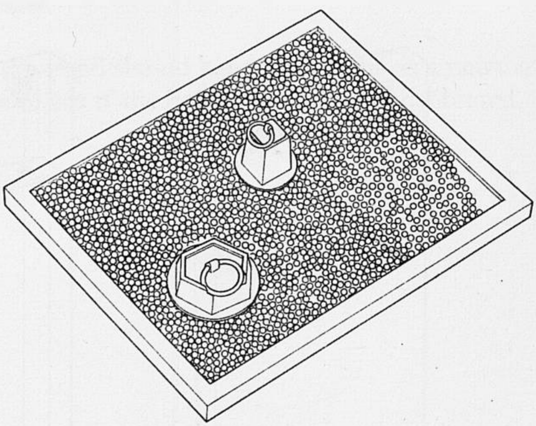


32c *Pupil demonstration*

Mass exhibit

Procedure

The exhibit of Experiment 25 is brought out again and kept available.



33a *Demonstration*

Test of newton balance by pulling trolley

Warning

As discussed in the *Teachers' Guide*, this direct calibration of the newton balance by a method that does not involve gravity is difficult to do with any precision. It is probably more important for the teacher's sense of justification than for most pupils. Therefore, it should be done quickly as a demonstration and not as a class experiment.

Apparatus

1 dynamics trolley	– item 106/1
1 runway	– item 107
1 newton spring balance (10N) (with scale markings concealed)	– item 81
1 stopclock	– item 507
1 domestic balance (5 kg)	– item 20

Purpose

In this demonstration, the force stretching a spring balance is applied to a trolley of known mass. The force is calculated, in absolute units, from the trolley's mass and measured acceleration, using $F = ma$. The result is the force stretching the spring of the spring balance, and it is compared with the reading of the balance to see whether the balance is correctly calibrated.

Procedure

Pupils are easily confused over the aim of the test and they are apt to take the spring balance reading as the 'right value'. That would be unfortunate in a demonstration to show how a scale of forces in newtons is essentially derived from measurements of mass and acceleration. Therefore, to keep the intention clear, the experiment should be conducted with the scale of the spring balance covered up and only revealed for the final comparison. A sheet of paper is pasted, temporarily, over the face of the balance and an ink line on the paper serves to mark the position of the pointer for the force to be measured in this experiment.

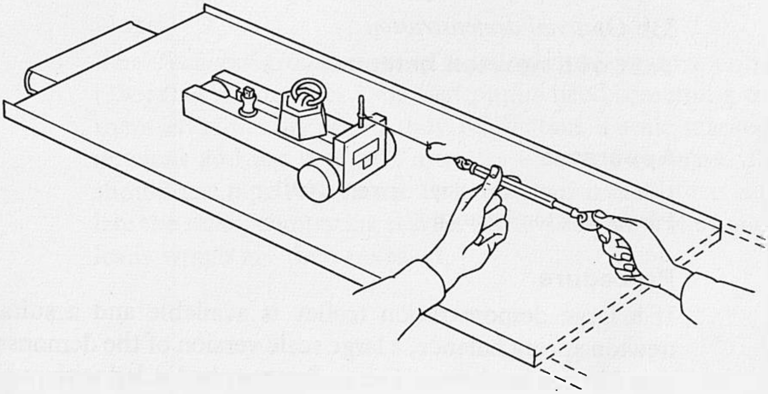
The trolley runway is compensated for friction. The trolley is loaded up, by adding kilograms and some fractions, so that its mass is an integral number of kilograms. This is shown by putting the trolley and load on the domestic balance. The spring balance is attached to the trolley by a length of string. The experimenter holds the spring balance in his hands, holding it so that its scale face is easily visible, and moves it along keeping the string taut and horizontal to accelerate the trolley.

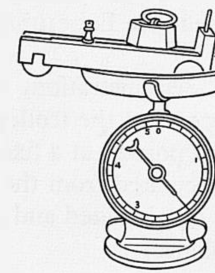
If preferred, the spring balance may be attached to the trolley by putting the hook over one of the pegs, and the balance and trolley together pulled along by a string attached to the spring balance; but in that case the whole spring balance must be weighed with the trolley.

A rehearsal before the demonstration is shown and will enable the teacher to choose a suitable force and put an ink mark on the paper. Then, for the demonstration, the teacher pulls the trolley along, keeping the spring balance pointer as close as possible to the ink mark.

The trolley is released to start from rest, and its accelerated motion is timed. The acceleration is calculated from measurements of distance and time. Then the product (mass) $\times$ (acceleration) is calculated. That gives the actual accelerating force, in newtons.

The paper is then carefully removed and the calculated 'true force' compared with the mark put by the makers at that point.





33b *Optional demonstration*

Test of a newton balance

Apparatus

1 demonstration trolley – item 160/1
1 large newton balance

Procedure

If a large demonstration trolley is available and a suitable newton spring balance, a large scale version of the demonstration 33a can be shown. The trolley may be loaded with pupils. Where a trolley is not available, a table fitted with roller-skates may be used (see Experiment 53).

As in the small demonstration, the face of the balance is covered with paper and the trolley is pulled with a constant force, keeping the pointer at a fixed mark on the paper. The acceleration is calculated from the time to travel a measured distance. $m \times a$ is calculated and compared with the reading on the spring balance.

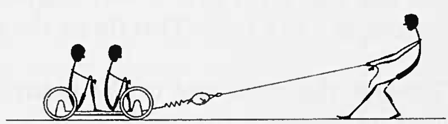
This is fun, but there are difficulties, such as allowing for friction and finding the mass in kilograms of the trolley plus pupils.

Friction can be allowed for by a separate pull by a second balance in parallel with the first. Alternatively the spring balance is first used to pull the trolley with whatever force is needed to maintain constant speed. The reading of the pointer for that is marked on the paper that covers the scale. Then an acceleration experiment is done, the pointer being kept at another mark for the larger force that is used. The paper is removed and the places of both marks are read off on the scale. The force calculated by using $F = ma$ is compared with the difference between those scale readings.

Pupils should be encouraged to know their own mass in kilograms ('How much do you weigh? Put that in pounds, halve that, take off 10 per cent.') The teacher can tell them the mass of the large trolley, or it can be weighed by using a large wooden beam as a seesaw.

Note

The *Teachers' Guide* suggests as an optional extra experiment (33c) that if a teacher feels that pupils need something to do themselves at this point, they might take a scale marked in newtons and use it to pull a trolley of unknown mass. They should use tape to measure the accelerations and then calculate the mass, comparing it with the total of the trolley and its loads which are then revealed.



34 *Demonstration*

Force of impact on floor

Apparatus

a. 1 ball of Plasticine ($\frac{1}{2}$ lb)
   1 domestic balance (5 kg) – item 20

b. 1 demonstration spring balance (5 kg) – item 85
   1 $\frac{3}{4}$ in metal sphere – item 131A
   2 retort stands – items 503–504
   4 bosses – item 505
   1 extra retort stand rod – item 503
   1 ball of Plasticine ($\frac{1}{2}$ lb)
   1 pivoted table – see below
   2 steel rods – see below

Procedure

a. As a preliminary simple illustration of the force of impact, a ball of Plasticine can be dropped on to the domestic balance.

b. A pivoted table is set up using a length of wood about 10 in long, 3 in wide and not more than $\frac{1}{2}$ in thick. Its weight will be neglected so it should not be heavy. Screw hooks fixed into one end pivot over a 3-in length of $\frac{1}{4}$-in steel rod held horizontally in a boss. This forms the pivot for the table.

Towards the other end of the beam another screw hook is used to support the table from a demonstration spring balance fixed above it. (See diagrams opposite.)

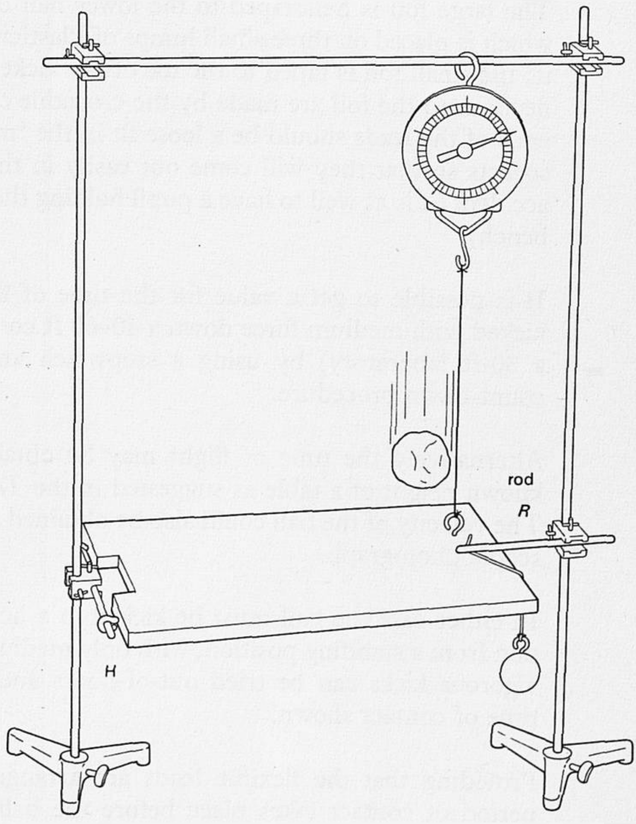
A second steel rod, *R*, held by a boss, is positioned so that the table is secured against it whilst the spring balance is under tension. About 3 in of twine is tied to the metal sphere and about $\frac{1}{4}$ in of the end of the twine is trapped between the steel rod and the table. This sphere acts as a signal ball which will fall when the table moves downward and there is no longer a reaction between table and rod.

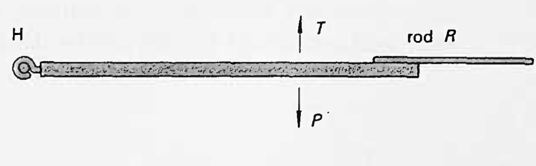
By adjusting the height of the demonstration spring balance, the tension can be altered within wide limits.

A ball of Plasticine (say, about $\frac{1}{2}$ lb) is then dropped on to the table from various heights until a height is found at which the signal ball is released. Care should be taken to drop the Plasticine as near to the hook attached to the spring balance as possible and always on the same point on the table (which can be marked with a drawing-pin).

When the table is pushed down releasing the sphere, there is no reaction between the rod *R* and the table and the force of impact *P* must exceed the tension *T* in the spring balance (neglecting the weight of the beam).

A suitable value for the tension in the spring balance is 3 kg wt. Thus the force of impact *P* must exceed this when the signal ball is released.





35 *Optional demonstration*

Force used to kick a football

Apparatus

1 scaler – item 130/1
1 football (rugby type not suitable)
2 12-ft flexible leads
1 stopwatch or stopclock – item 507
1 lever-arm balance – item 42

Also required is aluminium foil which should be cooking thickness or slightly thinner. A 6-in square and 3-in square are needed. Sellotape (item 92N) Plasticine. The flexible leads should be 2 amp. p.v.c. covered stranded wire or 26 s.w.g. D.C.C. single copper wire.

Procedure

The large foil is Sellotaped to the lower half of the football which is placed on three small lumps of Plasticine to stabilize it: the small foil is taped to the toe of the kicker's foot. Connections to the foil are made by the crocodile clips, the other ends of the leads should be a loose fit in the 'make to count' sockets so that they will come out easily in the event of an accident (it is as well to have a pupil holding the scaler on the bench).

It is possible to get a value for the time of flight of a ball kicked with medium force down a 40–60 ft corridor (or even a 30-ft laboratory) by using a stopwatch and adopting a count-down procedure.

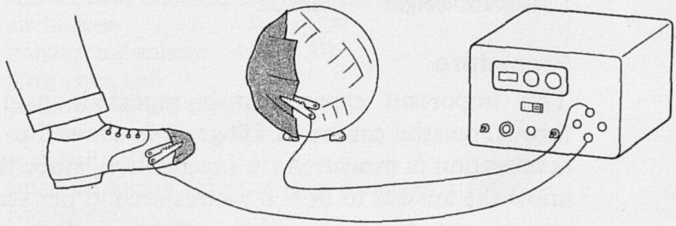
Alternatively the time of flight may be obtained from the known height of a table as suggested in the *Teachers' Guide*. The velocity of the ball could also be obtained from a stroboscopic photograph.

In either case the ball must be kicked in a horizontal direction from a standing position, with only medium force. More vigorous kicks can be tried out-of-doors and the changing time of contact shown.

Providing that the flexible leads are arranged so that the period of contact takes place before the ball pulls the foil away from the crocodile-clip contact, no difficulties should arise and consistent results can be obtained.

Note

For details of the operations of the scaler, see Appendix V at the end of this volumne.



36 *Demonstration*

Earth's gravitational field strength

Apparatus

1 kilogram weight – item 32

Procedure

This important experiment is repeated again and again throughout the course. A kilogram is allowed to fall and the acceleration is measured (in imagination, since the pupils all know the answer to be 9·8 metres/second per second). They can calculate the force acting as (1 kg) × (9·8 metres/second per second). So the Earth pulls with 9·8 newtons on 1 kilogram.

Repeat, wholly in imagination, using a mass of 5 kilograms. The Earth pulls with 5 × 9·8 newtons on the 5 kilograms. From this, the field strength (the pull *on each kilogram*) is 5 × 9·8 newtons/5 kilograms or 9·8 newtons per kilogram.

37 *Demonstration*

Bernoulli effects

Apparatus

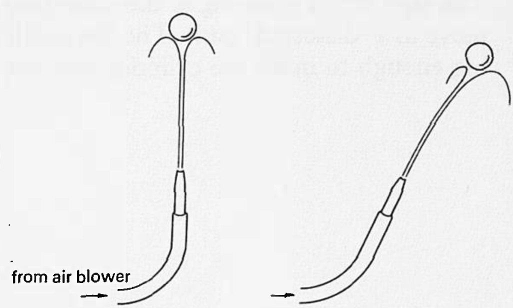
1 rubber tube attached to glass tube with narrow jet
1 air blower – item 165
1 polystyrene sphere – item 3B
1 ping-pong ball
1 glass funnel and tubing
1 cardboard tube (say, 2 in diameter, 1 ft long)
1 cork ball to fit
1 small cardboard tube (say 1 in diameter, 1 ft long)
1 rubber cord
1 piece of cloth

A toy air blower will not suffice for these experiments. A hair dryer (with the heating element turned off) will suffice for (a) but may not be enough for (c). The Electrolux type of vacuum cleaner with the flexible hose put on the 'blowing' end (as opposed to the 'sucking' end) works admirably.

Procedure

The following apparent 'paradoxes' should be shown as demonstrations of Bernoulli effects.

a. *Ball supported by an air jet*
Air is blown down the rubber tubing on the end of which is a glass tube with a narrow opening at the end. A ping-pong ball or light polystyrene sphere ($1\frac{1}{2}$ in diameter) can be supported on the jet and it will continue to be 'held' even if the jet is tilted over as shown.



b. *Ball supported by a water jet*
A ping-pong ball can similarly be held in a water jet connected to a water tap. Again the jet may be tilted over at an angle from the vertical and the ball will still be held.

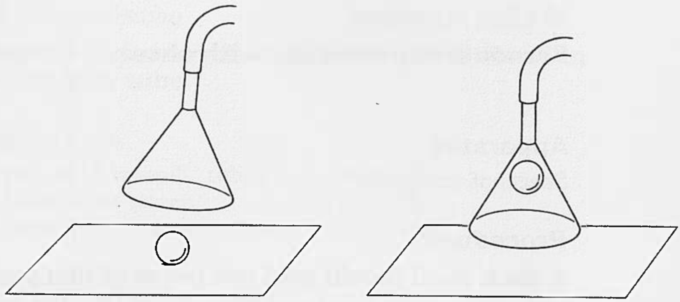
c. *Ball picked up by a funnel*
The glass funnel is connected by rubber tubing to the air blower. The light-weight ball is put on the table and the funnel brought over it. The air blast through the funnel picks up the ball and holds it.

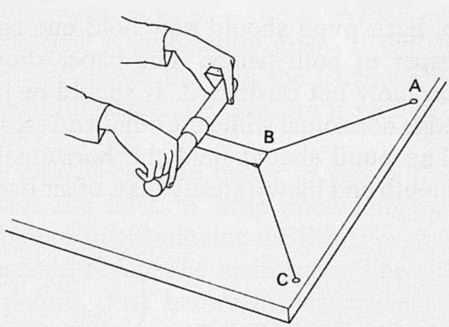
Experiments involving spin
d. *Optional.* A light ball, such as a 1 in-diameter ball of cork (used by fishermen) is placed in a long cardboard tube closed at the lower end. The experimenter holds the tube upright with the lower end in his hand. He holds it with arm outstretched, up behind his head. He then sweeps his outstretched arm quickly forward and down. During this motion the ball rolls out along the upper inside surface of the tube and emerges, spinning fast, around a horizontal axis. The ball's flight then shows a marked curve (upward).

This demonstration needs some practice.

e. *Optional.* A length of rubber cord or common elastic from the drapers is fixed to the bench at A and C. At its centre, B, a length of tape is attached. The other end of the tape is wrapped several times round the middle of a light cardboard cylinder (say, 1 in to 2 in diameter, 1 ft long, with its ends closed by paper or Sellotape). The cylinder is rolled along the bench to continue the wrapping until all the tape has been coiled up round it. The cylinder is pulled back across the bench thereby stretching the elastic cord.

The cylinder is released and the elastic catapults it forward. The tape sets it spinning at the same time. The cylinder will move in a 'distorted' path. The Bernoulli forces may even be big enough to make the cylinder loop the loop.




A
B
C

38 *Class experiment*

Bernoulli experiments with sheets of paper

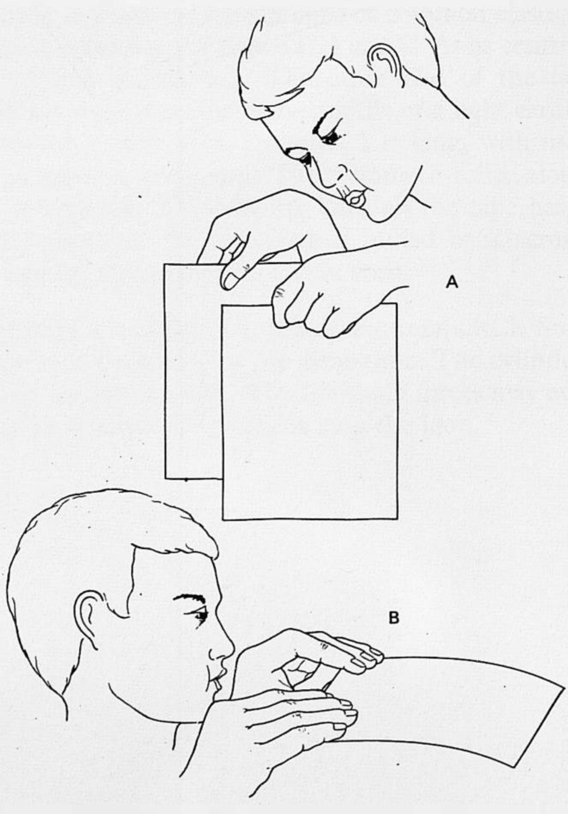
Apparatus

Sheets of thin paper

Procedure

a. Each pupil should hold two pieces of thin paper vertically a short distance apart and blow down into the space between them.

b. Each pupil should now hold one end of a small sheet of paper in both hands. The paper should not be too thick, certainly not cardboard. It should be held out with the held edge horizontal while the other end sags under its own weight. The pupil should hold the horizontal edge just below his mouth and blow a steady blast of air over the top of the paper.



39 *Demonstration*

Bernoulli demonstration with water flowing through a tube

Apparatus

1 pair of 'Bernoulli' tubes	– item 143
1 translucent screen	– item 46/1
1 lamp for translucent screen	– item 46/2

Procedure

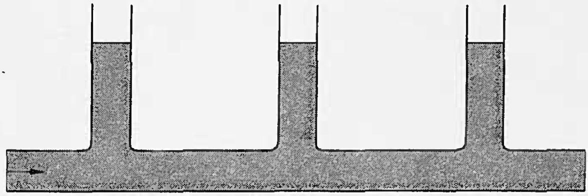
The tubes are set up as shown so that water flows through them in the direction indicated.

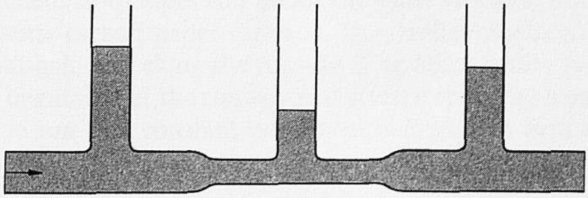
Provided the flow is sufficiently great, it will be seen that where the water passes through the narrower tube and the flow is necessarily faster, the pressure is reduced.

For a large class it may be better to colour the water in a reservoir near the inlet. A little potassium permanganate, methyl orange or ink is suitable for this. For that, a T-piece must be inserted before the main tube. The side branch is closed by a cork. Just before the experiment the cork is removed, some dye in a cloth bag is inserted in the side branch, and the cork is replaced.

Note

It will make it easier for the pupils to see the effect if the tubes are silhouetted agai ıst an illuminated translucent screen.





40 *Demonstration*

Newton's third law with a metre rule

Apparatus

1 metre rule – item 501

Procedure

Teacher and pupil pull on opposite ends of the metre rule as a basis for the discussion of Newton's Third Law. (See *Teachers' Guide*.)

41a *Class experiment*

Elastic collision of trolleys

Apparatus

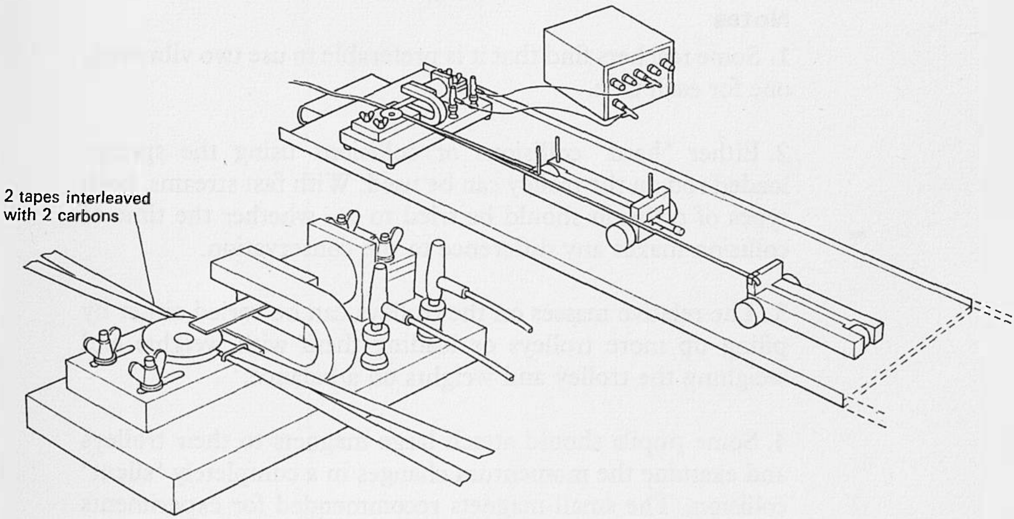
32 dynamics trolleys	– 106/1
16 runways	– 107
16 tickertape vibrators	– 108/1

Each group will require three trolleys, one runway and one or two tickertape timers.

Procedure

In these experiments the colliding bodies have constant speeds before collision and constant speeds (of different size) after collision. Before the experiment, the teacher must make it clear to pupils that they are to measure speeds, not accelerations.

A trolley board is set up and compensated for friction.



Two trolleys are put on the board, each with a tickertape attached. Both tapes run under the same vibrator, but with a separate carbon paper for each. One trolley is placed at rest about half-way along the runway. The other trolley is held at the beginning of the runway and given a shove by hand, then left to run with constant velocity until it collides with the first trolley.

Then pupils have records from which they can read the SPEED of the moving trolley before the collision, and of each of the two trolleys after collision; and they can calculate the total forward momentum before and after the collision. If the trolleys have equal masses and are arranged with spring buffers so that the collision is elastic, the moving trolley is brought practically to rest and the stationary trolley picks up the full motion. Although this special case is very amusing, it is probably better to start with a collision of unequal masses – otherwise velocities are confused with momenta. Therefore, the second trolley that is used as a projectile should be loaded up with an equal trolley so that it has twice the mass of the stationary trolley. On collision the trolleys do not stick together, but the lighter one bounces forward with greater speed while the original one moves more slowly after the collision. Tickertape records are obtained of the motion both before and after the collision and these are analysed. The pupils should find out whether momentum is conserved or not.

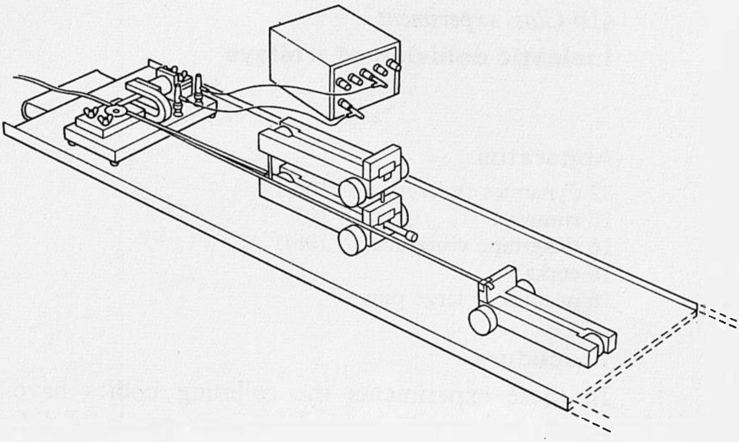
Notes

1. Some teachers find that it is preferable to use two vibrators, one for each tape.

2. Either 'hard' collisions or collisions using the spring-loaded rod on the trolley can be used. With fast streams, both types of collision should be tried to see whether the time of collision makes any difference to the conservation.

3. The relative masses on the trolleys can be varied either by piling up more trolleys or loading them with weights and weighing the trolley and weights on a balance.

4. Some pupils should attach large magnets to their trolleys and examine the momentum changes in a completely 'silent' collision. The small magnets recommended for experiments with toy train wagons will not be strong enough for this. Unless large horseshoe magnets can be obtained, this variant must be omitted.



41b *Class experiment*

Inelastic collision of trolleys

Apparatus

32 dynamics trolleys	– 106/1
16 runways	– 107
16 tickertape vibrators	– 108/1
16 corks	
16 needles or large pins	

Procedure

In these experiments the colliding bodies have constant speeds before collision and constant speeds (of different size) after collision. The teacher must make it clear beforehand that the pupils are to measure speeds, not accelerations.

The previous experiment (41a) is repeated, but this time a needle is fixed on the front of the moving trolley and a cork on the back of the second trolley, so that the trolleys stick together on collision. They then move on as one unit.

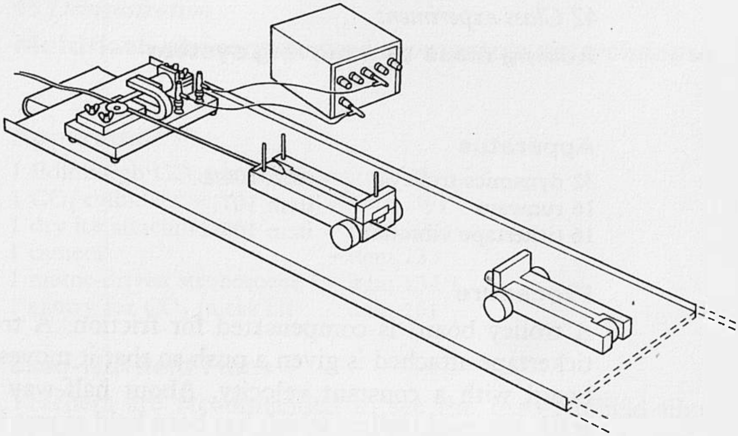
Provided the second trolley starts from rest, a record of the motion before and after collision can be obtained using a single tickertape attached to the back of the first trolley and put through a tickertape vibrator.

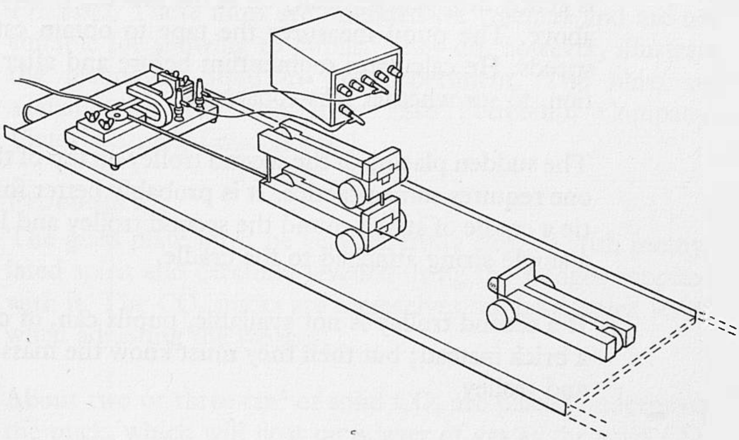
First a moving trolley should collide with an equal trolley at rest. Then another trolley should be put on top of the first, to double the mass.

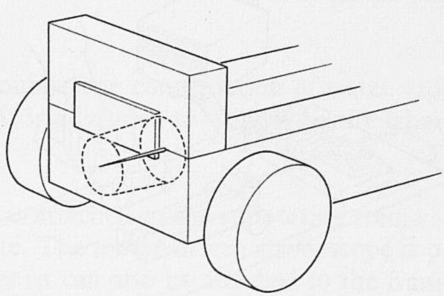
Analysis of the tapes should be carried out to see if momentum is again conserved.

Note

The method by which the cork and pins are attached to the trolleys will depend on the particular make used. With most it is easy to wedge a pin so that it sticks out from the trolley: it may be easier to fix a pin on both trolleys and stick a cork on one of them rather than to fix the cork directly on the trolley.







42 *Class experiment*

Adding mass to a moving system

Apparatus

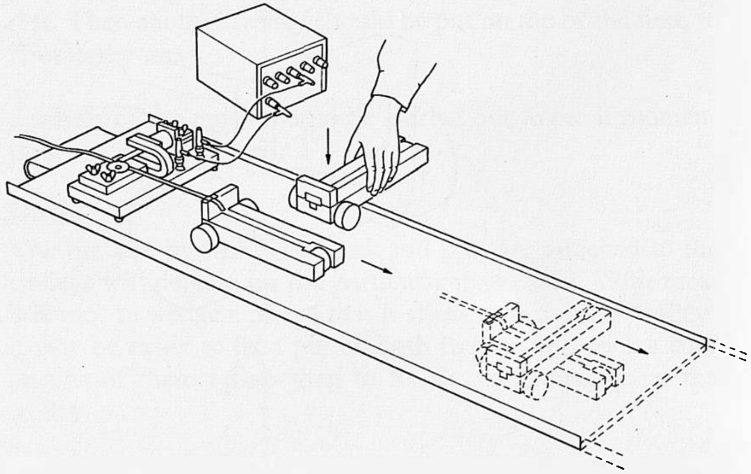
32 dynamics trolleys – item 106/1
16 runways – item 107
16 tickertape vibrators – item 108/1

Procedure

A trolley board is compensated for friction. A trolley with tickertape attached is given a push so that it moves along the board with a constant velocity. About half-way along the track a second trolley, which has been held at rest in mid-air, is gently dropped vertically on to the moving trolley from just above. The pupil measures the tape to obtain estimates of speeds. He calculates momentum before and after the addition, to see whether it is conserved.

The sudden placing of the second trolley on top of the moving one requires some practice. It is probably better for pupils to tie a cradle of string round the second trolley and lower it by a single string attached to the cradle.

If a second trolley is not available, pupils can, of course, use a brick instead; but then they must know the masses of brick and trolley.



43 Demonstration

Multiflash photographs of momentum interchanges

Apparatus

1 Edinburgh CO_2 pucks kit	– item 95
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2
1 camera	– item 133
1 motor-driven stroboscope	– item 134/1
1 gantry for CO_2 pucks kit	· item 161

Esso-Nuffield Films

Teachers are recommended to see the Esso-Nuffield films *Experiments in Force and Motion* and *Momentum and Collision Processes*. These films are intended for teachers and are not suitable for showing to pupils. They do, however, illustrate the techniques used in this experiment. The films are available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

Procedure

The glass plate must be very carefully cleaned with methylated spirit and carefully levelled using the wedges supplied with it. The CO_2 pucks are themselves the best 'spirit level' when adjusting the wedges.

About two or three cm^3 of solid CO_2 are placed underneath the puck, which will float on a layer of gas as the solid CO_2 evaporates.

To avoid troublesome condensation of water vapour on the glass plate, it is advisable to work with the laboratory windows open.

The camera is attached to the supporting frame set up over the glass plate. The motor-driven stroboscope is put in front of the camera (it can also be attached to the frame, as illustrated on page 89).

Alternatively a camera gantry can be improvised using laboratory stools and a trolley runway. See Appendix I at the end of this volume, which gives further details on multiflash photography.

a. First a multiflash photograph should be obtained of a single magnetic puck moving freely across the plate. The photograph should show constant velocity.

b. Secondly a magnetic ring should be photographed making a head-on collision with another ring of the same mass, originally at rest.

c. Experiment (b) should be repeated with the second puck twice the mass of the moving one: this is realized by putting one of the brass rings on top of the magnetic ring as all the rings provided have the same mass. With a fast stream of pupils, a number of variants of these head-on collisions can be tried by varying the masses of both the pucks.

d. Photographs should be taken when the collisions are not head-on. A magnetic puck moving at constant velocity makes a collision with a stationary magnetic puck at such an angle that the two move off in different directions. This important experiment will be an introduction to two dimensional collisions. It will need the analysis of the momenta as vectors and will raise important new questions.

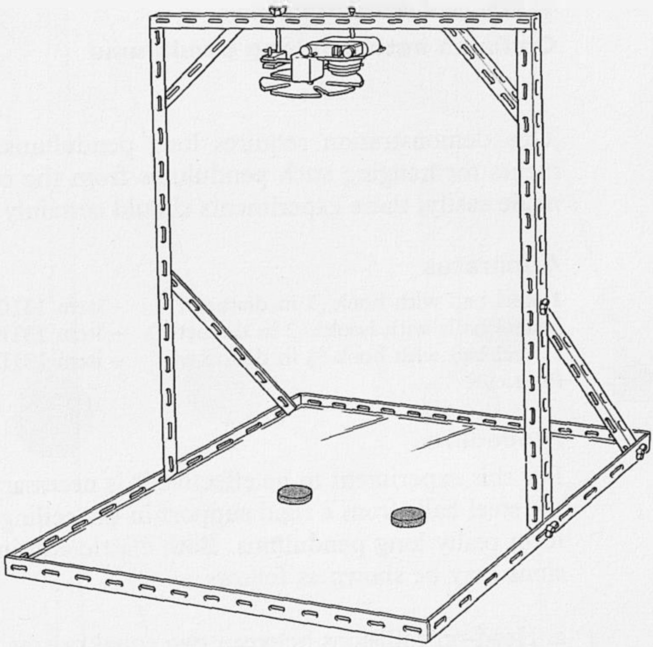
e. *Optional.* For fast groups. Collisions between two pucks which are already moving should be photographed. This is more difficult but rewarding.

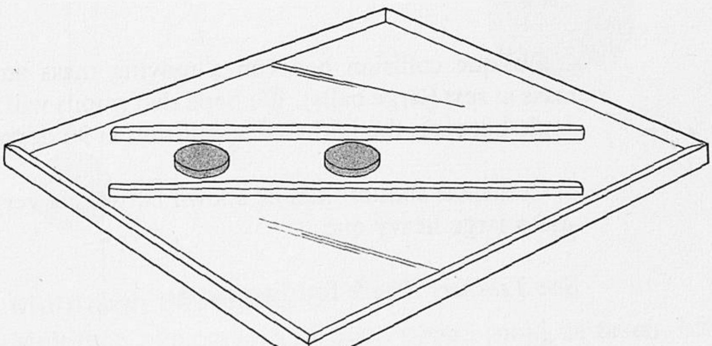
Notes

1. Care should be taken with the magnetic pucks to avoid their being chipped and thereby damaged as this will limit their effectiveness.

2. It is to be hoped that experiment (d) above will show a 90-degree angle between the tracks after collision.

3. In studying linear collisions with the CO_2 pucks, it is helpful to put magnetic strips across the glass plate, as illustrated, in order to confine the motion to one dimension. The repulsion between the strip and the pucks keeps the pucks' motion linear.





44 *Optional demonstration*

Collision between long pendulums

This demonstration requires long pendulums. If arrangements for hanging such pendulums from the ceiling can be made easily, these experiments should certainly be shown.

Apparatus

1 steel ball with hook (1 in diameter)	– item 131C
2 steel balls with hooks (2 in diameter)	– item 131B
1 steel ball with hook ($\frac{1}{2}$ in diameter)	– item 131D
Plasticine	

Procedure

For this experiment to be effective it is necessary to suspend the steel balls from a rigid support in the ceiling so that they form really long pendulums. Both elastic and inelastic collisions may be shown as follows:

a. Head-on collisions between two equal masses (large balls).

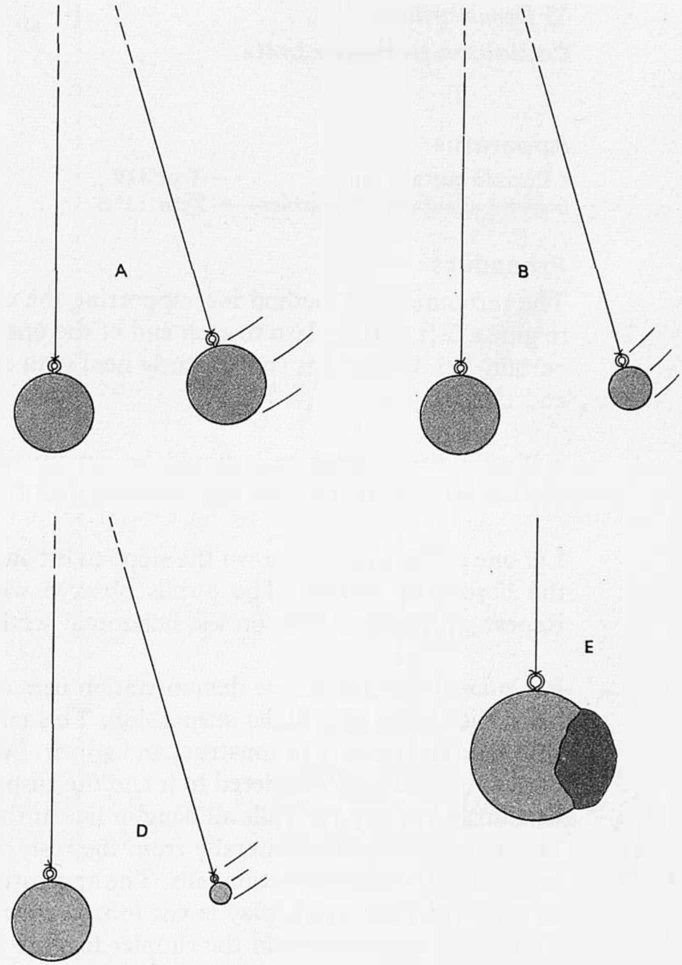
b. Head-on collisions between the medium size and large mass.

c. Oblique collision between a moving mass and an equal mass at rest (large balls). We hope that pupils will see that the angle between the paths after collision is 90 degrees.

d. Collisions should then be shown between a very small ball and a large heavy one.

See *Teachers' Guide* for discussion.

e. The collisions described are almost perfectly elastic. Inelastic collisions can be produced by putting wax or Plasticine on the ball at rest in such a way that the balls stick together on collision. Although such inelastic collisions are very important this particular demonstration is not one that pupils understand clearly and easily. It should be omitted for all but a very fast group.



Multiflash Photographs

Multiflash photographs of these events could be taken, but the experiments are better shown directly. The analysis of multiflash photographs would belong to a more advanced class. However, photographs can be taken by illuminating the spheres strongly and positioning the camera and strobe disc in a direction at right angles to the direction of collision.

45 *Demonstration*

Collisions between balls

Apparatus

1 flexible curtain-rail – item 119
6 steel balls (or glass marbles) – item 131A

Procedure

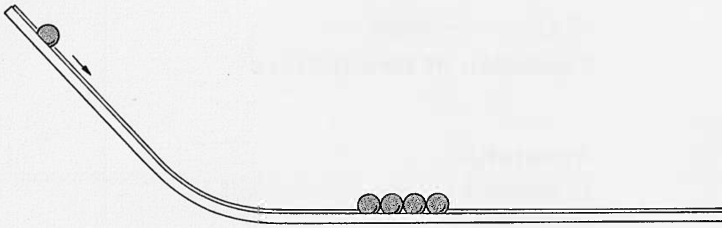
The recommended method for supporting the curtain-rail is to glue a 2-ft wooden lath to each end of the underside of the curtain-rail. One end is conveniently held with a retort stand and clamp.

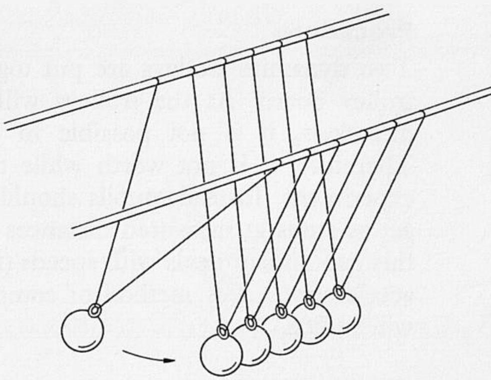
a. The plastic curtain-rail should be set up with its main section horizontal, but one end inclined slightly.

Let one of the balls roll down the slope to hit another ball on the horizontal section. The pupils observe what happens. Repeat with several balls on the horizontal section.

b. *Optional.* An alternative demonstration uses a line of steel balls, each hung by a bifilar suspension. This takes considerable time and trouble to construct and adjust. Each ball must have two small hooks soldered to it and the suspensions must be adjusted so that the balls all hang in line at the same level. If any ball is displaced laterally from the rest, or is too high or too low, the demonstration fails. The apparatus is a delight to play with; but much play is apt to upset the adjustment. Therefore, we recommend the simpler form in (a) above.

c. Pupils might try a simple form of this with a line of pennies, but that does not deserve much time. If they have some form of runway for common marbles, they can try this experiment on their own with marbles.






DEI·GRATIA·REGINA·F:D:+ELIZABETH·II·

46 *Class experiment*

Explosion of two trolleys

Apparatus

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

Also blocks of wood (to act as stops)

Procedure

Two dynamics trolleys are put together at the middle of a trolley board. As the trolleys will be moving in opposite directions, it is not possible to compensate for friction. Therefore, it is not worth while to use tickertape for this experiment. Instead, pupils should place blocks of wood to act as stops at measured distances along the runway. Since this experiment deals with speeds (for momenta) rather than accelerations, this method of comparing distances travelled will suffice.

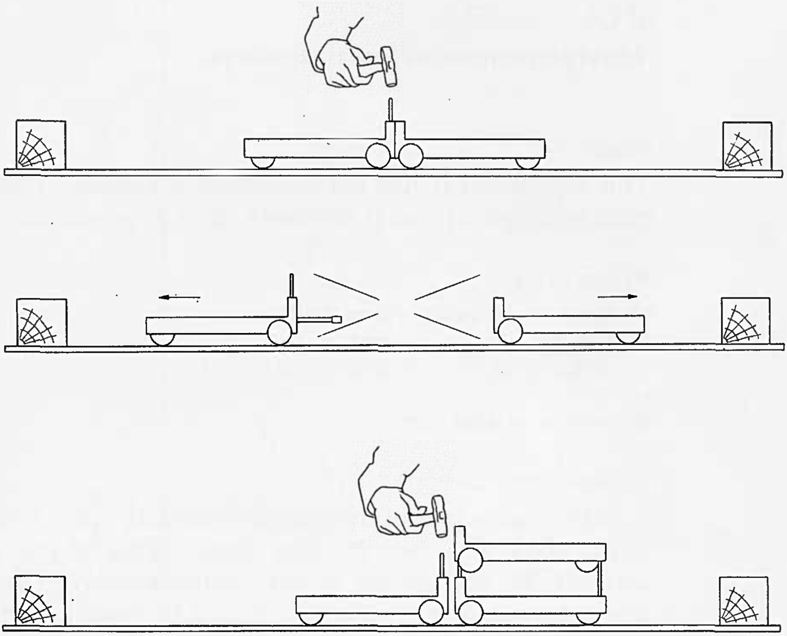
The buffer rods are pushed in against the built-in compression springs. Releasing one of the buffer rods by a smart tap on the vertical release rod produces the 'explosion' which causes the trolleys to fly apart.

The pupils should put a block of wood at each end of the trolley board to act as a stop. The blocks should be positioned first so that each trolley moves the same distance after the explosion before hitting its stop. With trolleys of equal masses, the pupils will find they hit their stops simultaneously.

Pupils repeat the experiment doubling the mass of one trolley by putting an extra trolley on top. They should now decide for themselves how to rearrange the stops (or the starting point) so that the trolleys again hit their stops simultaneously. Then pupils can find from the masses and distances whether the trolleys acquired equal and opposite amounts of momentum.

Note

Runways are not essential for this experiment. Teachers may prefer to dispense with them altogether and use the normal bench-top.



47 Class experiment

'Inverse explosion" with trolleys

Note

This experiment should not be allowed to take much time. If there is danger of this, it should be done as a demonstration.

Apparatus

32 dynamics trolleys	– item 106/1
16 runways	– item 107
32 elastic cords	– item 106/2
16 corks	
16 needles or large pins	

Procedure

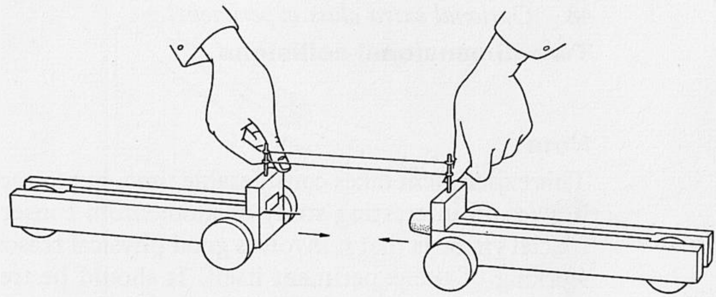
A pupil holds a pair of trolleys some distance apart with two elastic cords stretched between them, trying to pull them together. He releases the trolleys simultaneously. The trolleys come together. The impact should be made inelastic by attaching a cork to one trolley and a needle or large pin to the other so that the trolleys stick together at impact.

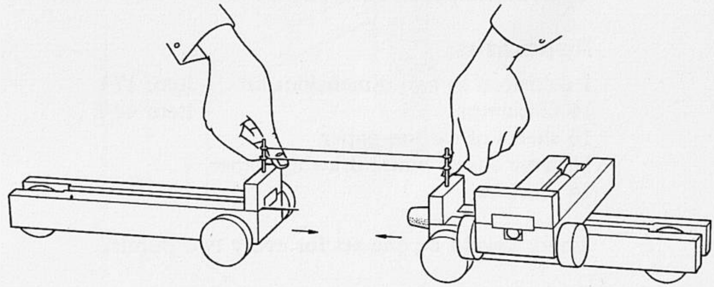
Pupils should watch to see what motion is left after impact.

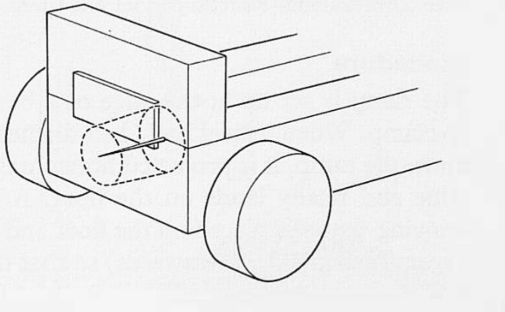
The experiment is repeated with one trolley made twice as massive by piling an extra one on top.

Note

As noted in Experiment 41b, the method by which the cork and pins are attached to the trolleys will depend on the particular make used. With most it is easy to wedge a pin so that it sticks out from the trolley: it may be easier to fix a pin on both trolleys and stick a cork on one of them rather than to fix the cork directly on the trolley.







48 *Optional extra class experiment*
Two-dimensional collisions

Note

This experiment takes considerable time, but in careful hands it gives an interesting study of momentum conservation. Its special virtue is that it involves good physical reasoning in the working of the experiment itself. It should be treated as an optional experiment because of the time it takes.

Apparatus

1 collisions in two dimensions kit	– item 174
16 G-clamps	– item 44/2
16 sheets of carbon paper	
16 large sheets white drawing-paper	
16 marbles	

There should be one set for every two pupils.

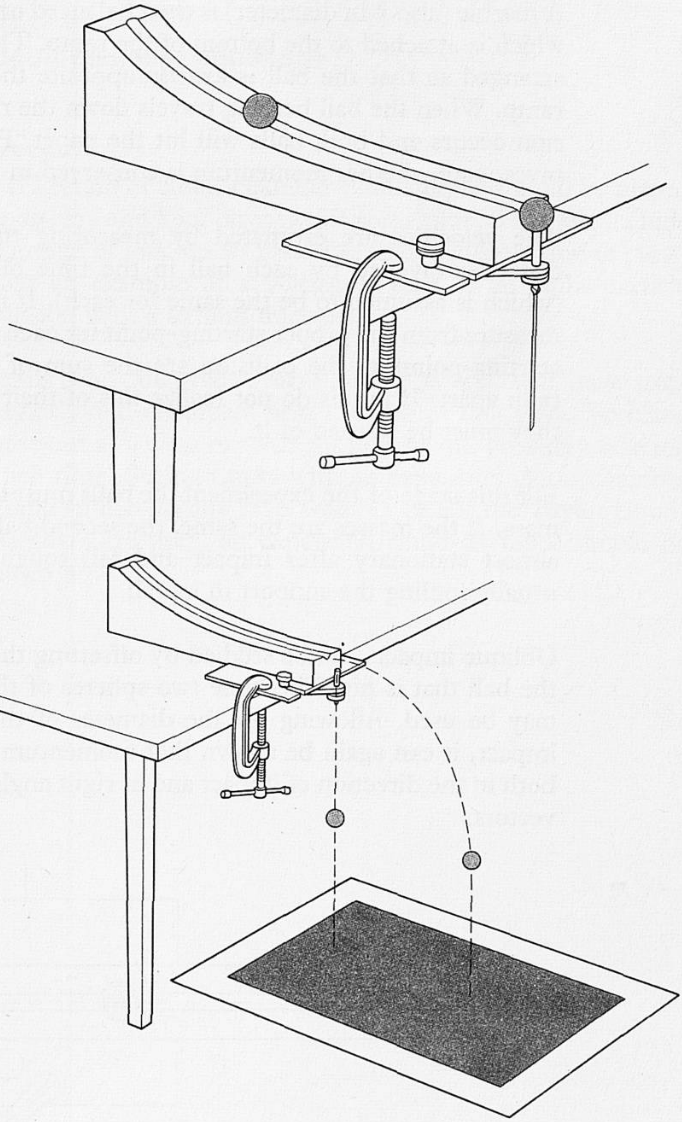
The collisions in two dimensions kit includes steel balls and the marbles in the experiment should have the same diameter: $\frac{5}{8}$ in is suitable, especially as this is the size of the marbles used in the Two-Dimensional Kinetic Model Kit (item 12).

Procedure

The ramp is set up at the edge of a bench and fixed with a G-clamp. When a steel ball ($\frac{5}{8}$ in diameter) is allowed to run down the ramp, it is projected horizontally off the edge of the table and finally lands on the floor. A large sheet of white drawing-paper is placed on the floor and covered with carbon paper (carbon side downwards) so that the point of impact is marked by the falling ball.

The point on the drawing-paper vertically below the point of projection is found with the plumb line, and is marked on the paper. The distance between this point and the point of impact is proportional to the horizontal velocity of the ball on projection.

Pupils need to understand the reasoning underlying this. This is an unusual experiment because the working of the apparatus itself involves interesting physical reasoning. Therefore, that reasoning should be brought out in discussion with pupils: it should not be given to them ready-made. The teacher should ask whether the vertical fall is dependent on the horizontal motion, and how long the vertical fall will



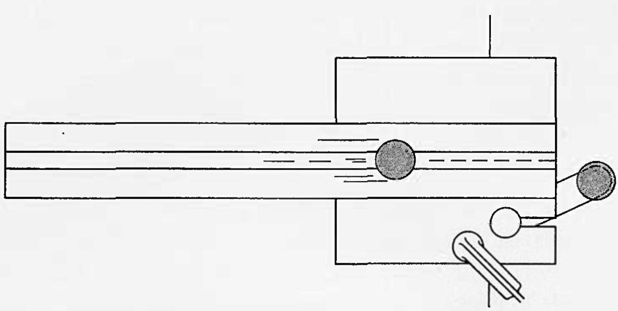
take for one ball compared with another. This needs full, clear discussion before the experiment is done.

A marble (also $\frac{5}{8}$ in diameter) is then balanced on the support which is attached to the bottom of the ramp. This should be arranged so that the ball is *exactly* opposite the end of the ramp. When the ball bearing travels down the ramp, a collision occurs and both balls will hit the paper. Pupils should investigate whether momentum is conserved in the collision.

The velocities are estimated by measuring the horizontal distance travelled by each ball in the time of vertical fall (which is assumed to be the same for each). It is essential to measure from the proper starting-point for each ball; the two starting-points at the collision are the sum of the two ball radii apart. If pupils do not realize this of their own accord, they must be warned of it.

For this stage of the experiment the balls must have different mass. If the masses are the same, the second ball will remain almost stationary after impact and fall roughly vertically, usually fouling the support in its fall.

Oblique impacts can be studied by offsetting the support for the ball that is hit. This time two spheres of the same mass may be used. Allowing for the diameter of the spheres on impact, it can again be shown that momentum is conserved both in the direction of impact and at right angles to it, using vectors.



Notes

1. A measure of the reliability of each reading may be judged by running the balls three or four times for each reading and observing the scatter.

2. For comparison with cloud chamber photographs of alpha-particles in helium, the 90-degree angle between paths of equal masses after collision should be looked for.

49a *Demonstration*

Cloud-chamber collisions

Procedure

A collection of cloud-chamber photographs should be placed on display and kept on view for some time. This will include examples of fork-tracks resulting from collisions and in particular an example of a 90-degree fork of an alpha-particle collision with a helium nucleus.

Pupils who followed Year I of the course will have used Taylor cloud-chambers near the end of that year. To bring those out as a class experiment now would probably take too much time. Seeing tracks with an expansion cloud-chamber should suffice. In any case, whether or not the Taylor cloud-chambers are used, an expansion cloud-chamber should be shown now.

49b *Demonstration*

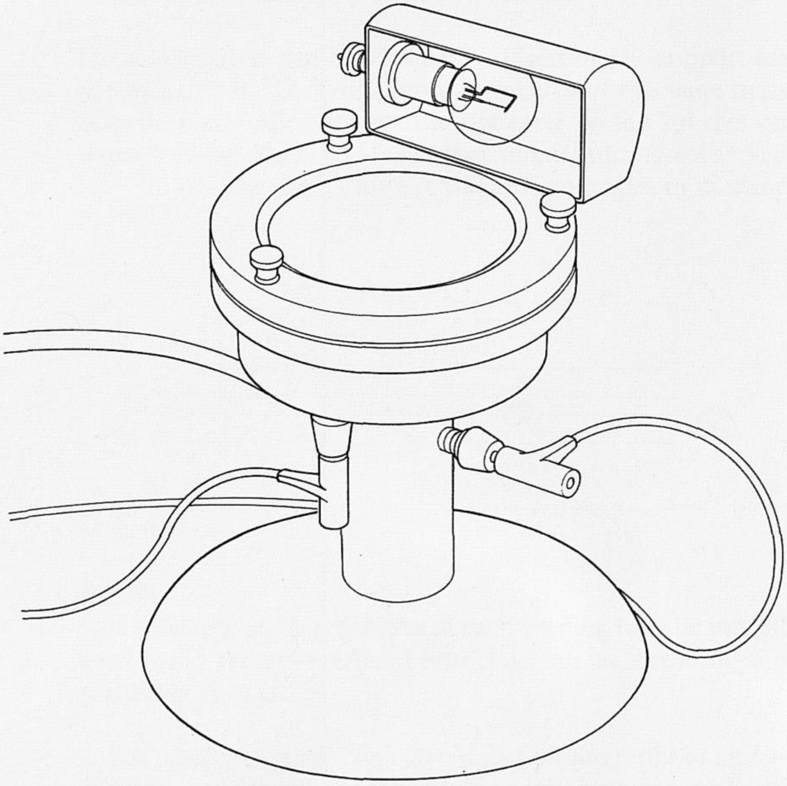
Expansion cloud-chamber

Apparatus

1 expansion cloud-chamber – item 18
1 E.H.T. power supply – item 14

Procedure

Various types of expansion cloud-chamber are commercially available and in each case the manufacturer's instructions should be followed carefully. The requirements are the expansion chamber itself, a bicycle pump or other device for producing the necessary expansion, an illuminant (and a source of voltage for it) and an E.H.T. power supply to provide the necessary sweeping field. Some cloud-chambers require special alcohol, some operate from methylated spirit or even water: the latter are to be preferred.



50 *Optional home experiment*

Collisions with coins

Apparatus

paper
coins

Procedure

The launching ramp is made of an exercise book cover or some other thin sheet of cardboard, or a sheet of stiff paper. It is propped up against some books on the table to make a curving ramp of smaller and smaller slope that is horizontal when it reaches the table.

A standard starting-place is chosen at the top of the ramp and a coin allowed to slide down the ramp and out along the level table. Arriving on the horizontal plane, it travels some distance decelerating, before it is brought to rest by friction. The distance it travels along the level in coming to a stop is noted.

Then the experiment is repeated with another coin placed at the bottom of the ramp. There is a collision and the two coins move along the table until friction brings them to a stop. Measurements of distance travelled are used to indicate the velocities just before and after collision.

However, the velocities are not directly proportional to those distances. If this experiment is suggested at all, the relationship of velocity and distance should not just be given but should be posed as a problem.

As explained in the *Teachers' Guide* this is only an optional experiment, not likely to be easily successful and one that needs considerable discussion for its analysis. However, it needs only simple materials and may be useful for an experiment at home.

51 *Optional demonstration*

Collisions with electrostatic forces

Note

This is a difficult demonstration and should therefore be considered optional.

Apparatus

2 ping-pong balls coated with Aquadag	– item 131E
1 Van de Graaff generator	– item 60/1
some fine nylon suspension	– item 51E

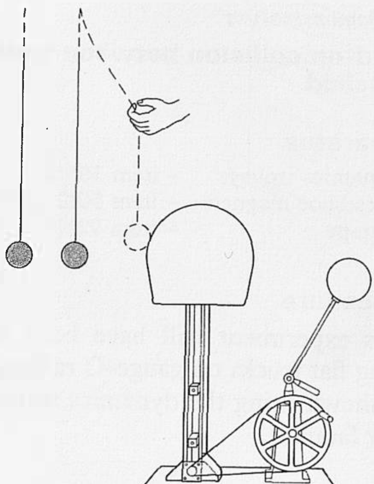
Procedure

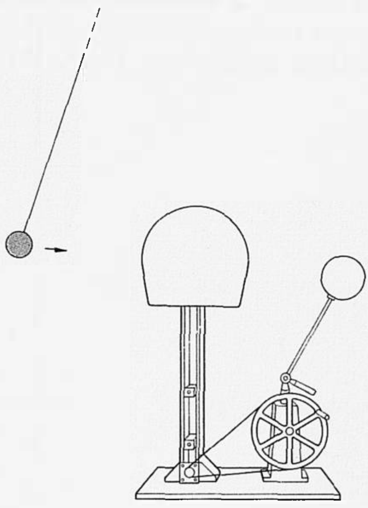
a. The two ping-pong balls should be coated with Aquadag to make them conducting and suspended one diameter apart by the fine nylon thread, preferably from the ceiling, in any case as long as possible.

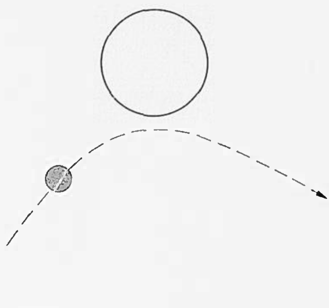
The Van de Graaff generator is set operating and each of the spheres is charged with the same sign by allowing them to touch successively the sphere of the Van de Graaff.

Collision processes between the balls can be studied by drawing back one of the threads and allowing the balls to swing together. The 90-degree angle between paths after collision may be seen by the pupils. Its interpretation should be left to a later stage. Here it is only suggested as an illustration of a collision with 'invisible forces'.

b. The collision of the charged ping-pong ball with the Van de Graaff sphere may also be shown. (This will be a useful introduction to the Year V work on the scattering of alpha-particles in gold foil, but not much time should be spent on it at this stage and no reference should be made to the alpha-particles work.)







52 Demonstration

Head-on collision between trolleys with magnets attached

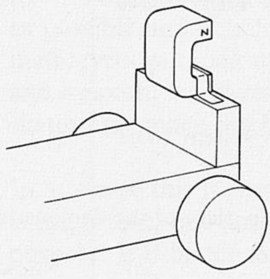
Apparatus

2 dynamics trolleys	– item 106/1
2 horseshoe magnets	– item 50/2
Sellotape	– item 92N

Procedure

This experiment will have been shown in previous years using flat trucks on gauge-O railway track. This time it may be shown using the dynamics trolleys with which pupils are now familiar.

The strong alnico horseshoe magnets are fixed on to the ends of the dynamics trolleys as indicated. Sellotape will be found necessary to secure them satisfactorily. Collisions should be shown between these trolleys (see *Teachers' Guide*).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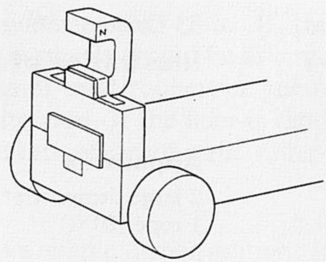
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53 *Demonstration*

Illustration of Newton's Third Law

Apparatus

2 large demonstration trolleys – item 160/1
1 rope (20 ft)

Tables on wheels can be used in place of the demonstration trolleys (see below).

Procedure

The large trolleys, A and B, are placed far apart at the sides of the room facing each other so that they can move towards each other on their wheels as freely as possible.

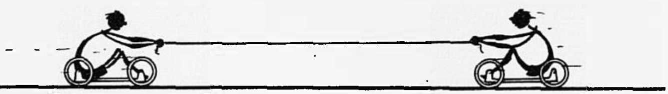
The large trolleys should have one or more pupils on each in order to add mass. Definite starting-points are marked on the floor and the rope is held taut between them.

Pupils on trolley A merely hold the rope whilst those on B haul the rope in until the trolleys collide. Both come to rest and their positions are noted.

This is repeated the other way round: pupils on A hauling whilst the second lot merely hold the rope.

Finally both groups of pupils haul on the rope.

In each case the trolleys should meet at the same point. See the discussion in the *Teachers' Guide*.

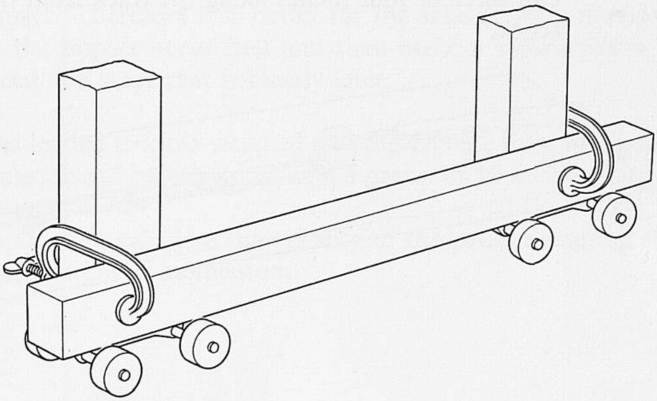


Tables on wheels

Since the motions of the two trolleys are essentially the same in all three cases, it is not necessary to make friction negligible – nor is that possible with large trolleys. However, it is important to make the friction drags as regular, repeatable, as possible. And it is good to make them relatively small. The best design of wheels to meet those conditions depends on the type of floor on which the trolleys run. If the floor is uneven or yields much, the wheels should be as large as possible and should have tyres of solid rubber, or pneumatic tyres pumped up to be quite hard. If the floor is rigid and smooth, or covered with sheets of hardboard, roller-skates may make the best wheels.

In any case this is intended to be a simple demonstration: it is important, but does not deserve special apparatus for the purpose. It is better to try it with any sturdy tables on wheels that are available. If the laboratory has robust tables without wheels, roller-skates are easily installed temporarily. Two skates are screwed on to a beam of wood which is clamped to two legs of the table near the bottom; and another beam with two roller-skates is clamped on the legs on the other side of the table. Each beam is as long as the table. A roller-skate is screwed to it near each end, care being taken to align the skates. Then the sides of these beams are clamped to the sides of the legs of the table, with the roller-skates projecting down below the feet of the legs.

The tables also need buffer-pads at the top where they hit in collision. A bundle of cloth, or a pile of strips of felt, or a block of foam rubber, should be strapped to the edge of the table with string. It is important that the excitement over the collision should not be overshadowed by damage to the tables.



54 *Demonstration*

The speed of a rifle bullet by momentum

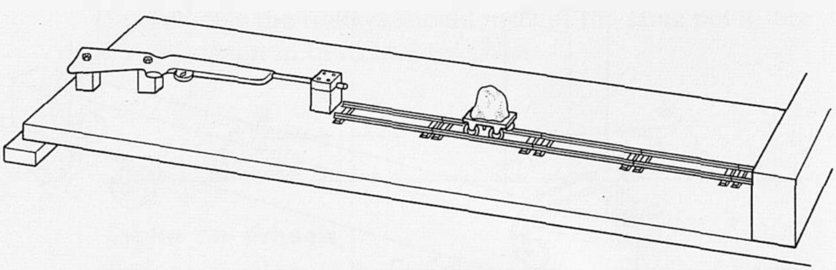
Apparatus

1 air rifle	– item 159
5 lengths gauge O straight railway track	– item 1OR
1 flat truck, gauge O	– item 10S
1 metre rule	– item 501
1 stopclock or stopwatch	– item 507
300 gm of Plasticine.	

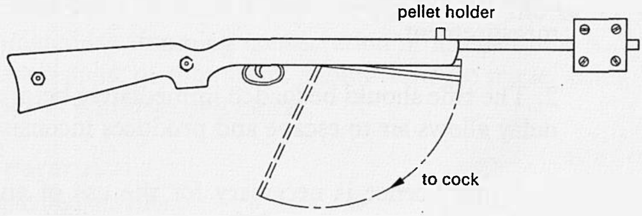
Procedure

The rifle is securely bolted on its side to a board near to one end. It is mounted on two blocks of wood of suitable height to ensure the pellet will hit the centre of a 200–300-gm mass of Plasticine on the truck. The bolts go through the two blocks of wood which act as spacers. The barrel of the gun must be parallel to the track, and the assembly should be such that the loading mechanism can be pulled out sideways.

The straight railway track is laid along the trolley board to take the flat truck with its Plasticine load. The board should be inclined slightly to compensate for friction so that the truck runs down the track at constant speed when given a start. The truck is placed a few inches from the muzzle. A metre rule is placed on the board parallel to the track with its end three or four inches along the track from the end of the truck.



There must be a safety stop at the end of the range to catch pellets. This may be a large block of Plasticine or clay or a large block of polystyrene with wooden backing (at least $\frac{3}{4}$ in thick). It would be wise to add a metal plate behind that. Alternatively a large box of sand can be used.



The loading mechanism is pulled back and then closed in order to cock the rifle. A pellet is inserted in its holder: this holder opens when the rifle is cocked and must be pushed home once the pellet is inserted. The rifle is then fired (after a count-down). The stopclock is started when the truck reaches the beginning of the metre rule and stopped when it reaches the end; that is, when the truck has travelled one metre. From this the velocity of the loaded truck is calculated.

It is tempting to place the beginning of the metre rule at the truck, before firing, and start the stopwatch when the rifle is fired, but that is likely to make pupils associate the measurement with a measurement of acceleration from rest. In fact, we want the constant velocity of the truck (and bullet) after impact. Therefore it is better for the sake of appearances to let the impact occur first and then make a measurement of speed at a stage that is clearly later.

The loaded truck is weighed and the average mass of a pellet is also found by weighing, say, a group of 10 or 20 of them.

Pupils then calculate the velocity of the pellet assuming the conservation of momentum.

Notes

1. Interesting alternative versions of this experiment could be made finding the velocity of the truck with a multiflash picture. However, finding the velocity is essentially a rough measurement, and we should not let attention be distracted from the essential principle by more complicated methods of measurement.

2. The rifle should be loaded immediately before firing as any delay allows air to escape and produces inconsistent results.

3. A gun licence is necessary for the use of an air rifle and is obtainable from Post Offices for ten shillings.

55 Demonstration

Speed of a rifle-bullet measured with a scaler

Purpose

In the previous experiment the velocity of the pellet was estimated by assuming conservation of momentum. A direct measurement of that speed should now be made, using the scaler as a millisecond clock.

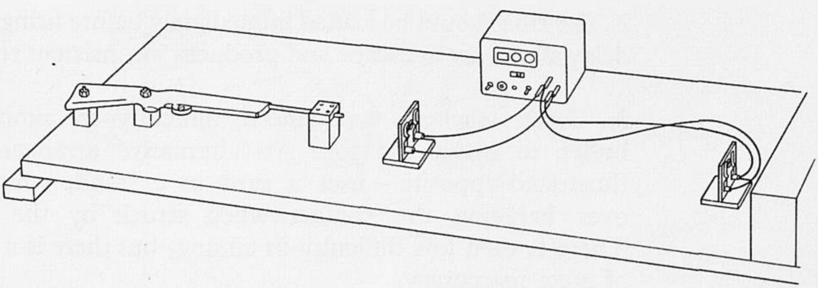
Apparatus

1 mounted air rifle	– item 159
2 circuit breakers	
1 scaler	– item 130/1

Procedure

For details on the use of the scaler as a timing device, see Appendix V at the end of this volume.

The rifle is aimed so that the bullet passes through two small strips of metal foil a measured distance apart, breaking each strip in turn. The scaler is connected to the strips in such a way that the scaler starts counting millisecond pulses when the first strip is broken and stops when the second strip is broken. Thus the scaler measures the time taken by the bullet to travel the measured distance between the strips. Even with a bullet as slow as the pellet from an air rifle, the time to travel one metre will be only a dozen or so milliseconds, so the strips should be placed as far apart as is convenient for aiming.



Since the metal strips must be broken by the bullet, they must be set up very carefully in the line of fire. Making that adjustment might waste a lot of time and spoil the demonstration by a series of misses. Therefore, a scheme such as the following for aligning the metal strips reliably beforehand is essential.

A small sheet of paper is set up at each of the positions where metal strips are to be placed. With the rifle clamped in position, a bullet is fired through these two sheets of paper. Then the strips of metal (which are about $\frac{1}{8}$ in across and 2 in long with a small nick cut in them at the middle) are positioned over the bullet-holes in those pieces of paper on the side away from the rifle in both cases.

Two 'circuit breakers' can be made with wood or hardboard frames. Each of these should have two terminals with spring clips to hold the aluminium foil strips. The first 'circuit breaker', which starts the 'clock', has its terminals connected to the red R-R sockets on the scaler. The terminals of the second are connected to the green G-G sockets.

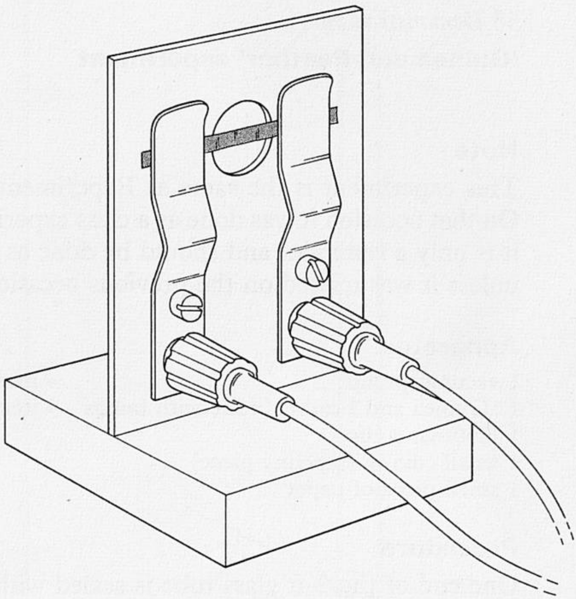
The two 'circuit breakers' are set up a metre apart on the board to which the air rifle is mounted (as described in the previous experiment, 54). Paper is fixed in the spring clips and a pellet is fired for sighting, as discussed above. Narrow strips of aluminium foil are then fixed in the clips to lie across the holes in the paper. The leads connect the terminals to the scaler as described above. Another pellet is fired and the scaler is read. From this reading, the velocity is calculated.

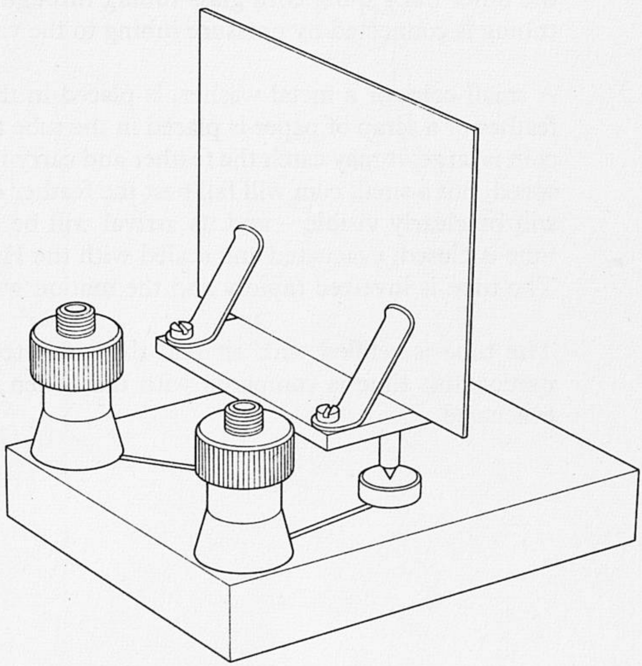
Notes

1. If thin pencil leads as used for propelling pencils are available, these serve well instead of strips of foil. They break more sharply.

2. The rifle should be loaded immediately before firing as any delay allows air to escape and produces inconsistent results.

3. Some teachers experienced difficulty in aiming the bullet to break the foil. An alternative arrangement – illustrated opposite – uses a card in a stand, which falls over breaking the contact when struck by the bullet. There is then less difficulty in aiming, but there is a danger of great inaccuracy.





56 *Demonstration*

'Guinea and Feather' experiment

Note

This experiment is the same as Experiment 65 in Year III. On that occasion it was done as a class experiment. This time it is only a reminder and should be done as a demonstration unless it was missed on the previous occasion.

Apparatus

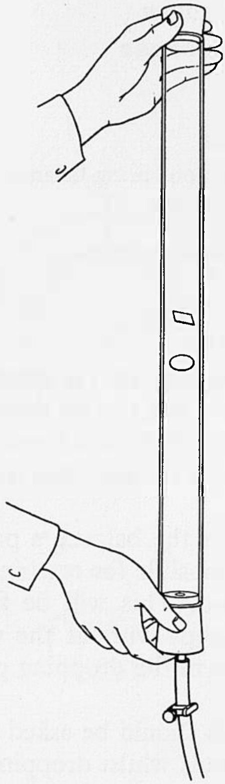
1 vacuum pump	– item 13
1 'Guinea and Feather' tube with bungs	– item 110
1 Hoffmann clip	
1 small coin (a sixpenny piece)	
1 small piece of paper	

Procedure

One end of the 2-ft glass tube is sealed with a rubber bung, the other has a bung with glass tubing through it. The glass tubing is connected by pressure tubing to the vacuum pump.

A small coin, or a metal washer, is placed in the tube and a feather or a scrap of paper is placed in the tube as well. If the coin is large, it may catch the feather and carry it down at full speed, but a small coin will fall past the feather easily and yet will be clearly visible – and its arrival will be audible. The tube is closed, evacuated and sealed with the Hoffmann clip. The tube is inverted rapidly and the motion watched.

The tube is refilled with air and then inverted again. The motion this time is compared with that when the tube was evacuated.



57 *Demonstration*

'Weightlessness'

Apparatus

1 demonstration spring balance	– item 85
1 kilogram weight	– item 32
1 camera	– item 133
1 motor-driven stroboscope	– item 134/1
1 lamp	

Procedure

a. The kilogram mass is attached to the demonstration spring balance and this clearly reads 1 kg. A cushion is put on the floor or pupils hold a blanket to catch the apparatus. The balance with the kilogram mass attached is dropped on it.

(To protect the balance a pupil, good at cricket, should be made responsible for catching the balance as the weight hits the cushion. This will be found easier if there are a few practice drops without the weight attached. A count-down is essential in the dropping process.)

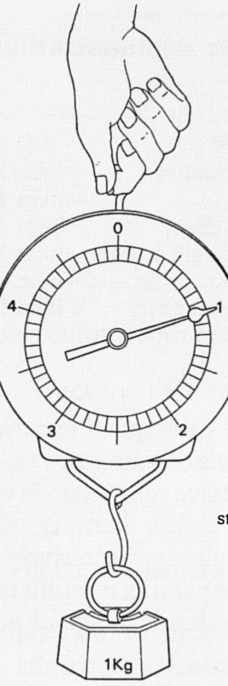
The pupils should be asked whether they can see what the balance reads whilst dropping.

b. *Optional.* A multiflash picture of this experiment can be taken. The motor-driven stroboscope is set up in front of the camera. The lamp illuminates the spring balance. The shutter is opened just before the balance is released and a photograph of the free fall obtained and exhibited.

The hand on the demonstration spring balance must be coloured white or, better, covered with aluminium foil so that its image is seen in the photograph.

Note

It is not easy to do the above fairly. When the system is released, the spring in the balance produces unwanted local motions.



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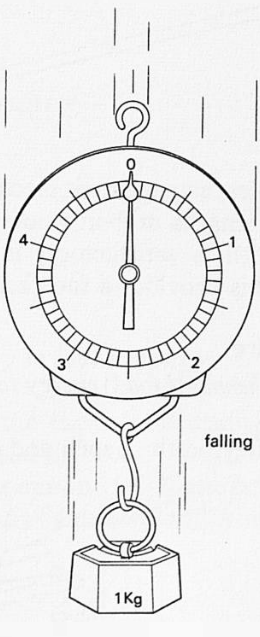


falling

Qualitative demonstrations of kinetic energy

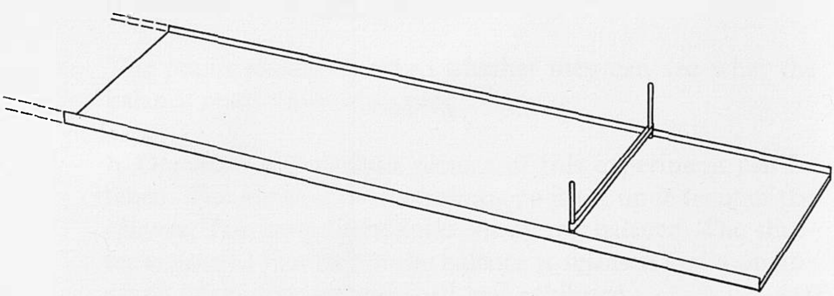
Apparatus

1 dynamics trolley	– item 106/1
1 runway	– item 107
1 pulley on clamp	– item 40
1 100-gm-weight hanger	– item 31/2
1 expendable spring	– item 2A
2 horseshoe magnets	– item 50/2

dowel rod and rubber bands – see below.

Adaptation of runway

In this and subsequent experiments, it is necessary to stretch a catapult across the runway. This could be done by setting up two massive retort stands on either side of the runway and stretching elastic between them. This method, however, would require an excessively large number of retort stands when the apparatus is required for class experiments, and has the further disadvantage of not being very rigid.

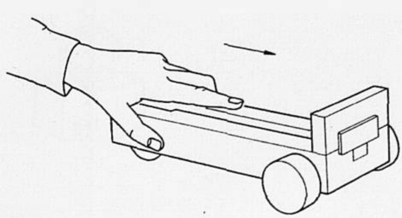


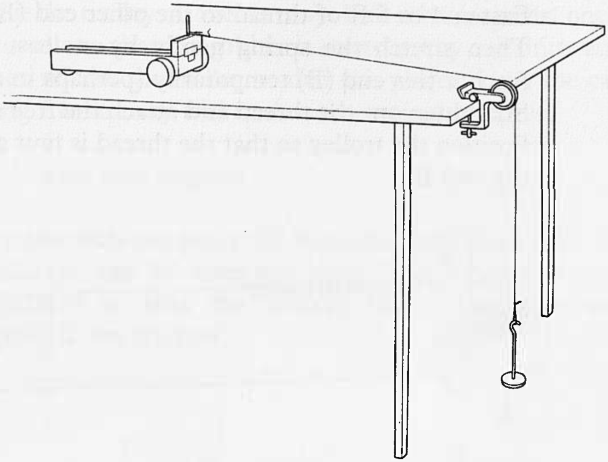
The simplest arrangement is to drill the runway with holes to take 6-in lengths of $\frac{3}{8}$-in wood dowel. If a 3-in elastic band ($\frac{1}{8}$ in width is satisfactory) is stretched between the two dowels, this provides a satisfactory and simple catapult.

Procedure

a. *From chemical (food) energy to kinetic energy*

Put a trolley on the bench and give it a push.

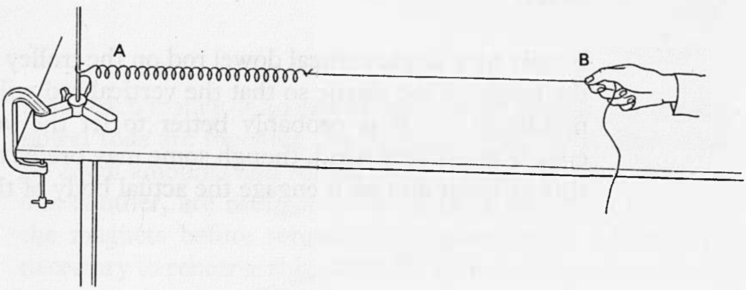




b. *From gravitational potential energy to kinetic energy*

Put a trolley on the bench. Fasten the pulley to the edge, running a thread over it from the trolley to a 100-gm-weight hanger. Let the load fall a short distance to the floor so that the thread falls slack, allowing the trolley to continue.

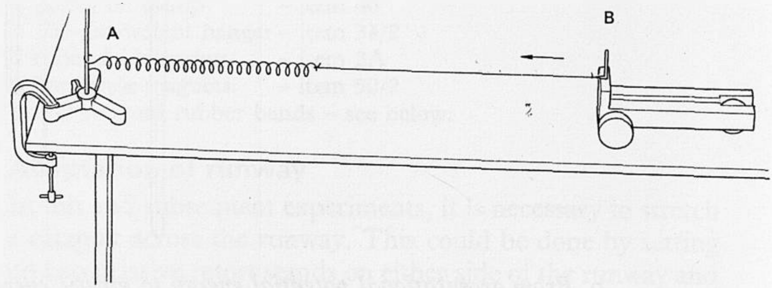
Repeat the demonstration, but in reverse. Start the trolley moving with a push away from the pulley and let it pull the thread taut and lift the load as it comes to rest.



c. *From strain energy to kinetic energy*

Pre-stretch one of the expendable springs from the Elastic Materials Kit (as used in Year I) until it is clearly an open, weak spring. Anchor one end (A) to the bench by slipping the end loop over the rod of a retort stand which is itself clamped to the bench.

Fasten 4 to 6 ft of thread to the other end (B) of the spring. Then stretch the spring gently by at least several inches. Anchor this end (B) temporarily (perhaps in a pupil's hand). Straighten out the thread and attach the free end to a trolley. Position the trolley so that the thread is taut and then release the end B.

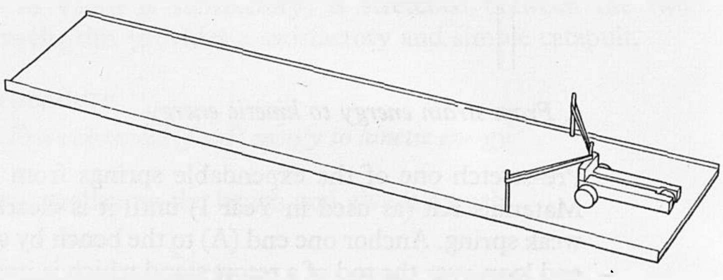


Repeat the experiment, but in reverse. Give the trolley a push so that it causes the spring to stretch.

d. *From strain energy to kinetic energy and to strain energy again*

Set up a catapult across each end of the runway (about 15 in from the ends) by stretching large elastic bands between dowel rods fixed at the sides of the runway as described above.

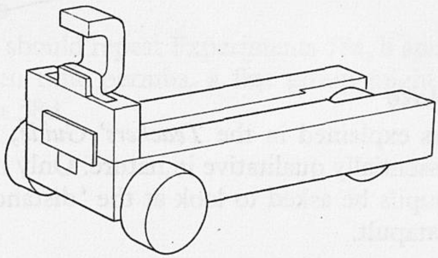
Firmly fix a single vertical dowel rod on the trolley and adjust the height of the elastic so that the vertical rod will catch the middle of it. (It is probably better to let the vertical rod engage the rubber band, though some may prefer to have the rubber lower and let it engage the actual body of the trolley.)

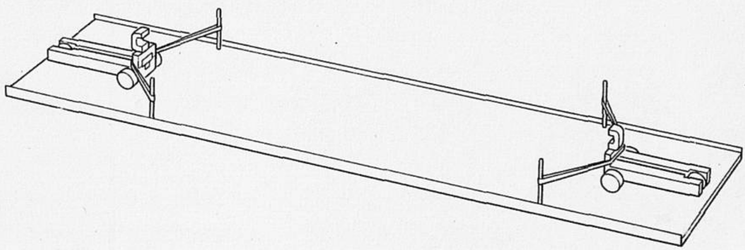


Place the trolley on the runway. Pull it back against one of the catapults so that the rubber is stretched by a definite amount. Then release the trolley so that it is projected by the catapult along the runway and strikes the second catapult.

e. *Collision with magnets*

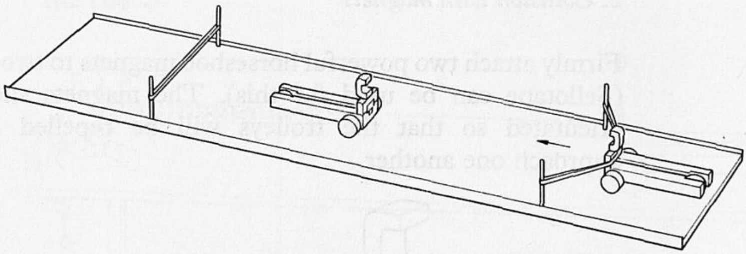
Firmly attach two powerful horseshoe magnets to two trolleys (Sellotape can be used for this). The magnets should be orientated so that the trolleys will be repelled as they approach one another.





Place each trolley at an end of the runway so that the vertical dowel rods are touching the catapults. Pull the trolleys back by equal amounts and release them so that they run towards one another, are brought to rest and pushed away again by the magnets before returning to the catapults. (It may be necessary to rehearse this rather difficult experiment carefully to ensure that the trolleys do not slew round as they approach one another.)

Finally, leave one of the trolleys with magnet attached in the middle of the runway. Draw back the other trolley against a catapult, by a definite amount. Release the trolley so that it collides with the stationary one, which moves away to collide with the second catapult.



Note

As explained in the *Teachers' Guide*, these experiments are essentially qualitative in nature. Only in (d) and (e), need the pupils be asked to look at the 'distance pulled back' by the catapult.

59 *Class experiments*

Qualitative experiments on kinetic energy

Apparatus

16 dynamics trolleys – item 106/1
16 runways – item 107
16 pulleys on clamps – item 40
16 100-gm-weight hangers – item 31/2
16 expendable springs – item 2A
dowel rod and rubber bands.

Procedure

The pupils should repeat Experiments 58a, b and c for themselves. When time permits, a fast group might also set up Experiment 58d.

60 *Class experiment*

Measurements with potential energy changing to kinetic energy

Apparatus

16 dynamics trolleys	– item 106/1
16 pulleys on clamp	– item 40
16 runways	– item 107
16 weight hangers with slotted weights (100 gm)	– item 31/2
1 domestic balance (5 kg)	– item 20
a supply of thread	

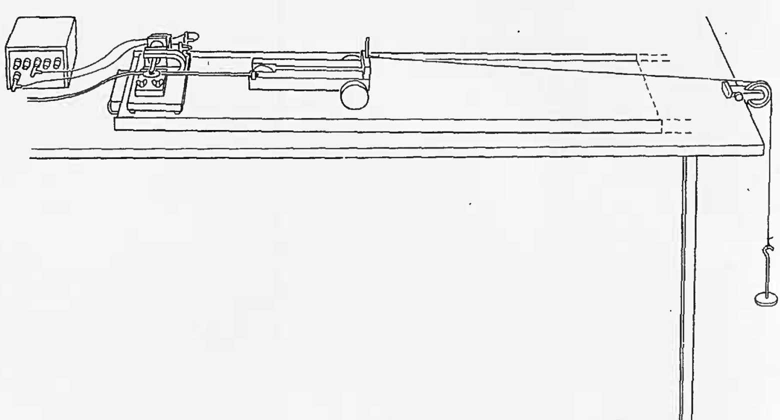
Procedure

a. The runway is compensated for friction in the usual way. A pulley at the end of the board enables a thread attached to the trolley to be connected to a 100-gm-weight hanger.

The falling load gives kinetic energy to the trolley, but it also gains some kinetic energy itself. Allowing for the latter energy would spoil the clear story at this introductory stage; so it should be neglected. Therefore, the mass of the pulling load must be only a very small fraction of the mass of the trolley.

The other end of the trolley has tickertape attached which passes through a vibrator.

When the trolley is released, the falling weight accelerates it until it hits the ground, after which the trolley moves with a *constant velocity*, v. The value of v is estimated from the tickertape. The mass of the trolley is measured (by weighing on a balance). $\frac{1}{2}mv^2$ is calculated. This is compared with the energy lost by the falling load.



Care must be taken that there is no drag by the tickertape comparable with the pulling load. In fact, the friction compensation should be arranged with the tickertape in use.

b. *An alternative procedure as a buffer optional experiment.*

The trolley board could alternatively be friction compensated the opposite way and the trolley used to raise a load.

A thread attached to the trolley carries a 100-gm-weight hanger as before; but the experiment starts with the trolley near the edge of the table, with the thread slack and some of it lying on the floor. Since the thread is slack, a pulley cannot be used, but a glass tube on a knitting needle serves as a roller instead. (Or a second pulley can be arranged very close to the first to prevent the thread leaving the groove.) The tickertape also runs out behind the trolley and passes through the vibrator.

The trolley is given a push with the vibrator switched on, it travels with constant velocity v down the compensated runway until half way down; then the thread goes taut and the load is raised a distance d as the trolley comes to rest. The kinetic energy lost is compared with the potential energy gained.

Note

This experiment could be extended into a series of readings for different loads, different distances of fall, to provide different values of v in $\frac{1}{2}mv^2$; and the mass of the trolley, m, could be changed. Then interesting graphs could be plotted to show relationships between d and v^2, and graphs for different masses.

However, these extensions would make the experiment much longer than it deserves at this time, without making the nature of kinetic energy much clearer, and without increasing pupils' trust in $\frac{1}{2}mv^2$. So extensions are not advised.

61a *Class experiment*

Measurements with strain energy changing to kinetic energy

Apparatus

16 dynamics trolleys	– item 106/1
16 runways	– item 107
16 tickertape vibrators	– item 108/1
16 rubber bands	
16 newton spring balances	– item 81

The runways should be adapted, as described in Experiment 58, so that there is a catapult at one end of each made with an elastic band stretched between dowel rods.

Procedure

Pupils compensate their runways for frictional losses (including friction of the tape) in the usual way. They set up a catapult towards the upper end of the runway by stretching a 3-in rubber band taut between two dowel rods. This should be at such a height that it will engage the vertical rod firmly fixed on the trolley.

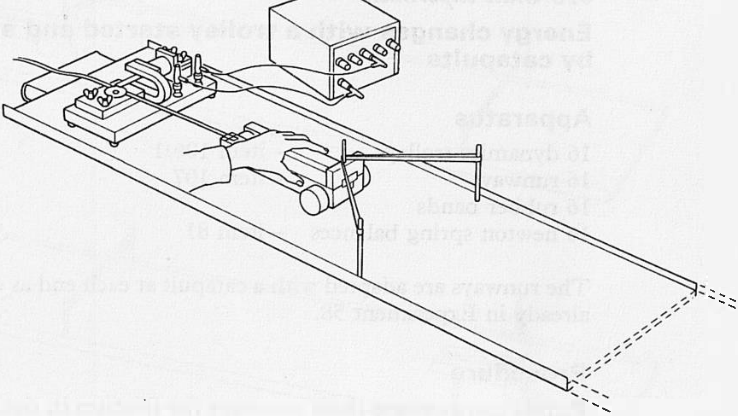
When the trolley is pulled back so that the rubber band stretches, energy will be stored in the catapult. As explained in the *Teachers' Guide*, calculation of this energy demands that measurements be made of the 'distance the trolley is pulled back', for various applied forces. One pupil pulls back the trolley with a newton spring balance from an initial mark and notes the spring balance reading whilst his partner measures the 'distance the trolley is pulled back' from that mark.

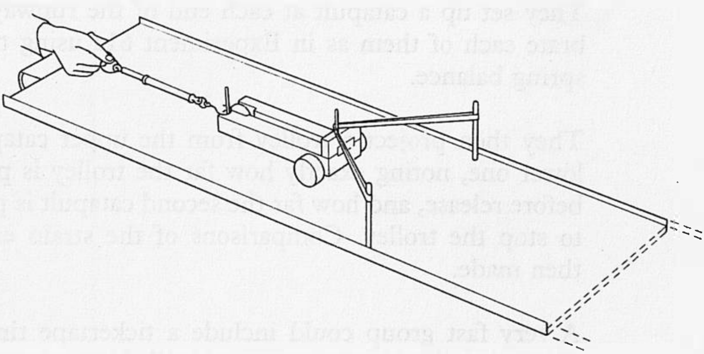
The pupils then obtain tickertape records of the constant velocities of a trolley released from the catapult after it has been pulled back through various known distances.

Notes

1. This experiment is by no means easy: and pupils should not be led to expect more than general agreement between their values of the strain energy lost and kinetic energy gained.

2. Alternatively, stopwatches and metre rules may replace the tape and timers.





61b *Class experiment*

Energy changes with a trolley started and stopped by catapults

Apparatus

16 dynamics trolleys	– item 106/1
16 runways	– item 107
16 rubber bands	
16 newton spring balances	– item 81

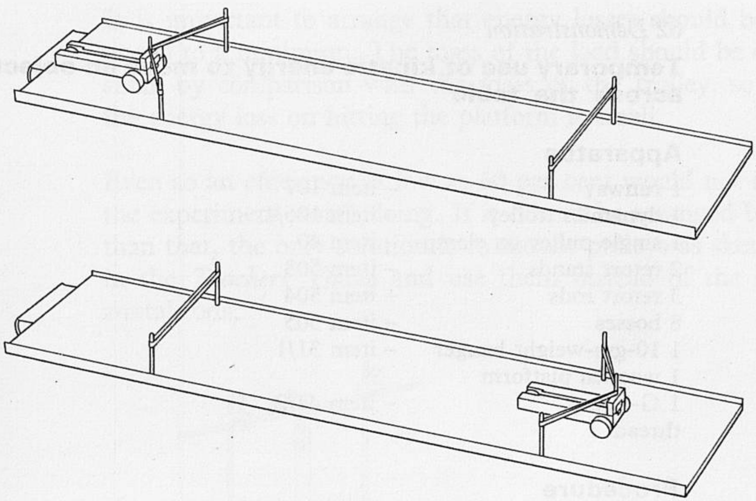
The runways are adapted with a catapult at each end as described already in Experiment 58.

Procedure

Pupils compensate their runways for friction in the usual way. They set up a catapult at each end of the runway and calibrate each of them as in Experiment 61a using the newton spring balance.

They then project a trolley from the upper catapult to the lower one, noting exactly how far the trolley is pulled back before release, and how far the second catapult is pulled back to stop the trolley. Comparisons of the strain energies are then made.

A very fast group could include a tickertape timer and so determine the kinetic energy as well. Slow groups could be content with the setting up of similar catapults and simply comparing the distances stretched.



62 Demonstration

Temporary use of kinetic energy to move an object across the table

Apparatus

1 runway	– item 107
1 dynamics trolley	– item 106/1
1 single pulley on clamp	– item 40
2 retort stands	– item 503
3 retort rods	– item 504
8 bosses	– item 505
1 10-gm-weight hanger	– item 31/1
1 wooden platform	
1 G-clamp	– item 44/2
thread	

Procedure

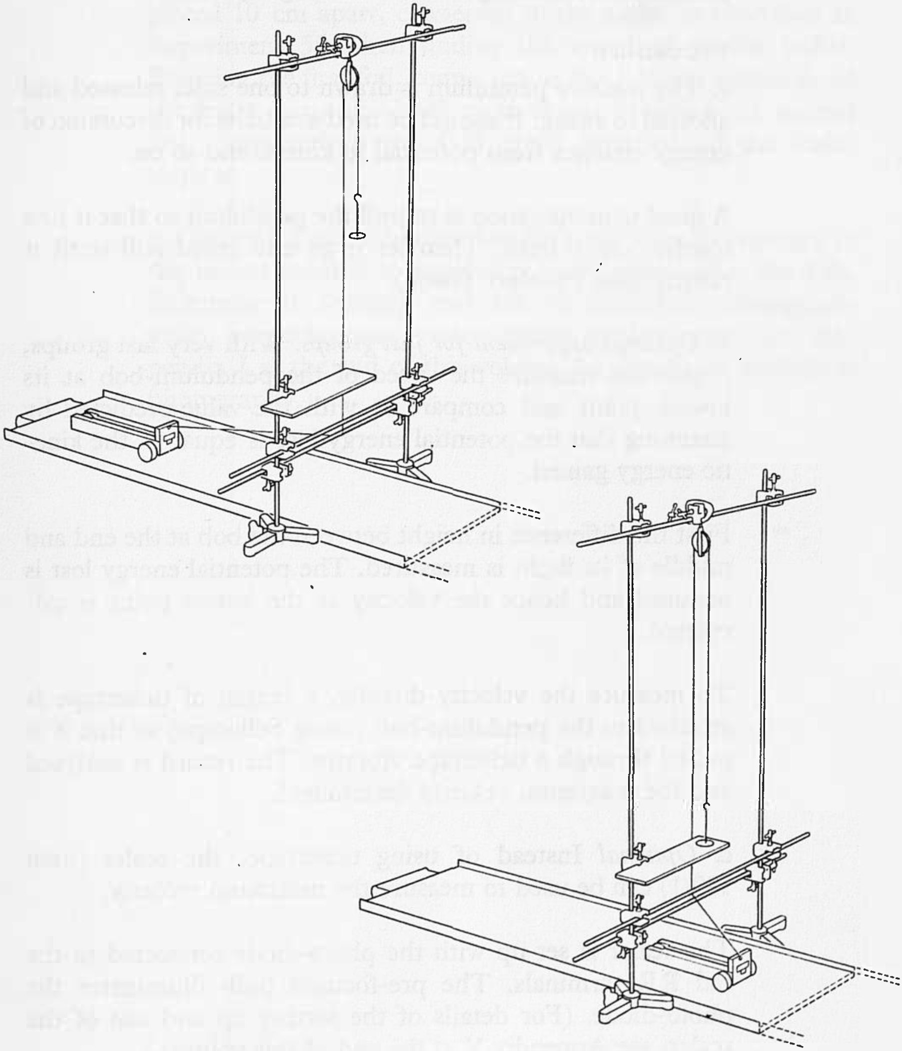
The runway is compensated for friction in the usual way. Half-way along the runway, a retort stand (preferably 100 cm high) is put on each side. A single rod is connected between the tops of the retort stands and a pulley on a clamp is suspended at the centre so that the pulley runs freely with the plane of the pulley parallel to the runway. About one foot below the pulley, a simple wooden platform is fixed between the retort stands. Lower down the retort stands, two rods are fixed parallel to each other and close together across the runway as illustrated. These must be at such a height that a trolley moving along the runway will just clear them. At least one of the retort stands should be clamped firmly to the bench with a G-clamp.

A length of thread is joined to the 10-gm-weight hanger on the wooden platform and over the pulley, down between the double rods to be fastened to the trolley. The thread should be just long enough for the trolley to be about a foot from the parallel rods.

The trolley is then pulled back so that the weight hanger rises to the pulley. Then the trolley is released. It is pulled by the descending mass for the first foot of its travel and then proceeds at constant velocity. Towards the end of its run, the thread tightens and the mass is hauled up again. Ideally, it should rise to its original position.

It is important to arrange that energy losses should be reduced to a minimum. The mass of the load should be quite small by comparison with the mass of the trolley, so that the energy loss on hitting the platform is small.

Even so an efficiency as low as 60 per cent would not make the experiment worth doing. If it cannot be arranged better than that, the only solution is to mount pulleys as sketched in the *Teachers' Guide* and use them instead of the horizontal rods.



63 *Demonstration*

Massive pendulum to show energy changes

Apparatus

1 massive pendulum

A 2-in steel sphere, as supplied in the Year IV General Kit could be used for this experiment. A more massive pendulum-bob such as a large brick or a 7-lb weight would be better. It should preferably be suspended by steel wire and should have a very rigid support, if possible from the ceiling so that it is as long as possible.

Procedure

a. The massive pendulum is drawn to one side, released and allowed to swing. It should be used as a basis for discussion of energy changes from potential to kinetic and so on.

A good demonstration is to pull the pendulum so that it just touches one's head. Then let it go and stand still until it returns (see *Teachers' Guide*).

b. *Optional experiment for fast groups.* With very fast groups, pupils can measure the speed of the pendulum-bob at its lowest point and compare it with the value predicted by assuming that the potential energy lost is equal to the kinetic energy gained.

First the difference in height between the bob at the end and middle of its flight is measured. The potential energy lost is deduced and hence the velocity at the lowest point is calculated.

To measure the velocity directly, a length of tickertape is attached to the pendulum-bob (using Sellotape) so that it is pulled through a tickertape vibrator. The record is analysed and the maximum velocity determined.

c. *Optional* Instead of using tickertape, the scaler (item 130/1) can be used to measure the maximum velocity.

The scaler is set up with the photo-diode connected to the red RR terminals. The pre-focused bulb illuminates the photo-diode. (For details of the setting up and use of the scaler, see Appendix V at the end of this volume.)

To avoid difficulties caused by rotation, the bob should either be spherical or should have a cardboard cylinder fixed round it. The pendulum, photo-diode and bulb are positioned so that the cylinder passes between the bulb and the photo-diode when the bob is at its lowest point. The scaler will record the time it takes for the cylinder to pass the photo-diode – hence its velocity is measured.

d. *Optional* Another method for measuring the velocity, instead of those suggested in (b) and (c) above, is to attach a spike to the bob and get it to break two aluminium foils, placed 10 cm apart, connected to the scaler as described in Experiment 55 when finding the speed of a rifle bullet. Breaking the first foil, connected to the RR red terminals of the scaler starts the 1000 cycle clock; breaking the second foil, connected to the GG green terminals of the scaler stops it.

e. *Optional.* Yet another method for measuring the velocity at the lowest point is to attach a polished steel ball to the bob, illuminate it strongly and take a multiflash photograph using a synchronous motor-driven stroboscope. (See Appendix I at the end of this volume for details on multiflash photography.)

64 *Class experiment*

Galileo's pin and pendulum experiment

This is a repetition of Experiment 53b in Year III.

Apparatus

16 simple pendulums	– item 527
16 6-in nails (or dowel rods)	– item 10H
16 retort stands	– items 503–504
16 clamps	– item 506
32 bosses	– item 505
32 2-in metal strips as jaws	– item 121
16 G-clamps	– item 44/1

Procedure

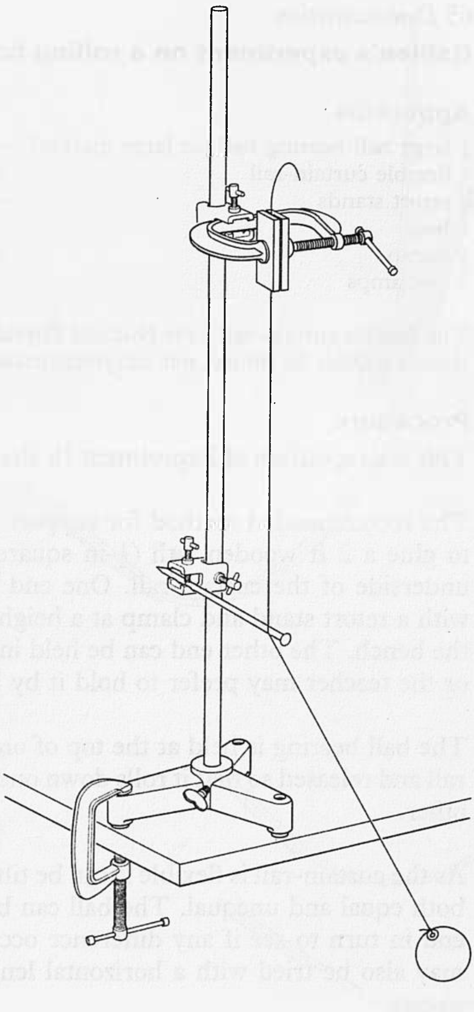
The pendulum is set up as illustrated.

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

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

Note

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



65 *Demonstration*

Galileo's experiment on a rolling ball

Apparatus

1 large ball-bearing ball (or large marble)	– item 131A
1 flexible curtain-rail	– item 119
2 retort stands	– items 503–504
1 boss	– item 505
1 clamp	– item 506
2 G-clamps	– item 44/2

The flexible curtain-rail – see Nuffield Physics *Guide to Apparatus* – should neither be flimsy, nor unsymmetrical.

Procedure

This is a repetition of Experiment 18 already seen in this year.

The recommended method for supporting the curtain-rail is to glue a 2 ft wooden lath ($\frac{1}{2}$-in square) to each end of the underside of the curtain-rail. One end is conveniently held with a retort stand and clamp at a height of about 1 ft above the bench. The other end can be held in another retort stand or the teacher may prefer to hold it by hand.

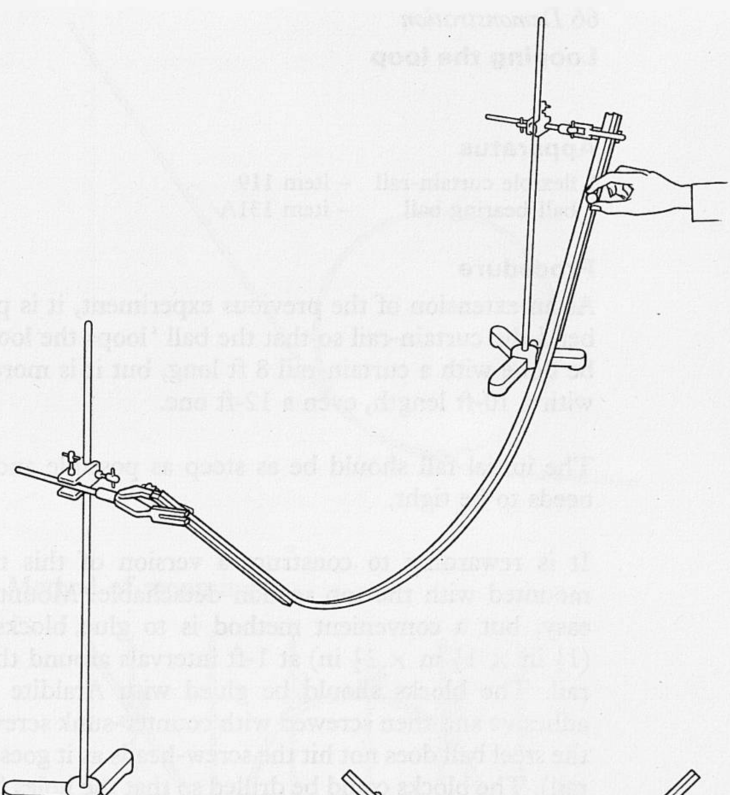
The ball bearing is held at the top of one end of the curtain-rail and released so that it rolls down one side and then up the other.

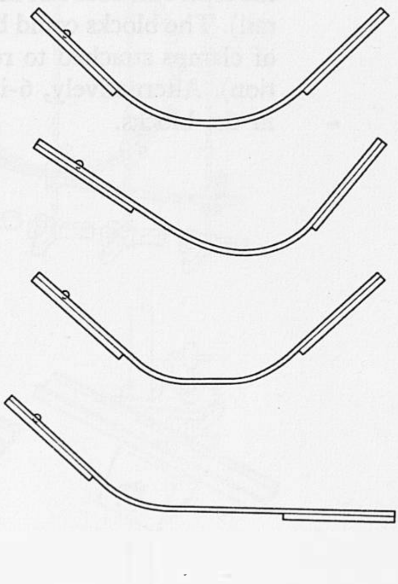
As the curtain-rail is flexible it can be tilted, to various slopes, both equal and unequal. The ball can be released from each end in turn to see if any difference occurs. The experiment may also be tried with a horizontal length between the two slopes.

As part of the discussion (see *Teachers' Guide*), the demonstration should finish with the slope on one side and the other side horizontal.

Note

It is very important for the support to be rigid if the experiment is to be effective. There must not be energy losses caused by the rail moving.





66 *Demonstration*

Looping the loop

Apparatus

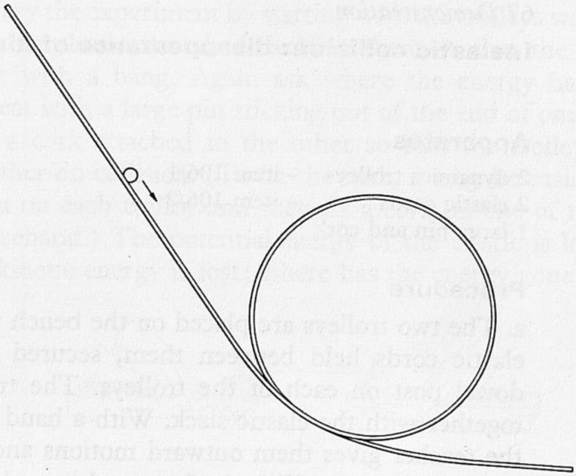
1 flexible curtain-rail – item 119
1 ball-bearing ball – item 131A

Procedure

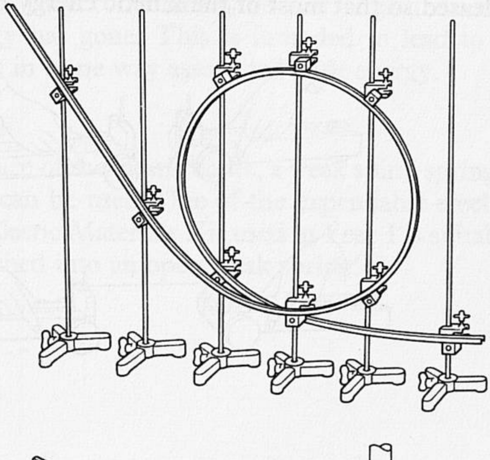
As an extension of the previous experiment, it is possible to bend the curtain-rail so that the ball 'loops the loop'. It can be done with a curtain-rail 8 ft long, but it is more effective with a 10-ft length, even a 12-ft one.

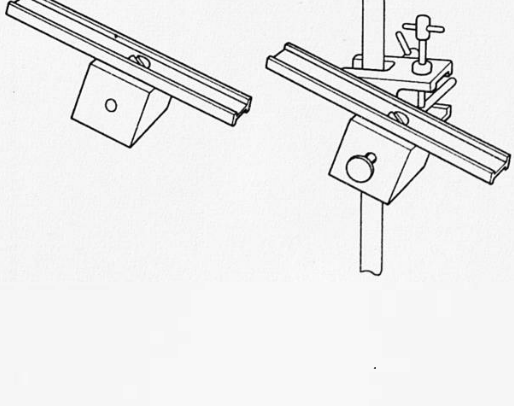
The initial fall should be as steep as possible and the loop needs to be tight.

It is rewarding to construct a version of this really well mounted with the top section detachable. Mounting is not easy, but a convenient method is to glue blocks of wood ($1\frac{1}{2}$ in $\times$ $1\frac{1}{2}$ in $\times$ $1\frac{1}{2}$ in) at 1-ft intervals around the curtain-rail. The blocks should be glued with Araldite or similar adhesive and then screwed with counter-sunk screws (so that the steel ball does not hit the screw-heads as it goes round the rail). The blocks could be drilled so that the holes fit the ends of clamps attached to retort stands with bosses (see illustration). Alternatively, 6-in nails can be put through the holes in the blocks.



Method of mounting:





67 *Demonstration*

Inelastic collision: disappearance of kinetic energy

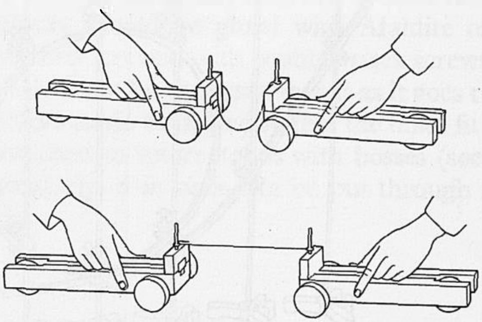
Apparatus

2 dynamics trolleys	– item 106/1
2 elastic cords	– item 106/2
1 large pin and cork	

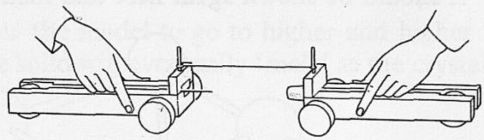
Procedure

a. The two trolleys are placed on the bench with one or two elastic cords held between them, secured over a wooden dowel post on each of the trolleys. The trolleys are close together with the elastic slack. With a hand on each trolley, the teacher gives them outward motions and lets go so that they move apart. The elastic stretches and brings them to rest and the teacher holds the trolleys in that position.

He asks where the energy has gone. The trolleys are then released so that most of the kinetic energy is got back.



b. Vary the experiment by starting with the trolleys well apart and the elastic stretched. Release them so that the trolleys meet with a bang. Again ask where the energy has gone. Repeat with a large pin sticking out of the end of one trolley and a cork attached to the other so that the trolleys stick together on collision. (To fix the cork, it may be easier to fix a pin on each trolley and then fix a cork on one of the pins beforehand.) The potential energy of the elastic is lost, and the kinetic energy is lost; where has the energy gone?



c. Repeat (b) using the trolleys with the sprung buffer-rods protruding from the trolleys. When the trolleys collide, they will now bound apart, be stopped by the elastic, return and collide again. This process will be repeated several times before they come finally to rest. Again discuss where the energy has gone. This is intended to lead to ideas of heat being in some way associated with energy.

Note

In place of the elastic cords, a weak spiral spring of good steel wire can be used. One of the expendable steel springs from the Elastic Materials Kit used in Year I is suitable if it is pre-stretched into an open weak spring.

68 *Demonstration*

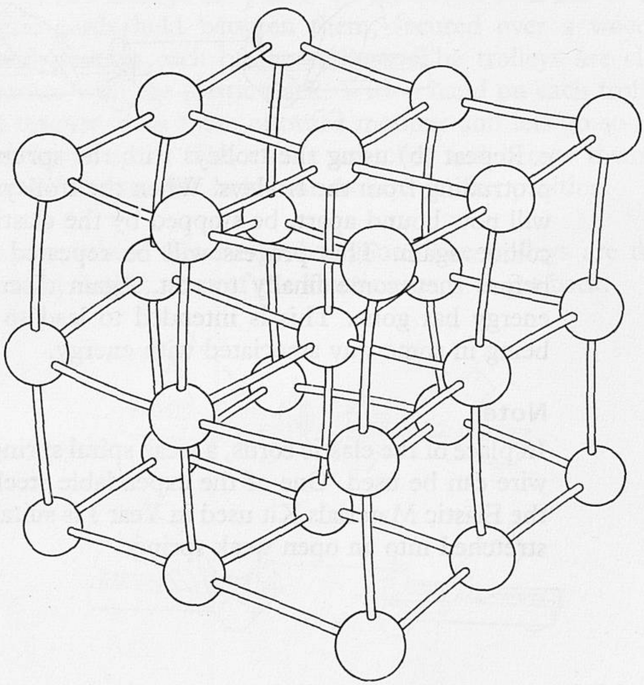
Model of atoms in a solid

Apparatus

1 atom model – item 22

Procedure

The model will already have been shown in earlier years, but it should be shown again here and made to vibrate.



69 *Optional demonstration*

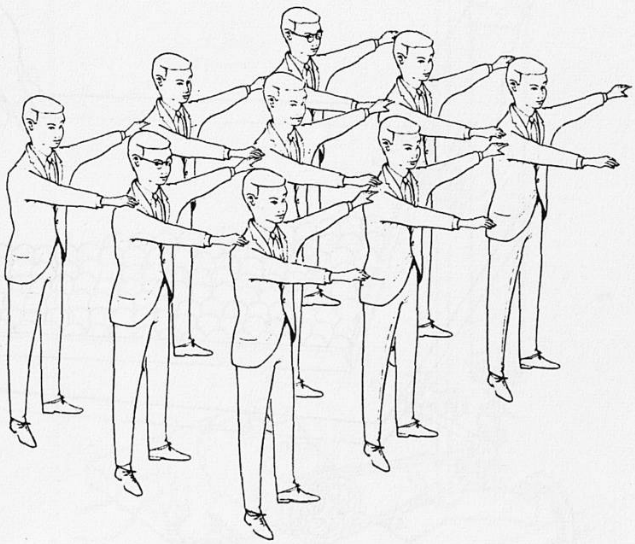
Model of a solid using pupils

Procedure

The pupils sit or stand in a regular array with arms stretched out to hold the shoulders of neighbours. They should start at 'absolute zero' and they should be asked to 'warm up' by vibrating to and fro.

If we allow the model to go to higher and higher 'temperatures', the solid will eventually 'melt' as the crystal comes to pieces.

For a model of molecules in a liquid, pupils should stand close together with arms folded, moving about as a fluid crowd.



70 *Class experiment*

Model of a liquid

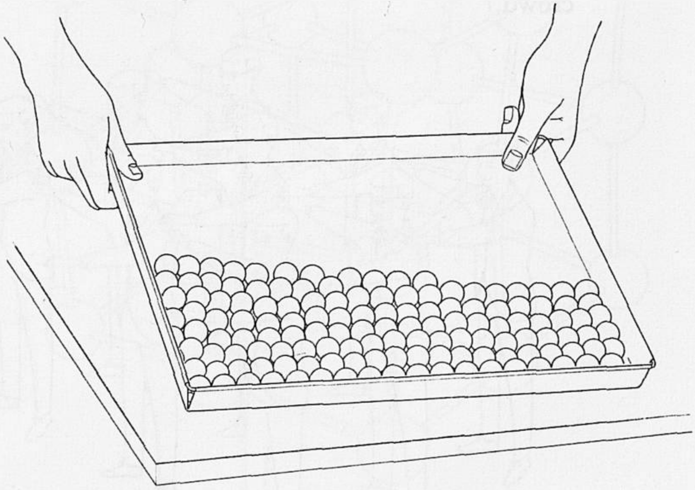
Apparatus

1 two-dimensional kinetic model kit – item 12

Procedure

Enough marbles should be put into the kinetic model trays to fill them at least one quarter full. The pupil inclines the tray with a slope of 1 in 10 or less and agitates it gently with one edge on the bench-top. He watches the motion of the marbles. (See *Teachers' Guide*.)

Both 'diffusion' and 'evaporation' can be illustrated using the model.



71 *Demonstration*

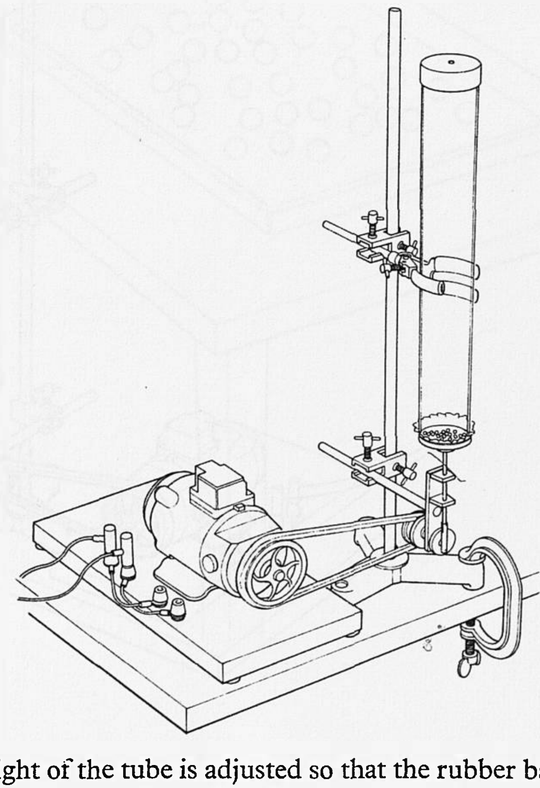
Three-dimensional kinetic model of a gas

Apparatus

1 kinetic model kit	– item 11
1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
1 retort stand	– items 503–504
1 boss	– item 505
1 clamp	– item 506

Procedure

The rubber diaphragm is fixed over the lower end of the plastic tube, which is held in a vertical position using a retort stand, boss and clamp.

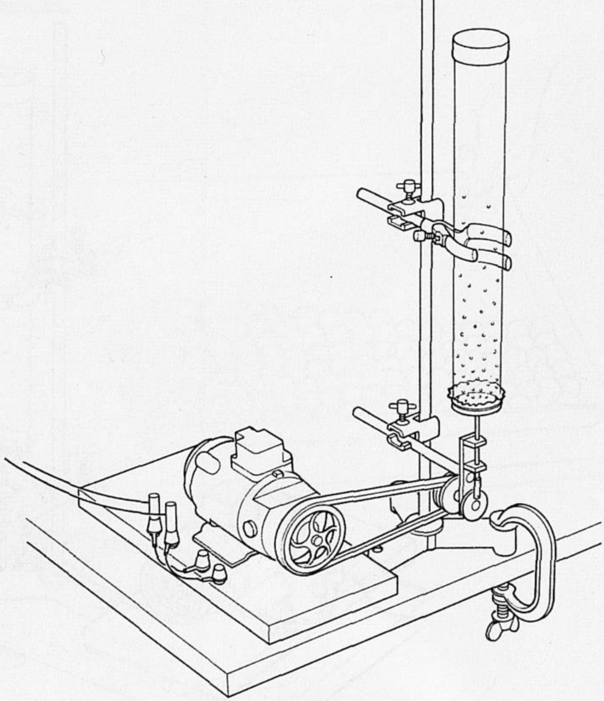


The height of the tube is adjusted so that the rubber base is a millimetre or two above the vibrating rod in its mean position. The f.h.p. motor is used to drive the vibrating rod. The d.c. terminals of the L.T. variable voltage supply are connected to the field and armature coils of the motor in parallel.

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 and gradually increase it. If the paper piston is put into the tube and is free to move, the pupils may notice for themselves the increase in volume: this will be used again later.



72 *Class experiment*

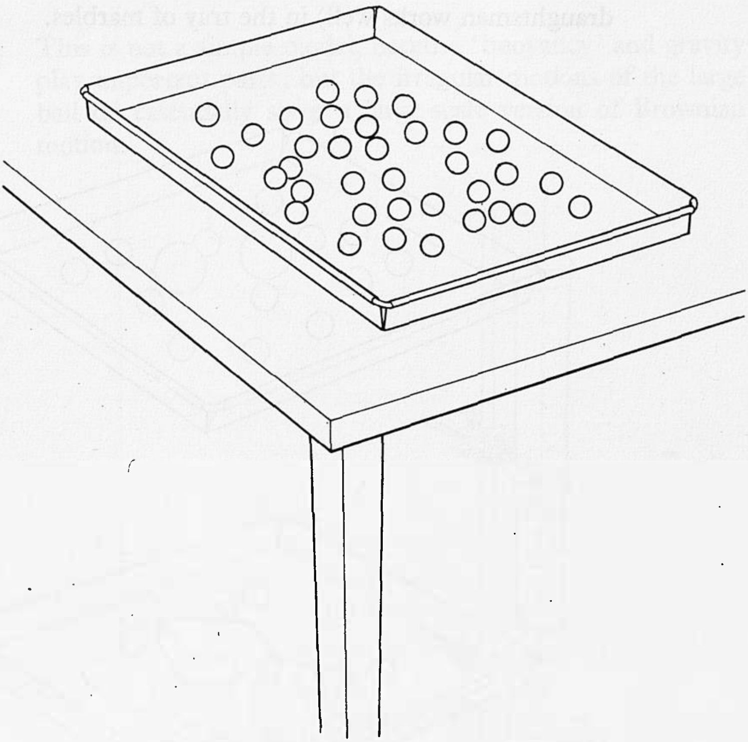
Two-dimensional kinetic model of a gas

Apparatus

1 two-dimensional kinetic model kit – item 12

Procedure

The pupils place a few marbles in the trays (already used in Experiment 70). The tray is kept horizontal on the table and agitated. The marbles now represent molecules of a gas instead of a liquid.



73a Class experiment

Model of Brownian motion with a large marble added to the tray of marbles

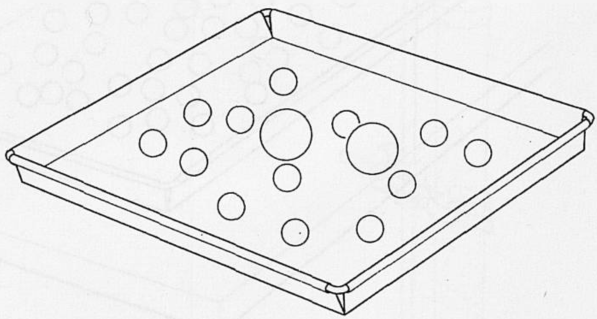
Apparatus

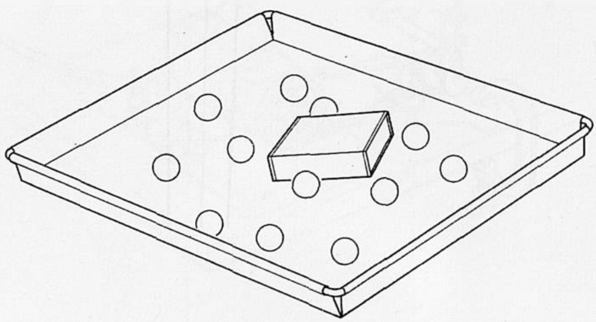
1 two-dimensional kinetic model kit – item 12

Procedure

The pupils should now add to the two-dimensional model one or two larger marbles (provided with it) and compare their motion with that of the smaller marbles.

They should also try putting a match-box (a wooden draughtsman works well) in the tray of marbles.





73b *Optional demonstration*

Model of Brownian motion, using a three-dimensional model

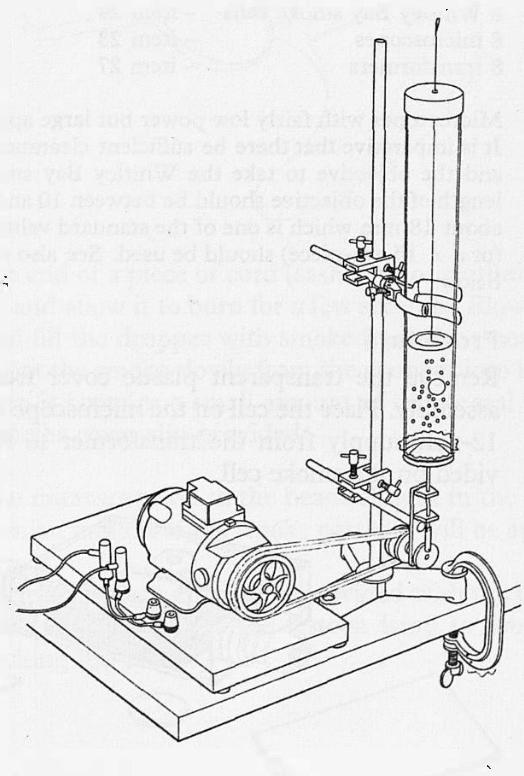
Apparatus

1 kinetic theory model kit	– item 11
1 small expanded polystyrene sphere	– item 51D

Procedure

Run the three-dimensional model as usual but insert the expanded polystyrene ball among the small balls. Pupils watch the motion of the large ball under bombardment by the small balls.

This is not a simple model, because 'buoyancy' and gravity play important parts; but the irregular motions of the large ball do essentially show a large-scale version of Brownian motion.



74 Class experiment

Brownian motion of smoke in air

Purpose

In the Nuffield programme, seeing the Brownian motion of particles in a gas plays an essential part as a *class* experiment. Each pupil should see this for himself, as one of the few places where he can make personal contact with the microphysical world in an experiment that he does himself.

Pupils first see the Brownian motion in Year I. Some may have missed it and they must therefore see it in Years III and IV. But even if they did see it, they may not all remember it clearly and we would urge a further look at it at this stage as it is such an important experiment.

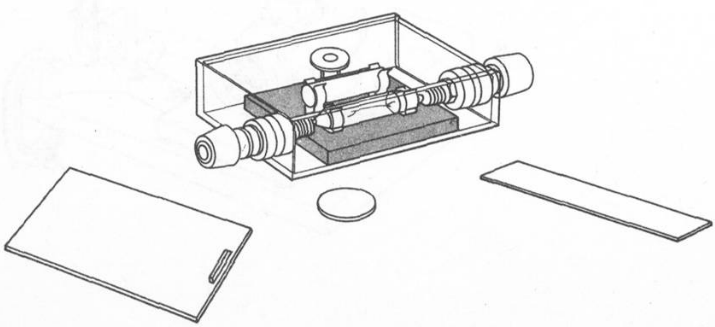
Apparatus

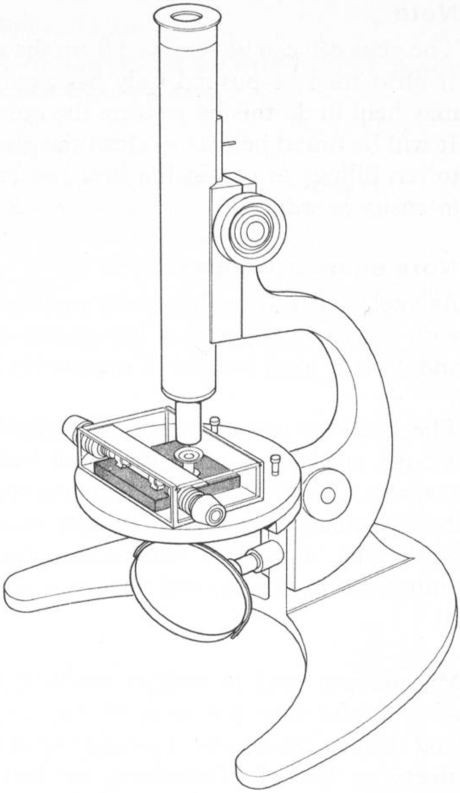
8 Whitley Bay smoke cells	– item 29
8 microscopes	– item 23
8 transformers	– item 27

Microscopes with fairly low power but large apertures are required. It is imperative that there be sufficient clearance between the stage and the objective to take the Whitley Bay smoke cells. The focal length of the objective should be between 10 and 30 mm, preferably about 18 mm which is one of the standard values. A $\times 10$ eye-piece (or a $\times$ 15 eye-piece) should be used. See also note on microscopes below.

Procedure

Remove the transparent plastic cover from the smoke-cell assembly. Place the cell on the microscope stage. Connect the 12-volt supply from the transformer to the terminals provided on the smoke cell.





Light the end of a piece of cord (sash cord or clothes line are suitable) and allow it to burn for a few seconds. Blow out the flame and fill the dropper with smoke from the smouldering cord. Inject the smoke slowly from the dropper into the glass cell. When it contains a small amount of smoke seal with the $\frac{5}{8}$-in diameter cover slip provided.

Focus the microscope on to the beam of light in the cell and the Brownian motion of the smoke particles will be apparent.

A small piece of black material is provided with the cell, and this should be placed over the festoon lamp to avoid stray light reaching the eye.

Note

The glass cell can be removed from the assembly and cleaned. It must then be pushed fully back into the assembly and it may help to do this by wetting the outside of the glass tube. It will be found helpful to clean the glass cell after every five to ten fillings to obtain the best results, otherwise the light intensity is reduced.

Note on microscopes

As explained above, the smoke particles should be observed with a microscope with a low power objective (between 15 and 30 mm focal length) of reasonably large aperture.

The small toy microscopes now available do *not* have a large enough aperture, nor do the small 'field microscopes' now available. A skilful teacher, knowing what to expect, may see the Brownian motion with an instrument of small aperture; but pupils, unfamiliar with microscopes, and not knowing quite what to expect, will not see it with clear conviction at all.

Microscopes used in biology teaching would, of course, do very well for this; but many biology departments hesitate to lend their microscopes for young pupils to use in class experiments in Year I. Therefore, we listed microscopes with reasonable aperture as essential equipment to be bought, if they could not be borrowed for Year I. At this later stage of Years III and IV, we hope that it will be possible in many cases for the physics class to borrow microscopes from the biology department, for pupils to use with smoke cells. The smoke cells are clean and easily manipulated, so microscopes are very unlikely to come to any harm. If they cannot be borrowed, microscopes should be bought, even now, because this class experiment is so important.

Film

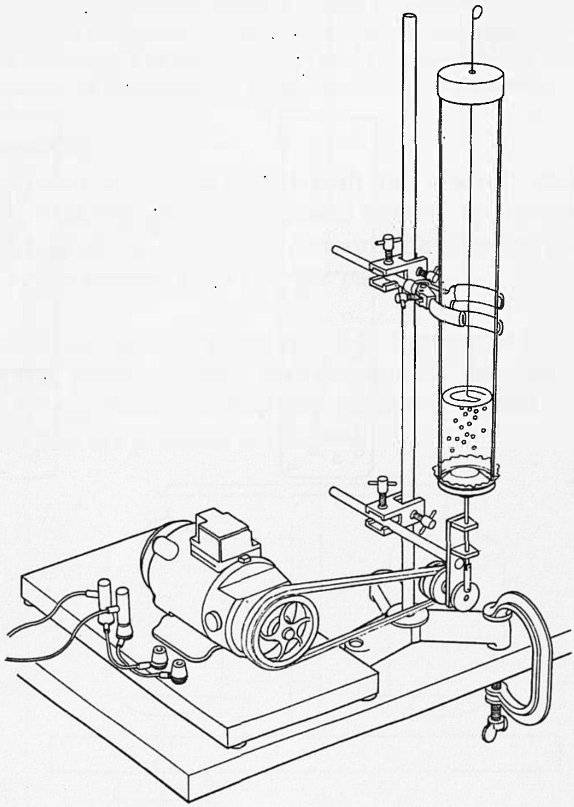
Details of this experiment are shown in the Esso-Nuffield film for science teachers *An Approach to Kinetic Theory*. It is *not* suitable for showing to pupils, but may help teachers. The film is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

75a Demonstration

Three-dimensional kinetic model used to illustrate Boyle's law

Apparatus

1 kinetic theory model kit	– item 11
1 chinagraph pencil	– item 543
1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
1 retort stand	– items 503–504
1 boss	– item 505
1 clamp	– item 506



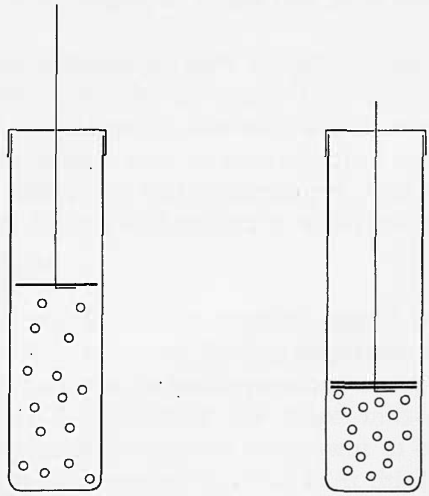
Procedure

The three-dimensional kinetic model is set up as already described – see Experiment 71 – but with a limited number of balls inside, say three dozen. The paper piston must be inserted in the tube this time and it must be free to move. Increase the voltage to about 6 volts.

Note the position of the paper piston: this can be marked on the cylinder with a chinagraph pencil.

Pour in more balls to double the number. The paper piston will float higher in the cylinder. Additional weights of paper have to be added to bring the piston back to its original position showing the greater pressure exerted by the larger number of balls.

Now add more paper weights to the piston and show that as the pressure increases the volume decreases.



75b *Optional demonstration*

Larger kinetic model to illustrate Boyle's law

If apparatus is available, and if the teacher wishes to take the time to set up a more elaborate illustration, something much nearer to a quantitative demonstration can be arranged with a chemical balance to 'weigh' the pressure.

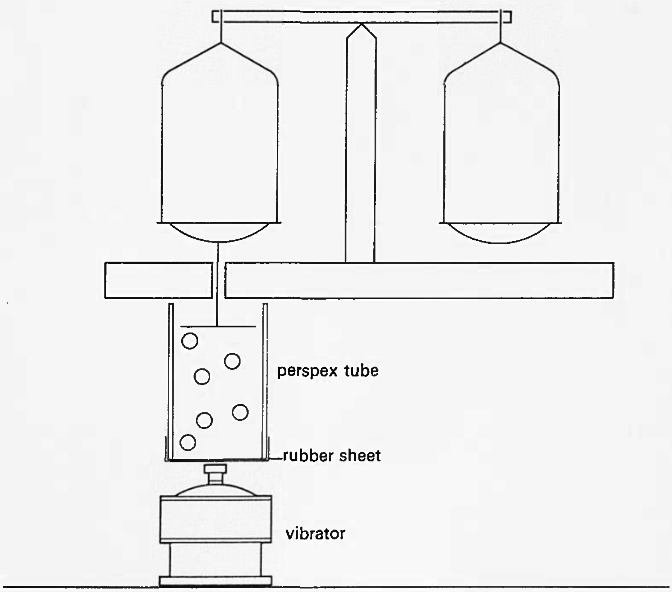
Apparatus

A light piston of aluminium sheet is hung by a thread from the pan on one side of a chemical balance, the thread running through a hole in the floor of the balance. That piston is made to fit loosely in a wide vertical cylinder, several inches in diameter. Large balls of plastic, such as those used for electrostatics experiments, are placed in the cylinder. The rubber sheet and vibrator rod are installed at the bottom of the cylinder, as in the smaller experiment.

Procedure

The piston is counterpoised with the vibrator turned off. Then, with the vibrator running, weights are added on the other side of the balance to measure the force on the piston due to the bombardment by the balls.

When more balls are added it will be found that the pressure increases proportionally. Furthermore, if the vibrator and cylinder are raised, so that the volume is halved, it will be found that the pressure is doubled.



76 Demonstration

Boyle's law

Apparatus

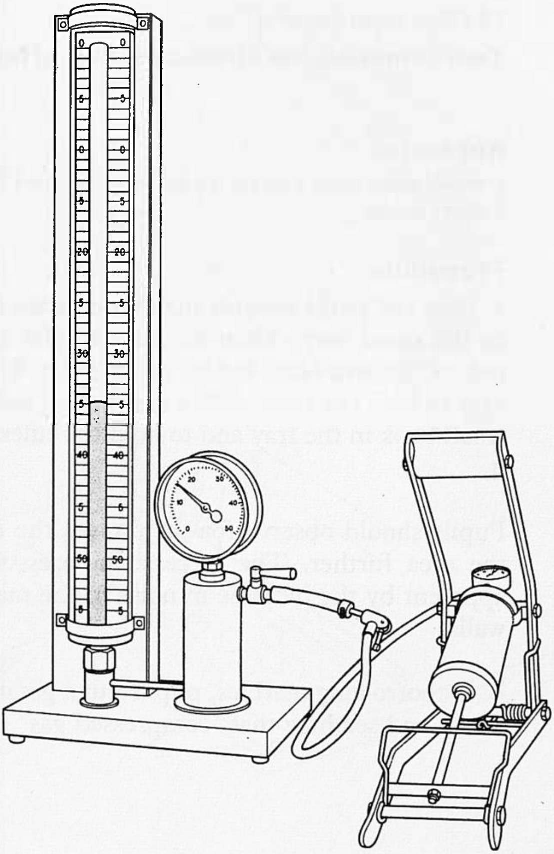
1 Boyle's law apparatus – item 109
1 foot pump and adaptor – item 45

Procedure

The apparatus has been specially designed to give quick clear readings which the class can see for themselves. The sample of dry air is confined in a tall, wide tube by a piston of oil, the volume being measured by the length of the air column, which is clearly visible at the back of the class. The pressure is read from the Bourdon gauge connected to the air over the oil reservoir. This is calibrated to read absolute pressure and is also visible from the back of the class.

The foot pump is attached to the oil reservoir by rubber pressure tubing securely fixed with hose bindings, if necessary. The pressure is changed using this pump. A quick demonstration should show that doubling the pressure halves the volume.

The gauge reads up to 50 lb/in^2 absolute. The pressure can be safely taken to this value. It should not be taken beyond.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77 Class experiment

Two-dimensional kinetic model: effect of crowding

Apparatus

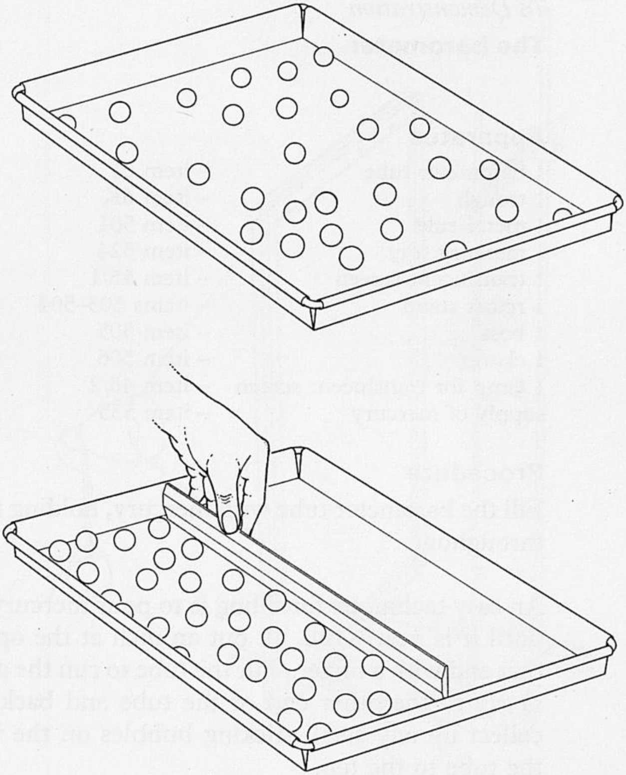
1 two-dimensional kinetic model kit – item 12
8 short rulers

Procedure

a. First the pupil agitates the two-dimensional kinetic model in the usual way. Then he puts a ruler across the tray to reduce the area occupied by the marbles. It will not be found easy to hold the ruler still: a convenient technique is to put a small book in the tray and to hold the ruler firmly up against it.

Pupils should observe for themselves the effect of reducing the area further. The increase in pressure may be made apparent by the increase in noise of the marbles striking the walls.

b. By borrowing marbles, pupils put a great many marbles in a tray and see how that 'compressed gas' behaves.



78 *Demonstration*

The barometer

Apparatus

1 barometer tube	– item 6I
1 trough	– item 6K
1 metre rule	– item 501
1 mercury tray	– item 524
1 translucent screen	– item 46/1
1 retort stand	– items 503–504
1 boss	– item 505
1 clamp	– item 506
1 lamp for translucent screen	– item 46/2
supply of mercury	– item 535

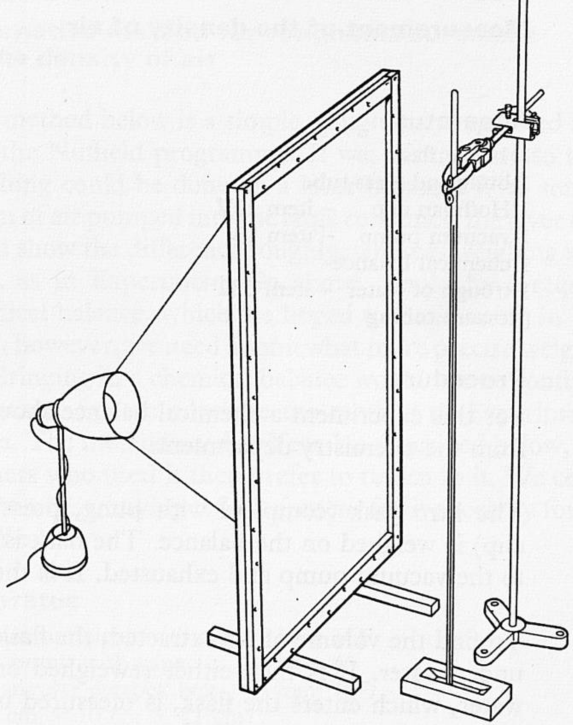
Procedure

Fill the barometer tube with mercury, holding it over the tray throughout.

An easy technique for filling is to pour mercury into the tube until it is nearly full, all but an inch at the open end. Close that end with a finger. Tilt the tube to run the air bubble very *slowly* to the other end of the tube and back again. It will collect up any small sticking bubbles on the way. Then fill the tube to the top.

Hold a finger on the open top of the full tube and invert into the trough. Do not remove the finger until the end of the tube is below the surface. Hold the barometer in a clamp to measure the height.

The whole experiment should be done in front of the translucent screen and lamp so that it is clearly visible to the class by silhouetting against the bright background.



79a *Demonstration*

Measurement of the density of air

Apparatus

1 1-litre flask
1 bung and glass tube
1 Hoffman clip – item 10V
1 vacuum pump – item 13
1 chemical balance
1 trough of water – item 532
pressure tubing

Procedure

For this experiment a chemical balance should be borrowed from the chemistry department.

The litre flask (complete with bung, pressure tubing and clip) is weighed on the balance. The flask is then connected to the vacuum pump and exhausted. It is then reweighed.

To find the volume of air extracted, the flask is then opened under water. It is then either reweighed or the volume of water, which enters the flask, is measured using a 1,000 ml measuring cylinder.

Note

A 500-ml flask should NOT be used.

79b *Demonstration*

Alternative method for rough measurement of the density of air

The method below is a simple, rough one, suggested in Year I of the Nuffield programme. It was given there so that the weighing could be done on a lever balance. With some 8 or 10 gm of air pumped into the large container, the lever balance could show the difference roughly, whereas weighing a 1-litre flask, as in Experiment 79a above, would have required a chemical balance, which we hoped to avoid using in Year I. Now, however, we need a somewhat more precise weighing of air. Bringing in a chemical balance would not be confusing at this stage. So, we advocate the method of Experiment 79a above. The method used in Year I is described below, in case teachers who used it then prefer to return to it. We certainly do not advise buying the equipment for it specially for use in this Year.

Apparatus

1 plastic container with tap	– item 10E
1 foot pump with gauge	– item 45
1 rectangular perspex box (10 cm × 10 cm × 11 cm)	– item 10D
1 lever-arm balance	– item 42
1 trough of water	– item 532

Procedure

A 3-ft length of rubber tubing is attached to the outlet of the plastic container. The whole is weighed on the lever-arm balance, the air inside being at normal atmospheric pressure.

Air is then pumped into the container using the foot pump and then the tap on the container is closed. The more air that can be got inside the better. The container is weighed again. With the containers provided, a difference of at least 8 gm is possible and this can be measured on the lever-arm balances. The pressure should not go further than about 25 $lb/in.^2$

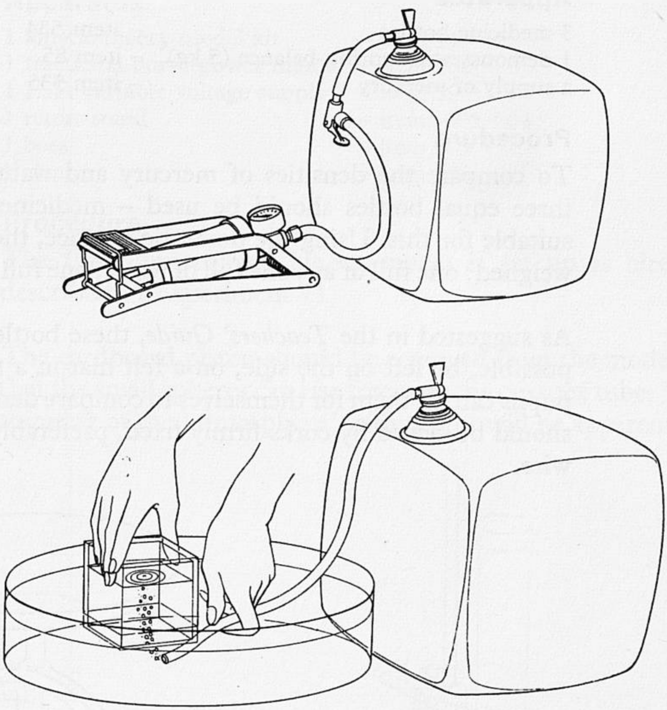
The rectangular perspex box is immersed full of water in a large trough of water with the open side downwards. The rubber tubing is put in the water with the end of the tubing well under the inverted box. The tap is opened until the box of cross-section 10 cm × 10 cm is filled with excess air to a height of 10 cm. The tap is closed and the air in the box released. The box is again immersed. The process is repeated several times until no more excess air comes out. Each time 1,000 cm^3 of air are released. The last fractional filling is estimated.

Knowing the weight of the excess air and its volume at atmospheric pressure, the density can be found.

With some forms of lever-arm balance, the reading changes when the large plastic container is shifted to a different position on the balance pan. The change, though small, is sufficient to spoil completely the small difference that is being measured. To avoid such changes, hang the container on a long thread from the balance instead of placing it on the pan. The approved lever-arm balances provide a hook to which the thread can be attached.

Note

The containers will withstand at least 10 gm of air being pumped into them. Tests have shown that they may burst at excess pressures, about 10 p.s.i., but without danger to spectators. In some cases the tap blew out at lower pressures, but this is easily replaced.



80 *Demonstration*

Quick comparison of the density of air, water and mercury

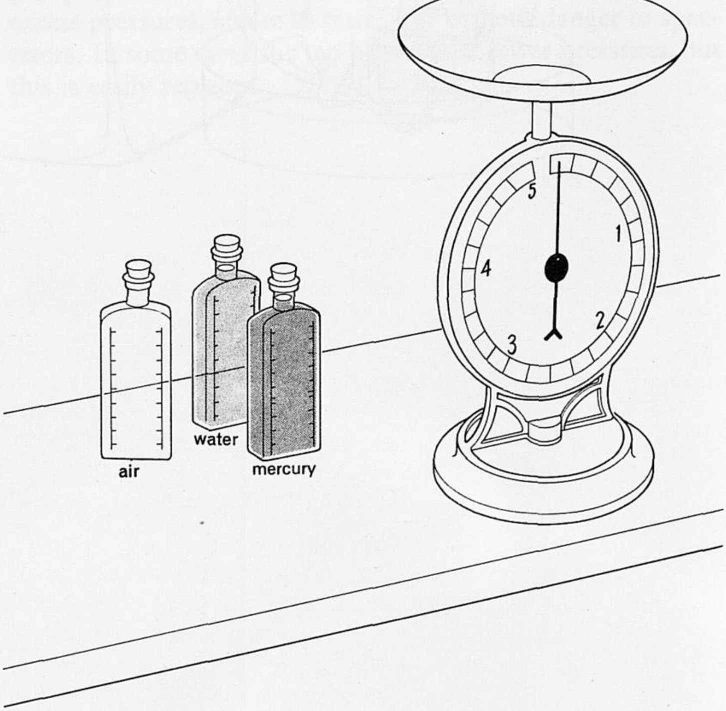
Apparatus

3 medicine bottles	– item 534
1 demonstration spring-balance (5 kg)	– item 85
a supply of mercury	– item 535

Procedure

To compare the densities of mercury and water (roughly), three equal bottles should be used – medicine bottles are suitable for this. Using the domestic balance, the bottles are weighed: one full of air, one full of water, one full of mercury.

As suggested in the *Teachers' Guide*, these bottles should, if possible, be left on the side, on a felt mat in a tray, so that pupils can lift them for themselves to compare densities. They should be closed by corks firmly fixed, preferably held in by wire.



81 *Demonstration*

Model showing atmospheric thinning higher up

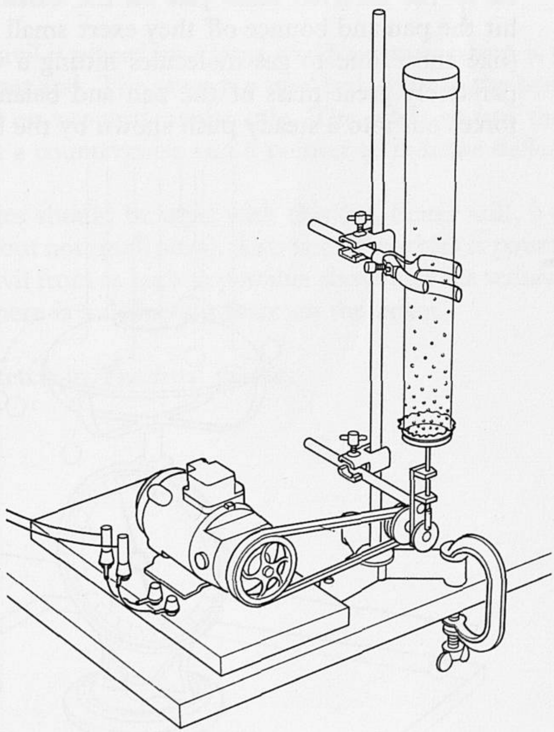
Apparatus

1 kinetic theory model kit	– item 11
1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
1 retort stand	– items 503–504
1 boss	– item 505
1 clamp	– item 506

Procedure

The three-dimensional kinetic model is set up as already described in Experiment 71

The cardboard piston should be removed from the model so that the small spheres can rise freely up the perspex tube. The thinning of the 'atmosphere' with height will be apparent.



82a *Demonstration*

Pressure exerted by a stream of balls

Apparatus

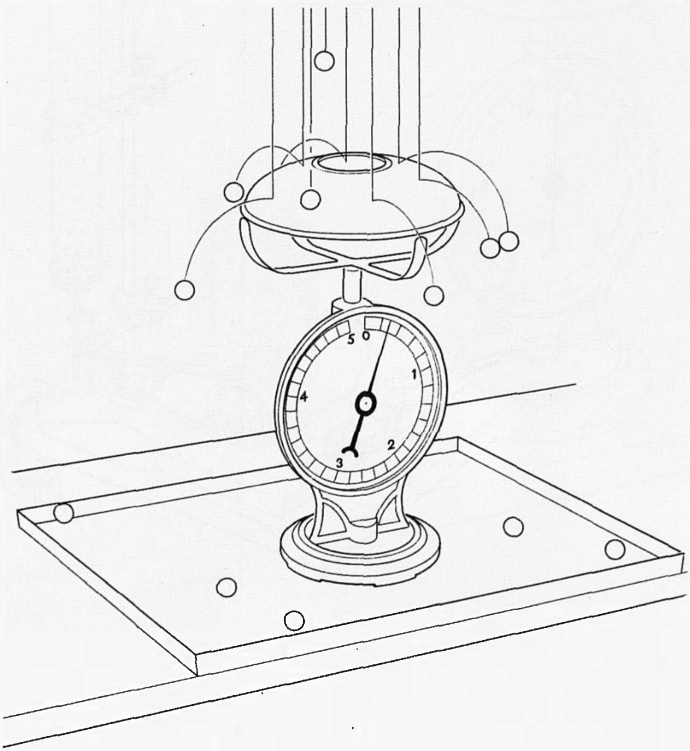
Lead shot, steel balls or toyshop marbles
domestic balance or lever-arm balance

Procedure

Either the domestic balance or the lever-arm balance can be used for this experiment with the scale pan turned over so that the balls bounce off without collecting on the pan and upsetting the readings by adding an accumulating weight.

A large tray should be placed under the balance (or a barrage of books can be set up around the balance) to catch the balls.

A stream of balls is poured by hand, from a foot or so above, on to the inverted scale pan on the balance. As the balls hit the pan and bounce off they exert small impulsive forces (like those due to gas molecules hitting a wall). The comparatively great mass of the pan and balance smears those forces out into a steady push shown by the balance.



82b *Optional demonstration*

Massive beam and anvil to show pressure exerted by stream of balls

This is an optional experiment suggested only in case a teacher wishes to construct it.

Apparatus

1 anvil and beam
marbles

Procedure

A seesaw is constructed with a massive elastic anvil at one end.

(A very good elastic anvil is made by placing a sheet of $\frac{1}{2}$-in perspex on top of a massive block of steel, with a thin layer of glycerine between them. The perspex can be screwed into the steel near the edges.)

The anvil is placed on a large wooden beam, which is pivoted near that end. The pivot is a steel rod, fixed to the beam, free to roll on supports at the side. The other end of the beam carries a counterpoise and a pointer to indicate deflections.

Marbles should be used with this (or, better still, $\frac{1}{2}$-in steel balls, but not small ones). A stream of marbles is poured on to the anvil from as high as possible above and the seesaw shows that there is a deflecting force on the beam.

See sketch in *Teachers' Guide*.

83 *Demonstration*

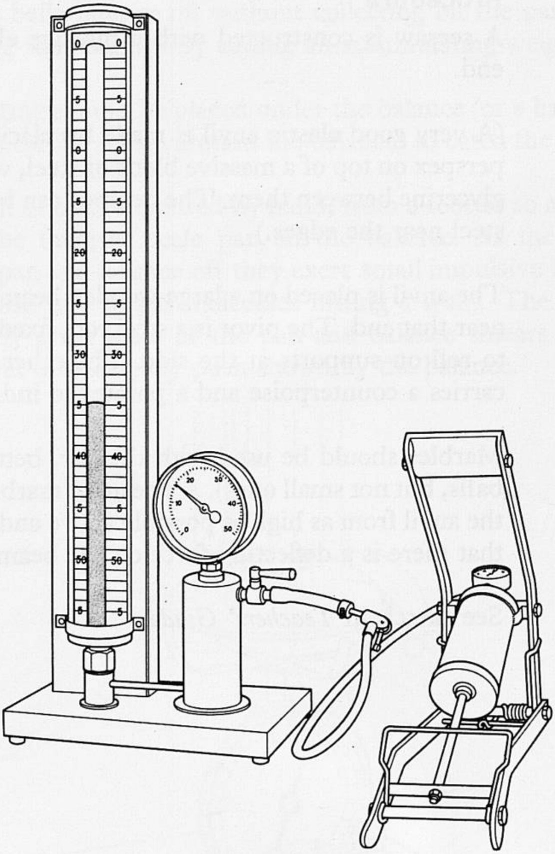
Boyle's law

Apparatus

1 Boyle's law apparatus – item 109
1 foot pump and adaptor – item 45

Procedure

This is the same as Experiment 76.



84 *Demonstration*

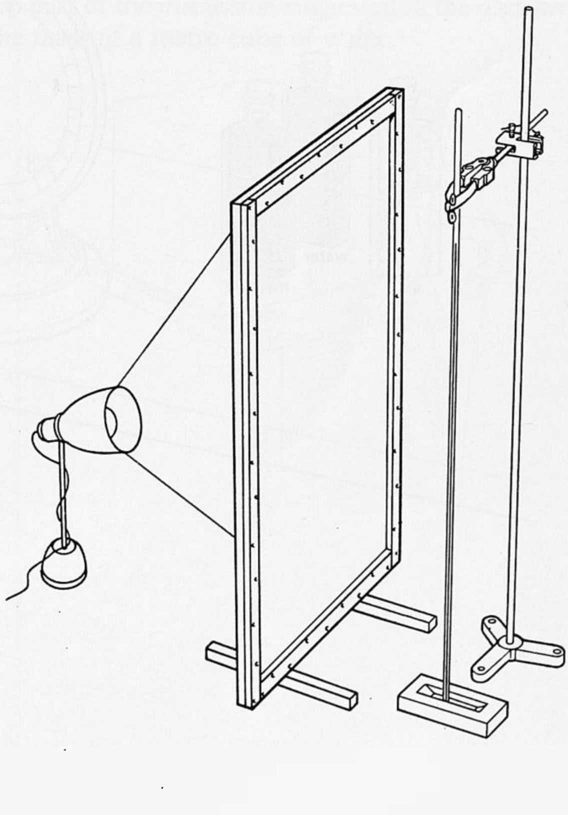
The barometer

Apparatus

1 barometer tube	– item 6I
1 trough	– item 6K
1 metre rule	– item 501
mercury	– item 535
1 mercury tray	– item 524
1 translucent screen	– item 46/1
1 lamp	– item 46/2
1 retort stand	– items 503–504
1 boss	– item 505
1 clamp	– item 506

Procedure

This is the same as Experiment 78.



85 Demonstration

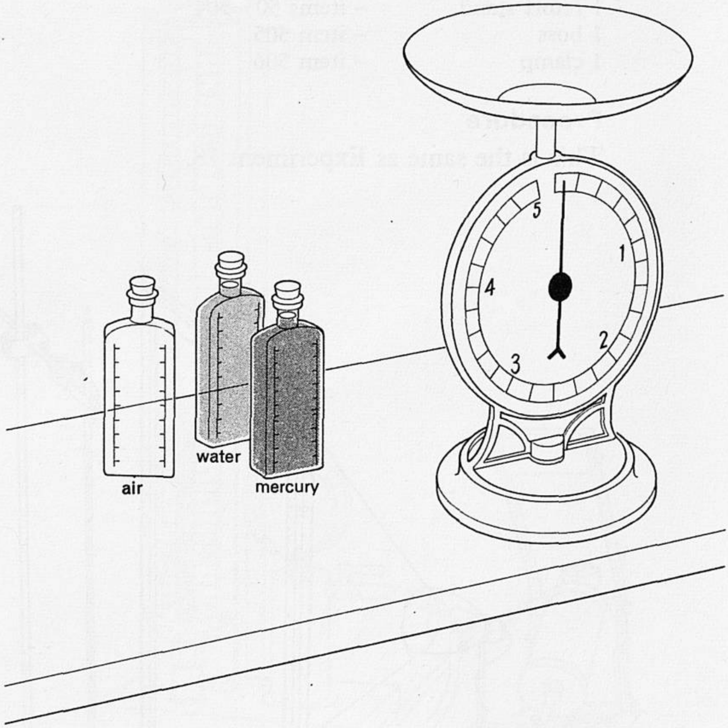
Quick comparison of the density of air, water and mercury

Apparatus

3 medicine bottles	– item 534
mercury	– item 535
1 domestic balance	– item 20

Procedure

This is the same as Experiment 80.



86 *Optional Demonstration*

Weight of water

Apparatus

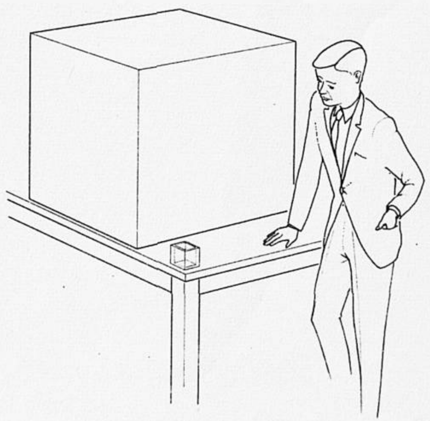
1 perspex box (10 cm × 10 cm × 11 cm) – item 10D
1 domestic balance – item 20
1 cardboard metre cube

The demonstration metre cube can be made out of cardboard. It should of course be collapsible for the sake of storage.

Procedure

a. The perspex box is weighed empty on the domestic balance. It is then filled with water to a depth of 10 cm and reweighed.

b. The cardboard metre cube is placed beside the perspex box as part of the discussion suggested in the *Teachers' Guide* on the mass of a metre cube of water.



87a *Demonstration*

Measurement of the density of air

Apparatus

1 1-litre flask	
1 bung and glass tube	
1 Hoffman clip	– item 10V
1 vacuum pump	– item 13
1 chemical balance	
1 trough of water	– item 532
pressure tubing	

Procedure

This is the same as Experiment 79a.

87b *Demonstration*

Alternative method for rough measurement of the density of air

Apparatus

1 plastic container with tap	– item 10E
1 foot pump with gauge	– item 45
1 rectangular perspex box (10 cm × 10 cm × 11 cm)	– item 10D
1 lever arm balance	– item 42
1 trough of water	– item 532

Procedure

This is the same as Experiment 79b. It is merely a rough alternative to Experiments 79a and 87a. The recommended method is the more precise one, but this rough method is mentioned here in case teachers, who used it in Year I, prefer to return to it.

88 *Film*

'Chopper' experiment to measure gas molecule speeds

It would be helpful to show a film of a direct measurement of gas molecular speeds. A 'chopper' experiment, similar to that due to Zartman, would be ideal at this stage. The experiment is described in *Physics for the Inquiring Mind*, page 365, and it is hoped that in the future such a film will be made commercially for school use.

89 *Demonstration*

Diffusion of bromine into air

Purpose

We want to show, in a clear demonstration, brown bromine vapour, acting as a gas, diffusing into air – and, in Experiment 90, spreading in a vacuum.

Apparatus

1 bromine diffusion kit	– item 8
1 retort stand	– item 503–504
1 boss	– item 505
1 clamp	– item 506
1 translucent screen	– item 46/1
1 lamp for translucent screen	– item 46/2
1 pliers	– item 530
1 large bucket (plastic)	– item 533

supply of ammonia solution '880' diluted to half strength

Bromine can be bought in ordinary chemical bottles but transferring samples from an open bottle to apparatus is dangerous. Fortunately bromine is now available commercially in 1 ml 'ampoules', capsules of very thin glass. The apparatus has been specially designed so that the capsule is placed in a side tube attached to the apparatus and then crushed inside a piece of rubber tubing from the outside with a pair of pliers, thereby releasing the bromine safely for use.

Warning

Bromine is a dangerous substance. If liquid bromine splashes on to skin it makes a bad blister. Bromine vapour will also attack skin and will produce a sore throat if used carelessly. In general, bromine attacks almost everything except glass and paraffin-wax. Great care should therefore be taken with this important experiment.

Safety precautions

Both when preparing the experiment and when doing it, the experimenter should have a beaker of strong ammonia solution at hand: ammonia combines with bromine to form harmless ammonium bromide. Strong ammonia solution, the '0·880' concentrated ammonia solution, diluted to half strength, provides an excellent safety precaution. If bromine splashes on table or skin, pour ammonia solution on at once. Ammonia should not be used near eyes, for which plenty of cold water is the treatment.

The apparatus

The main diffusion tube is a closed glass tube (18 in long, 2 in diameter) with only one opening to a side tube. (There is, therefore, no danger of an accident releasing bromine to the pump when diffusion into a vacuum is done – see Experiment 90). A rubber bung fits into the side tube and carries the glass tube of the stopcock. The glass tube from the stopcock extends through the rubber bung, thus ensuring that only bromine vapour and not liquid comes into contact with the bung. In any case, the bung can and should be replaced, after a few days' use.

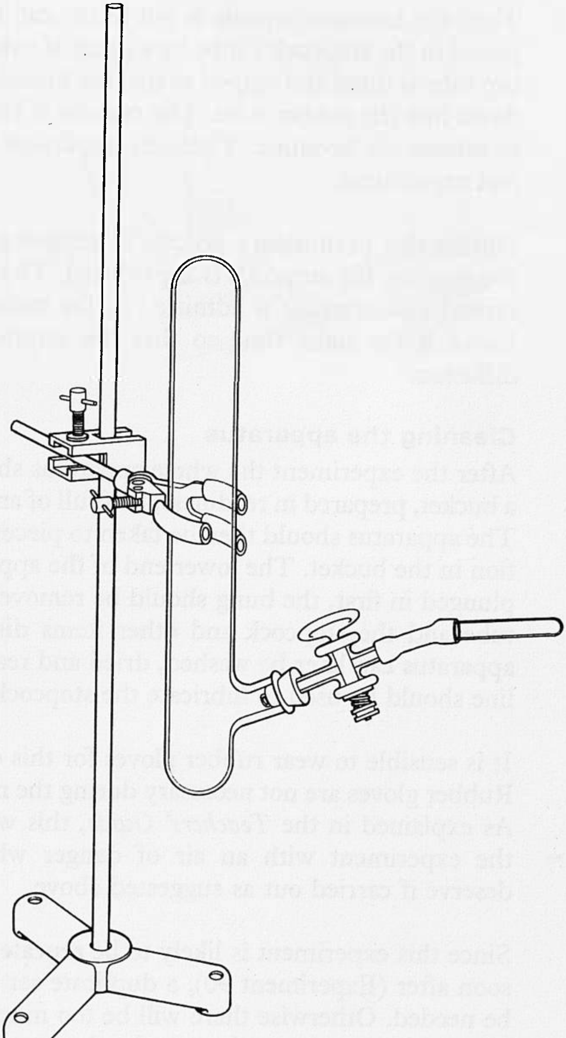
The tube in the rubber bung leads to a stopcock with large bore. This should be of good quality, such as Interkey, with bore at least 8 mm. The tap of the stopcock must be spring-held for safety (but the stopcock may be of ordinary quality, not the special high-vacuum quality). The glass tube that leads out on the other side of the stopcock is joined to a closed glass cap by a short section of rubber tube, in which the bromine capsule is to be broken. That rubber tubing must have a fairly thin wall so that it can be squeezed with pliers to crush the capsule.

With this arrangement, the breaking of the capsule to release bromine is done separately, before the stopcock is opened to admit bromine to the main tube. This enables the experimenter to concentrate on the crushing of the capsule first and then pay full attention to the main experiment.

(*Note:* the rubber tubing should not be very short, otherwise there is a danger of pulling it off the glass tube when squeezing it with pliers. Rubber tubing must, of course, have a bore large enough to let the capsule slide into it. The tube belonging to the stopcock and the cap tube must be still larger, so that the rubber tube fits tightly on them.)

Procedure

The main diffusion tube is held firmly in a vertical position using a retort stand, boss and clamp. A translucent screen and lamp are set up behind it so that the tube is silhouetted against a bright background. The bung carrying the stopcock is fixed in place. A short piece of rubber tubing is fitted tightly on the glass tubing at the other end of the stopcock. A bromine capsule is put inside the glass cap tube that is connected to the rubber tubing.



Then the bromine capsule is put in the cap tube, and that is joined to the stopcock's tube by a piece of rubber tubing. The cap tube is tilted and tapped so that the bromine capsule slides down into the rubber tube. The capsule is broken with pliers to release the bromine. Then the apparatus is ready for the real experiment.

During this preliminary process of releasing the bromine in the capsule, the stopcock is kept closed. The stopcock is now turned and bromine is admitted to the main diffusion tube. Leave it for some time so that the pupils can watch the diffusion.

Cleaning the apparatus

After the experiment the whole apparatus should be put into a bucket, prepared in readiness, half full of ammonia solution. The apparatus should then be taken to pieces under the solution in the bucket. The lower end of the apparatus should be plunged in first, the bung should be removed from the main tube and the stopcock and other items disassembled. The apparatus can later be washed, dried and reassembled. Vaseline should be used to lubricate the stopcock, not tap grease.

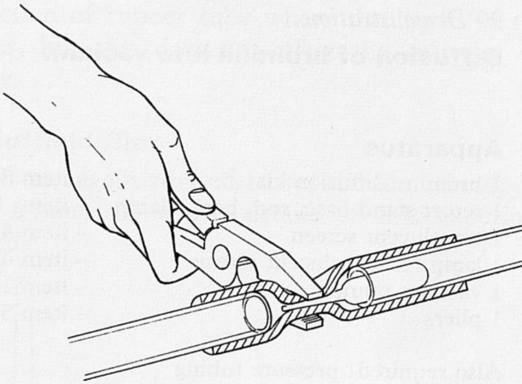
It is sensible to wear rubber gloves for this cleaning process. Rubber gloves are not necessary during the main experiment. As explained in the *Teachers' Guide*, this would only invest the experiment with an air of danger which it does not deserve if carried out as suggested above.

Since this experiment is likely to be repeated with a vacuum soon after (Experiment 90), a duplicate set of apparatus will be needed. Otherwise there will be too much delay in cleaning and drying the equipment for the second experiment.

If the apparatus has to be cleaned and dried quickly for use with another class, a hair dryer, with heater, provides much the easiest way of drying the main tube.

Esso-Nuffield film

The details of this equipment are shown in the Esso-Nuffield film for science teachers *An Approach to Kinetic Theory.* It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1, and it is recommended that teachers should see it.



90 *Demonstration*

Diffusion of bromine into vacuum

Apparatus

1 bromine diffusion kit	– item 8
1 retort stand base, rod, boss, clamp	– items 503–506
1 translucent screen	– item 46/1
1 lamp for translucent screen	– item 46/2
1 vacuum pump	– item 13
1 pliers	– item 530

Also required: pressure tubing

A duplicate set of apparatus should be used for this experiment to avoid delay while the apparatus used in Experiment 89 is being cleaned, dried and re-assembled. The bromine diffusion kit (item 8) includes two complete sets of apparatus with some spares.

Note

See Experiment 89 for the warning note regarding safety, the description of the apparatus, the safety precautions necessary and the details for cleaning the apparatus.

Procedure

The main tube is set up as in Experiment 89 with the translucent screen and lamp behind it so that the tube is silhouetted against a bright background. The bung carrying the stopcock is fixed in place, but the cap tube and bromine capsule are not attached.

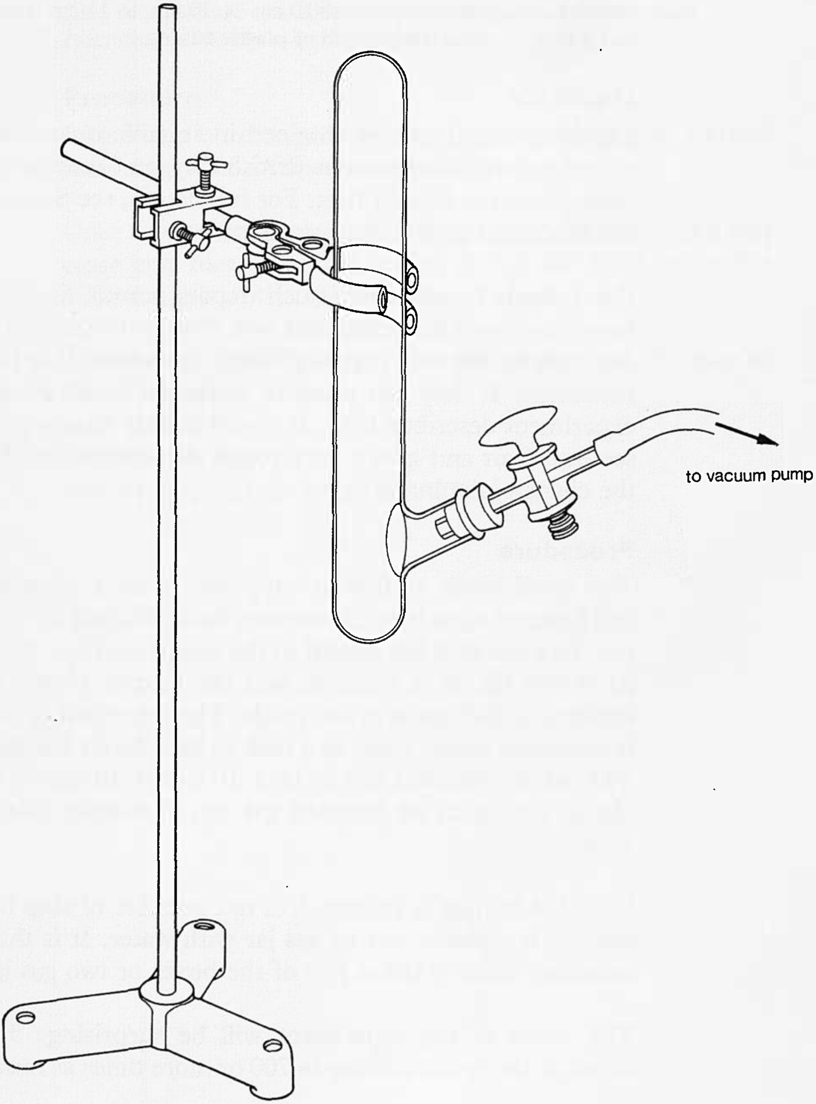
The outlet tube from the stopcock is connected by pressure tubing to the motor-driven vacuum pump. (An adaptor is necessary for this owing to the different diameters of tubing.) The stopcock is opened and the main tube is exhausted. The stopcock is turned off and the pressure tubing is removed.

Then the bromine capsule is put inside the cap tube, the short rubber tube is attached and the whole connected to the main apparatus in place of the connection to the pump. The bromine capsule is jolted gently down into the rubber tube and broken with pliers as in Experiment 89. The stopcock is then opened to admit the liquid bromine into the main tube. The motion of the bromine vapour is immediately apparent.

The section of rubber tube where the liquid was released collapses, but this does not affect the entry of sufficient bromine.

Esso-Nuffield film

Teachers are again advised to see the film *An Approach to Kinetic Theory* in which details of this experiment are discussed.



91a *Demonstration*

Change of volume: liquid air to gas

Apparatus

A supply of liquid air (or liquid nitrogen) is essential for this experiment – see below.

Also required is one 5-ml plastic bottle or volumetric flask, two gas jars or two perspex boxes, size 10 cm × 10 cm × 11 cm (item 10D) and a tank of water and length of plastic tubing.

Liquid air

Liquid nitrogen can be obtained in suitable quantities (one or two gallons) from various British Oxygen Company depots throughout the British Isles. For full details, see Section C of the Nuffield Physics *Guide to Apparatus.*

For schools remote from such depots, an air liquefier has been developed for school use (see Physics *Guide to Apparatus*), but as this only produces small quantities, it is barely a substitute. It does not produce sufficient liquid air for the experiment described here. It would merely enable pupils to see liquid air and give a very rough demonstration showing the change in volume.

Procedure

The small bottle or flask is supported from a piece of wire and lowered open into the vacuum flask of liquid air or nitrogen. As soon as it has cooled to the temperature of the liquid air it will fill. It is removed and the flexible plastic tubing attached to the outlet of the bottle. The other end of the tube is immersed under water in a tank so that the air bubbles out. The air is collected either in a 10 cm × 10 cm × 11 cm plastic box or in an inverted gas jar, previously filled with water.

Once the boiling is started, it is not possible to stop it while one refills a plastic box or gas jar with water. It is therefore necessary to have either two of the boxes or two gas jars.

The result of the experiment will be surprising: 5 ml of liquid in the bottle turning to 700 or more times as much gas.

91b *Optional alternative demonstration*

Density of liquid air

Apparatus

A supply of liquid air (or liquid nitrogen) is essential for this experiment – see note on Liquid Air in Experiment 91a and also Section C of the Nuffield Physics *Guide to Apparatus*.

Also required are one 100-ml measuring flask and a chemical balance, preferably a quick-reading one.

Procedure

Liquid air or nitrogen is poured quickly into the 100-ml. measuring flask of known mass.

Once the jar has cooled sufficiently the violent bubbling will cease and more liquid is added to top the level up to the 100-ml mark so that the volume is known.

The whole is quickly weighed on the balance and the mass of liquid found.

Note

100 ml of liquid air weigh about 90 gm.

91c *Alternative demonstration*

Change of volume: solid to gaseous carbon dioxide

Apparatus

1 block of 'dry ice'
1 bowl of water
1 1000-ml measuring cylinder – item 518/2

Procedure

Saw a small brick of dense dry ice (about 1 cm cube) from a block and quickly measure its dimensions.

Put the 'brick' into water in a bowl and cover it with an inverted measuring jar full of water. The gas will be collected and its volume can be measured.

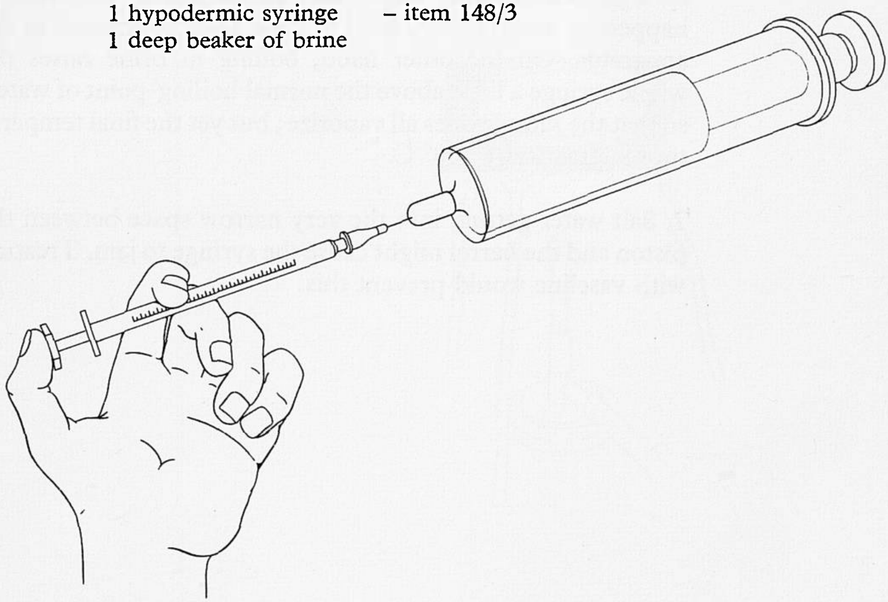
91d *Optional demonstration*

Change of volume: water to steam

This is only a rough demonstration to show the great change in volume. It cannot be expected to show the 1:1,600 expansion accurately.

Apparatus

1 glass syringe	– item 148/1
1 rubber cap	– item 148/2
1 Bunsen, tripod, gauze	– items 508, 510, 511
1 hypodermic syringe	– item 148/3
1 deep beaker of brine	



Procedure

The syringe kit includes a large glass syringe. The piston should be pushed in to remove all the air. Over the end of the syringe the small rubber cap is placed. The small hypodermic syringe (also included in the kit) is filled with a measured volume of water (say 0·05 ml). This water is then injected through the rubber cap into the nozzle of the large syringe.

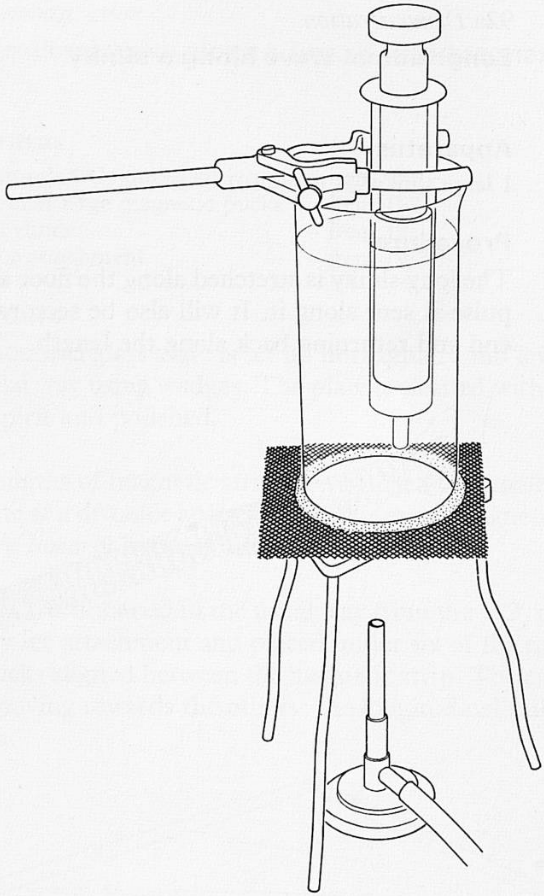
The large syringe is then held in a deep beaker of boiling brine (salt and water). The great increase in volume will be apparent as the small sample of water boils and turns to steam.

Unfortunately the heating of the syringe takes considerable time. The best arrangement therefore is to preheat the syringe in boiling water before injecting the sample of water.

Notes

1. We do not advise an electrical method for heating the syringe. The heating coils make it difficult to see what is happening and it is very hard to show the temperature of the apparatus. On the other hand, boiling in brine raises the whole syringe a little above the normal boiling-point of water, so that the sample does all vaporize; but yet the final temperature is practically 100° C.

2. Salt water getting into the very narrow space between the piston and the barrel might cause the syringe to jam. Treating with vaseline would prevent this.



92a *Demonstration*

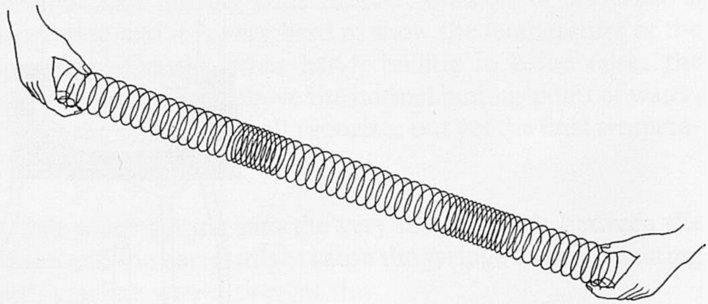
Longitudinal wave along a slinky

Apparatus

1 large slinky – items 101

Procedure

The long slinky is stretched along the floor and a longitudinal pulse is sent along it. It will also be seen reflected at the far end and returning back along the length.



92b *Demonstration*

Longitudinal wave along a line of ring-magnet pucks

Apparatus

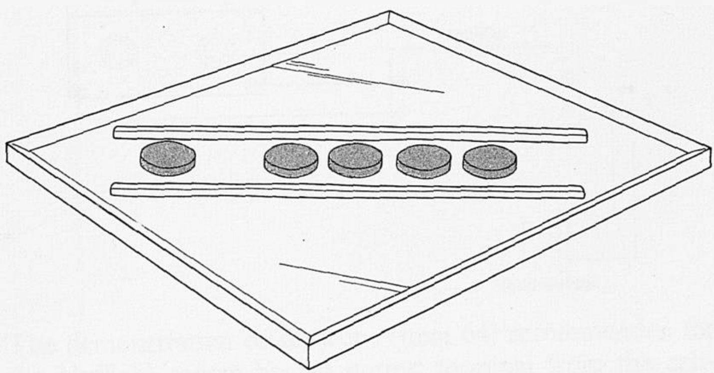
1 Edinburgh CO_2 pucks kit	– item 95
4 additional large magnetic pucks	– item 169
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2

Procedure

The mounted glass plate is set up horizontally and levelled in the usual way using wedges. The plate is cleaned with methylated spirit and polished.

Two lengths of magnetic strip are stretched diagonally across the plate at a distance apart which enables the magnetic pucks to move *linearly* between them.

Solid CO_2 is obtained in the usual way from the CO_2 cylinder and dry ice attachment and placed under six of the magnetic ring pucks aligned between the magnetic strip. The end puck is set moving towards the others: the longitudinal pulses will be seen.



93a *Demonstration*

Measuring the speed of sound

Procedure

A rough estimate of the speed of sound can be made by timing echoes.

This is best done out-of-doors. The experimenter stands as far away as possible from a large reflecting wall and claps his hands rapidly at a regular rate. He adjusts the rate until each clap just coincides with the return of the echo of its predecessor, or until clap and echo are heard as equally spaced.

A stopwatch measurement of the rate of clapping and a rough measurement of the distance to the wall and back will give an estimate of the speed of sound. Alternatively a short 'broomstick' pendulum of the type used in Year I could be used for timing.

93b *Optional demonstration*

Measurement of the velocity of sound

The advantage of the method advocated below is that it is not dependent on standing waves, which are not likely to be understood, but the method does make a direct measurement of the speed.

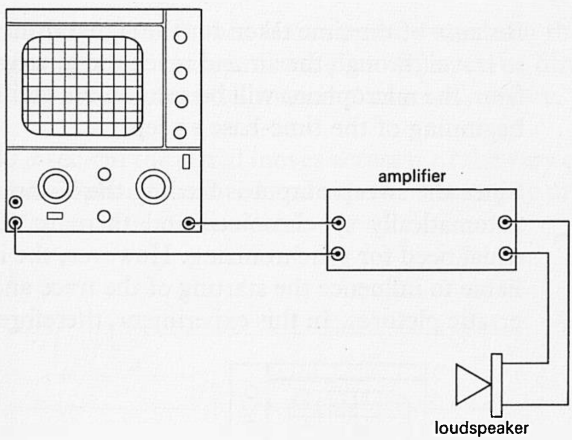
Apparatus

1 oscilloscope – item 64
1 microphone – item 157
1 amplifier – item 181
1 loudspeaker

For details on a suitable amplifier see the Nuffield Physics *Guide to Apparatus*. The input impedance should be at least 100 kΩ.

Procedure

For details on the operation of the oscilloscope, see Appendix III at the end of this volume (page 368).



The demonstration oscilloscope (item 64) recommended for the Nuffield course has an output terminal from the calibrated time-base and it is this output which makes this demonstration possible.

The sweep output and the earth terminals of the oscilloscope are connected to the input of the amplifier, as shown. The amplifier should have its volume control set very low. The output of the amplifier is connected to the loudspeaker.

As the time-base sends the spot on the screen back to the left at the start of its trace, a pulse comes from the sweep output and a signal is sent to the loudspeaker. It may help the pupils to understand the principle of the demonstration if the time-base is first operated slowly at 100 ms/cm so that they see how the click from the loudspeaker coincides with the time-base.

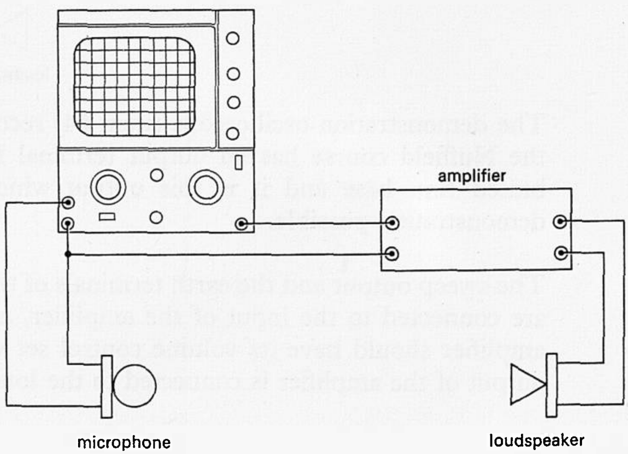
The microphone is connected to the input and earth terminals of the oscilloscope. The gain of the Y amplifier in the oscilloscope is set at the maximum value (0·1 volts/cm).

To achieve the calibrated speed for the time-base, the fine control knob should be set in the CAL (calibrated) position, fully clockwise, and the X-gain control should be at its minimum position, fully counter clockwise.

The loudspeaker and microphone are positioned so that the sound from the loudspeaker passes through the air and reaches the microphone.

Because of the time taken for the signal from the loudspeaker to travel through the air and reach the microphone, the signal from the microphone will be seen on the oscilloscope after the beginning of the time-base sweep.

Since the sweep output is feeding the Y-input, the picture is automatically synchronized and there is therefore not the usual need for synchronizing. However, the input signals are liable to influence the starting of the trace and could produce erratic pictures. In this experiment, therefore, it is best to set



both the 'STABILITY' and the 'TRIG LEVEL' controls to their maximum clockwise position: this makes the time-base run independently of any input signals.

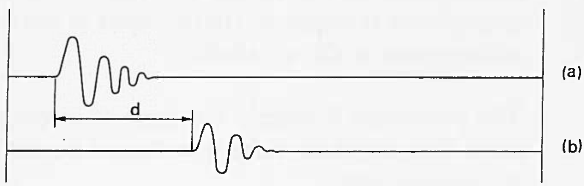
The X-shift control should be adjusted so that the left-hand end of the sweep is visible.

The gain control of the amplifier connected to the loudspeaker should be turned up as much as is safe (or bearable).

With the microphone close to the loudspeaker and the time-base running at 100 ms/cm, the signal received by the microphone can just be seen. At 10 ms/cm it is clearer and at 1 ms/cm the signal is very large. With the time-base set at this value, the microphone is moved away from the loudspeaker. The signal pulse received by the microphone moves across the tube. (Although the signal may not be exactly as the pattern shown below, it is clear that some pattern is moving across the tube.)

As the microphone is moved one metre away from the loudspeaker, the trace changes from (a) to (b) and the distance d gives the time it takes the sound to travel one metre.

At 100 μ sec/cm the signal moves across the tube very quickly as the microphone is moved and some teachers may prefer to use the time-base at this speed.



Note

The result depends on the calibration accuracy of the instrument – as do most results. If the calibration of the oscilloscope is doubted, it can be checked by connecting the output of the 1 kilocycle/sec oscillator from the scaler (item 130/1) to the Y-input. The calibration of the oscillator in the scaler can be checked by running the scaler for some time and checking with a stopwatch.

94 *Optional demonstration*

Comparison of velocities of sound at different pressures and in different gases

The object of this experiment is to confirm results that can be deduced from the work on kinetic theory.

Apparatus

1 tube (3 ft long, 3 in diameter)	
1 oscilloscope	– item 64
1 microphone	– item 157
1 earphone or miniature loudspeaker	
1 amplifier	– item 181
1 vacuum pump	– item 13
1 CO_2 cylinder	– item 19/1

Procedure

The experiment is similar to the previous one (93b), except that the sound travels inside the glass or perspex tube.

The output signal from the calibrated time-base of the oscilloscope is fed via the amplifier through the bung in one end of the tube to an earphone, which acts as the sound source.

At the other end of the tube, the bung has a glass tube through it and this is connected by pressure tubing to the vacuum pump. Also through this bung there are leads to the microphone placed inside the tube. The output from the microphone is connected to the input to the oscilloscope. The arrangement is shown above.

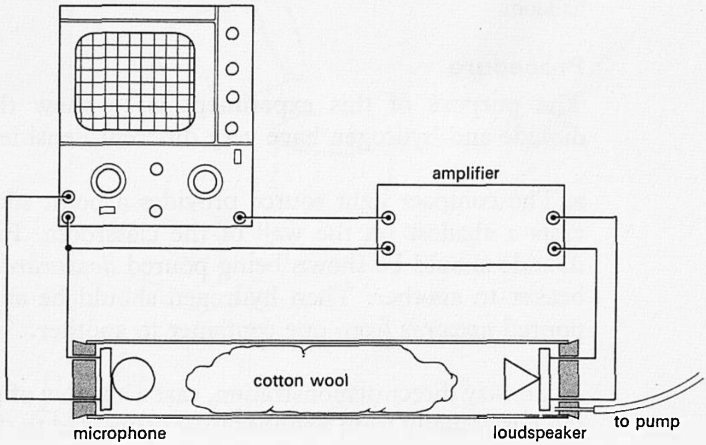
The procedure is exactly the same as in the previous experiment 93b, to which reference should be made for details on the oscilloscope.

Some air is pumped out of the tube. It is clear from the trace on the oscilloscope that the sound is received at the microphone at the same time interval after the signal, but with lower intensity. The velocity is independent of pressure.

If coal gas is admitted to the tube in place of air, it will be found that the speed of sound is greater. After re-evacuating the tube, admission of CO_2 shows a marked decrease in the speed.

(*Note:* the CO_2 should not be admitted directly from the cylinder as this may blow out the bung. It is suggested it be blown through the open tube or that it is used to fill a balloon first.)

It will be found in practice that a little cotton wool introduced in the tube dampens out any standing waves and makes the experiment clearer.



95 *Demonstration*

Different densities of gases

Apparatus

carbon dioxide
hydrogen
compact light source – item 21
crude balance – item 10C
balloons

Procedure

The purpose of this experiment is to show that carbon dioxide and hydrogen have very different densities from air.

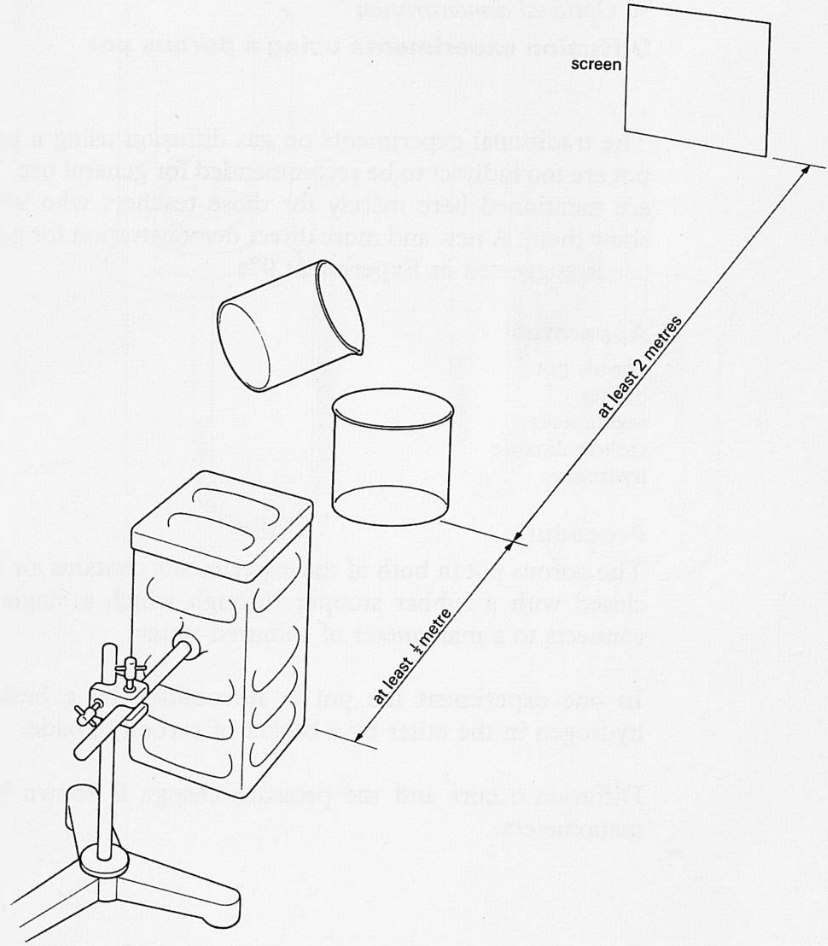
a. The compact light source provides a point source which casts a shadow on the wall of the classroom. First carbon dioxide should be shown being poured *downwards* from one beaker to another. Then hydrogen should be shown being poured *upwards* from one container to another.

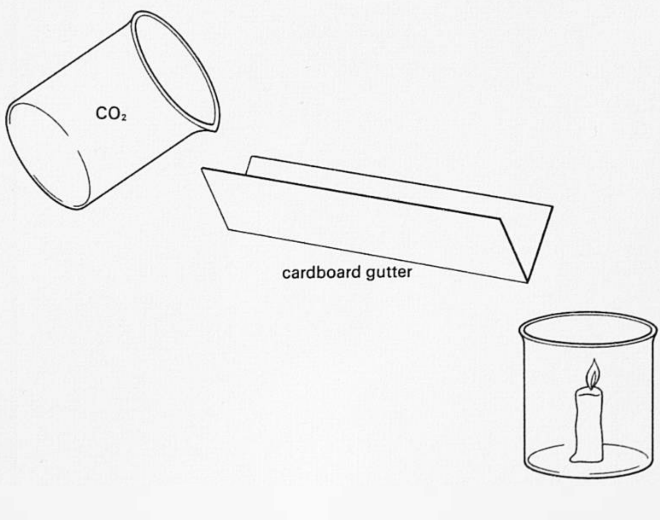
As an easy direct demonstration, cast a shadow of gas emerging horizontally from a rubber tube connected to the cylinder or other supply. The inequalities of refraction will show a shadow-stream falling or rising.

b. *Optional extra.* Pour carbon dioxide into a beaker containing a small lighted candle.

Optional extra. Pour carbon dioxide down a sloping 'gutter' made of a piece of cardboard folded to make a long vee channel. The lower end of the channel should rest on the edge of a beaker containing a small lighted candle.

c. Balloons should be filled with air, carbon dioxide and hydrogen and balanced on the crude balance to show the difference in density qualitatively.


screen
at least 2 metres
at least ½ metre


CO_2
cardboard gutter

96 *Optional demonstration*

Diffusion experiments using a porous pot

The traditional experiments on gas diffusion using a porous pot are too indirect to be recommended for general use. They are mentioned here merely for those teachers who wish to show them. A new and more direct demonstration for general use is suggested in Experiment 97a.

Apparatus

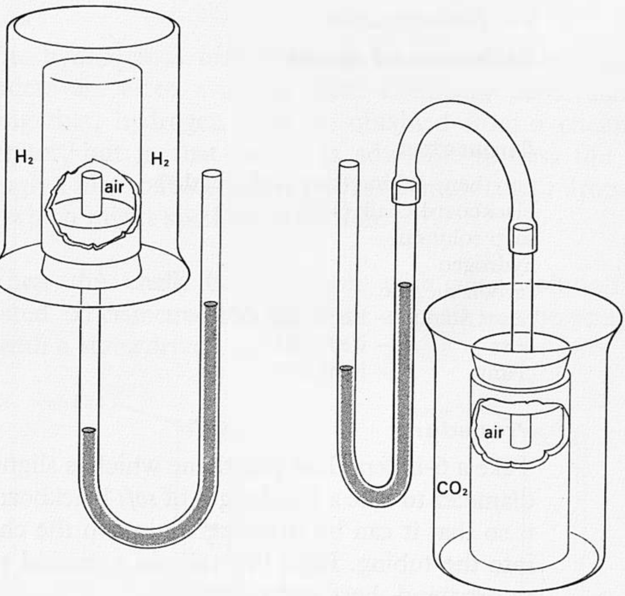
porous pot
beaker
manometer
carbon dioxide
hydrogen

Procedure

The porous pot in both of the experiments contains air and is closed with a rubber stopper through which a *single* tube connects to a manometer of coloured water.

In one experiment the pot is surrounded by a beaker of hydrogen in the other by a beaker of carbon dioxide.

Diffusion occurs and the pressure change is shown by the manometers.


H₂
H₂
air
air
CO_2

97a *Demonstration*

Diffusion of gases

Apparatus

polythene tubing (two 6-in lengths)
blackboard chalk (soft)
soap solution
hydrogen
carbon dioxide
retort stand – items 503–504
boss – item 505
clamp – item 506

Procedure

Take a 6-in length of polythene which is slightly too small in diameter to take a $\frac{1}{2}$-in length of *soft* blackboard chalk. Warm it so that it can be stretched and push the chalk a little way into the tubing. Hold this tube in a vertical position using a retort stand, boss and clamp.

Make a soap film at the top end by smearing soap solution across it.

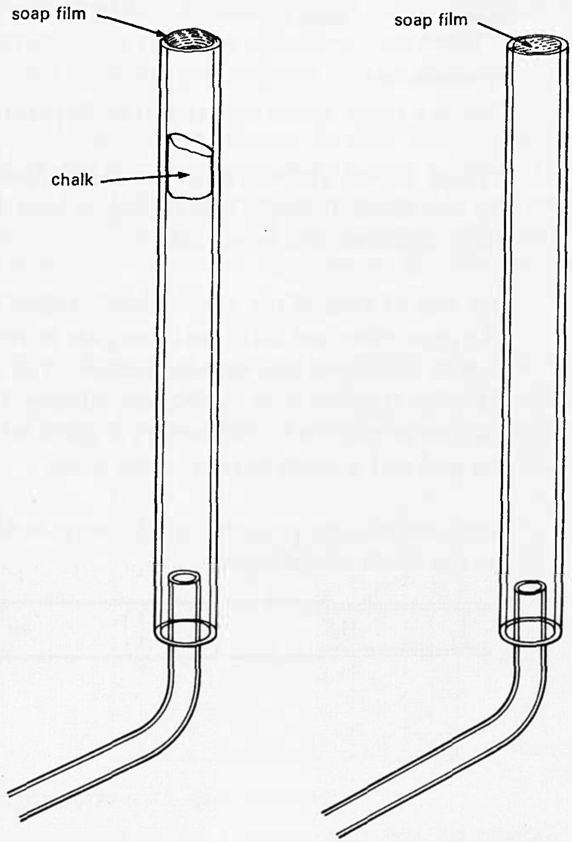
Hydrogen is fed in through a fine tube inserted in the lower end of the polythene tubing. The hydrogen molecules pass more rapidly through the chalk than does the air downwards, so on diffusion the pressure below the soap solution rises above atmospheric and blows a soap bubble.

A control experiment will be necessary to show it is not the hydrogen rising from the fine tube which blows the bubble. This is done by repeating the experiment using another piece of tubing without the chalk.

Notes

1. The hydrogen is best obtained from a cylinder – small cylinders are often available from chemistry departments. Failing that, hydrogen must be obtained from a chemical generator, but in that case it is advisable to pass the gas through a filter of loose glass wool to remove small drops of acid which might spoil the soap film.

2. When the chalk becomes wet with soap solution in repeated experiments, the top layer of chalk can be scraped out with a screwdriver.



97b *Optional demonstration*

Watching two gases diffuse

Apparatus

polythene tubing (6-in length)
blackboard chalk (*soft*)
glass tube (two 3-in lengths)
soap solution
hydrogen
carbon dioxide
retort stand – items 503–504
boss – item 505
clamp – item 506

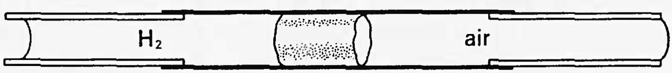
Procedure

This is a more elaborate version of Experiment 97a.

A piece of soft chalk is used for the diffusion barrier inside the polythene tubing. The tubing is held horizontally in a clamp attached to a retort stand.

One end of each of the glass tubes is sealed with a soap film. The glass tubes are filled with samples of two different gases, such as hydrogen and carbon dioxide. The open ends of the tubes are attached to the polythene tubing. Thus we have two samples of gas, each enclosed by a glass tube, a soap film at one end and a chalk barrier at the other.

Pupils watch the progress of the soap-bubble indicators to see the effect of diffusion.



98 *Class experiment*

Random walk experiment

Apparatus

32 dice
32 sheets 60-degree isometric grid graph paper – item 175

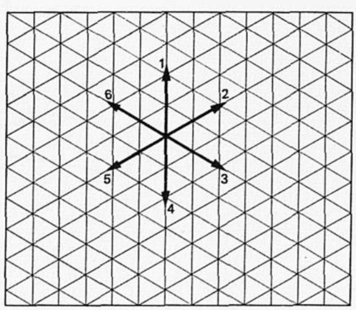
Procedure

See *Teachers' Guide* for general explanation.

Each pupil draws on a sheet of paper six spokes each making 60 degrees with the next (the first line being vertical) and labels each direction successively 1, 2, 3, 4, 5, 6.

The pupil takes a die, throws it and uses the uppermost number to tell him the direction in which to move. He starts in the middle of the paper and moves, say, 1 'unit stride' in that direction. He throws the die again and takes a further stride in the new direction. He repeats the process until 25 strides have been taken.

Then he measures the distance in strides from the starting-point to his finishing-point. The teacher records on the blackboard all the distances obtained and obtains an average value.



Alternative form with squared paper

As an alternative to the random walk test on triangle ruled paper, with directions decided by throwing a die, pupils may use *squared* paper and limit their equal steps to four directions, up, down, left, right. The instruction for choosing the direction must be provided by a random sample of, say, 25 objects drawn from a large collection of such objects labelled in equal numbers up, down, left, right.

99 *Demonstration*

Diffusion of bromine in air

Apparatus

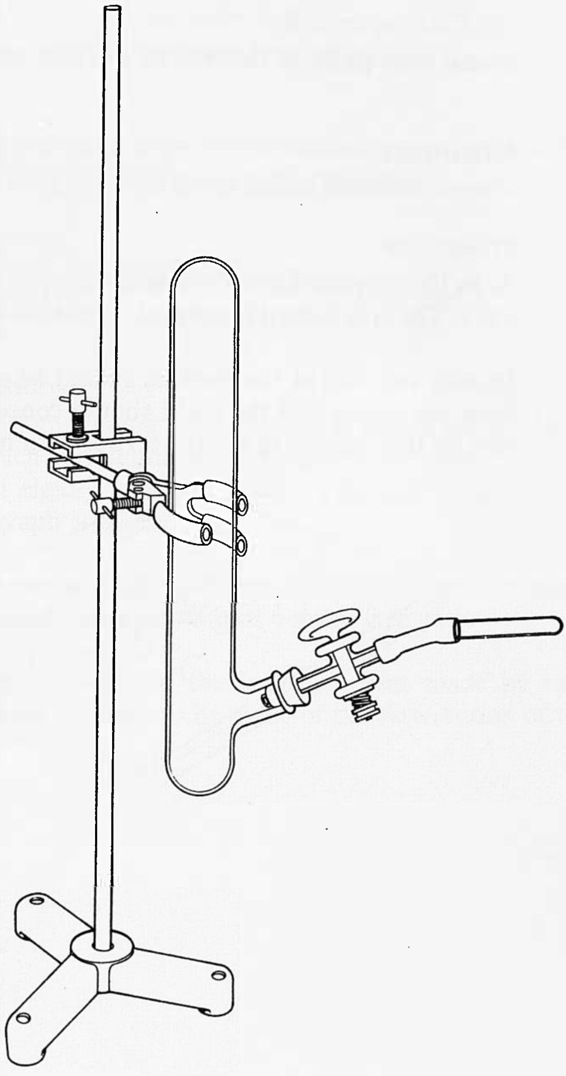
1 bromine diffusion kit	– item 8
1 retort stand	– items 503–504
1 boss	– item 505
1 clamp	– item 506
1 translucent screen	– item 46/1
1 lamp	– item 46/2
1 chinagraph pencil	– item 543
1 pliers	– item 530
1 metre rule	– item 501

(or, better, a transparent cm rule)

Procedure

The same procedure should be followed – with the same safety precautions and cleaning procedure – as in Experiment 89.

This time the pupils estimate by direct observation the 'average distance' travelled in a measured time (say, 500 seconds, i.e. 8 min 20 sec). See the *Teachers' Guide*.



100 *Class experiment*

Mean free path of marble in a tray

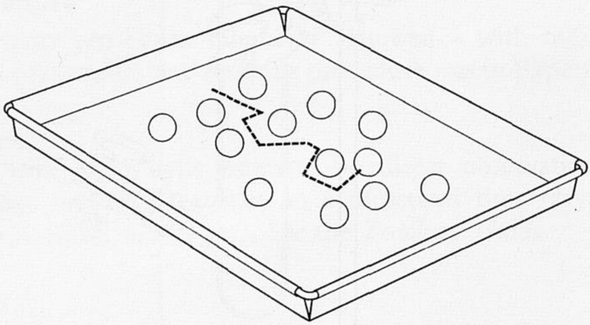
Apparatus

1 two-dimensional kinetic model kit – item 12

Procedure

As in Experiment 72, a few marbles are placed in each of the trays. The tray is kept horizontal on the table and agitated.

In each tray one of the marbles should be a different colour from the others and the pupil should concentrate his attention on that marble to see the sort of path it follows.



101 *Optional demonstration (buffer)*

Photograph of marbles in motion

This experiment is not recommended except to an enthusiast who wishes to experiment with exposures.

Apparatus

1 two-dimensional kinetic model kit	– item 12
1 camera	– item 133
1 lamp	

Procedure

The tray containing a few marbles is placed flat on the top of the bench and illuminated strongly by the lamp. The camera is held rigidly over the bench. The tray is agitated and a photograph is taken.

The exposure must be chosen so that it shows the motion of each marble for a fraction of a mean free path.

A rough estimate of the length of blur made by marbles enables an estimate to be made of the distribution of velocities.

102a *Demonstration*

Change of volume liquid air to gas

Apparatus

A supply of liquid air (or liquid nitrogen) is essential for this experiment – see experiment 91a.

Also required is one 5-ml plastic bottle or volumetric flask, two gas jars or two perspex boxes, size 10 cm × 10 cm × 11 cm (item 10D) and a tank of water and length of plastic tubing.

Procedure

This is the same experiment as 91a, which should be shown here if not done before. Optional alternative experiments were described in experiments 91b and 91c.

102b *Film*

Change of volume: liquid air to gas

It would be helpful to show a short film on the change of volume when liquid air turns into gas, especially in those schools remote from depots where liquid nitrogen can be obtained. It is hoped that in future such an 8 mm cassette film will be made commercially for school use.

103 *Demonstration*

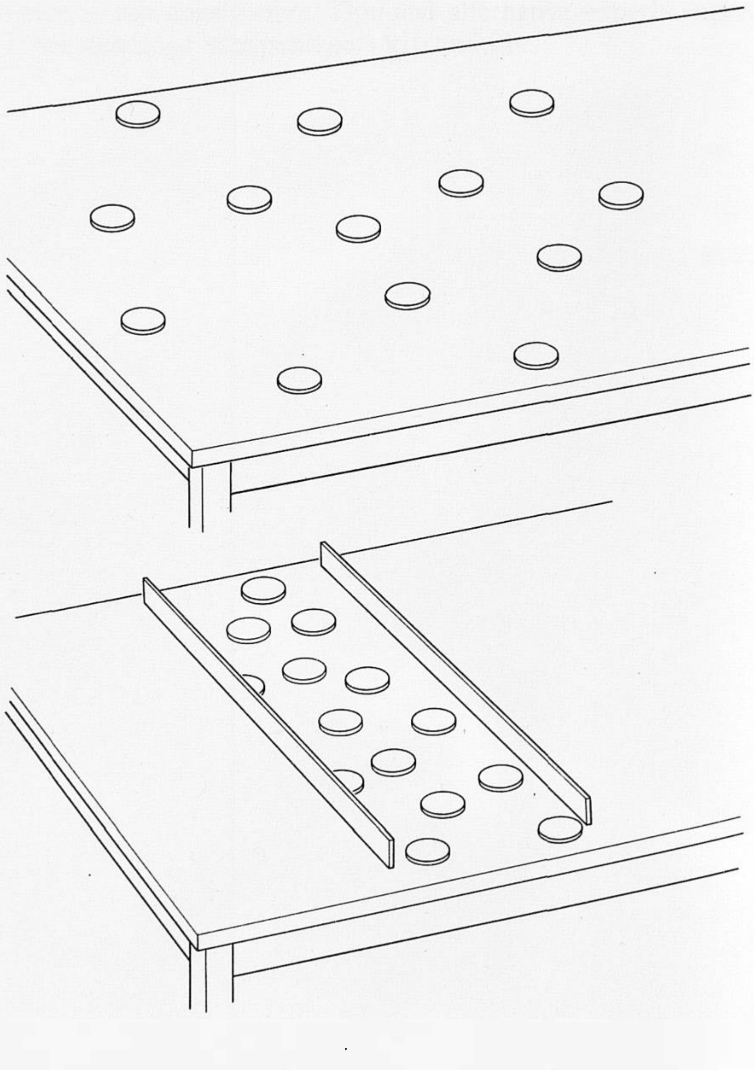
Simple molecular model

Apparatus

20 to 30 pennies

Procedure

Twenty or so pennies are scattered upon the table and spaced so that they are well apart from one another. A ruler is then used to sweep them together and several closer spacings are examined. The possible 'mean free path' of a typical coin is discussed. For full discussion, see the *Teachers' Guide*.



104 *Chart*

Chart of molecular data for air

AIR

$\left\{\begin{array}{l}\text{80 per cent nitrogen + 20 per cent oxygen} \\ \text{+ a little } CO_2 \text{ + water vapour} \\ \text{+ a very little helium, etc.}\end{array}\right\}$

Density

One 'mole'	
(one gram molecule) weighs	28·8 grams
occupies, at 1 atmosphere	22·4 litres at 0° C. 23–24 litres at room temp.
One 'kilomole' weighs	28·8 kilograms
occupies, at 1 atmosphere	22·4 cubic metres at 0° C. 23–24 cubic metres at room temp.
Density at room temp., 1 atmosphere	1·2 kg/cubic metre

Measurements for Molecules, at Room Temperature and 1 Atmosphere Pressure

From pressure, density and P.V. = $\frac{1}{3}$ Nmv^2	*Average speed* of molecules (R.M.S.)	500 metres/sec (about 1,650 ft/sec)
From densities or change of volume (liquid to gas)	*Average spacing* (distance between neighbours) (the side of a cube in space that would hold one molecule)	9 or 10 molecule diameters
From diffusion	*Average travel* between collisions ('Mean free path', mfp)	10^{-7} metres or 1000 A.U.
From mfp and densities	*'Diameter' of a molecule*	3 or 4 × 10^{-10} metre or 3 or 4 A.U.
	∴ *Average spacing* (See above)	35 × 10^{-10} metre or 35 A.U.

105 *Demonstration or class experiment*

Converting mechanical energy to heat

Apparatus

a. electric drill
blunt drill
piece of metal

b. hammers
lead piping or a piece of sheet lead
iron wire to hold piping

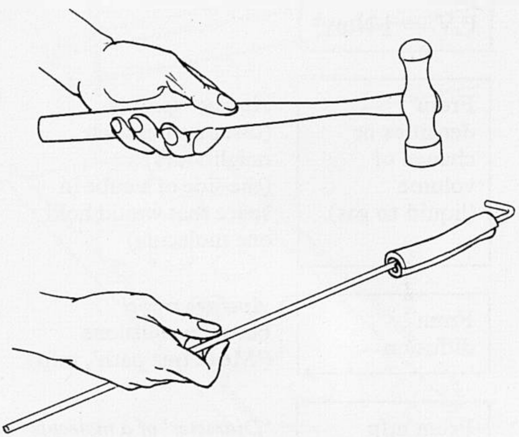
c. bicycle pumps

Procedure

a. A piece of metal is bored using a blunt drill. The drill is then passed round and felt.

b. The stiff iron wire is put through the lead piping and bent at the end in order to hold the lead. The lead is hammered violently and then felt. Instead of using lead piping a piece of thin sheet lead may be bent round the wire, as in the illustration below.

c. Pupils push the piston of a bicycle pump in quickly whilst holding a finger on the outlet. They feel the heating.



106a *Demonstration*

Revision experiment, measuring heat exchanges between hot and cold water

Apparatus

2 plastic buckets	– item 533
1 demonstration thermometer	– item 145
1 domestic balance	– item 20

a supply of hot water and a supply of cold water

Procedure

Weigh 3 kg of hot water into one of the plastic buckets. Weigh 2 kg of cold water into the other. Note the temperature of each.

Pour the cold water into the hot water and stir. Take the final temperature. For a discussion of the results, see the *Teachers' Guide*.

The temperatures may be read with a mercury thermometer: the teacher should ask a pupil to take the actual readings. Alternatively a bimetallic thermometer may be used.

Note

Although a mercury in glass thermometer can be used, it is not possible for the class to see the reading. The use of a thermistor for temperature measurement is too indirect and may confuse an otherwise simple experiment. A Rototherm demonstration thermometer (mercury in steel) with a 6-in or 8-in dial is ideal, but its cost is much too great to be justifiable for these simple experiments. An inexpensive bimetallic thermometer with a 2½-in dial is available and may be used here.

106b *Class experiment*

Measuring heat

Purpose

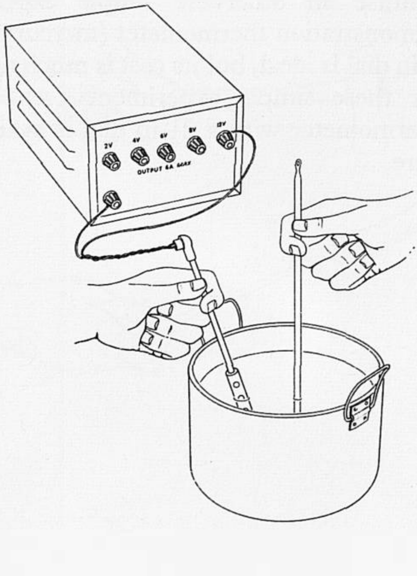
The purpose of these experiments is to show how heat can be measured. They may have been done in Year II, but should be done again here unless the pupils are already very familiar with them. It will not make sense to treat the conservation of energy if the pupils do not, at this point, have a clear feeling for the measurement of heat in calories.

Apparatus

8 immersion heaters	– item 75
8 transformers	– item 27
8 aluminium containers	– item 76
8 thermometers	– item 542
8 lever-arm balances	– item 42
8 stopclocks	– item 507

Procedure

The immersion heaters are connected to the 12-volt output of the transformers. Pupils, working in groups of four, use them to heat 1 kg of water in an aluminium saucepan for five minutes. They then repeat the experiment with, say, ½ kg having cooled their saucepan first. In each case they find out how much heat their electric heater gives in five minutes.



106c *Class experiment*

Measurement of heat produced on burning 1 ml of alcohol

Apparatus

8 aluminium containers	– item 76
8 lever-arm balances	– item 42
8 5-ml beakers	
8 metal supports	
methylated spirit	
8 thermometers	– item 542

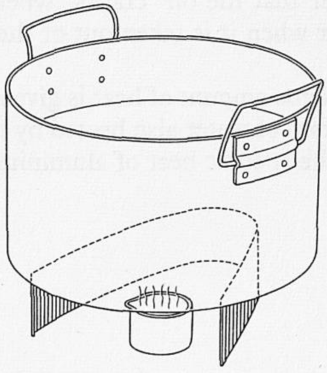
The metal support is conveniently made from a strip of aluminium 8 in × 3 in bent to form both a wind shield and support.

Procedure

A kilogram of water is weighed into the aluminium saucepan. The saucepan is supported on the metal stand. The teacher gives each pupil 1 ml of methylated spirit in the small beakers. The methylated spirit is burnt underneath the saucepan and the rise in temperature is measured.

Note

1 ml of alcohol burnt fully will yield about 4·5 kilocalories to the saucepan of water.



106d *Class experiment*

Rough estimate of the specific heat of aluminium

Apparatus

8 immersion heaters	– item 75
8 transformers	– item 27
8 aluminium blocks	– item 77
8 aluminium saucepans	– item 76
8 lever-arm balances	– item 42
8 thermometers	– item 542
3 stopclocks or stopwatches	– item 507

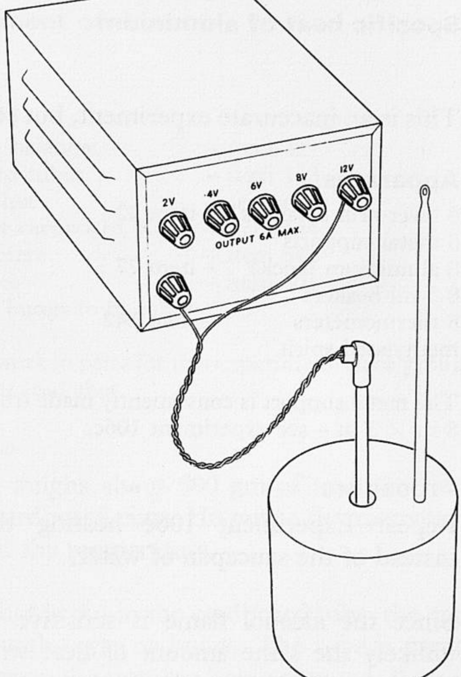
Procedure

The immersion heaters are connected to the 12-volt terminals of the transformers.

The aluminium block is weighed on the balance and then the thermometer and electric heater are inserted in the appropriate holes. The heater is switched on for five minutes and the maximum temperature is noted.

(Oil should be put in the thermometer hole to help thermal transfer. It is not necessary to put oil around the heater: the thermal transfer is quite good without it, with it there is a danger that the oil 'cracks' when a little of it is left on the heater when it is taken out of the block.)

The same amount of heat is given to the block as is given to a kilogram of water also heated by the immersion heater. From this the specific heat of aluminium is estimated.


2V
4V
6V
8V
12V
OUTPUT 6A MAX

106e *Optional class experiment*

Specific heat of aluminium

This is an inaccurate experiment, but some may like to try it.

Apparatus

8 lever-arm balances	– item 42
8 metal supports	
8 aluminium blocks	– item 77
8 5-ml beakers	
8 thermometers	– item 542
methylated spirit	

The metal support is conveniently made from a strip of aluminium 8 in × 3 in – see experiment 106c.

Procedure

Repeat Experiment 106c heating the aluminium block instead of the saucepan of water.

Since the alcohol flame is sensitive to air currents, it is unlikely the same amount of heat will be supplied to the aluminium block as to the saucepan. The estimate of specific heat will therefore be even more unreliable than that in Experiment 106d, but it has a simplicity which may make some teachers wish to try it.

107 *Class experiment*

Measurement of J

Apparatus

8 lever-arm balances	– item 42
16 cardboard tubes	– item 163
16 lb lead shot	– see below
16 plastic or cardboard cups	– item 164
8 thermometers	– item 542
8 metre rules	– item 501
32 corks or bungs to fit tubes	

Pupils will work in pairs for this experiment. Each group will require about 1 lb of lead shot.

Procedure

The pupil weighs about 500 gm of lead shot in one of the plastic or cardboard cups. He puts a thermometer in the lead shot to find the temperature.

The lead shot is put in the cardboard tube, the ends of which are sealed with corks or bungs. The tube is turned over 20, 40 or 50 times, the number being counted. The shot is then quickly poured into the cup and the temperature measured again. The rise in temperature is measured.

From their readings the pupils deduce a value of J – see discussion in *Teachers' Guide*.

108 *Demonstration*

Models

This demonstration uses completely home-made models where the teacher wishes to make them. Some may merely wish to run an egg beater (brought from home) in a beaker of water and to push the piston of a bicycle pump quickly. Others may care to make paper or cardboard models.

We certainly do not advocate commercially manufactured schematic models. They are liable to be expensive and would be unfortunately misleading if pupils thought a commercial model was a copy of the original.

109 *Demonstration*

Chart of methods and results of experiments on J

This chart can be made from the details given in the *Teachers' Guide.* It should be left on display throughout this section of the work.

110 *Demonstration*

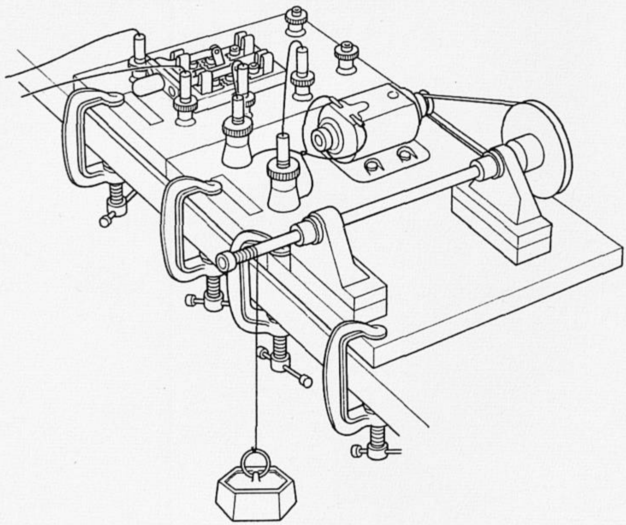
Comparison of the powers of electric motors

Apparatus

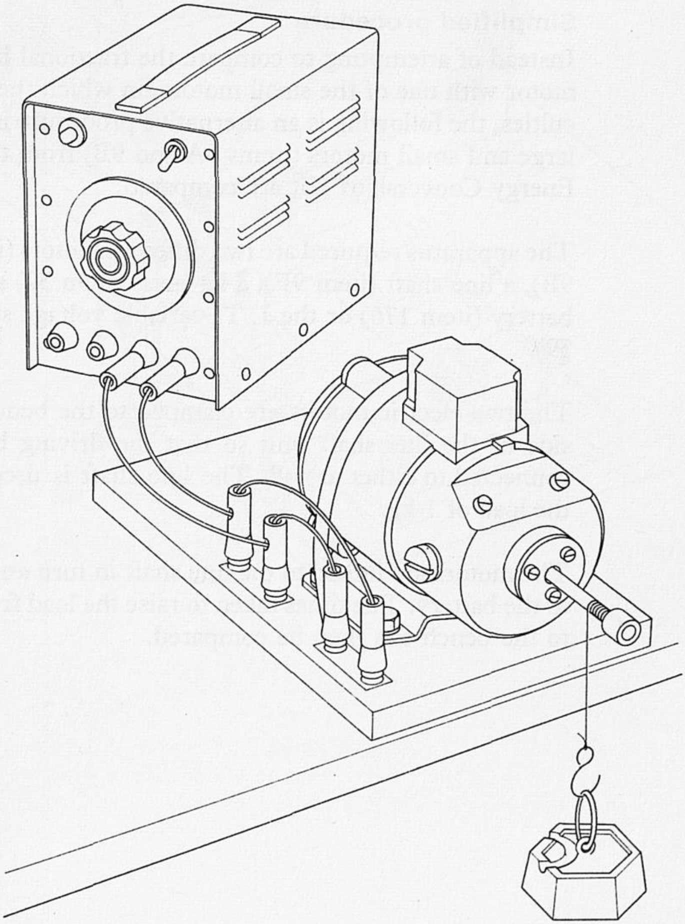
1 electric motor	– item 9A
1 line shaft	– item 9F
1 Kg-weight	– item 32
1 L.T. variable voltage supply	– item 59
1 fractional horse-power motor	– item 150

Procedure

The small electric motor – from the Malvern Energy Conversions Kit – is used to lift 1 kg. It is operated from the d.c. terminals of the L.T. variable voltage supply, which is set at 6 volts. The line shaft is used for lifting the load. The time for the load to be raised 1 metre, say, is noted.



The field and armature terminals of the fractional horse-power motor are connected in parallel to the d.c. terminals of the L.T. variable voltage supply which is set at 6 volts. The 1 kg is attached to the shaft by cord so that it is lifted when the motor is switched on. The time for raising the load through 1 metre is noted and compared with time taken with the small motor.



Note

There are difficulties in attempting to compare two different motors in this way. The better way would be to apply the same voltage to each and to measure the braking force to stall the motor using a pulley of the same diameter in each case.

An alternative arrangement would be to use only one motor, say the small motor from the Malvern Energy Conversions Kit, to operate it first at 4 volts with a 6- or 12-volt lamp in parallel with it. In this case the load is raised very slowly and the lamp glows faintly. Then to operate it at 6 volts. The lamp glows more brightly (showing there is more power) and the load is raised faster.

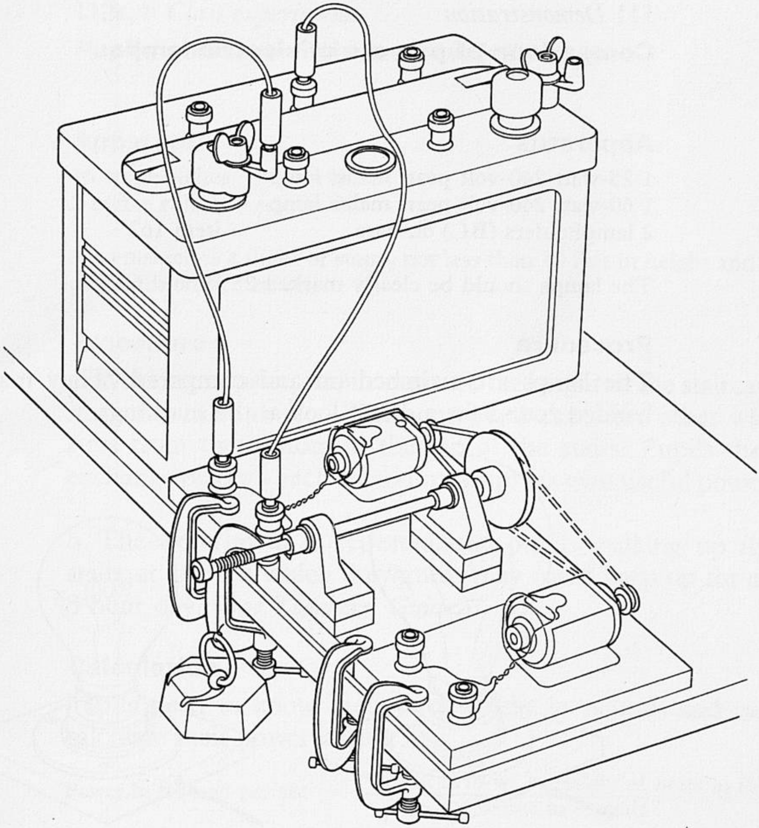
Simplified procedure

Instead of attempting to compare the fractional horse-power motor with one of the small motors, in which there are difficulties, the following is an alternative procedure in which the large and small motors (items 9A and 9B) from the Malvern Energy Conversions Kit are compared.

The apparatus required are two different motors (item 9A and 9B), a line shaft (item 9F), a kg-mass (item 32) and a 6-volt battery (item 176) or the L.T. variable voltage supply (item 59).

The two electric motors are clamped to the bench on either side of the line shaft unit so that the driving belt may be connected to either at will. The line shaft is used for lifting the load of 1 kg.

The motors are linked to the line shaft in turn and connected to the battery. The times taken to raise the load from the floor to the bench can then be compared.



111 *Demonstration*

Comparison of powers of electric lamps

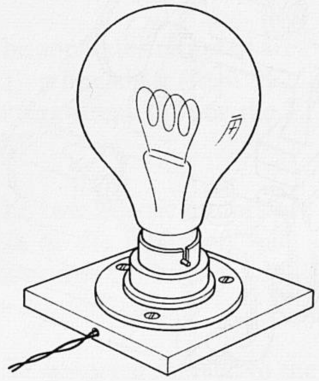
Apparatus

1 25-watt 240-volt pearl mains lamp
1 60-watt 240-volt pearl mains lamp
2 lampholders (BC) on base – item 162

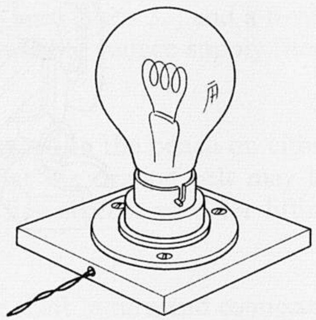
The lamps should be clearly marked 25 W and 60 W.

Procedure

The lamps are switched on and compared. They may be handed round for a direct look at the markings.



60 watt mains lamp



25 watt mains lamp

112a, b *Class experiment*

Pupils measure their own useful power

Apparatus

16 stopwatches – item 507
2 metre rules – item 501

Also needed is a flight of stairs, not less than 10 feet in height and preferably much more.

Procedure

a. Working in pairs, pupils measure the height of the staircase in metres, also in feet. Then one pupil times the other who runs from the bottom to the top of the stairs. Pupils then exchange places – each should measure his own useful power.

b. The experiment is repeated, the pupils walking up the stairs at a speed which they guess they could keep up for an 8-hour day. (See *Teachers' Guide.*)

Calculation

Pupils need to know their own weight in pounds and can calculate their power output:

$$\text{Power in ft lb-wt per sec} = \frac{\text{Weight in lb-wt} \times \text{Height of stairs in feet}}{\text{Time in seconds}}$$

This can be expressed in horse power by dividing by 550.

Pupils then find their weight in kg-wt (1 kg = 2·2 lb) and hence their weight in newtons by using the Earth's gravitational field strength (9·8 newtons per kilogram). They then calculate power in joules per second.

112c *Wallchart*

Human energy—food supplies and activity demands

The following information will have been displayed in Year I, but should be displayed again at this stage of Year IV.

1. Energy from food

Some idea can be gained of the energy available from different sorts of food if we work out the number of kilocalories liberated per ounce.

Food	*Energy Value*	*Food*	*Energy Value*
Butter	211 kilocal/oz	Margarine	226 kilocal/oz
Sugar	108 kilocal/oz	Beef	92 kilocal/oz
White bread	73 kilocal/oz	Fried fish	58 kilocal/oz
Potato	21 kilocal/oz	Boiled fish	20 kilocal/oz
Oranges	10 kilocal/oz	Cheese	120 kilocal/oz
Turnip	5 kilocal/oz	Oatmeal	115 kilocal/oz
Lentils	84 kilocal/oz	Eggs	46 kilocal/oz

2. Human energy demands

How much energy do we need each twenty-four hours? The answer depends very much on the sort of people we are, particularly our age and our occupation. Some average figures are as follows:

Children (either sex)	
0–1 yr	1,000 kilocal/day
2–6 yrs	1,500 kilocal/day
7–10 yrs	2,000 kilocal/day

Teenagers	*Males*	*Females*
11–14 yrs	2,750 kilocal/day	2,750 kilocal/day
15–19 yrs	3,500 kilocal/day	2,500 kilocal/day

Adults (20 years and over)	*Males*	*Females*
Lying in bed	1,750 kilocal/day	1,500 kilocal/day
Light work	2,750 kilocal/day	2,250 kilocal/day
Heavy work	3,500 kilocal/day	3,000 kilocal/day
Extremely heavy work	5,000 kilocal/day	

Pregnancy		
first half		2,500 kilocal/day
second half		2,750 kilocal/day
lactation		3,000 kilocal/day

The energy needed by an adult to perform various tasks has been estimated as follows (the data were obtained over a period of one week from a coal miner who was 32 years old, 5 ft 9 in tall and weighed 10 stone 8 lb).

Resting in bed	0·94 kilocal/min
Washing, shaving, dressing	3·3 kilocal/min
Walking	4·9 kilocal/min
Standing	1·8 kilocal/min
Cycling	6·6 kilocal/min
Hewing coal	6·7 kilocal/min
Loading coal	6·3 kilocal/min
Walking (in mine)	6·7 kilocal/min

Generally speaking, energy consumption by an adult man ranges from 12·5 kilocal/min for the heaviest work to 2·5 kilocal/min for the lightest. Such estimates are, of course, only average.

112d *Optional extra experiment*

Working against a band brake

This is useful as a buffer experiment if the apparatus is available in the laboratory.

Apparatus

1 wheel with band brake
2 spring balances (0–20 kg)
1 stopwatch

The wheel with band brake can readily be improvised where a laboratory possesses a whirling table. The belt is slipped off and a webbing belt or length of thick string is substituted. Alternatively, a bicycle ergometer can be used.

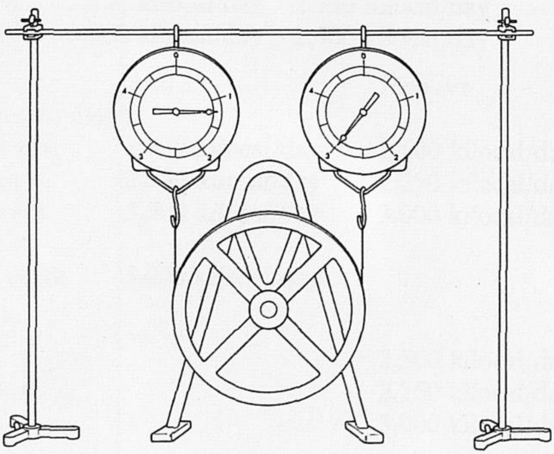
Procedure

The belt is firmly secured at the ends of the two spring balances, which are themselves supported from above.

The belt tension is adjusted by raising or lowering the support so that both balances read about half full scale.

The wheel is then turned by hand at a steady rate for at least 30 seconds and the 'steady' readings of the two balances recorded. The time taken to turn the wheel is noted and the number of turns is counted by a partner.

See the *Teachers' Guide* for help that can be given in explaining the calculation.



112e *Optional home experiment*

Output of power cycling up a hill

Procedure

Pupils with bicycles can be encouraged to time themselves in cycling up a rise, the height of which may be determined from the 6-in Ordnance map. Alternatively, two pupils might estimate the slope with a sighting pole, a plumb line and a big cardboard protractor.

Knowing their own weight and estimating that of their bicycle, the output of 'useful' power can be calculated.

Note

In estimating the weight of a bicycle, it would be noticeably light if this is less than 10 lb, but if more than 40 lb it would be difficult to lift. So the weight lies between these limits and is of the order of 20 lb. This figure would be acceptable, particularly as the weight of the boy is probably of the order of 150 lb.

113 *Class experiment*

The energy transfer box

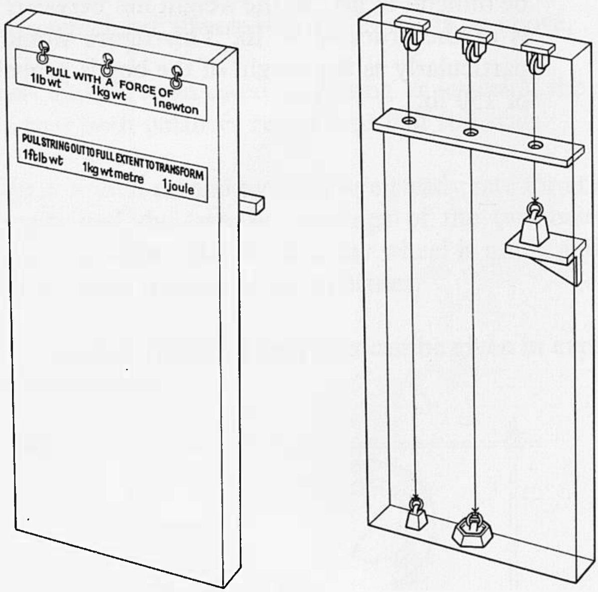
Apparatus

1 forces demonstration box – item 63

Procedure

The forces demonstration box used in earlier years should again be firmly clamped to a bench and left for some time so that pupils can experience for themselves forces of 1 lb-wt, 1 kg-wt and 1 newton.

On this occasion they should also use the box to experience energy transfers of 1 ft lb-wt, 1 kg-wt metre and 1 joule by pulling the appropriate strings to the fullest extent. The front panel must carry a clear statement of these energy changes.



114 *Class experiment*

The newton balance

Apparatus

8 newton spring balances (10N)	– item 81
8 1-kg weights	– item 32
8 1-lb weights	– item 36

Procedure

Pupils hang the masses in turn on the spring balance and observe the weight in newtons.

115 *Demonstration*

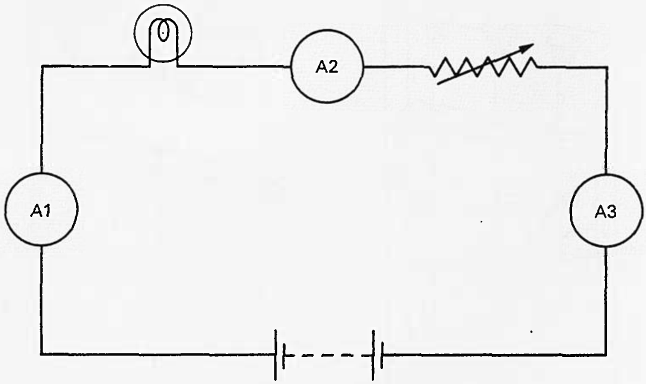
Series and branching circuits

Apparatus

1 12-volt battery	– item 176
6 d.c. ammeters (0–1 amp)	– item 79
2 lamps (12-volt, 6-watt)	– item 177
2 lampholders (S.B.C.) on bases	– item 74
2 rheostats (10–15 ohms)	– item 541/1

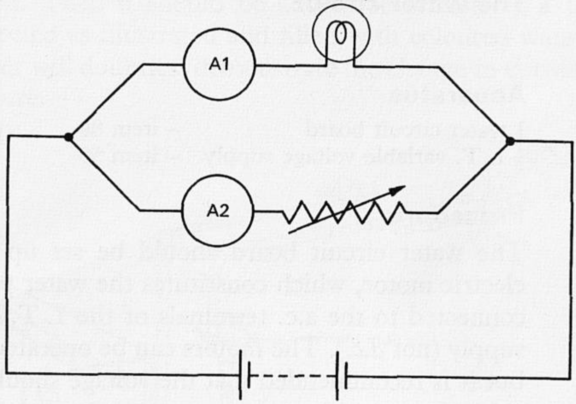
These experiments are important, but they should necessarily be quick demonstrations. For this reason they must be mounted in the vertical plane (preferably attached to a board) so that the layout can readily be seen. In a demonstration of this nature where a very clear display is required, it is advisable to use straight, stiff bare copper wire and to make T connections with crocodile clips.

a. The following circuit should be set up:

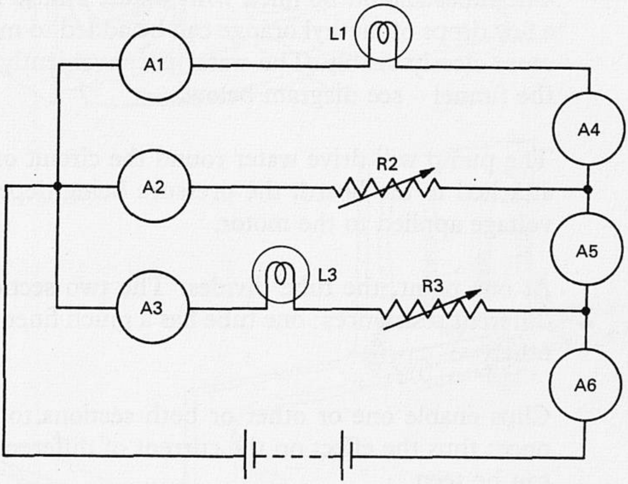


The current is adjusted to a suitable value (such as 0·4 amps) by means of the rheostat. It would also be instructive to include a fourth meter between two of the cells in the battery if the battery permits this.

b. As a simple branching circuit, set up the following:



c. Finally, set up the following:



Specimen readings:

With a 12-volt battery and 12-volt 6-watt lamps, A_1 will read 0·5 amps. Adjust R_3 so that A_3 reads 0·3 amps and R_2 so that A_2 reads 0·2 amps. Then A_4 reads 0·5 amps, A_5 0·7 amps, and A_6 1·0 amps.

116 *Demonstration*

The 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 electric motor, which constitutes the water pump, should be connected to the a.c. terminals of the L.T. variable voltage supply (not *d.c.*). The motors can be operated up to 18 volts, but it is recommended that the voltage should not exceed 16 volts.

The tubes should be filled with water: a little fluorescein or a few drops of methyl orange can be added to make the water more clearly visible. The water is conveniently poured in at the funnel – see diagram below.

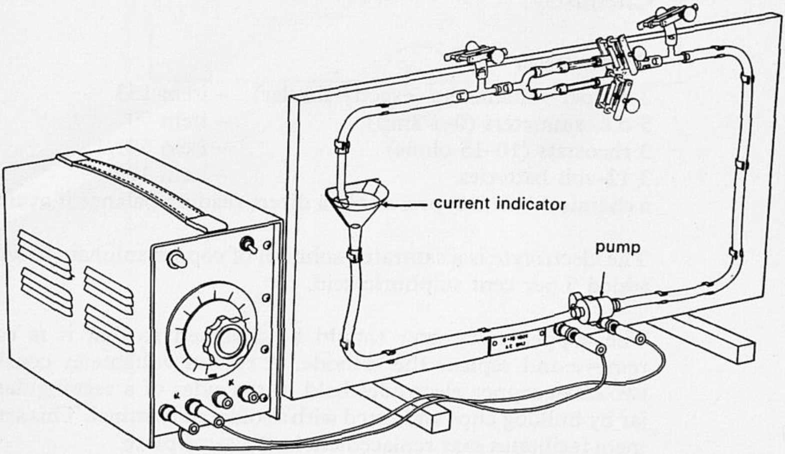
The pump will drive water round the circuit of glass tubing attached to the board, the pressure being dependent on the voltage applied to the motor.

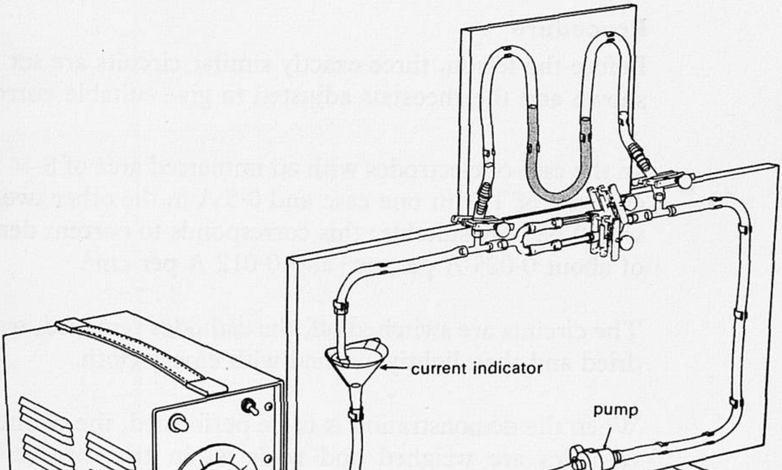
At one point, the tube divides. The two sections represent different resistances: one tube has a much finer bore than the other.

Clips enable one or other or both sections to be opened at once: thus the effect on the current of different 'resistances' can be seen.

Where there is a break in the circuit, the funnel catches the water flowing down from the tube above. The rate of flow of water is apparent and this indicates the current. Alternatively, if there is a pool of water in the funnel the faster the flow of water the more rapid the swirling motion in the funnel. A small piece of cork floating on the water in the funnel acts as an indicator of the rate of swirling, which thus shows the current.

In this demonstration, the pressure gauge should not be used at first. Then it should be added. It consists of a U-tube connected as illustrated and filled with coloured water. The teacher will doubtless demonstrate the change in current with pressure.





117 *Demonstration*

Electrolysis of copper sulphate solution

This experiment can be omitted if it has been done in Chemistry.

Apparatus

3 copper voltameters (exactly similar) – item 153
3 d.c. ammeters (0–1 amp) – item 79
3 rheostats (10–15 ohms) – item 541/1
3 12-volt batteries – item 176
a chemical balance, preferably a direct reading balance if available.

The electrolyte is a saturated solution of copper sulphate to which is added 5 per cent sulphuric acid.

The copper voltameter should be designed so that it is easy to remove and replace the cathode. A typical voltameter consists of two clean copper electrodes held to the sides of a rectangular glass jar by bulldog clips and fitted with a soldered terminal. This arrangement facilitates easy replacement in the same place.

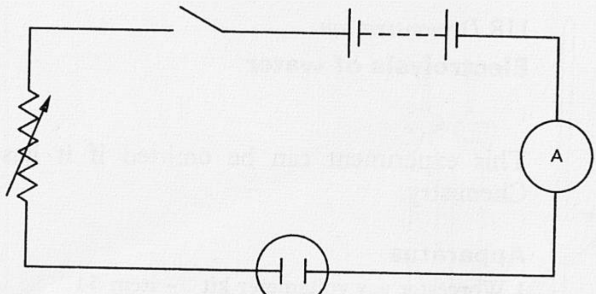
Procedure

Before the lesson, three exactly similar circuits are set up as shown and the rheostats adjusted to give suitable currents.

In the case of electrodes with an immersed area of 8×5 cm, currents of 1 A in one case and 0·5 A in the other two cases would be very suitable: this corresponds to current densities of about 0·025 A per cm^2 and 0·012 A per cm^2.

The circuits are switched off, the cathodes removed, washed, dried and then lightly cleaned with emery cloth.

When the demonstration is to be performed, the cleaned dry cathodes are weighed and replaced in the three circuits. These are then switched on together and the currents allowed to flow. After ten minutes the currents in the circuit carrying 1 A and one of the circuits carrying 0·5 A are switched off. After twenty minutes the third current is switched off. The cathodes are removed, washed, dried and reweighed, care being taken to record which is which. It should be found that the copper carried across is proportional to current $\times$ time.


A

118 *Demonstration*

Electrolysis of water

This experiment can be omitted if it has been done in Chemistry.

Apparatus

1 Worcester gas voltameter kit	– item 54
1 rheostat (10–15 ohms)	– item 541/1
1 d.c. ammeter (0–1 amp)	– item 79
1 12-volt battery	– item 176

The L.T. variable voltage supply (item 59) can be used instead of the 12-volt battery and rheostat.

Procedure

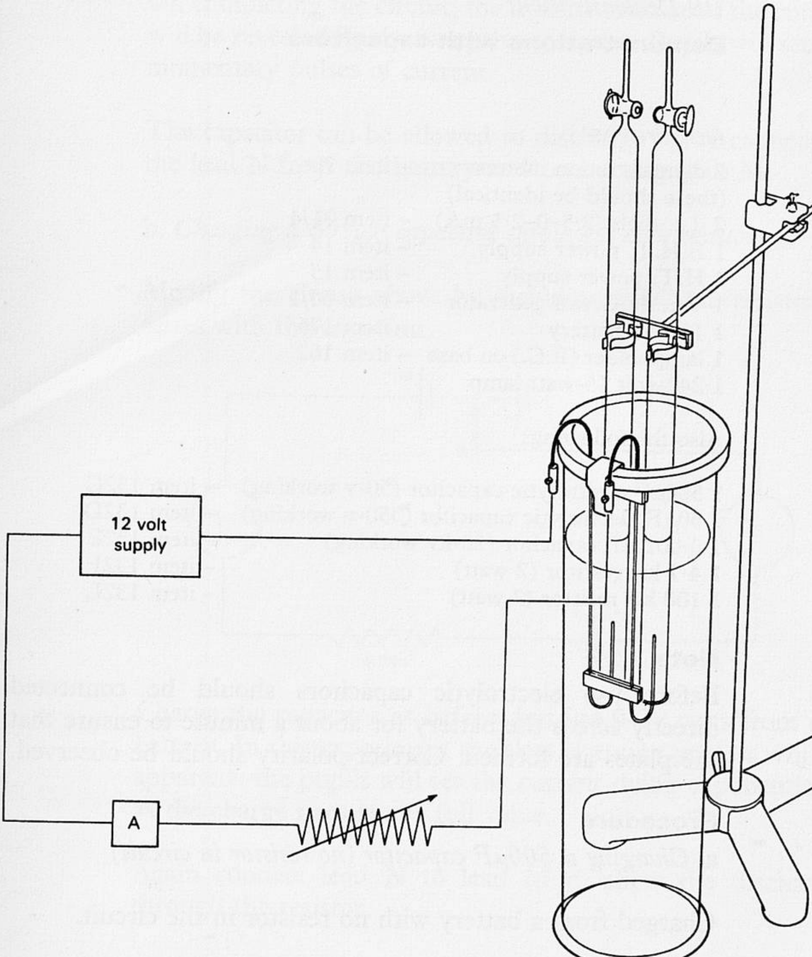
The circuit is connected as shown. The voltage supply is either the 12-volt battery or the L.T. variable voltage supply.

Only one of the two 250 ml burettes need be used and this should be filled with the acidulated water after it is placed over the cathode. This is achieved by squeezing the plastic bottle firmly, slipping the tube connection over the bottle outlet and the top of the burette, opening the tap of the burette and then allowing the bottle to regain its normal shape. The tap is then closed, the bottle removed, emptied again of air and the procedure repeated until the burette is completely filled.

The current is then switched on and adjusted to a value of 1 amp (note that the position of the burette relative to the electrode has a marked effect upon the current).

After this adjustment, the current is switched off and the gas in the burette removed and the water again brought up to the top. The current is then allowed to flow for, say, twenty minutes.

After switching off, the burette is slid in its holding clip until the levels of the water inside and outside the tube are the same. The volume of the hydrogen gas is then read. The mass liberated by the current in twenty minutes can be determined (density of hydrogen is about 10^{-4} gm cm^{-3}) and compared with the results of the previous experiment.


12 volt
supply
A

119 *Demonstrations*

Demonstrations with capacitors

Apparatus

2 demonstration meters (these should be identical)	– item 70
2 d.c. dials (2·5–0–2·5 mA)	– item 71/4
1 E.H.T. power supply	– item 14
1 H.T. power supply	– item 15
1 Van de Graaff generator	– item 60/1
1 12-volt battery	– item 176
1 lampholder (B.C.) on base	– item 162
1 240-volt 15-watt lamp	

Also the following:

1 500μF electrolytic capacitor (50-v working)	– item 132C
1 50μF electrolytic capacitor (350-v working)	– item 132D
1 0·001 μF capacitor (20-kv working)	– item 132E
1 4·7 kΩ resistor (2 watt)	– item 132J
1 100 kΩ resistor (2 watt)	– item 132L

Note

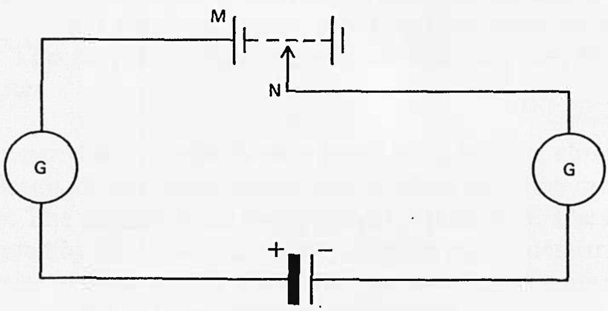
Before use electrolytic capacitors should be connected directly across the battery for about a minute to ensure that the plates are formed. Correct polarity should be observed.

Procedure

a. *Charging a 500μF capacitor (no resistor in circuit)*

Charged from a battery with no resistor in the circuit.

Set up the series circuit shown, tapping 4 volts from the battery and using the 500μF electrolytic capacitor (50-volt working).

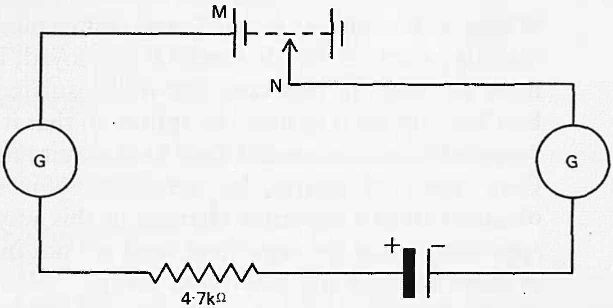


On completing the circuit, the transient nature of the current will be revealed by the two galvonometers. Pupils will see the momentary pulses of current.

The capacitor can be allowed to discharge by disconnecting the lead N from the battery and connecting it to M.

b. *Charging a 500μF capacitor through a high resistor*

Modify the circuit above by including a 4·7-kΩ resistor in series with the capacitor.



Charge the capacitor as before, but use 9–12 volts from the battery. In this experiment the slow charging process will be apparent: the pupils will see the current dying exponentially as the charge rises to the full value.

Again connect lead N to lead M to show the discharge through the resistor.

c. *Charging a 0·001μF capacitor to a high voltage and then short circuiting it.*

The E.H.T. power supply is set to provide 5kV and is then used to charge the 0·001 μF capacitor.

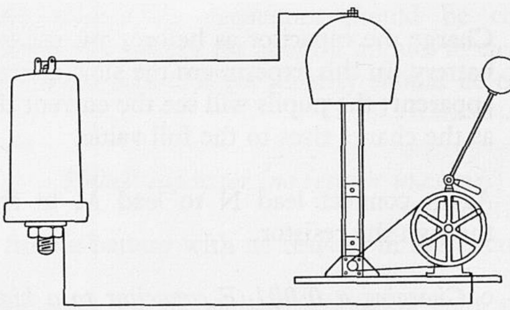
This is best done by holding the capacitor horizontally in a clamp and connecting the stud mounting end to the earthed negative terminal of the power supply. The positive terminal is connected to the capacitor through a 100kΩ resistor. (If the power supply has a built-in 50MΩ safety resistance, this can be used in place of the 100 kΩ resistor, but as it is less obviously part of the circuit it is better to use a separate 100 kΩ resistor.) Care should, of course, be taken working at these voltages.

Connection between the end of the resistor and the top of the capacitor is made with a well-insulated flexible lead held by hand.

After a moment or two, this lead is removed. Another insulated lead is used to short circuit the capacitor.

d. *Repeat of (c) using an electrostatic generator*
This experiment is repeated using a Van de Graaff or a Wimshurst generator. Again it will be found best to clamp the capacitor in position.

Where a Wimshurst is used, the connection can be made directly: where a Van de Graaff is employed, the flying leads must be used. In this case, the well-insulated flying lead is best held by hand against the sphere so that it can readily be removed from contact and used to short circuit the capacitor. Care must, of course, be exercised. ½-in sparks can be obtained from a capacitor charged in this way. It should be appreciated that the capacitors used are not intended for use at these voltages and may break down.



e. *50μF capacitor discharged through a lamp*
Charge a 50μF electrolytic capacitor (350-volt working) from an H.T. power supply set to give 240 volts. A safety resistor of 100kΩ should be included in the charging circuit. Allow thirty seconds for charging.

Disconnect the capacitor and allow it to discharge through a 240-volt 15-watt mains lamp. (The safety resistor should *not* be included when discharging.)

120 *Demonstration*

Lamp comparison

Purpose

To show that the two lamps which take about the same current give quite different amounts of light.

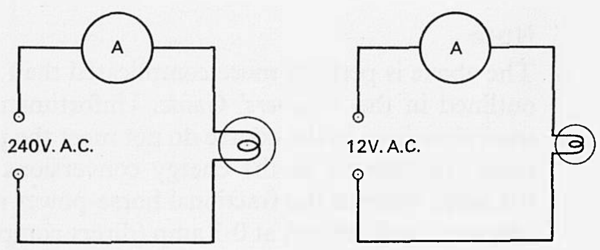
Apparatus

1 lamp holder (B.C.) on base – item 162
1 lamp holder (S.B.C.) on base – item 74
1 240-volt 100-watt B.C. lamp
1 lamp (12 volt, 6 watt) – item 177
1 demonstration meter – item 70
1 a.c. dial: 1 amp – item 71/8
1 transformer – item 27

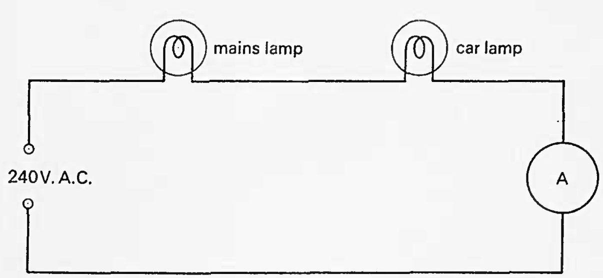
The two lamp holders should preferably be fitted with insulated 4-mm terminals.

Procedure

a. Separate circuits are prepared in which a mains lamp taking about 0·4 amp and car side-light lamp taking about 0·5 amp are connected to a 240-volt and a 12-volt a.c. supply respectively.



b. The two lamp bases are then connected in series with the ammeter and the circuit connected to the 240-volt main supply.



121 *Demonstration*

Comparison of two different electric motors running on the same current

Apparatus

1 L.T. variable voltage supply	– item 59
1 demonstration meter	– item 70
1 d.c. dial: 0–5 amp	– item 71/2
3 motor/generators	– item 9A
1 small motor/generator	– item 9B
4 2-in G-clamps	– item 44/2
2 lamp units (with bulbs)	– item 9D
2 thin 3-in elastic bands	

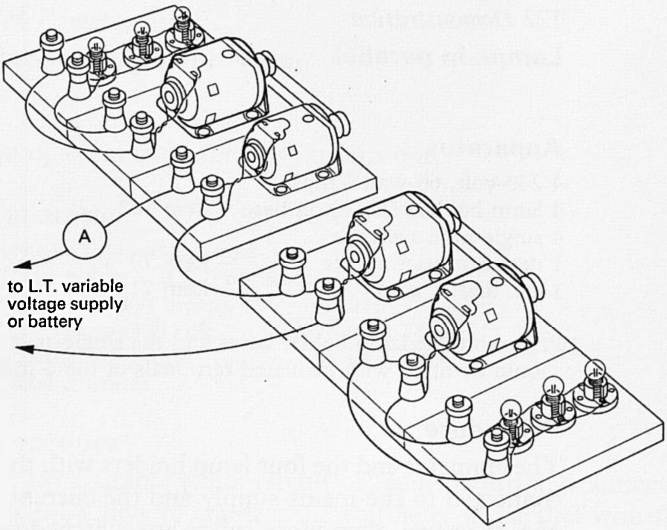
Procedure

The lamp units are connected to the generators which are driven (via elastic bands), one by the small motor, the other by the large motor: these motors being connected in series with the ammeter and the variable d.c. supply.

The supply is gradually increased to about 1·6 amps when the large motor will drive the generator and light three lamps, whilst at the same time, the small motor will just about turn the other generator when it is unloaded: connecting a lamp to this generator stalls the small motor.

Note

The above is perhaps more complicated than the experiment outlined in the *Teachers' Guide*. Unfortunately, the motors used elsewhere in the course do not meet the precise requirement: the motors in the energy conversions kit take about 0·3 amp, whereas the fractional horse-power motor takes 2·5 amps and will not run at 0·3 amp (direct comparison is unfair in any case because the latter has to have its field coils actuated as well). If the laboratory possesses two different motors which take the same current, they should be demonstrated instead of the procedure suggested above.


A
to L.T. variable
voltage supply
or battery

122 *Demonstration*

Lamps in parallel

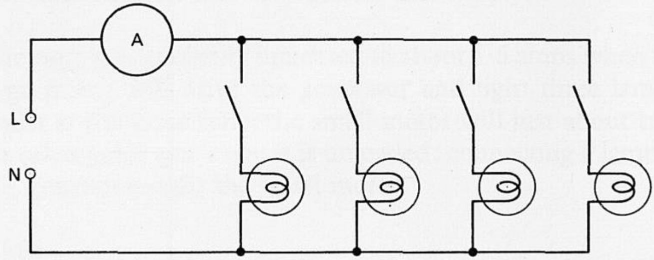
Apparatus

4 240-volt, 60-watt lamps
4 lamp holders (B.C.) on base – item 162
4 single-pole switches
1 demonstration meter – item 70
1 a.c. dial: 1 amp – item 71/8

Preferably the lamp holder bases and the single-pole switches should be fitted with insulated terminals of the 4-mm. type.

Procedure

The ammeter and the four lamp holders with the switches are connected to the mains supply and the current noted as first one, then two, then more lamps are switched on.



123 *Demonstration*

Connecting a voltmeter

An optional extra for slow groups only.

Apparatus

2 240-volt, 60-watt lamps	
2 lamp holders (B.C.) on bases	– item 162
2 demonstration meters	– item 70
1 a.c. dial: 0–300 volt	– item 71/9
1 a.c. dial: 0–1 amp	– item 71/8
1 radiant heater	– item 58C

Procedure

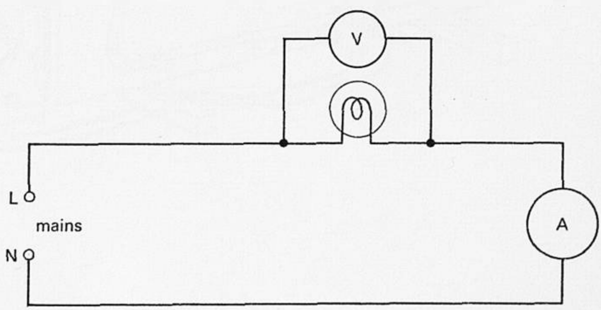
Set up a simple series circuit of mains lamps and ammeter and show how to connect the voltmeter in parallel with the lamp.

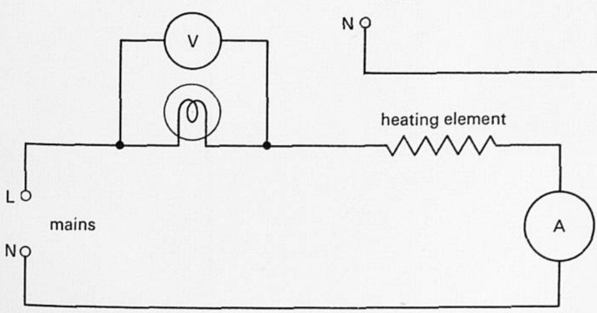
Add an electric heating element or mains motor to the circuit and show how the voltmeter may be connected across, first, the lamps and, then, the heating element.

Finally, connect up a series circuit of two similar lamps in series and repeat.

Note

The circuit should always be switched off while changes in wiring are made.





124 *Demonstration*

The water circuit

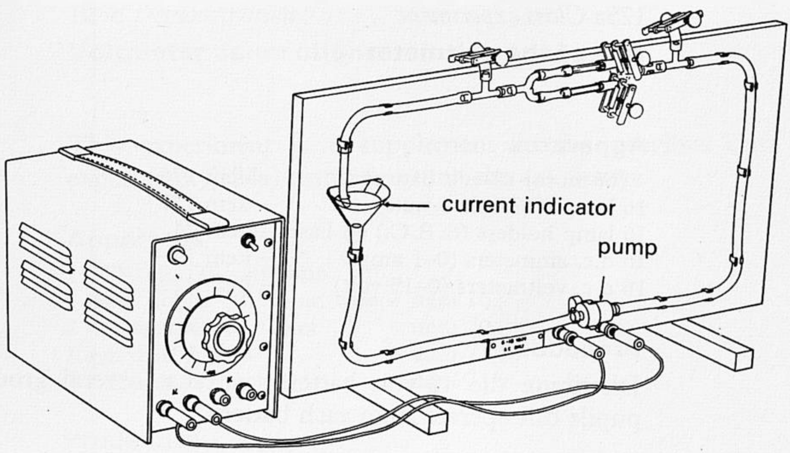
Apparatus

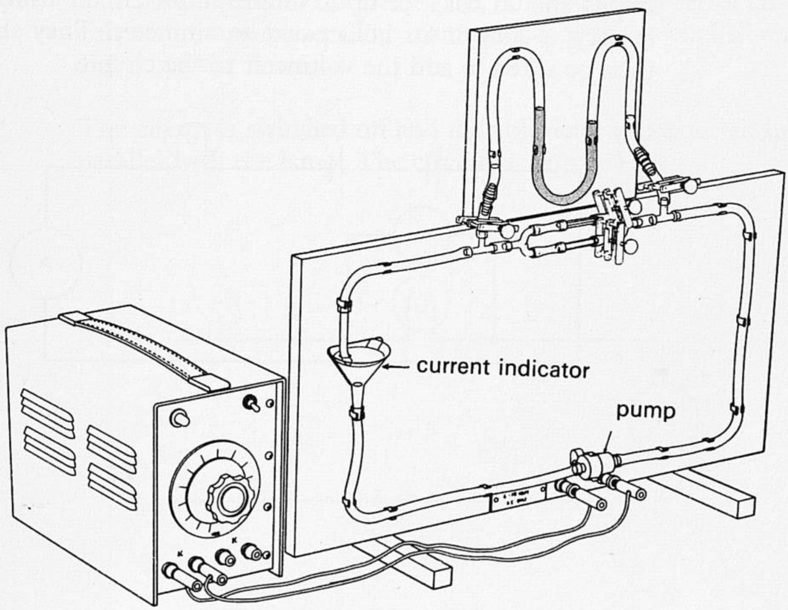
1 water circuit board	– item 89
1 L.T. variable voltage supply	– item 59

Procedure

The water circuit board is set up and operated as explained in Experiment 116. It should be shown (a) without the pressure gauge, then (b) the pressure gauge, which consists of a U-tube connected as illustrated and filled with coloured water, is added.

The teacher will doubtless demonstrate the change in current with pressure and also the change in current which results from increasing or decreasing the resistance, keeping the pressure difference constant. The resistance is changed by opening one or other or both of the two parallel tubes in the circuit, one of which has a finer bore than the other.


current indicator
pump


current indicator
pump

125a *Class experiment*

Use of the voltmeter

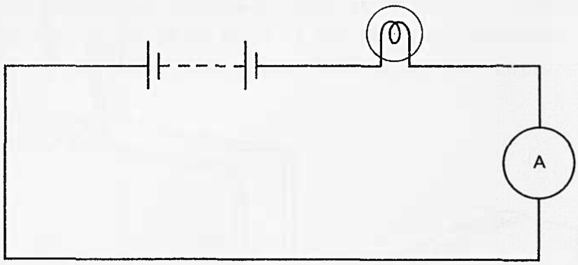
Apparatus

4 (or more) 12-volt batteries	– item 176
16 lamps (12-volt 6-watt)	– item 177
16 lamp holders (S.B.C.) on bases	– item 74
16 d.c. ammeters (0–1 amp)	– item 79
16 d.c. voltmeters (0–15 volt)	– item 179

Procedure

Distribute the 12-volt batteries so that several groups of pupils can operate from each battery.

Pupils should connect up a simple series circuit using the battery, a lamp in its holder and an ammeter. They should then be asked to add the voltmeter to the circuit.



125b *Demonstration*

Voltmeter connections

This experiment is a supplement to the previous class experiment (124a) using this time the a.c. mains

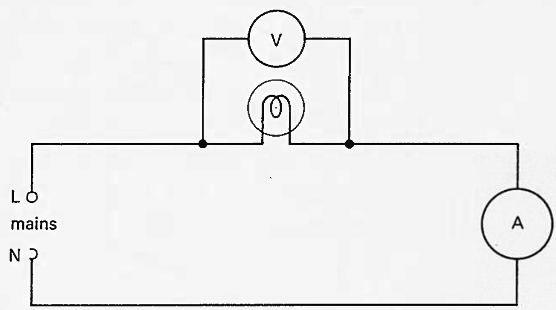
Apparatus

1 240-volt, 60-watt lamp	
1 lamp holder (B.C.) on base	– item 162
2 demonstration meters	– item 70
1 a.c. dial: 1 amp	– item 71/8
1 a.c. dial: 300 volt	– item 71/9

Procedure

The lamp, fitted to the lamp base, is wired into a series circuit with the ammeter. The mains supply is then switched on and a current flows.

The circuit is switched off and the voltmeter is connected in parallel with the lamp. The circuit is switched on.



126 *Class experiment*

Voltmeter as cell counter

Apparatus

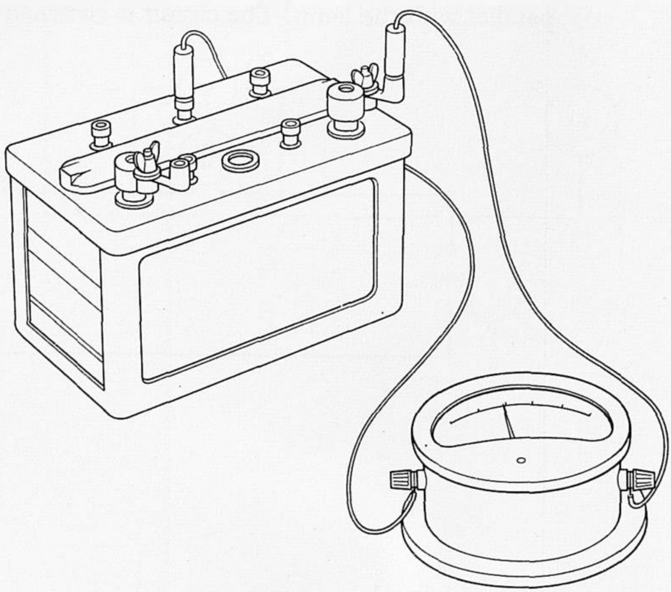
4 (or more) 12-volt batteries	– item 176
16 voltmeters (0–15 volt)	– item 179

Procedure

Pupils apply their voltmeter to one of the cells of the 12-volt battery. Then to two, three, four, five and six cells.

Note

The 12-volt batteries (item 176) must be such that it is possible to tap off intermediate voltages: 4-mm sockets are also an asset. Ordinary car batteries can be used, but the latest type is such that it is not easy to take off intermediate voltages. Some manufacturers supply such batteries adapted for school use, and these are recommended.



127 *Optional extra class experiment*

Calibrating a voltmeter

Apparatus

8 immersion heaters	– item 75
8 voltmeters (0–15 volt)	– item 179
8 ammeters (0–5 amp)	– item 178
8 thermometers	– item 542
8 stopwatches or stopclocks	– item 507
8 plastic cups	– item 164
4 (or more) 12-volt batteries	– item 176

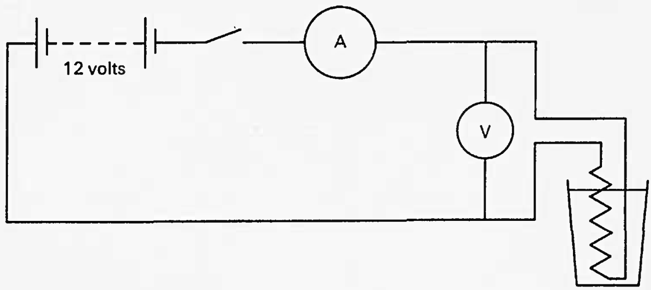
Plastic drinking-cups (item 164) are very suitable for this experiment having a low heat capacity. Alternatively the Perspex containers (item 26), which were used in Year I, could be used.

Procedure

200 grams of cold water are placed in a container. The immersion heater is then placed in the water and connected into the circuit shown. The temperature is recorded.

The circuit is switched on and the watches started at the same instant. The heater is used as a stirrer and the current allowed to flow for two minutes. During this time ammeter and voltmeter readings should be recorded.

At the end of two minutes the current is switched off, the water stirred again and the maximum temperature noted. (A rise of about 7 deg C can be expected.)



128 *Demonstration*

Potential difference and electromotive force

Apparatus

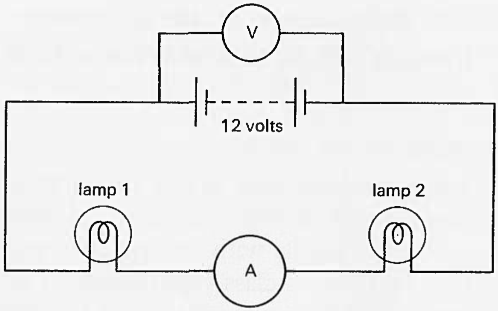
1 12-volt battery	– item 176
2 lamps (12-volt 6-watt)	– item 177
2 lamp holders (S.B.C.) on bases	– item 74
2 demonstration meters	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 d.c. dial: 15 volt	– item 71/10

Procedure

a. The battery, ammeter and lamps are connected into a simple series circuit as shown.

The voltmeter is supported above the battery and is connected first across lamp 1, then across the ammeter, then across lamp 2, then across the three together (between P and Q), and finally across the battery. The p.d. is noted in each case.

b. With a very fast group, it is worth repeating this demonstration with a battery possessing internal resistance (a series of dry cells). See also Experiment 157. Such a battery can also be prepared using accumulators joined together with about 24 in of SWG 26 Eureka wire.


V
12 volts
lamp 1
lamp 2
A

129a *Demonstration or class experiment*

Using a C.R.O. to show wave-form of a.c. mains

Note

Some teachers may prefer to do this and the subsequent experiments as demonstrations. However, in order to familiarize the pupils with the oscilloscope, we recommend that they be done as class experiments. This experiment enables pupils to become familiar with the various controls on the C.R.O. Perhaps the best arrangement would be for the teacher to show it first as a demonstration and then let the pupils achieve the same on their oscilloscopes.

Apparatus

As a demonstration

1 oscilloscope – item 64
1 transformer – item 27

As an alternative to the transformer, the low voltage power unit (item 104) can be used.

As a class experiment

8 class oscilloscopes – item 158
8 transformers – item 27

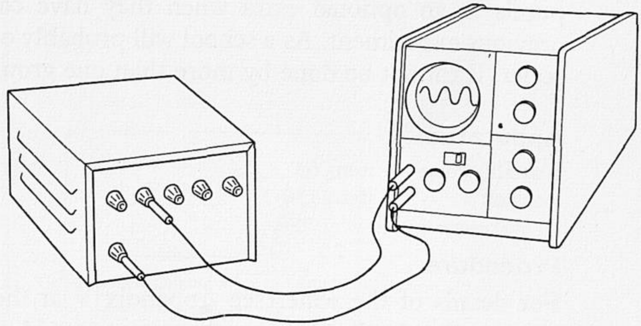
The low-voltage power units (item 104) can be used instead of the transformers.

Procedure

For details of the demonstration oscilloscope (item 64) see Appendix III at the end of this volume. For details of the class oscilloscope, see Appendix IV.

As a demonstration, the oscilloscope, item 64, is set with the volt/cm switch to 1, the time-base control to 1 ms/cm and the a.c.–d.c. switch to a.c. The a.c. terminals of the low-voltage power unit (2 volt a.c.) or the 2-volt terminals of the transformer are connected to the Input and E terminals of the oscilloscope. The variable control on the time-base is turned anticlockwise until four or five cycles of the waveform appear on the screen. When correctly adjusted (see Appendix III), the pattern traced on the screen will remain fixed in position.

As a class experiment, the 2-volt a.c. supply is connected in the same way to the input terminals on the class oscilloscope. The gain should be set at 1, the time-base on range 2 and the a.c.–d.c. switch on d.c. Pupils should adjust the variable control on the time-base to see the pattern opening up and closing.



129b *Optional demonstration or class experiment*

Using a C.R.O. to show pulse shape from the scaler

Note

This can be shown as a demonstration or it could be done by pupils as an optional extra when they have completed the previous experiment. As a school will probably only have one scaler, it cannot be done by more than one group at a time.

Apparatus

1 oscilloscope – item 64
1 scaler – item 130/1

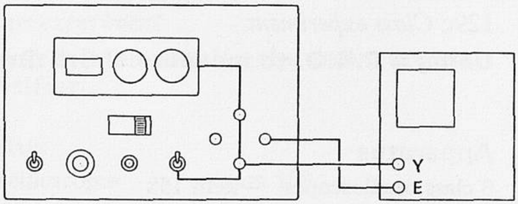
Procedure

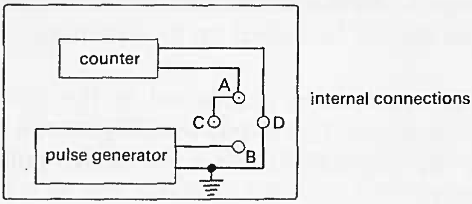
For details of the scaler see Appendix V at the end of this volume. For details of the oscilloscope, item 64, see Appendix III.

The oscilloscope is set with the volt/cm control at 0·2, the time base control at 100μs/cm and the a.c.–d.c. switch to a.c. The triggering should not be on auto: turn up the trig level to get a trace and turn back the stability to its lowest value without the trace going out.

The scaler 'make to count' sockets are connected together and a lead is taken from one of the two sockets to the input of the oscilloscope to display the shape of the millisecond pulse. Earth connection can be achieved through the mains earth link, but it is probably better teaching at this stage to show a definite earth connection, as shown. It is unnecessary to switch the scaler to 'count': the clicks are in any case distracting. Adjust the variable control on the time-base for the best display.

It is probably helpful to teachers to appreciate that points A and C are connected internally to each other and to the counter. D is connected to the earth and the chassis, while B is connected to the oscillator.


Y
E


counter
A
C
D
pulse generator
B
internal connections

129c *Class experiment*

Using a C.R.O. to measure short time intervals

Apparatus

8 class oscilloscopes – item 158
8 microphones – item 157

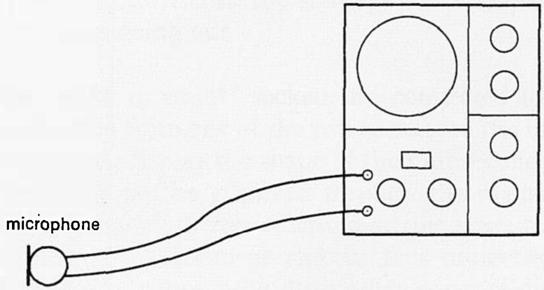
Procedure

The time base on the class oscilloscopes should be set on range 1 and the fine control at the slowest sweep speed. The gain should be turned up to maximum.

The microphone is attached to the input terminals of the oscilloscope. The pupils should give two short whistles close to the microphone to see successive pulses a short interval apart.

Note

If the teacher wishes, he could repeat Experiment 93b to show short time intervals being measured and used to determine the velocity of sound.



129d *Class experiment*

Using a C.R.O. to display the valve action of a rectifier

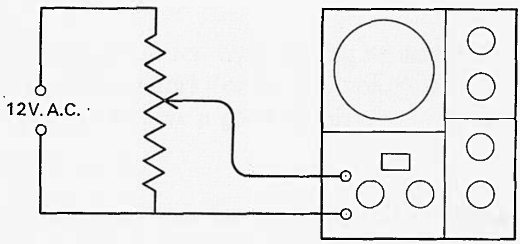
Apparatus

8 class oscilloscopes	– item 158
8 transformers	– item 27
8 rheostats (10–15 ohms)	– item 541/1
8 rectifiers	– item 52G

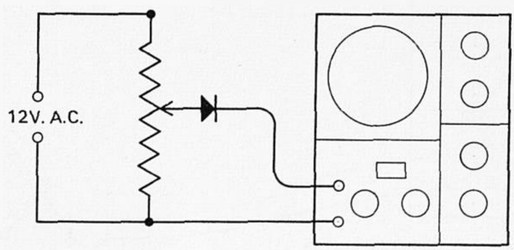
The rectifiers listed above are those contained in the Worcester circuit board kit. Radiospares REC 50 A silicon rectifiers are suitable.

Procedure

Connect the rheostat across the 12-volt a.c. terminals of the transformer so that it acts as a potential divider. Set the sliding contact to the half-way position. Connect, as shown, to the oscilloscope to display the wave-form. The gain control should be set to 0·5 and the time-base on range 2.

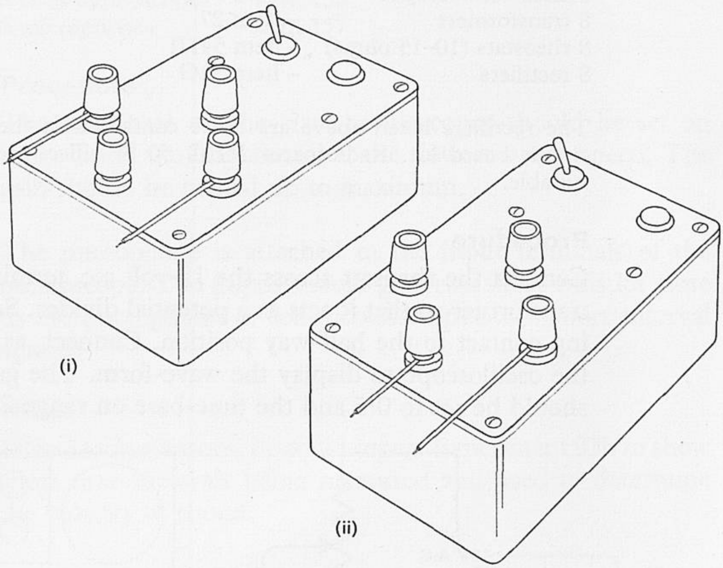


Switch off the 12-volt supply and connect the rectifier into the circuit as shown below. Switch on and observe the wave-form.



Repeat with the rectifier reversed.

Each pupil should then connect the a.c. terminals of a low-voltage power unit to the input terminals of the oscilloscope – as shown in Fig. (i). They will see the pattern produced. If one of the leads is transferred – as shown in Fig. (ii) – the rectified wave-form will be displayed



129e *Class experiment*

Using a C.R.O. to show acoustic wave-forms

Apparatus

8 class oscilloscopes	– item 158
8 microphones	– item 157
8 tuning-forks	– item 520

Procedure

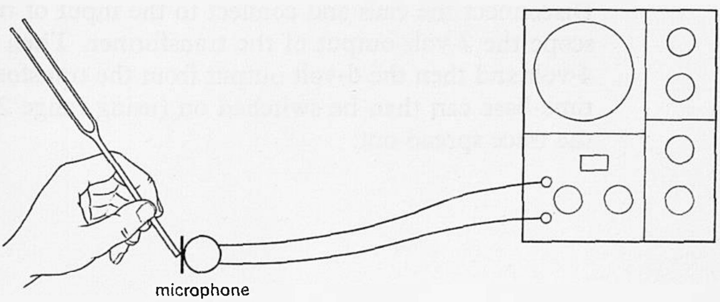
For details on the class oscilloscopes, see Appendix IV at the end of this volume.

The small microphones are connected to the input terminals of the oscilloscope. Set to maximum gain with the time-base to the middle of range 2. Using the base of the tuning fork like this often gives extra frequencies. The ideal arrangement is to hold the microphone near a vibrating tuning fork (preferably on a sounding board or box), but there may not be sufficient amplification.

The microphone is excited by touching its case with the base of a vibrating tuning-fork (or by the voice). Adjust the fine time-base control to give a good display.

Note

Carbon microphones can be used instead of those recommended. They will require a battery and transformer for use in series with them. The output from the transformer is put on the input terminals of the oscilloscope.



129f *Optional class experiment*

Using a C.R.O. as a voltmeter

Apparatus

8 class oscilloscopes	– item 158
8 Worcester circuit boards	– item 52C
(each with 3 U2 cells)	– item 52B
8 transformers	– item 27
8 d.c. voltmeters (0–5 volt)	– item 80

The circuit boards each with 3 U2 cells provide a convenient way of doing this experiment if they are available.

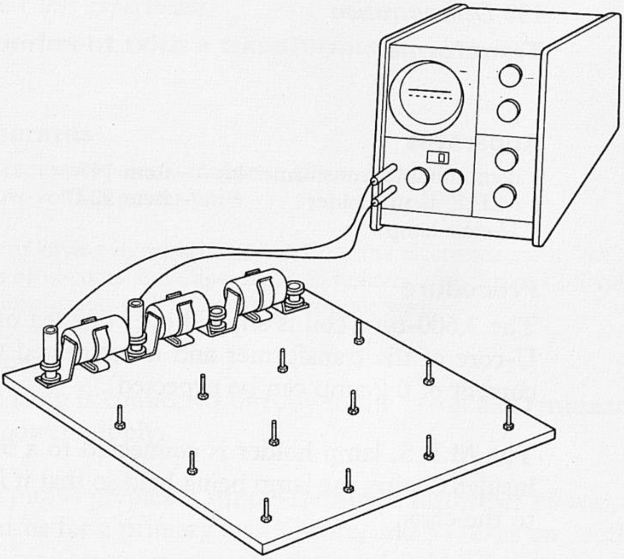
Procedure

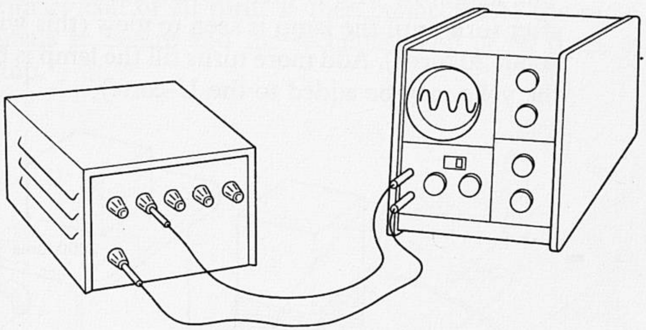
Fix the U2 cells in the circuit boards. Set up the class oscilloscopes with the gain at 0·5, the time-base off and the a.c.–d.c. switch on d.c. Adjust the focus and brightness controls to give a clear spot. Pupils should be warned not to have the spot unnecessarily bright, to avoid damage to the tube.

Connect across one of the cells to the input of the oscilloscope. Adjust the gain so that the deflection is one division on the graticule. Put the voltmeter in parallel with the oscilloscope across the cell.

Then connect across two cells, then across three. The leads to the oscilloscope should then be *reversed* to show the deflection across one, two and three cells in the opposite direction. The C.R.O. will then be calibrated as a voltmeter.

Disconnect the cells and connect to the input of the oscilloscope the 2-volt output of the transformer. Then apply the 4-volt and then the 6-volt output from the transformer. The time-base can then be switched on (using range 2) to show the trace spread out.





130 *Demonstration*

Transformer

Apparatus

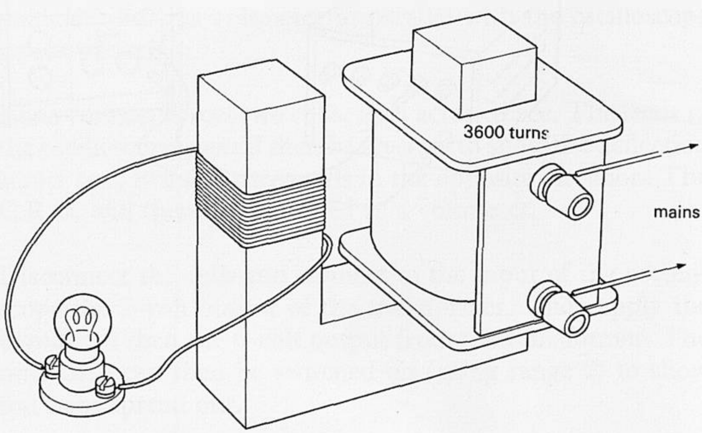
1 demountable transformer kit – item 147
1 M.E.S. lamp holder – item 92T
1 $1\frac{1}{2}$-volt lamp

Procedure

The 3,600-turn coil is slipped over one leg of the laminated U-core of the transformer and is connected to the mains (a current of 0·2 amp can be expected).

The M.E.S. lamp holder is connected to a 5-yard length of insulated wire, the lamp being held so that it is clearly visible to the class.

The length of wire is then wound round the other leg turn after turn until the lamp is seen to glow (this will occur after about 20 turns). Add more turns till the lamp is bright. (Then the yoke may be added to the U-core.)



131a *Class experiment*

Experiment with a transformer

Apparatus

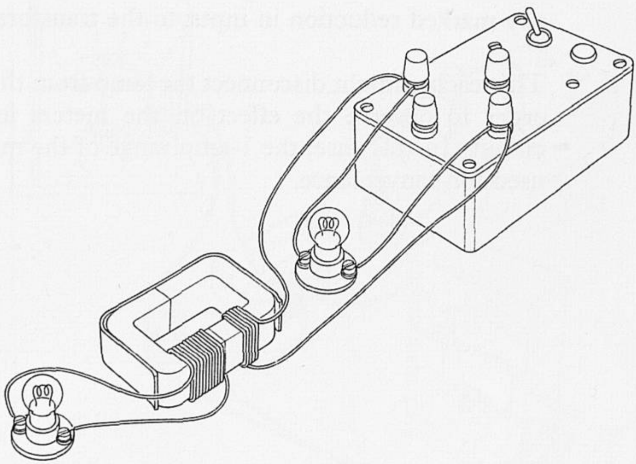
1 Westminster electromagnetic kit – item 92
16 low-voltage power units – item 104

The following items are needed from the electromagnetic kit: pairs of C-cores and clips, M.E.S. holders with lamps (2·5 volts, 0·3 amp), reels of PVC covered copper wire.

Procedure

The lamp is connected directly to the 1-volt a.c. terminals of the power supply.

The pupils prepare a simple step-up transformer by winding 20 turns for a primary on a C-core, and 50 turns on another. The two cores are put together and held by the clip. The primary coil of 20 turns is then connected to the same terminals as before and the secondary coil of 50 turns to the lamp.



131b *Demonstration*

The transformer

Apparatus

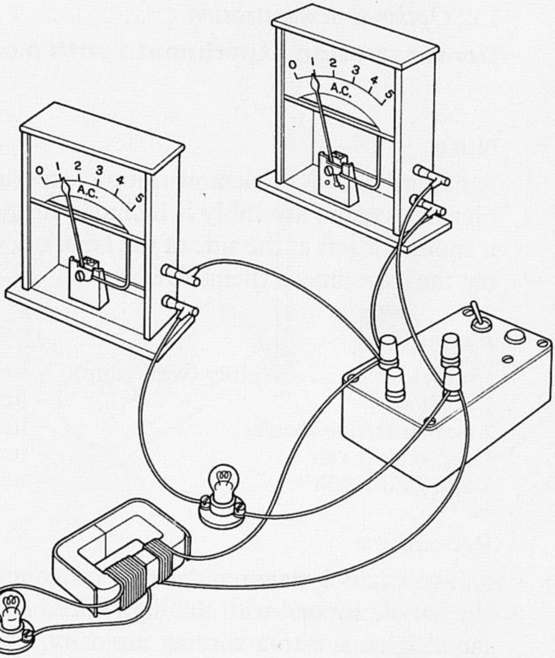
1 low-voltage power unit	– item 104
2 demonstration meters	– item 70
1 a.c. dial: 5 amp	– item 71/7
1 a.c. dial: 5 volt	– item 71/5
1 a.c. dial: 1 amp	– item 71/8
1 pair of C-cores and clip	– item 92G
2 M.E.S. holders	– item 92T
2 M.E.S. bulbs (2·5 volt, 0·3 amp)	– item 92R
1 reel PVC covered copper wire	– item 92K

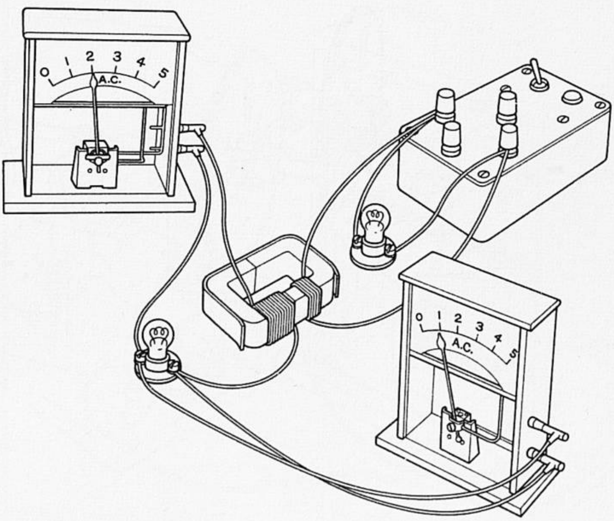
Procedure

The teacher sets up the same circuit that the pupils have done in Experiment 131a. He inserts the demonstration ammeter and voltmeter first in the primary circuit and then in the secondary circuit. The readings obtained are compared.

Although the primary current is less than 1 amp, it is advisable to use the 5-amp range of the ammeter. This avoids any marked reduction in input to the transformer.

The teacher might disconnect the lamp from the secondary in order to observe the effect on the meters in the primary circuit. In this case, the 1-amp range of the meter should be used for convenience.


0 1 2 3 4 5
A.C.
0 1 2 3 4 5
A.C.


0 1 2 3 4 5
A.C.
0 1 2 3 4 5
A.C.

132 *Optional demonstration*

Demonstration experiments with a.c.

Note

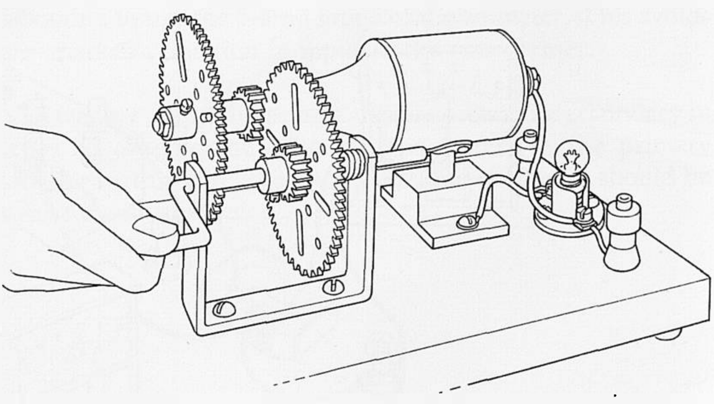
Although this is a demonstration experiment as only one bicycle dynamo assembly is included in the list of apparatus, it should be left at the side of the laboratory so that pupils can try the experiment themselves.

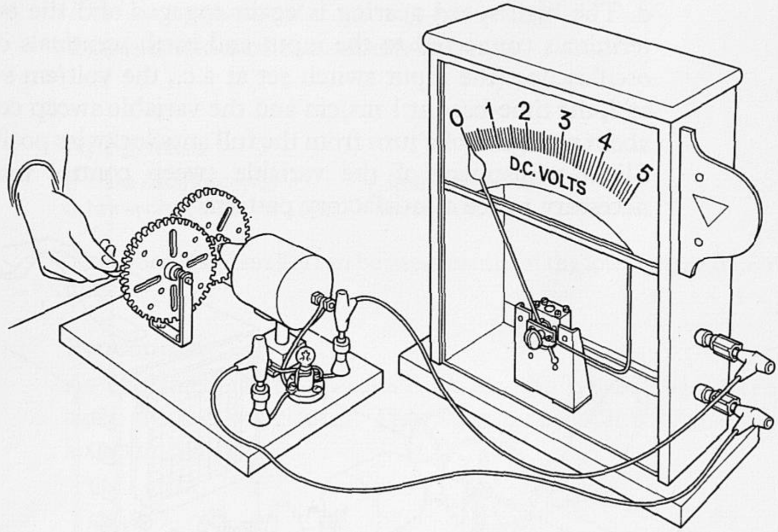
Apparatus

1 bicycle dynamo assembly (with lamp)	– item 103
1 oscilloscope	– item 64
2 demonstration meters	– item 70
1 d.c. dial: 5 volt	– item 71/3
1 a.c. dial: 5 volt	– item 71/5

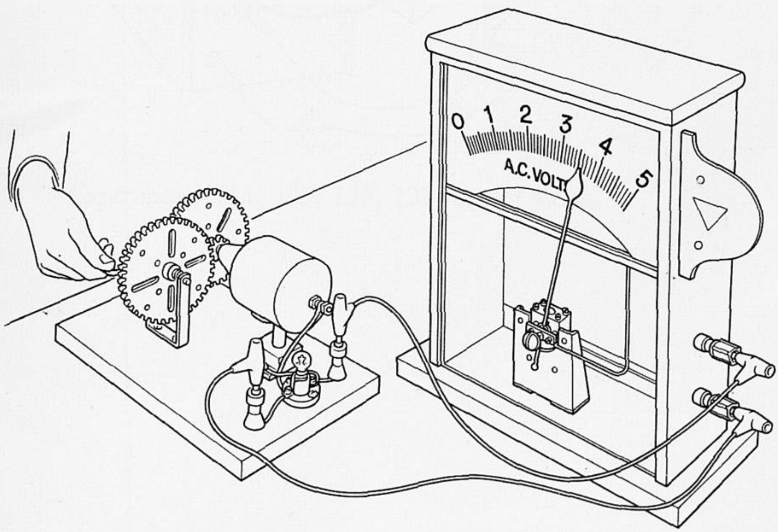
Procedure

a. The cycle dynamo and lamp are connected together and the handle rotated with the high-speed gearing engaged. The lamp lights – with a varying intensity.



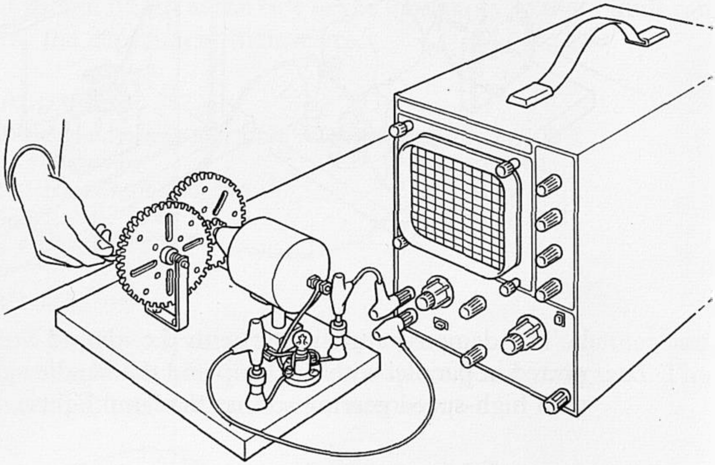


b. The demonstration meter with d.c. dial (5 volts) is connected in parallel with the lamp and the handle again rotated with high-speed gearing so that the lamp lights.



c. The demonstration meter with a.c. dial (5 volts) replaces the d.c. instrument. A reading of 2 to 4 volts will be obtained.

d. The high-speed gearing is again engaged and the output terminals connected to the input and earth terminals of the oscilloscope (the input switch set at a.c., the volt/cm switch at 2, the time-base at 1 ms/cm and the variable sweep control about an eighth of a turn from the full anticlockwise position). Slight adjustment of the variable sweep control may be necessary to see a satisfactory pattern.



133 *Class experiment*

Examination of a.c. wave-form

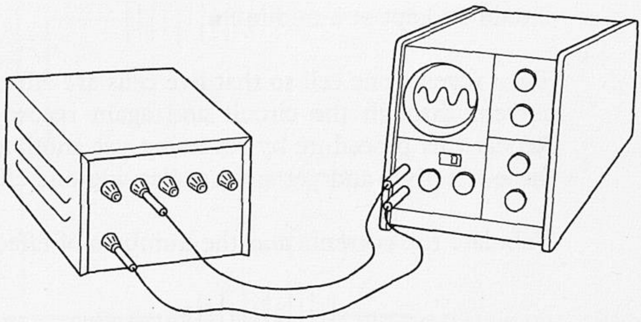
Apparatus

8 class oscilloscopes – item 158
8 low-voltage power units – item 104

Transformers (item 27) can be used instead of the low-voltage power units.

Procedure

As explained in the *Teachers' Guide*, the pupils should see again the a.c. wave-form. They should repeat for themselves Experiment 129a.



Experiments 134, 135, 136, 137 do not exist.

138 *Demonstration*

Introduction to voltmeter as a cell counter

Apparatus

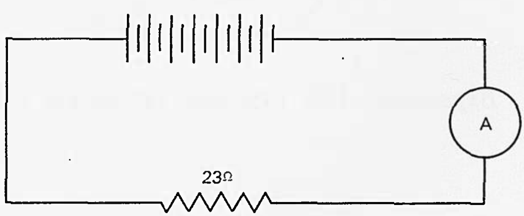
7 dry cells (3 circuit boards with 7 cells)	– item 52B
3 rheostats (10–15 ohms)	– item 541/1
2 demonstration meters	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 d.c. dial: 15 volt	– item 71/10

Procedure

a. Connect up a series circuit consisting of seven dry cells, the two rheostats and the ammeter, and record the current. Two rheostats are used in series in order to keep the current down. In any case, the time for which the current actually flows should be kept at a minimum.

Then reverse one cell so that five cells are effectively driving current through the circuit and again record the current. Repeat this procedure by reversing yet another cell (leaving three effective) and yet another (leaving one effective).

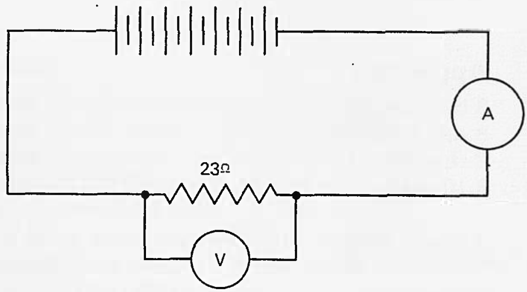
Tabulate the currents and the numbers of effective cells.



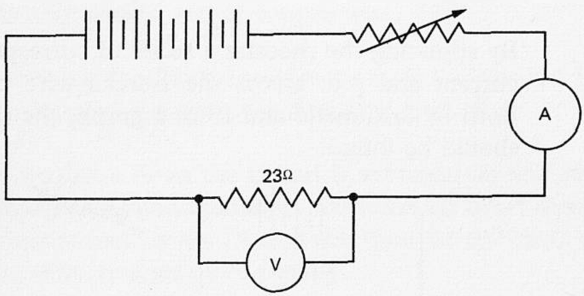
Note

If a school has the necessary apparatus, this experiment may be done as a class experiment instead of a demonstration.

b. Then add the voltmeter to the circuit so that it acts as a cell counter keeping track of what happens in the resistor.



Now change the current, either by reversing cells as before, or by adding a rheostat to the circuit.



Again corresponding values of the ammeter and voltmeter readings should be tabulated.

Notes

1. Dry cells, if used, should be fresh stock.

2. The time during which the current flows should be kept to the minimum.

139 *Class experiment*

Ohm's Law

Apparatus

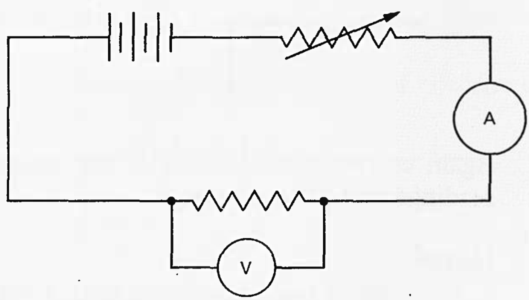
8 d.c. ammeters (1 amp)	– item 79
8 d.c. voltmeters (5 volt)	– item 80
8 rheostats (10–15 ohms)	– item 541/1
8 10-cm lengths Eureka wire (SWG 34)	– item 52P

The d.c. voltage supply for each group could be three dry cells (from Worcester circuit board) or three accumulators or 6-volt batteries or the appropriate number of cells from the 12-volt batteries.

Procedure

The pupils set up the circuit shown.

By adjusting the rheostat a series of corresponding values of current and p.d. across the Eureka wire can be obtained. Both by arithmetic and from a graph, the ratio p.d./current should be found.



140 *Optional class experiment (buffer)*

Temperature change and resistance

Apparatus

4 (or more) 12-volt batteries	– item 176
8 rheostats (10–15 ohms)	– item 541/1
8 aluminium containers	– item 76
8 d.c. ammeters (0–5 amp)	– item 178
8 d.c. voltmeters (0–12 volt)	– item 179

Also required are 8 coils of copper wire, each made from 1 metre of SWG 32 enamelled copper wire.

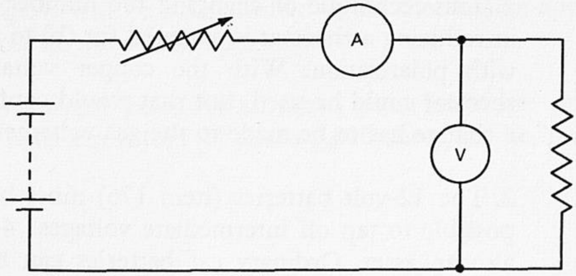
Procedure

a. The pupils set up a simple series circuit with long leads to the loosely wound coil of copper wire.

The rheostat is adjusted to give a current of about 4·5 amps in the coil and the circuit is then switched off.

After a minute or so the circuit is switched on and readings of the ammeter and voltmeter taken several times during the next half-minute or so. During this time the coil heats up and the current changes quite rapidly.

b. The experiment is repeated with the coil of copper wire suspended in water in the container. The water should be kept very well stirred – and care should be taken to avoid short circuiting the coil.



141 *Optional demonstration (buffer)*

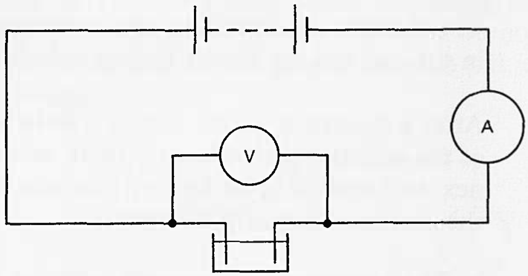
Relationship between volts and amps for electrolytes

Apparatus

1 12-volt battery	– item 176
2 demonstration meters	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 d.c. dial: 15 volt	– item 71/10
1 copper voltameter	– item 153
1 Worcester gas voltameter kit	– item 54

Procedure

a. The copper voltameter is connected into a simple series circuit as shown. The voltage/current relationship is determined by connecting 1, then 2, 3, 4, 5, 6 cells across the voltameter. A graph of voltage against current is drawn.



b. The same procedure is adopted using the gas voltameter.

Notes

1. This technique of changing the number of cells without introducing a rheostat is essential for (b) to avoid difficulties with polarization. With the copper voltameter in (a), a rheostat could be used, but that would confuse pupils when a change has to be made to the gas voltameter.

2. The 12-volt batteries (item 176) must be such that it is possible to tap off intermediate voltages: 4-mm sockets are also an asset. Ordinary car batteries can be used, but the latest type is such that it is not easy to take off intermediate voltages. Some manufacturers, however, are supplying such batteries adapted for school use, and these are recommended.

142 *Demonstration*

Voltage/current relationship for a gas

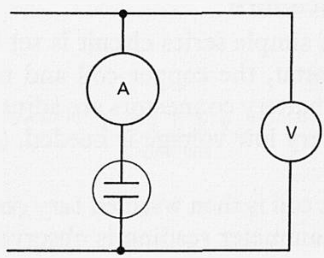
Apparatus

1 neon lamp (240 volt, 5 watt)	– item 66
1 lamp holder (B.C.) on base	– item 162
1 H.T. power supply	– item 15
2 demonstration meters	– item 70
1 d.c. dial: 300 volt	– item 71/11
1 d.c. dial: 100 mA	– item 71/12

Procedure

Set up a series circuit consisting of the H.T. supply, the neon lamp and the 100-mA meter. Connect the voltmeter across the lamp and 100–mA meter.

Apply increasing voltages from 0 to 240 volts and record both the current and the voltage.



Notes

1. The striking potential for a neon lamp is about 170 volts. The glow will be extinguished when the voltage applied is reduced to about 150 volts.

2. To prevent excessive currents, neon lamps are provided with ballast resistors (of about 2,000 ohms) in the bases.

143 *Optional class experiment*

The effect of temperature changes on conductivity

Note

These class experiments – and the demonstrations that follow (144, 145, 146) – show how various materials change their conductivity with change of temperature. The class experiments suggested here are intended as 'open' investigations: they present technical difficulties which a pupil must surmount. They should be optional, except for fast groups.

Apparatus

4 (or more) 12-volt batteries	– item 176
8 coils bare copper wire (1 metre, SWG 32)	– item 2B
8 coils bare Eureka wire (1 metre, SWG 28)	– item 98
8 d.c. ammeters (0–1 amp)	– item 79
8 test tubes containing small quantities of paraffin-wax	

Procedure

a. A simple series circuit is set up with a voltage supply, the rheostat, the copper coil and the ammeter. The rheostat or the battery connectors are adjusted until about 0·8 amp flows. A very low voltage is needed. (See circuit opposite)

The coil is then warmed *very gently* in a low Bunsen flame and the ammeter reading is observed.

The experiment can be extended by immersing the coil in a mixture of ice and salt – or it can be put in some solid CO_2 – but the high probability of shorting out some of the coils is likely to mask the true current change.

b. The copper coil is replaced by the coil of Eureka wire and the experiment is repeated. A greater e.m.f. will be necessary.

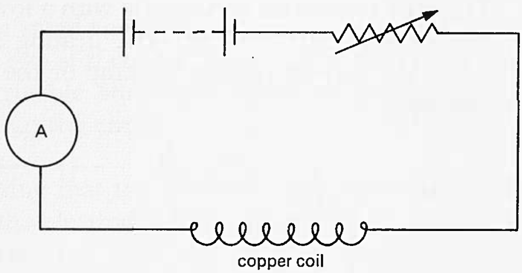
c. A thermistor (item 132N) can also be used and should replace the copper coil and be gently warmed.

d. A block of salt can be tried. It is put in a crucible, into which two stout pieces of copper wire dip. It can then be gently heated.

e. Two stout pieces of copper wire are embedded into the paraffin-wax in the test tube so that they do not touch. These pieces of wire are then connected into the circuit in place of the Eureka coil. The tube is then heated gently and the current observed carefully. (The paraffin-wax fails to pass a current even when melted.)

f. A rod of glass can be tried. Two or three turns of stout copper wire are wound round three or four inches of glass rod and connected into the circuit. The rod is gently heated and nothing happens. It does not appear to conduct.

The above class experiments all involve gentle heating. The demonstrations that follow (Experiments 144, 145, 146) take the investigation to higher temperatures.



144 *Optional demonstration (buffer)*

The effect of heat on a thermistor

Apparatus

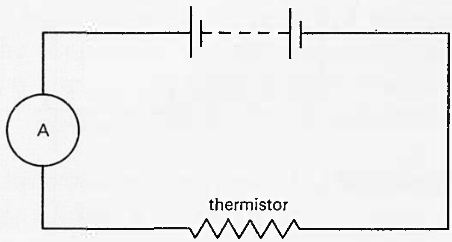
1 12-volt battery	– item 176
1 demonstration meter	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 thermistor	– item 132N

A suitable thermistor is a Radiospares type TH3 with a cold resistance of 400 ohms and a hot resistance of 28 ohms.

Procedure

When the thermistor is cold, the current will not be detectable with the meter (being of the order of 25 mA).

Heat the thermistor *very* gently with a low bunsen flame and the current starts to rise. The heating should be stopped when the current reaches 0·3 amp or the thermistor may be damaged.



145 *Optional demonstration (buffer)*

The effect of heat on common salt and paraffin-wax

Apparatus

1 12-volt battery	– item 176
1 demonstration meter	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 rheostat (10–15 ohms)	– item 541/1
1 small crucible	
1 pipe-clay triangle	
1 tripod	– item 511
1 Bunsen burner	– item 508

Also required are common salt and paraffin-wax.

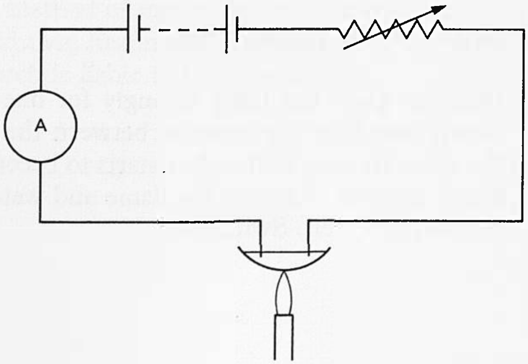
Procedure

a. Place a small amount of salt in the bottom of the crucible. Support two stiff copper wires so that they reach the bottom of the crucible and make electrical contact with the salt. Connect up the circuit.

After noting that the solid salt does not conduct electricity, remove the electrodes from the salt (they conduct away too much heat) and heat the crucible strongly until the salt melts.

Replace the electrodes and adjust the rheostat to show a current of about 1 amp. Remove the burner and allow the salt to cool: current rapidly falls to zero.

b. Repeat the experiment using paraffin-wax instead of salt. It will be found that paraffin wax fails to pass a current even when melted.



146 *Optional demonstration*

Current in a heated glass rod

Apparatus

1 demonstration meter – item 70
1 a.c. dial: 5 amps – item 71/7
2 8-in lengths bare copper wire (SWG 14, approx)
1 15 cm length soft soda glass rod
2 retort stands – items 503–504
2 bosses – item 505
one radiant heater (item 58 C) for use as a limiting resistor.

Procedure

Make two closely fitting coils of three or four turns of the stout copper wire on the glass rod at points about $1\frac{1}{2}$ to 2 in apart. Bend the lengths of wire at right angles to the rod and terminate them in two well-insulated 4 mm plugs. Support this assembly in two bosses attached to two retort stands, the insulation of the plugs being lightly clasped in the bosses, so that the electrodes are insulated from the stands.

The rod should be at such a height above the bench that the flame from a Bunsen can be used to heat it. It is advisable to cover the bench-top immediately below the rod with a piece of asbestos.

Connect the two electrodes into a series circuit consisting of the radiant heater (which serves as a limiting resistor) and the 240-volt a.c. mains supply. Great care with this circuit is needed and 4 mm female socket plugs should be used to make the connections to the electrodes. Both retort stands and the Bunsen should be connected to earth. An a.c. ammeter (0–5 amp) may be included in the circuit.

Switch on. No current flows.

Heat the glass rod fairly strongly for one or two minutes, closely watching the contacts between the copper coils and the glass. As soon as the glass starts to become self-luminous, it will conduct. Remove the flame and watch the rod slowly redden, and melt. Switch off.

147 *Optional demonstration*

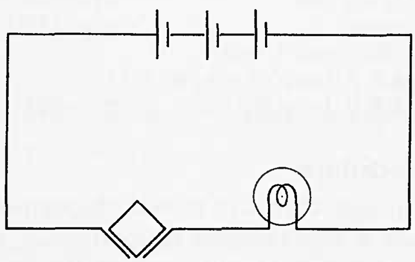
Conductivity of germanium

Apparatus

1 circuit board with 3 cells	– item 52
1 6-volt 0·4-amp M.E.S. lamp	
1 M.E.S. lamp holder	– item 52D
1 mounted slice of germanium	– item 132P
1 25-watt soldering iron or beaker of boiling water	

Procedure

The mounted slice is connected in series with the three cells and the lamp. The lamp does not light. The slice is then heated by touching it with a small soldering iron (25 watt) or by immersing in boiling water. The lamp then lights.



Notes

1. The germanium slice (n type) is 5 mm square, 1–2 mm thick and has leads soldered as shown so that the resistance cold is of the order of 300Ω.

2. With some specimens the number of cells may need to be increased to give a good effect.

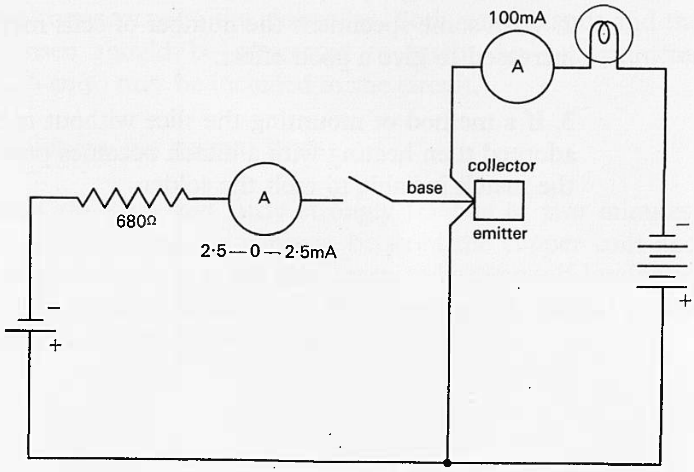
3. If a method of mounting the slice without using solder is adopted then heating with a match becomes possible. If not, the match is liable to melt the solder.

148 *Demonstration*
The transistor

Purpose
The object of this demonstration is to let the pupils see transistors in action. In the example chosen, a minute current in the base-emitter circuit is used to control a current about thirty times larger in the collector-emitter circuit.

Apparatus
1 transistor (O C 81)	– item 132M
2 demonstration meters	– item 70
1 d.c. dial: 2·5–0–2·5 mA	– item 71/4
1 d.c. dial: 100 mA	– item 71/12
1 12-volt battery	– item 176
1 U2 dry cell	– item 52B
1 resistor (680 ohms, 1 watt)	– item 132G
1 M.E.S. lamp (6 volt, 60 mA)	
1 M.E.S. lamp holder	– item 92T

Procedure
It is convenient to mount the transistor on a base-board in such a way that the application of a small potential to the base-emitter circuit controls the current through a 6-volt, 60-mA M.E.S. lamp in the emitter-collector circuit. If an O C 81 transistor is used, a 680-ohm radio type resistor is needed to limit the current in the base-emitter circuit, as shown.



The collector-emitter circuit is completed by connecting the lamp, a 6-volt supply (from the 12-volt battery) – care must be taken to get the correct polarity – and the demonstration meter (reading to 100 mA) in series. The lamp will not light and the ammeter indicates only a very small current (of the order of 1/20 mA). To show how small the current, it may temporarily be helpful to put the 2·5–0–2·5 mA dial in the meter.

The base-emitter circuit consists of the dry cell and the 680-ohm limiting resistor. The circuit is completed by plugging in the demonstration meter with the 2·5–0–2·5 mA dial.

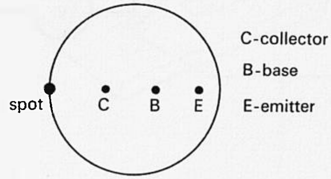
The lamp in the former circuit is seen to light with the meter in series with it indicating some 60 mA. Meanwhile the current in the base-emitter circuit will be seen to be about 2 mA.

Note

If a school has sufficient meters, this is an experiment pupils might all do for themselves.

Base connections

The base connections for the OC 81 are:



149a *Class experiment*

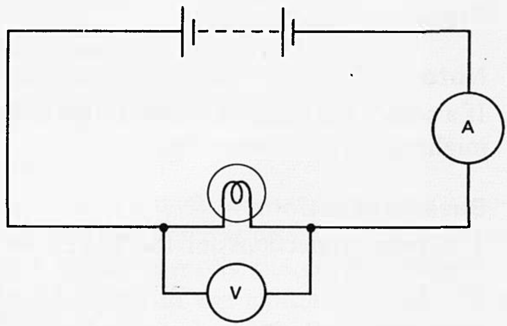
Measurement of power transferred with a lamp

Apparatus

4 (or more) 12-volt batteries	– item 176
16 S.B.C. lamps (12-volt, 6 watt)	– item 177
16 lamp holders (S.B.C.) on base	– item 74
16 d.c. ammeters (0–1 amp)	– item 79
16 d.c. voltmeters (0–15 volt)	– item 179

Procedure

Pupils should connect up the circuit shown and take readings of the ammeter and voltmeter and deduce the number of joules transferred each second from electrical energy to heat and radiation.



149b *Class experiment*

Measurement of power transferred with a motor

Apparatus

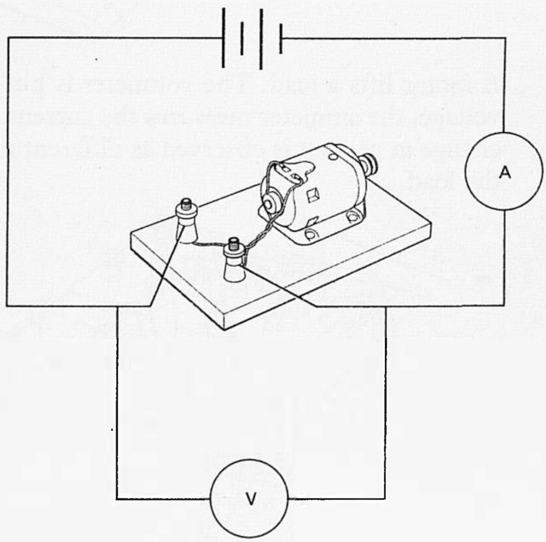
4 (or more) 12-volt batteries	– item 176
16 motor/generators	– item 155
16 d.c. ammeters (0–1 amp)	– item 79
16 d.c. voltmeters (0–5 volt)	– item 80

If only 8 motor/generators (item 9A) are available, pupils should work in groups of four.

Procedure

Pupils should then do a similar experiment to the previous one (149a) using an electric motor in place of a lamp.

The circuit is set up as shown.

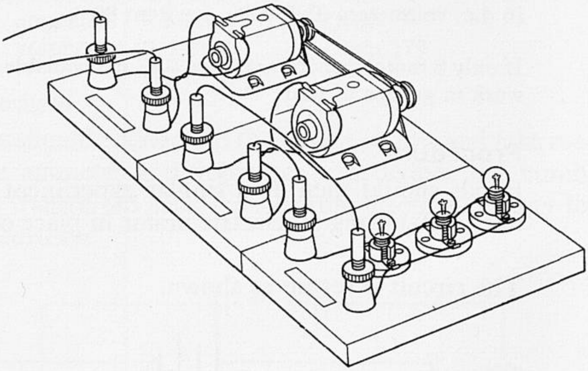


Only 4 volts are necessary to drive the motors. From the readings of the ammeter and voltmeter, the number of joules transferred each second is deduced.

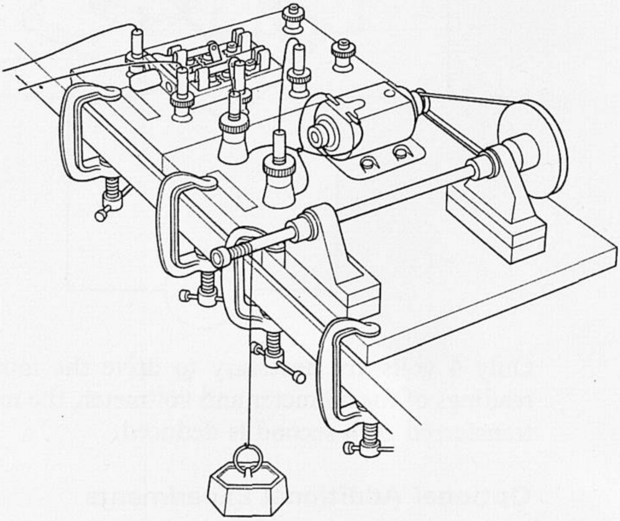
Optional Additional Experiments

The energy conversions kit (item 9) provides scope for some optional experiments on measuring power. The following are suggested experiments.

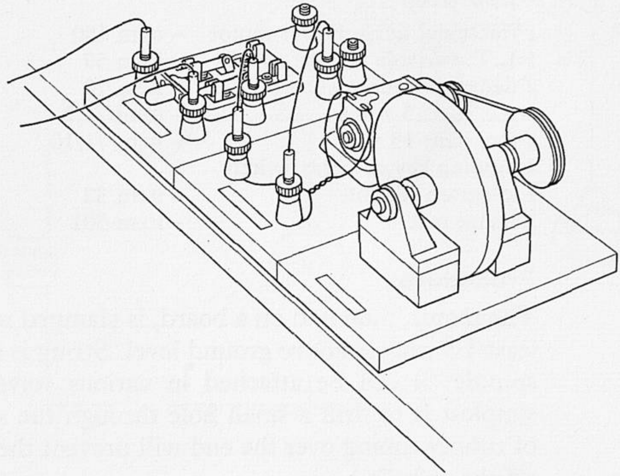
A motor drives a generator which lights one, two, or three bulbs in the lamp unit. The voltmeter is put across the voltage supply and the ammeter measures the current to the motor. The effect of changing the load is noticed. The voltmeter is then put across the generator and the current to the lamps is measured. The input power and the output power are compared.



A motor lifts a load. The voltmeter is put across the supply voltage, the ammeter measures the current to the motor. The change in current is observed as different masses are used for the load.



A motor drives a flywheel. Again a voltmeter and ammeter are used. The high current is observed when the flywheel is being accelerated, it falls to a steady value once the flywheel is moving at a constant speed.



150 *Demonstration*

Power of a fractional horse-power motor

Apparatus

1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
2 demonstration meters	– item 70
1 d.c. dial: 5 amps	– item 71/2
1 d.c. dial: 15 volts	– item 71/10
1 tapping key or press switch	
1 kilogram weight	– item 32
1 metre rule	– item 501

Procedure

The motor, mounted on a board, is clamped to a table-top at least 1·5 metres above ground level. String is attached to the spindle (it can be attached in various ways: perhaps the simplest is to drill a small hole through the spindle. A $\frac{1}{4}$-in of rubber tubing over the end will prevent the string coming off the spindle.)

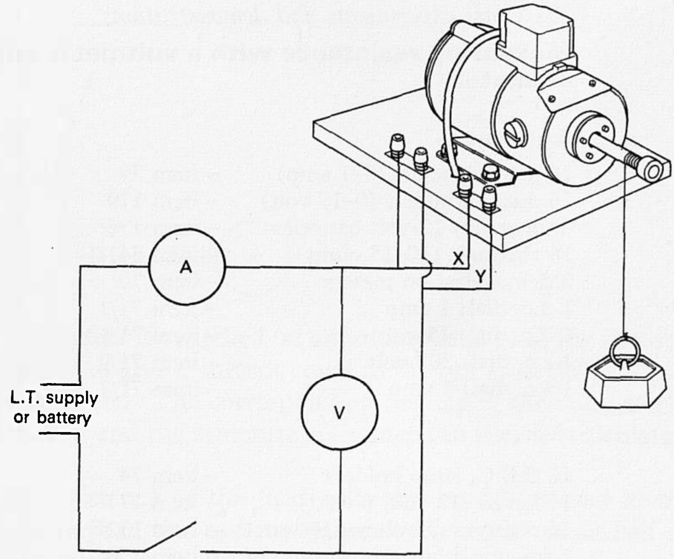
The circuit is set up as shown with the field coil and armature in parallel.

The supply is adjusted to about 4–5 volts. A kilogram mass is attached to the lower end of the string. On pressing the switch, the string winds up on the spindle and the mass is raised. It will rise a metre in 4 or 5 seconds.

It is important to select a voltage so that the mass rises without marked acceleration. If smaller masses are used, the L.T. supply voltage will have to be reduced so that the mass rises steadily.

Note

If a 100:1 worm gear is available, some teachers might like to attach it and then use the motor to lift a boy.


A
X
Y
L.T. supply
or battery
V

151 *Class experiments and demonstrations*

Measuring resistance with a voltmeter and an ammeter

Apparatus

16 d.c. ammeters (0–1 amp)	– item 79
16 d.c. voltmeters (0–15 volt)	– item 179
4 (or more) 12-volt batteries	– item 176
16 rheostats (10–15 ohms)	– item 541/1
2 demonstration meters	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 d.c. dial: 15 volt	– item 71/10
1 a.c. dial: 300 volt	– item 71/9
1 a.c. dial: 5 amp	– item 71/7

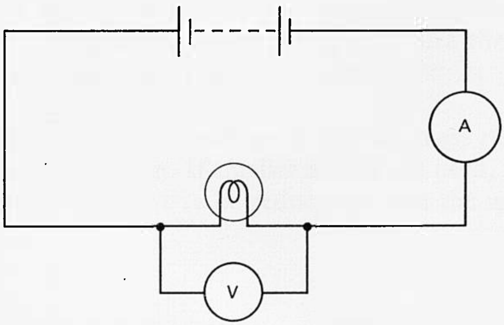
also:

16 S.B.C. lamp holders	– item 74
16 lamps (12 volt, 6 watt)	– item 177
16 resistors (15 ohms, 10 watt)	– item 132F
1 fractional horse-power motor	– item 150
4 radiant heaters	– item 58C

Procedure

a. *Class experiment: resistance of a lamp*

Pupils set up a circuit as shown. By taking readings of the ammeter and voltmeter, they can calculate the resistance of the lamp at its running temperature.

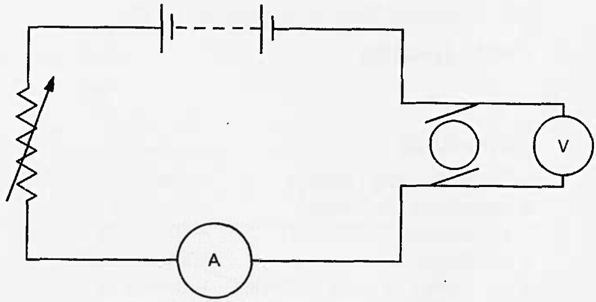


b. *Class experiment: resistance of radio type resistor*

With the radio resistor replacing the lamp in the circuit, the experiment is repeated and the resistance calculated.

c. *Demonstration: resistance of motor armature*

The armature has a resistance which is below 1 ohm. The circuit should therefore include a rheostat set to its maximum resistance in series with the armature.



The current is switched on and the resistance of the rheostat reduced to give a current equal to the full scale deflection of the ammeter. The corresponding reading of the voltmeter is recorded and the armature resistance can then be calculated.

The resistance of the field coils can be determined in the same way: in this case an ammeter reading of about half an ampere will be found suitable.

d. *Class experiment: heating element of an electric fire*
No rheostat is necessary in this case and the same procedure as in (a) is suitable. The current reading is of the order of 0·1 amp.

After this has been done as a class experiment, the teacher should measure the resistance of the element on 240 volts, a.c. The demonstration meters can be used to measure the current (about 2 amps) and the voltage. (The temperature coefficient of nichrome wire is fairly small.)

e. *Optional class experiment: resistance of voltmeter*
This should be set as a problem to the pupils without giving any instruction.

f. *Optional class experiment: modifying a milliammeter for use as a voltmeter or ammeter*
Where a class has discussed this possibility, pupils can modify the basic meters used by putting them with improvised shunt resistors and series resistors and checking the readings.

152 *Optional class experiment*

Fault finding

Apparatus

8 'fault-finding' boards	– see below
8 ammeters (0–1 amp)	– item 79
8 voltmeters (0–15 volt)	– item 179
8 rheostats	– item 541/1
4 (or more) 12-volt batteries	– item 176

Fault-finding boards

These should be home-made as follows: a board about 2 ft long and 4 in wide carries on one side two 18-in lengths of resistance wire (for example, Eureka SWG 28). The resistance of each wire should not be less than 3 ohms.

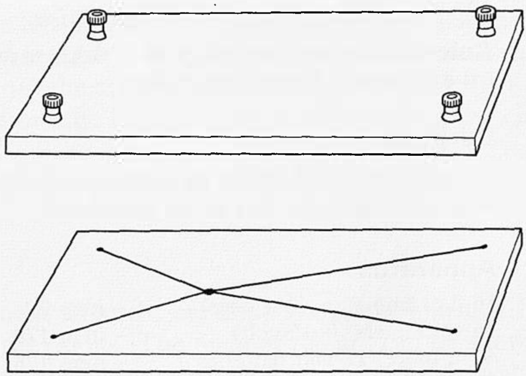
Each of the wires terminates in terminals providing electrical access from the other side of the board.

Two-thirds of the way along the wires, a soldered link is provided. This arrangement simulates a short circuit in a pair of telephone wires.

Procedure

The pupils are to measure the resistance of the wires from each of the two ends and hence to determine the position of the fault. The method used is that of Experiment 151 using an ammeter and voltmeter.

The wires have a resistance of about 3 ohms (end to end) and the 'fault' is so placed that provided only one cell is used, the maximum current is 1 amp.



153 *Class experiment with demonstration*

Calculation and testing of a resistance to make an arc work from the mains

Purpose

To get the pupils both to work out and try a practical case where a resistance has to be calculated.

Apparatus

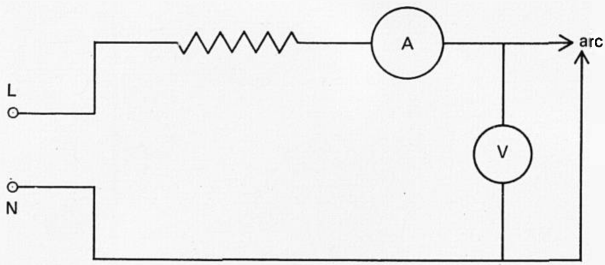
16 d.c. ammeters (0–1 amp)	– item 79
16 voltmeters (0–15 volt)	– item 179
4 (or more) 12-volt batteries	– item 176
1 reel of nichrome wire (SWG 24)	
2 demonstration meters	– item 70
1 a.c. dial: 300 volt	– item 71/9
1 a.c. dial: 5 amp	– item 71/7
1 arc	– see below
2 radiant heaters	– item 58C

Procedure

A very small arc will run with a 1 cm separation between carbons at 4 to 5 amps. There will be about 50 volts across the arc, but a resistor in series is necessary for stability. (The striking voltage is in fact about 70 volts, but the arc will then run on 50 volts.)

The problem put to the pupils is to calculate the resistance that must be put in series with the arc to reduce the voltage across the arc to 50–70 volts when operated from the a.c. mains.

They are provided with lengths of nichrome wire (SWG 24) and are asked to measure its resistance using an ammeter, voltmeter and 12-volt battery by the method described in Experiment 151. They then calculate the length of nichrome wire necessary for use with the arc.



It will be found that the length required is nearly the same as that used in a 1 kW electric fire element. The teacher should then set up the arc including such a heater element (radiant heaters from the Radiation kit can be used) in the circuit.

The ammeter should read to 5 amps a.c., the voltmeter to 300 volts a.c.

Notes

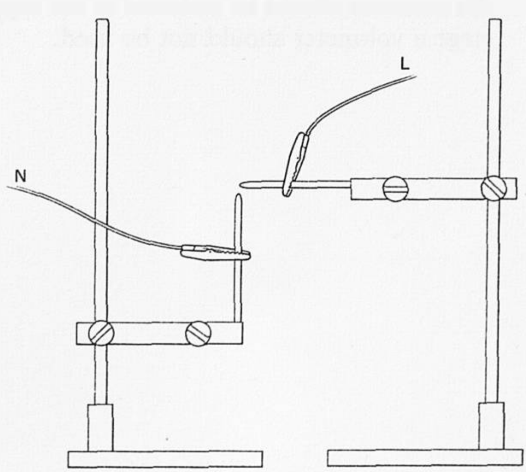
1. The light from the arc lamp should be shielded from the eyes of the pupils. The form of the arc can be shown to the pupils by projecting a real image of it on to the wall using a suitable convex lens.

2. An improvised arc is better than a specially made one. Such an arc can be made from two wooden burette stands, and two arc carbons. Crocodile clips should be used to provide electrical connection and should be attached to the carbon above the wooden clamp.

The carbon connected to the neutral terminal of the mains should, of course, be the one which is adjusted.

3. It is possible to use pencil leads in place of arc carbon. (These will burn dramatically on first switching on since they have a high wax content.) These pencil leads will get red-hot in use, but make a fine little arc, running at 2 to 4 amps according to the resistor.

4. Teachers are warned to be particularly careful in this experiment because of the dangerous voltages involved.



154a *Class experiment*

D.C. model power line

Apparatus

16 power line terminal rods	– item 99
16 retort stands	– items 503–504
16 bosses	– item 505
16 lamp holders (S.B.C.) on base	– item 74
16 S.B.C. lamps (12-volt, 24-watt)	– item 72
16 4-ft lengths bare Eureka wire (SWG 28)	– item 98
4 (or more) 12-volt batteries	– item 176
8 ammeters (0–5 amp)	– item 178

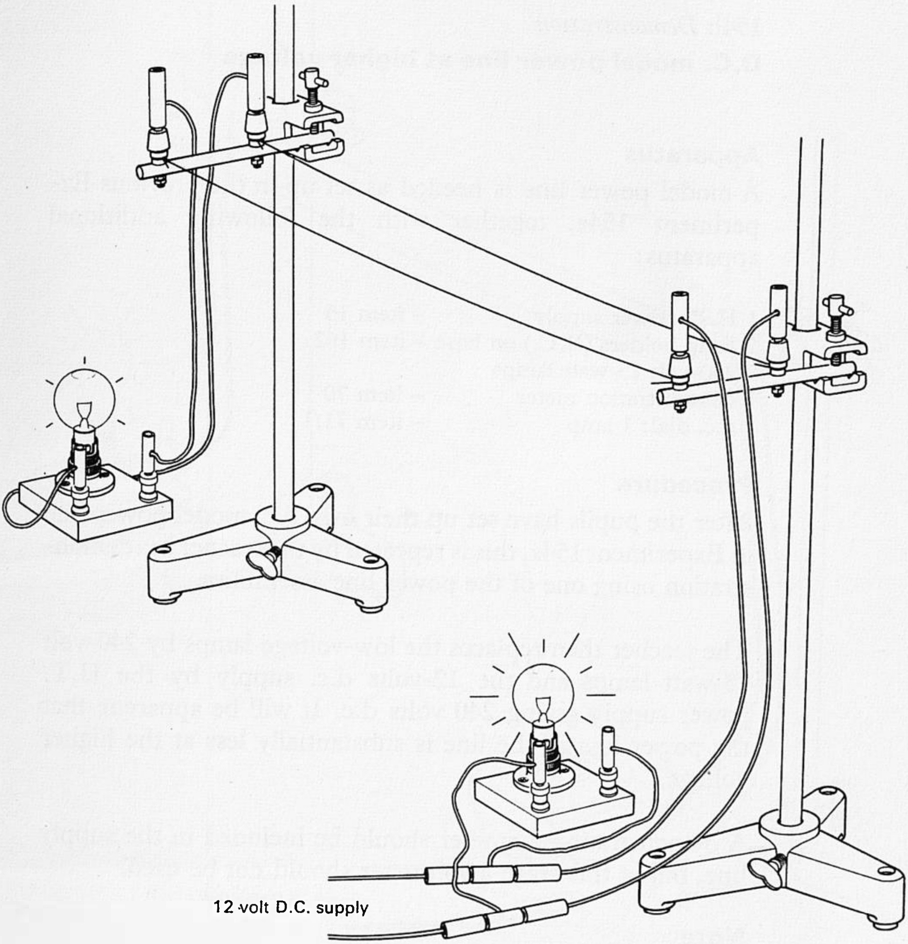
Procedure

For each group, two of the dowel rods, which form the power line terminal rods, are held horizontally in two bosses at a height of about 1 ft above the bench and 4 ft apart. Two lengths of resistance wire (Eureka SWG 28) are stretched between the terminals to form the power line.

One of the two lamp holders with a 12 volt, 24 watt S.B.C. lamp is connected straight to the 12-volt d.c. supply at the 'power station' end. The supply is also connected direct to one of the terminal rods.

The second lamp is connected to the other end of the power line where it represents the 'village'. With the values given, the 'village' lamp will just glow, in contrast with the fully-lit pilot lamp at the 'power station'. If a second lamp is added in parallel to the single 'village' lamp, neither will glow.

An ammeter should be included in the supply line, but at this stage a voltmeter should not be used.


12 volt D.C. supply

154b *Demonstration*

D.C. model power line at higher voltage

Apparatus

A model power line is needed as set up in the previous Experiment 154a, together with the following additional apparatus:

1 H.T. power supply	– item 15
2 lamp holders (B.C.) on base	– item 162
2 240-volt 15-watt lamps	
1 demonstration meter	– item 70
1 d.c. dial: 1 amp	– item 71/1

Procedure

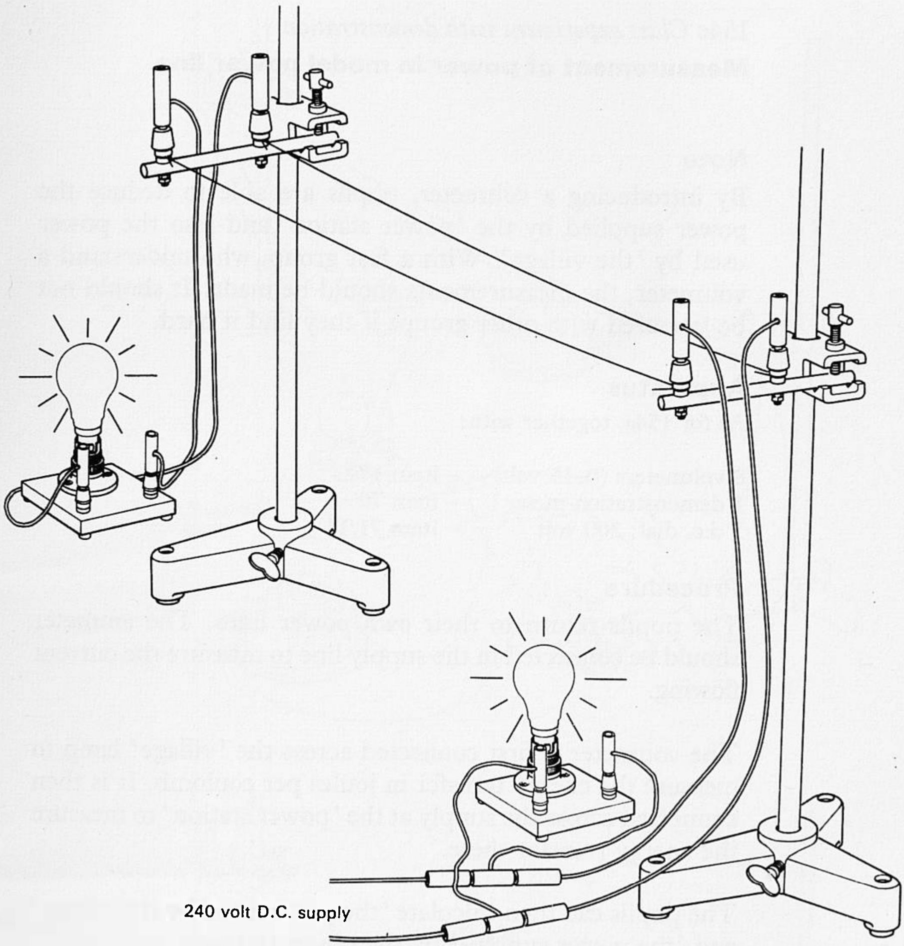
After the pupils have set up their own d.c. model power line in Experiment 154a, this is repeated by the teacher as a demonstration using one of the power line assemblies.

The teacher then replaces the low-voltage lamps by 240-volt 15-watt lamps and the 12-volts d.c. supply by the H.T. power supply giving 240 volts d.c. It will be apparent that the power loss in the line is substantially less at the higher voltage.

A demonstration ammeter should be included in the supply line, but at this stage a voltmeter should not be used.

Note

Teachers are warned to be careful in this experiment because of the high voltage involved.


240 volt D.C. supply

154c *Class experiment with demonstration*

Measurement of power in model power line

Note

By introducing a voltmeter, pupils are able to deduce the power supplied by the 'power station' and also the power used by 'the village'. With a fast group, who understand a voltmeter, the measurements should be made. It should not be laboured with other groups if they find it hard.

Apparatus

As for 154a, together with:

8 voltmeters (0–15 volt)	– item 179
1 demonstration meter	– item 70
1 d.c. dial: 300 volt	– item 71/11

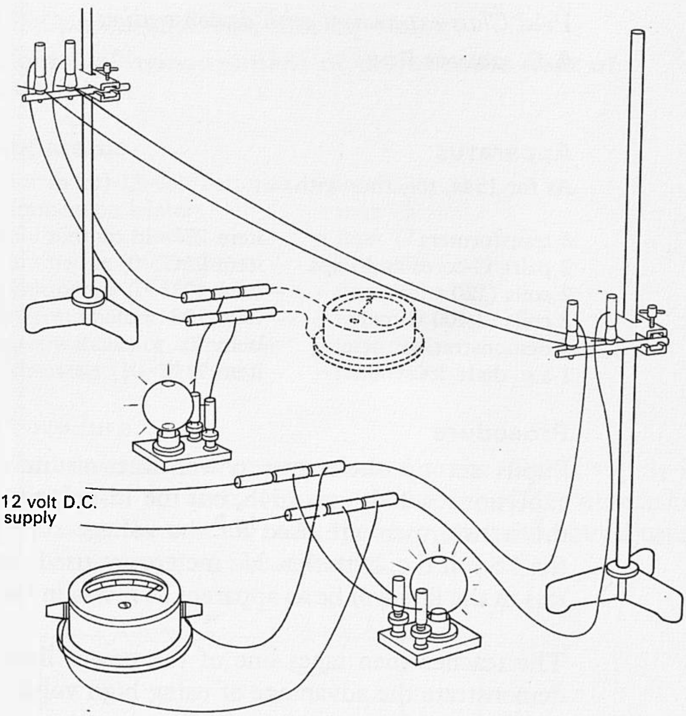
Procedure

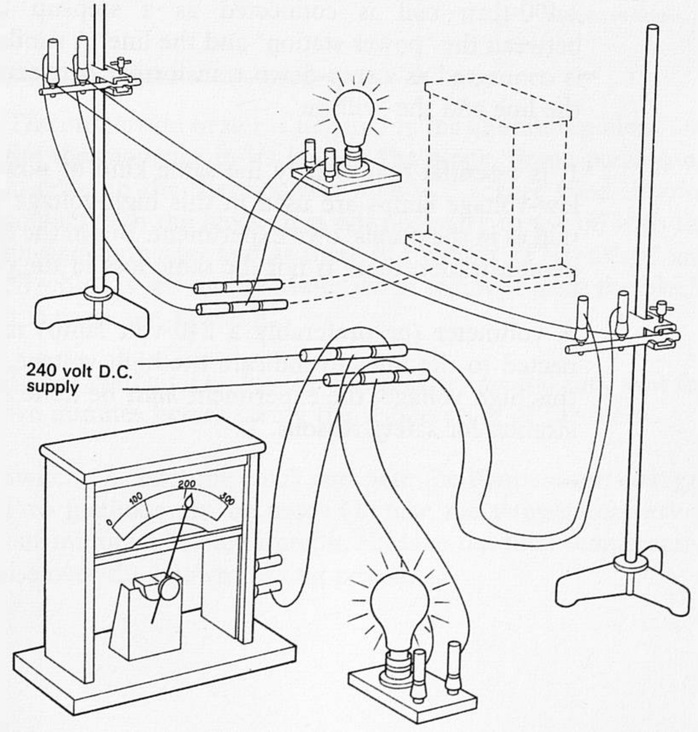
The pupils return to their own power lines. The ammeter should be connected in the supply line to measure the current flowing.

The voltmeter is first connected across the 'village' lamp to measure the energy transfer in joules per coulomb. It is then connected across the supply at the 'power station' to measure the energy transfer there.

The pupils can then calculate 'the power used by the village' and 'the power supplied by the power station'.

The teacher then returns to his demonstration power line at the higher voltage. Similar measurements are made with a voltmeter and ammeter. Care must be taken by the teacher because of the high voltage involved.


12 volt D.C.
supply


240 volt D.C.
supply
100
200
300

154d *Class experiment with demonstration*

A.C. power line

Apparatus

As for 154a, together with:

8 transformers	– item 27
2 pairs C-cores and clips	– item 92G
2 coils (120 turns)	– item 127
2 coils (2,400 turns)	– item 128
1 demonstration meter	– item 70
1 a.c. dial: 300 volt	– item 71/9

Procedure

Pupils set up their own power lines as in the previous experiments, 154a and 154b, but the 12-volt a.c. terminals of the transformers are used for the voltage supply instead of the 12-volt d.c. batteries. No meters are used, but the power loss in the line will be as apparent as it was in the d.c. case.

The teacher then takes one of the power lines in order to demonstrate the advantage of using high voltage.

A complete C-core and clip with a 120-turn coil and a 2,400-turn coil is connected as a step-up transformer between the 'power station' and the line. A similar assembly is connected as a step-down transformer between the end of the line and the 'village'.

It is essential that exactly the same kind of power line and low-voltage lamps are used in this high-voltage demonstration as in the pupils' own experiment. But in the high-voltage demonstration there is not the same loss in the power line.

A voltmeter (or preferably a 240-volt lamp) may be connected to the lines to indicate the high voltage. Because of this high voltage, the experiment *must* be done as a demonstration for safety reasons.

155 *Optional additional class experiment*

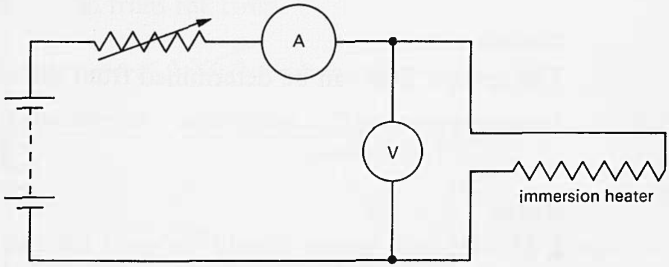
Electrical measurement of the specific heat of aluminium

Apparatus

4 (or more) 12-volt batteries	– item 176
8 immersion heaters	– item 75
8 aluminium blocks	– item 77
8 ammeters (0–5 amp)	– item 178
8 voltmeters (0–15 volt)	– item 179
8 thermometers	– item 542
8 stopwatches or stopclocks	– item 507
8 rheostats (10–15 ohms)	– item 541/1

Procedure

The immersion heater is connected to the 12-volt supply in series with an ammeter and a rheostat. The immersion heaters are 12 volt, 60 watt, the rheostat should be adjusted to give a current of about 4 amps.



The immersion heater is inserted in the aluminium block and the thermometer in its hole in the block. Some paraffin-oil inserted in the thermometer hole will ensure good thermal contact with the block: it is not necessary to use oil with the immersion heater and as there is a danger of 'cracking' any oil which is left on the heater when removed from the block, it is wiser not to use it.

Before switching on for the actual experimental run, wait for five minutes before taking the temperature of the block.

Switch on, start the clock and note the temperature change. Two methods can be used: (1) take the temperature every half-minute and plot a graph, (2) take the total temperature rise over the known heating period.

In both cases, continue taking temperature after the supply is switched off. In a typical case, a p.d. across the heater gave a current through it of $3\frac{1}{2}$ amps. The temperature rose from 24·5° to 37·8°C in six minutes when the supply was turned off. The temperature continued to rise to a maximum of 40·1° C after $8\frac{1}{2}$ minutes.

This lag does not matter if graphical plotting is used. Take the slope of the straight plot of the graph. This gives a marginally better result than the total temperature rise method.

If the latter method is used, the full temperature rise must be recorded. The procedure becomes: switch on the current, starting the clock, having noted the temperature; switch off after an approximately 10 deg C rise, noting the time for which the heater was in operation; note the temperature after a further four minutes has elapsed.

Calculation

The specific heat can be determined from the relationship:

$$\frac{\text{Temperature rise (deg C)} \times \text{specific heat}}{\text{Time (seconds)}} = \frac{\text{Current (amps)} \times \text{P.D. (volts)}}{\text{J}}$$

Notes

1. Moving-coil meters should be used for this experiment when the smoothed d.c. supply from the 12-volt batteries is being used. The use of moving-coil instruments on unsmoothed d.c. supplies can lead to errors in the result of 20 per cent more.

2. If desired, the aluminium blocks may be lagged by enclosing them in foamed polystyrene.

156 *Optional additional demonstration*

Investigation of the light from a lamp

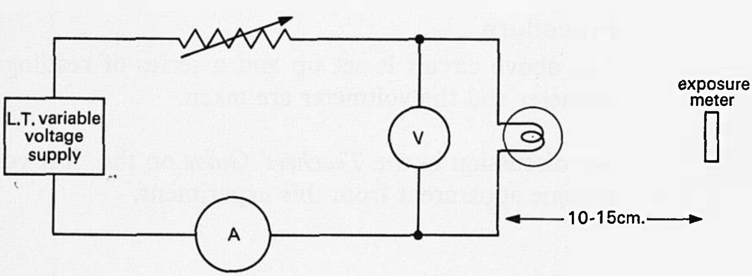
Apparatus

1 L.T. variable-voltage supply – item 59
1 S.B.C. lamp (12-volt, 24 watt) – item 72
1 S.B.C. lamp holder – item 74
1 rheostat (10–15 ohms) – item 541/1
2 demonstration meters – item 70
1 d.c. dial: 5 amp – item 71/2
1 d.c. dial: 15 volt – item 71/10
1 photograpic exposure meter

The lamp can be lit from the a.c. terminals of the L.T. variable-voltage supply and not the d.c., but in that case a.c. meters will be required.

Procedure

The circuit shown is set up with the exposure meter some 10–15 cm from the lamp.



Values of the light meter reading are noted for various currents through the lamp. The input powers should be changed from 10 to 30 watts (corresponding to a change of 7–14 volts). A plot of light meter readings against power input will give approximately a straight line, not passing through the origin.

Note

The investigation can be undertaken using a mains lamp. In this case the exposure meter is put a little farther away from the lamp. For a 100-watt lamp, a variac provides a suitable supply used with an a.c. meter giving 1 amp full scale deflection (or better 500 mA full scale deflection).

157 *Optional demonstration (buffer)*

Discussion of power wasted inside a battery

Apparatus

3 accumulators	
2 demonstration meters	– item 70
1 d.c. dial: 1 amp	– item 71/1
1 d.c. dial: 5 volt	– item 71/3
1 rheostat (10–15 ohms)	– item 541/1

Also required is a 1-metre length of Eureka wire SWG 28 (item 98).

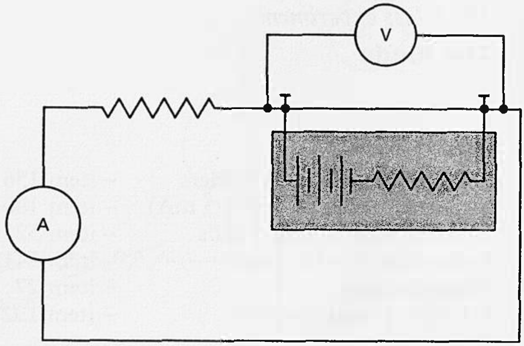
Preparation of the cell

The three accumulators (with negligible internal resistance) are enclosed in a suitable box. The terminals are connected to two external terminals on the box. The Eureka wire is coiled and put in series with the accumulators inside the box: this provides the 'internal resistance'.

Procedure

The above circuit is set up and a series of readings of the ammeter and the voltmeter are taken.

See discussion in the *Teachers' Guide* on the 'lost volts' that become appararent from this experiment.


V
A

158 *Class experiment*

The diode

Apparatus

8 diodes (EA 50) and holders	– item 156
8 galvanometers (3·5–0–3·5 mA)	– item 180
8 circuit boards with 3 cells	– item 52
8 rheostats (10–15 ohms)	– item 541/1
8 transformers	– item 27
8 1·5kΩ, ½-watt resistors	– item 132I

Procedure

The purpose of this experiment is to compare the current/voltage response of a simple resistor with that for a diode valve.

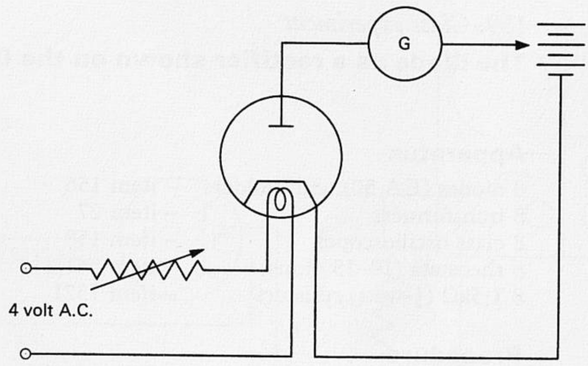
a. The voltage supply consists of the three 1·5-volt dry cells. Voltage is assessed by cell-counting. Connect up the 1,500 ohm resistor as shown and take a series of readings of current against, 3, 2, 1, 0, -1, -2, -3 cells and plot graph of current against number of cells.

b. Set up the EA 50 circuit as shown.

To obtain readings using the galvanometer recommended, the heater of the diode must be *under-run*. The rheostat is put in series with the 4-volt a.c. output of the transformer. Set the slider to a mid-position and connect up the circuit.

Adjust the voltage by moving the slider until almost a full-scale deflection is obtained on the galvanometer with the maximum number of cells connected across the valve. (Note: the slider position must be moved slowly as it is necessary for the temperature of the heater to stabilize for a steady reading on the galvanometer.) Do not touch the rheostat thereafter.

Take a series of readings of current against 3, 2, 1, 0, -1, -2, -3 cells, as in (a). Plot a graph of current against number of cells.


G
4 volt A.C.

159. *Class experiment*

The diode as a rectifier shown on the C.R.O.

Apparatus

8 diodes (EA 50) with holders	– item 156
8 transformers	– item 27
8 class oscilloscopes	– item 158
8 rheostats (10–15 ohms)	– item 541/1
8 1·5kΩ ($\frac{1}{2}$-watt) resistors	– item 132I

Procedure

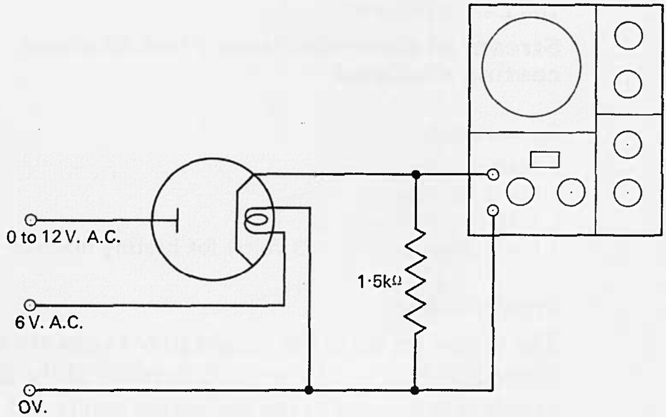
For details on the use of the class oscilloscope, see Appendix IV at the end of this volume.

The diode is connected to the oscilloscope and transformer as shown:

The oscilloscope is set on time-base range 2, with the input switch to d.c. and the gain set between 0·1 and 0·5 div/volt. The internal resistance between the input terminals of the oscilloscope could be used for the load, but it is probably better teaching to use the 1·5kΩ ($\frac{1}{2}$-watt) resistors as illustrated.

The separate tappings on the transformer can be used to vary the input.

By shorting out the diode by connecting the anode to the cathode the effect of the diode as a rectifier is made very obvious.


0 to 12 V. A.C.
6 V. A.C.
OV.
1·5kΩ

160 *Demonstration*

Stream of electrons from a hot filament casting shadows

Apparatus

1 Maltese cross tube	– item 136
1 stand for tube	– item 140
1 E.H.T. power supply	– item 14
1 low-voltage supply (6·3 volts) for heating filament	– item 27

Procedure

The tube is set up in the stand and 6·3 volts are applied to the filament to heat it. The positive terminal of the E.H.T. power supply is connected to the perforated anode and also to earth. The negative terminal of the supply is connected to the filament.

With 0 volts from the E.H.T. supply, the light from the filament can be seen on the fluorescent screen at the end of the tube and there will be a sharp shadow of the Maltese cross.

As the voltage is raised to about 3 kV, the thermionic emission produces fluorescence on the screen.

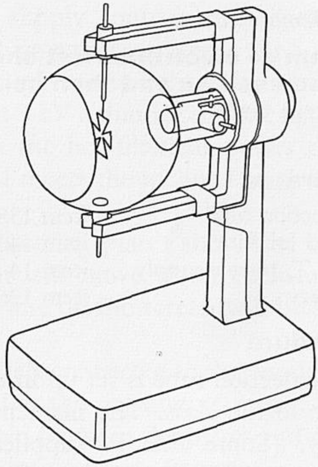
If a magnet is brought up near the tube, the fluorescent shadow is seen to move. The optical shadow, however, is undeflected.

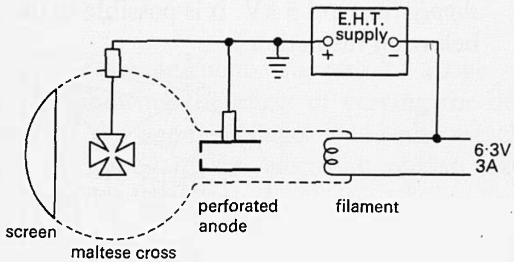
Notes

1. It is not essential to connect the Maltese cross to the anode, but it is advisable to do so.

2. Since the 50 MΩ safety resistor incorporated in the power supply is not used in this experiment, care should be taken.

3. Some Maltese cross tubes have an indirectly heated cathode in which case there is no optical shadow, only the fluorescent one.





Film

This experiment is demonstrated in the Esso-Nuffield film for science teachers, *An Approach to the Electron*. It is *not* suitable for showing to pupils, but it may help teachers to see the film which is available on free loan from Esso Petroleum Company, Victoria Street, London s.w.1.

161 *Demonstration*

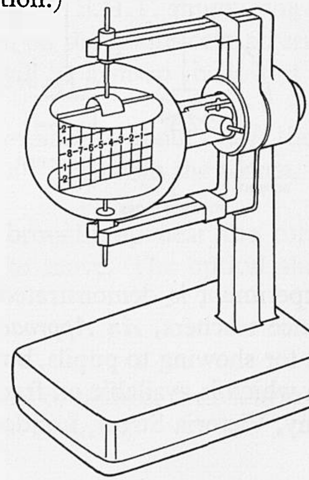
Stream of electrons first shown striking an inclined screen and then being deflected in an electric field

Apparatus

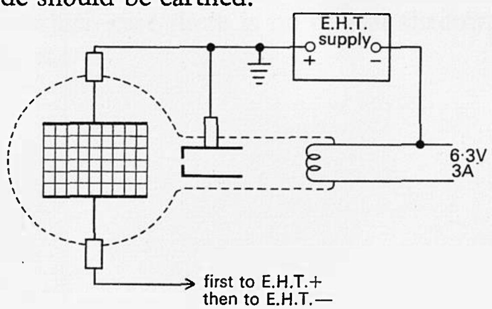
1 deflection tube	– item 138
1 stand for tube	– item 140
1 E.H.T. power supply	– item 14
1 battery	– item 176

Procedure

The deflection tube is set up in the special stand so that it is visible to the class. The filament is connected to a 6·3 volt supply. (Some E.H.T. supplies available for school use incorporate this output: *it must of course be a well-insulated supply* to stand 5 kV. It is possible to use a battery. See notes below on insulation.)



The negative terminal of the E.H.T. supply is connected to the filament, the positive terminal is connected to the anode. The anode should be earthed.



With the power supply controls turned to minimum, the light from the filament produces a line on the inclined fluorescent screen where the light strikes it. As the voltage is increased to about 3 kV a fluorescent line appears as the beam of electrons from the hot filament passes through the perforated anode and meets the inclined screen.

First both the deflecting plates should be connected to the anode. The beam will move in an enclosure at a uniform potential and the line on the screen will be straight.

Then one plate is left connected to the anode whilst the other plate is connected to the negative terminal. This produces a vertical electric field between the plates and consequently the beam is deflected into a parabolic path.

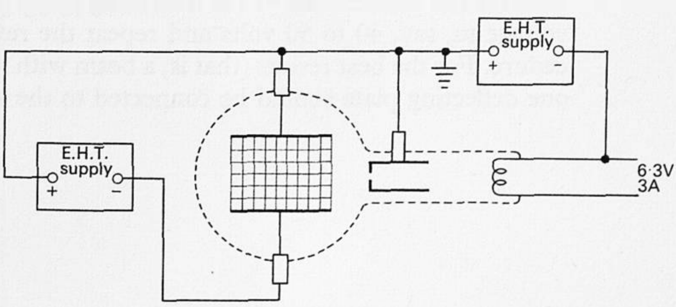
Notes

1. The simple arrangement suggested above is not convenient for showing the effect of varying the deflecting voltage because the anode voltage would also be changed. This alters the speed of the electrons and so leaves the deflection unchanged.

If, however, two E.H.T. power supplies are available and if it is wished to show this varying effect, the following arrangement may be used. It is very important to earth the anode in this case.

2. When the anode is earthed, the heater supply is about 3 kV below earth potential. It is advisable to use a battery to supply the heaters and to stand it on an insulator (say, polythene) and to cover it with a polythene sheet held in place by an elastic band.

The deflecting power supply can be connected the other way round to make the deflecting plate negative to the anode.



162a *Demonstration*

Fine-beam tube to show the deflection of an electron beam in an electric field

Apparatus

1 fine-beam tube and base	– items 61–62
1 H.T. power supply	– item 15
4 12-volt batteries	– item 176

Procedure

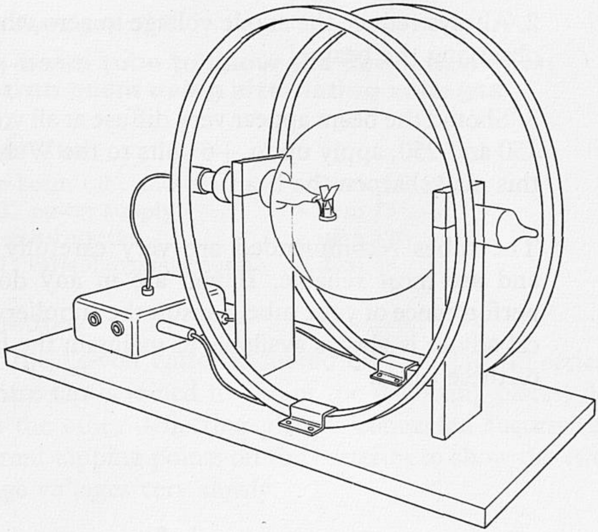
The tube is connected, by means of the connecting box, to the H.T. power supply so that 0 to 150–200 volts can be applied to the anode. The Wehnelt cylinder is connected by the teacher to the cathode (note that there is an internal connection between H2 and the cathode). Connect the heaters HH to the 6·3-volt supply on the power supply (item 15).

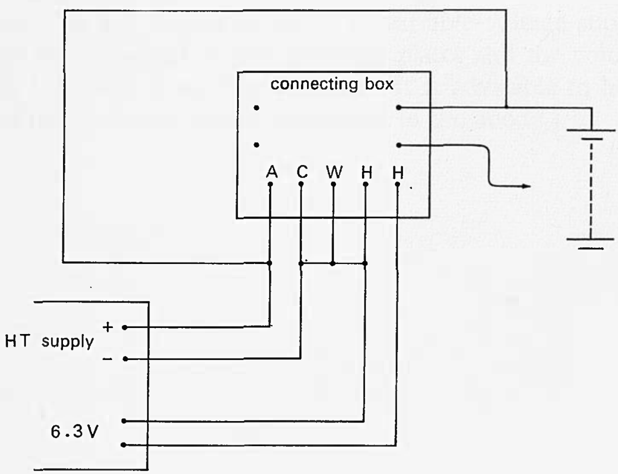
One of the deflecting plates is connected to the anode as shown, and also to the positive end of the battery. The other deflecting plate has a lead for connection to one of the other battery connections.

Before switching on check that the power supply potentiometers are set so that the anode potential will be zero. Turn the tube so that the electron gun points vertically upwards.

When the filament is glowing, carefully increase the anode voltage. At a voltage which may be as low as 50 volts, the fine blue beam should be seen. With some tubes, it may take three or four minutes for it to be clearly visible. As the voltage is slowly increased, the beam will lengthen and strike the glass envelope of the tube. It is inadvisable to increase the potential above about 200 volts.

With the beam striking the wall apply 10 to 20 volts (d.c.) to the deflecting plates and observe the movement of the beam. Reverse the connections to the deflecting plates. Increase the voltage to, say, 40 to 50 volts and repeat the reversing procedure. For the best results (that is, a beam with no diffusion) one deflecting plate should be connected to the anode.





Notes

1. This experiment should be demonstrated to the pupils in groups of four or five in a well-darkened room if full value is to be obtained.

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

3. Should the beam appear very diffuse at all voltages between 150 and 250, apply up to +6 volts to the Wehnelt cylinder – this may sharpen the beam.

The tubes recommended are very carefully manufactured and are most reliable. If you are in any doubt about the performance of your tube, consult the suppliers whose technical advice is always available to maintain the high reputation of these tubes.

162b *Demonstration*

Fine-beam tube to show the deflection of an electron beam using alternating voltages

Apparatus

1 fine-beam tube and base	– items 61–62
1 H.T. power supply	– item 15
4 12-volt batteries	– item 176
1 L.T. variable voltage supply	– item 59

Procedure

First the 12-volt batteries should be connected in series and a centre tap is joined to one of the deflecting plates. A lead from the other deflecting plate is connected successively to different tapping points on the batteries to show the effect of change voltages very slowly.

Then deflection with alternating voltages should also be shown. The a.c. output of the L.T. variable-voltage supply should be connected to the deflecting plates and the voltage slowly increased from 0 to 25 volts. (It is advisable to have one of the deflecting plates connected to the anode.)

163 Demonstration

Fine-beam tube to show the deflection of an electron beam in a magnetic field

Apparatus

1 fine-beam tube	– item 61
1 fine-beam tube base	– item 62
1 H.T. power supply	– item 15
2 magnadur magnets	– item 92B
1 coil	– item 139
1 12-volt battery	– item 176
1 rheostat (10–15 ohms)	– item 541/1

Procedure

The fine-beam tube is set up as described in the previous experiment 162a. The deflecting plates are connected together and to the anode.

A magnet with face polarity (a magnadur magnet from the electromagnetic kit) is brought near to the envelope of the tube and the deflection of the beam observed.

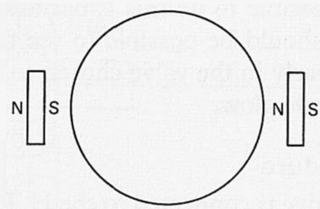
Two such magnets can be used on opposite sides of the tube to produce a more uniform field. See diagram opposite.

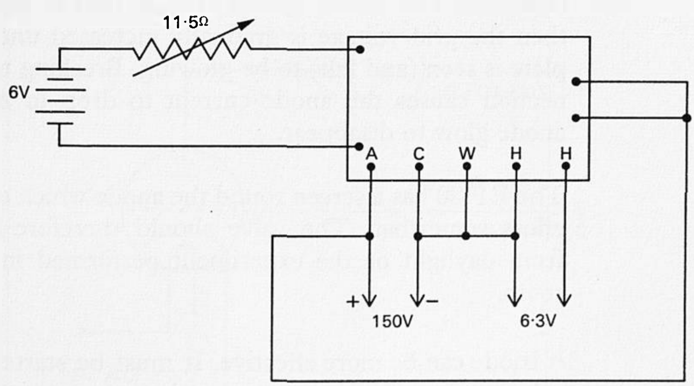
Care must be taken not to bring a magnet into violent contact with the glass.

The effect of a single coil on the beam is easily shown with *one* of the coils (item 139) brought near the tube. It is advisable to supply the coil with 6 volts from the 12-volt battery and not from a power supply (whose voltage may not be smooth enough); 6 volts will give a current of about 1 amp.

Finally great uniformity of field is obtained using the Helmholtz coils attached to the fine-beam tube base. The circuit is as shown opposite.

The effects of altering the current through the coils and then reversing the current through the coils should be shown.


N
S
N
S


11·5Ω
6V
A
C
W
H
H
+
−
150V
6·3V

164 *Optional Demonstration*

Stream of electrons hitting a metal plate and heating it

Apparatus

1 valve (EF 80 pentode)
1 base for valve (B 9A)
1 H.T. power supply – item 15
1 demonstration meter – item 70
1 d.c. dial: 100 mA – item 71/12

Note

An EF 80 valve is suggested partly because it has an open structure and allows the action to be clearly seen. Also, since this experiment ruins the valve, it should be an old valve and there are many valves of this type in old wireless and television sets.

It is possible to do this experiment with many other valves, but it should be possible to see the cathode glow separately and clearly in the valve chosen so that it is not confused with the anode glow.

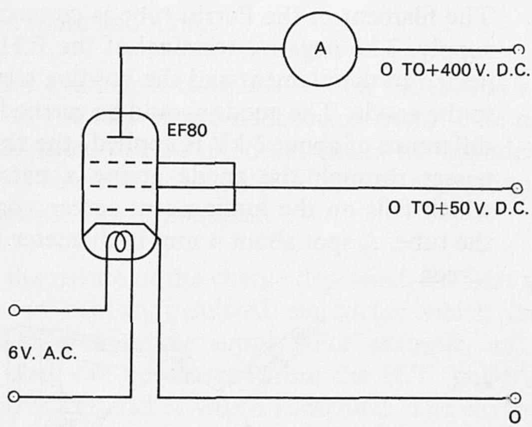
Procedure

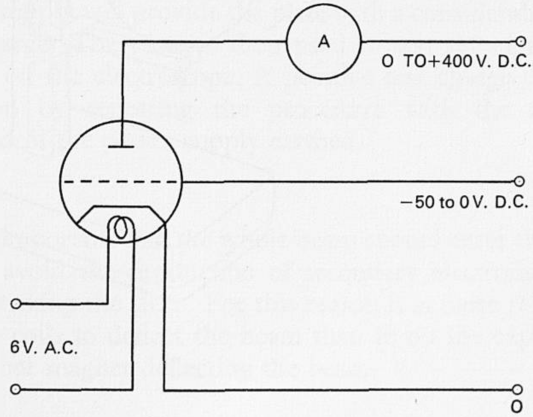
The valve is connected to the H.T. power supply as shown in the circuit diagram above. All variable voltages should be at zero before switching on.

The unit is switched on and the glow of the filament is observed. The anode voltage is increased to maximum and then the grid voltage is gradually increased until the anode plate is seen (and felt) to be glowing. Breaking the grid connection causes the anode current to drop to zero and the anode glow to disappear.

The EF 80 has a screen round the anode which does hide the effect somewhat. The valve should therefore be screened from daylight or the experiment performed in a darkened room.

A triode can be more effective. It must be started with —50 volts on the grid so that the anode current starts at nought. As the grid voltage is raised to nought, the anode current rises to a high value.


A
O TO+400 V. D.C.
EF80
O TO+50 V. D.C.
6V. A.C.
O


A
O TO+400 V. D.C.
−50 to 0 V. D.C.
6V. A.C.
O

165 *Optional additional demonstration*

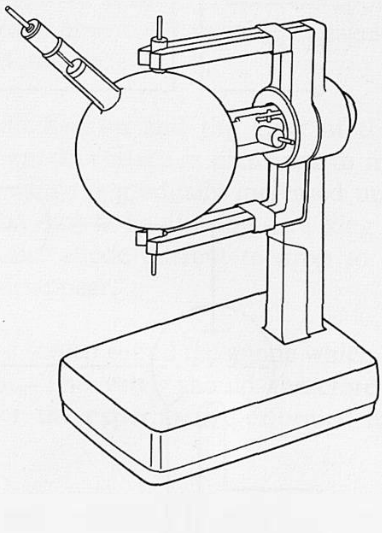
Stream of electrons from a hot filament collected in a cylinder inside a Perrin tube

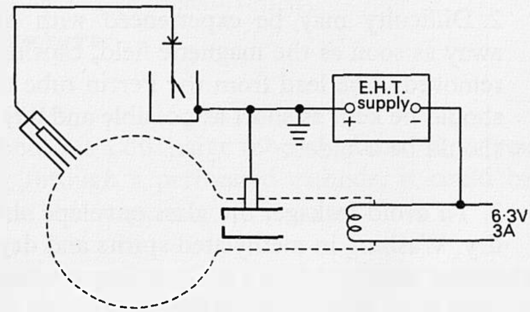
Apparatus

1 Perrin tube	– item 137
1 stand for tube	– item 140
1 pair coils for deflecting beam	– item 139
1 E.H.T. power supply	– item 14
1 low voltage supply (6 volt) for heating filament	– item 27
1 12-volt battery	– item 176
1 rheostat (10–15 ohms)	– item 541/1
1 gold-leaf electroscope	– item 51A/B
1 H.T. power supply	– item 15

Procedure

The filament of the Perrin tube is connected to the 6·3-volt supply. The negative terminal of the E.H.T. supply is connected to the filament and the positive terminal is connected to the anode. The anode should be earthed. When a potential difference of about 3 kV is applied, the thermionic emission passes through the anode giving a narrow circular beam which falls on the luminescent screen coated on the end of the tube. A spot about 4 mm in diameter is produced on the screen.





The coils for deflecting the beam are placed round the tube and the 12-volt battery is connected to them in series with the rheostat. By steadily increasing the current through the coils the spot formed by the beam striking the screen can be deflected more and more.

A Faraday cylinder is contained within the tube at about 45 degrees to the axis of the undeflected beam. The magnetic field is adjusted so that the beam enters the cylinder. If the cylinder is connected to a gold-leaf electroscope, there will be an immediate rise in potential.

To test the nature of the charge deposited, the best arrangement is to use an insulated conductor which has been charged from a power supply. For example, an electrophorus plate can be charged from the H.T. power supply, the positive terminal of which is earthed. The electrophorus plate is stood on a sheet of paper which itself lies on the bench. Momentary contact with the negative terminal of the power supply will provide the plate with a considerable negative charge. The plate is then used to test the sign of the charge on the electroscope. A positive test charge could be obtained by repeating the procedure with the negative terminal of the power supply earthed.

Notes

1. It is important that the whole beam should enter the cylinder to avoid the production of secondary electrons by the beam striking the sides. For this reason it is more reliable to use the coils to deflect the beam than to do the experiment with a bar magnet deflecting the beam.

2. Difficulty may be experienced with the charge leaking away as soon as the magnetic field, causing the deflection, is removed. The lead from the Perrin tube to the electroscope should be kept as short as possible and any sharp projections should be avoided.

3. To avoid leakage, the glass envelope should be clean and dry. Washing in methylated spirits and drying in hot air will ensure this.

4. As the anode is earthed, the heater supply is therefore at 3 kV below earth potential. Care should therefore be taken (as discussed in Experiment 161).

Film

Teachers are advised to see the Esso-Nuffield film for science teachers in *An Approach to the Electron* in which this experiment and others in this series are shown. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

166 *Optional extra demonstration*

Positive rays

Procedure

If a school has a discharge tube which can show positive rays passing through a perforated cathode, it could be demonstrated at this stage.

If the cathode and anode are both perforated, a magnet can be brought near to one end of the tube to show how easy it is to deflect the negative particles which pass through the anode and how very much more difficult it is to deflect the positive particles which pass through the cathode.

167 *Demonstration*

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

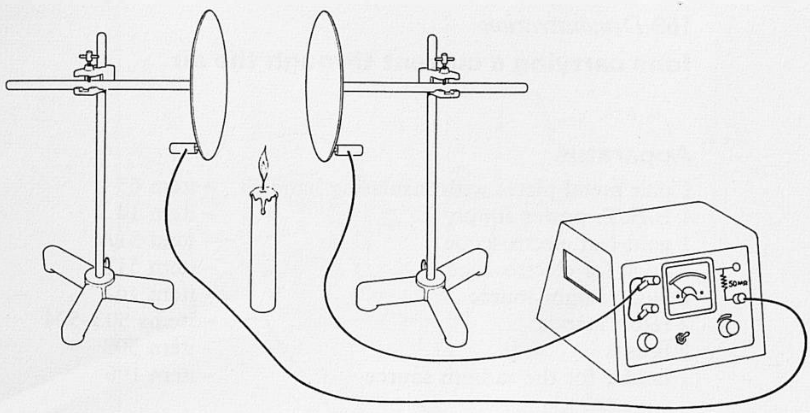
Apparatus

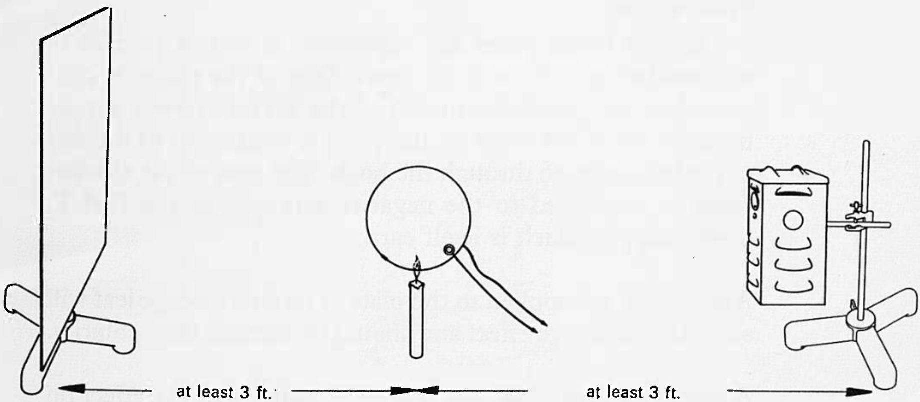
1 pair metal plates with insulating handles	– item 65
1 E.H.T. power supply	– item 14
1 compact light source	– item 21
1 candle	
1 translucent screen	– item 46/1

Procedure

Fix the plates in vertical planes parallel to each other and two to three inches apart with their insulating handles held in bosses attached to retort stands. A candle-flame is lit a little below them and the small bright light source is set up some feet away so that a sharp shadow of the plates and the flame falls on a screen behind (see lower diagram).

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.




at least 3 ft.
at least 3 ft.

168 *Demonstration*

Ions carrying a current through the air

Apparatus

1 pair metal plates with insulating handles	– item 65
1 E.H.T. power supply	– item 14
1 gold-leaf electroscope	– item 51A
1 hook for electroscope	– item 51J
1 5μC radium source	– item 16
2 retort stands	– items 503–504
2 bosses	– item 505
1 holder for the radium source	– item 196

Procedure

a. The two metal plates are supported in bosses parallel to one another and about 5 cm apart. One of the plates is connected to the positive terminal of the E.H.T. power supply through the safety resistor; the other is connected to the leaf of the electroscope through the hook. The case of the electroscope is connected to the negative terminal of the E.H.T. power supply which is itself earthed.

About 2 kV are applied to the plate. The electroscope leaf will show the inductive effect and should be earthed momentarily.

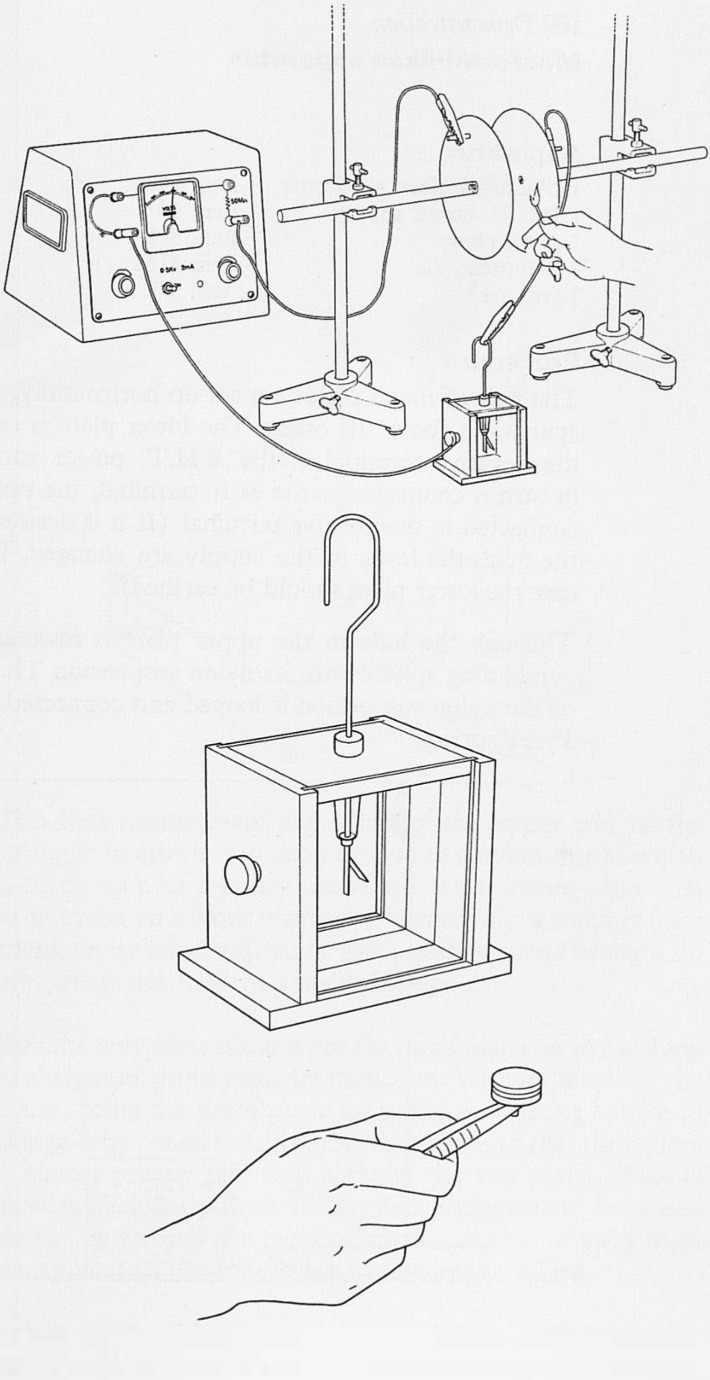
A match flame is held just below the plates and the effect on the leaf observed.

Then the connection to the charged plate is removed and the power supply switched off. This plate (A) is then earthed and a second match is used to show the discharge of the electroscope.

b. The experiment is repeated using a 5μC radium source, held between the plates.

Note

The class may be helped to see the movement of the gold-leaf electroscope if the translucent screen and lamp are used.


50MΩ
0-5Kv 2mA

169 *Demonstration*

Macro-Millikan apparatus

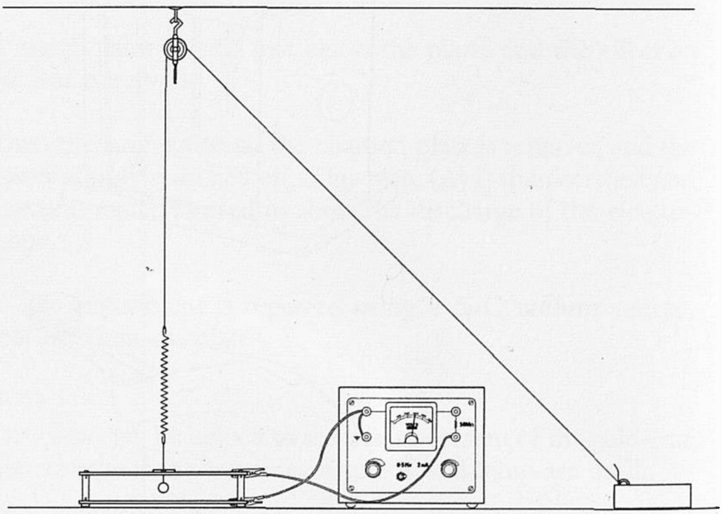
Apparatus

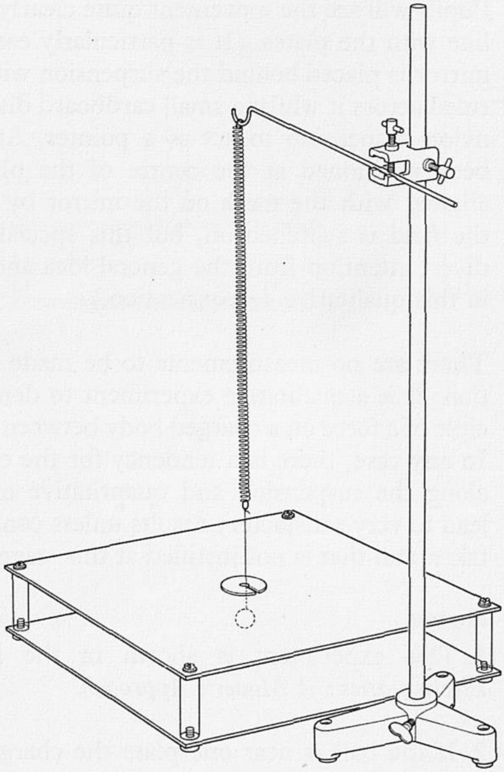
1 Macro-Millikan apparatus	– item 142
1 E.H.T. power supply	– item 14
1 proof plane	– item 51L
1 polythene tile	– item 51M
1 'rubber'	– item 51I

Procedure

The pair of metal plates are set up horizontally, 3 in to 4 in apart, one above the other. The lower plate is connected to the negative terminal of the E.H.T. power supply, which in turn is connected to the earth terminal, the upper plate is connected to the positive terminal. (If it is desired to reverse the field, the leads to the supply are changed, but in each case the lower plate should be earthed).

Through the hole in the upper plate is lowered the small conducting sphere with its nylon suspension The upper end of the nylon suspension is looped and connected to the glass Pyrex spring.





The best arrangement for securing the upper end of the spring is to attach it to another loop in a nylon thread which is taken up over a pulley connected to the ceiling, and then to an eyelet on a block of wood. Alternatively, a support from a long retort stand rod can be used, as shown, and brought up over the plates to form a hooked support.

Rub the polythene tile and put the proof plane on it, touching to charge the proof plane by induction. Without touching the plates, bring the proof plane up to the conducting sphere to charge it by contact. Adjust the suspension so that the sphere is almost exactly half-way between the two plates. This is most conveniently done in the first arrangement described above: by moving the block of wood nearer to or away from the apparatus, the sphere can be lowered or raised.

Switch on the E.H.T. supply with 2,000 to 4,000 volts; the sphere will be seen to move as the extra force stretches the spring. The sphere can be brought back to the central position by moving the block of wood.

Pupils will see the movement quite clearly if their eyes are in line with the plates. (It is particularly easy to see if a plane mirror is placed behind the suspension with a horizontal line ruled across it whilst a small cardboard disc is attached to the nylon suspension to act as a pointer. After the sphere has been positioned at the centre of the plate this pointer is aligned with the mark on the mirror by no parallax before the field is switched on, but this special arrangement may divert attention from the general idea and need not be used in this qualitative demonstration.)

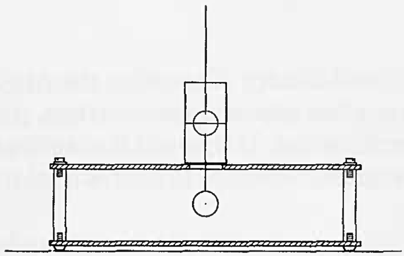
There are no measurements to be made in this demonstration: it is a qualitative experiment to demonstrate the principle of a force on a charged body between two parallel plates. In any case, there is a tendency for the charge to leak away along the suspension and quantitative experiments do not lead to very satisfactory results unless considerable trouble is taken and that is not justified at this stage of the course.

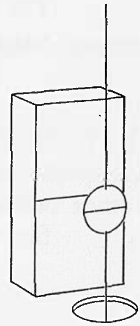
Notes

1. This experiment is shown in the Esso-Nuffield film *Electrostatics: A Modern Approach.*

2. If the ball is near one plate the charge on it induces an opposite charge on that plate, so there is attraction. We do not wish that 'image-force' to appear in the demonstration. Therefore the ball must be almost exactly half-way between the two plates, so that the image forces cancel out.

3. Teachers may like to experiment with a realistic model of the Millikan experiment by placing a very light metal-coated ball in the field between the plates and adjusting the field to make the ball float upwards, fall slowly downwards, or even remain poised for a short time. The ball is charged by contact with one of the plates, which then repels it. A *very* light ball is needed or perhaps a scrap of aluminium leaf. When the ball is poised, its equilibrium is made unstable by image forces – to minimize that disadvantage, the charge on the ball should be made as small as possible and the electric field as large as possible.





170 *Film*

Millikan's experiment

In view of the difficulty of showing the Millikan experiment to more than a few pupils at any one time, it is suggested that a film be used instead. It is hoped that in the future a suitable film will be made commercially for school use.

171 *Class experiment*

Oscilloscopes used to show acoustic wave-forms

Experiments 171 and 172 will be done in Year V of the course, and some may have been done earlier in the year, but the oscilloscope is such a useful instrument that some first experience with it in Year IV is important.

Apparatus

8 class oscilloscopes	– item 158
8 microphones	– item 157

Procedure

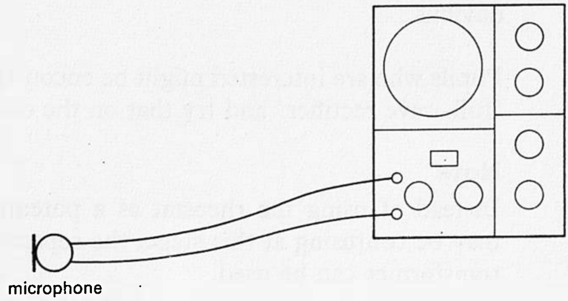
For details on the use of the class oscilloscopes see Appendix IV at the end of this volume.

The small microphones are connected to the input terminals of the oscilloscope. Set to maximum gain. The time-base to the middle of range 2.

Pupils should try their own voices and musicians should be encouraged to try their own musical instruments.

Note

Carbon microphones can be used instead of those recommended. They will require a battery and transformer in series with them. The output from the transformer is put on the input terminals of the oscilloscope.



172 *Demonstration*

The diode as a rectifier shown on a C.R.O.

This demonstration is a repetition of the Class experiment 159 earlier in this year.

Apparatus

1 EA 50 diode with holder	– item 156
1 transformer	– item 27
1 oscilloscope	– item 64
1 rheostat	– item 541/1

Procedure

For details on the use of the demonstration oscilloscope see Appendix III at the end of this volume.

The diode is connected to the oscilloscope and transformer as shown.

The oscilloscope is set with time-base at 1 ms/cm and the gain at 5 volts/cm. The resistor shown between the input terminals of the oscilloscope is its own internal resistance: a separate component is not needed.

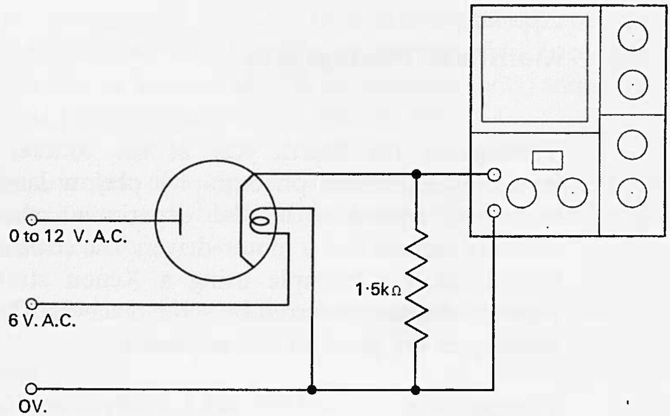
The slider on the rheostat may be altered to show the effect on the output.

By shorting out the diode by connecting the anode to the cathode, the effect of the diode as a rectifier is made very obvious.

Pupils who are interested might be encouraged to construct a 'full-wave rectifier' and try that on the oscilloscope.

Note

Instead of using the rheostat as a potential divider, which may be confusing at this stage, the separate tappings on the transformer can be used.


0 to 12 V.A.C.
6 V.A.C.
OV.
1·5kΩ

Appendix I

Multiflash Photography

Throughout the fourth year of the course, experiments involving multiflash photography play a large part. The technique advocated in the experiment sheets uses an ordinary camera and a motor-driven disc stroboscope. Other techniques, for example using a Xenon stroboscope, are possible and are preferred by some teachers. Details of these techniques are given in this appendix.

Teachers may also require information to enable them to do the necessary photography and it is hoped the details given in Appendix II may be of use to them.

Method 1: Strobe photography using an ordinary camera and a synchronous strobe disc

A camera focusing down to about $1\frac{1}{2}$ or 2 metres is required. It must have a lens aperture of at least f 8, though f 6·3, f 4·5 or f 3·5 are to be preferred. Either a camera which takes 35-mm or 120–size film may be used, though some of the techniques described have been worked out for the 35-mm film. The developing and printing process (discussed in Appendix II), which can be carried out in front of the class without blackout, is only suitable for 35-mm film and more traditional methods will be necessary for 120-size film. The shutter should be fitted with T or B settings: in practice the B setting is the more convenient.

Unless the camera has a reflex viewfinder, it is as well to check the field of view by putting a strip of translucent material in the position normally occupied by the film, opening the shutter in the B setting and seeing directly that all the motion you wish to photograph is in view.

Once this is done, of course, a note can be kept of the camera distance and the area of view covered.

The camera is set up firmly on a level with, and about $1\frac{1}{2}$ m away from, say, the inclined plane or the falling sphere. This distance is measured carefully and the lens mount set for this distance.

The synchronous motor is then fitted with the appropriate black disc (the 5-slit disc gives an interval of 1/25 sec, and the 6-slit disc an interval of 1/30 sec between shots) and is placed about $\frac{1}{2}$ inch in front of the camera lens.

The number of exposures can be varied by covering unwanted slits with black adhesive tape (this should be done symmetrically).

For example, with a synchronous motor running at 300 r.p.m.

5-slit disc
1 slit open gives 5 exposures per second.
2 slits open gives 10 exposures per second.
5 slits open gives 25 exposures per second.

6-slit disc
1 slit open gives 6 exposures per second.
2 slits open gives 12 exposures per second.
6 slits open gives 36 exposures per second.

This will enable one to choose a suitable number of exposures to appear in the final picture. The width of the slit controls the sharpness of the images obtained and the narrowest slit consistent with adequate illumination should be chosen.

The scene is readily illuminated by means of a 500–1,000-watt 2 in × 2 in slide projector, placed so that the beam of light illuminates the whole of the action without (a) illuminating the background (b) spilling light on to the camera and strobe. Photofloods (or Photolita lamps) can be used but will require careful screening to avoid these faults.

A clean blackboard may be used as a background. A matt black cloth surface would give better contrast, but this is not essential.

In the case of experiments on free fall it will be found convenient to use a mirror held in a stand to direct the beam of light down the path of the falling ball. It is worth experimenting with and without the projection lens in place to find the best illumination. It is not advisable to tilt the projector lamps themselves through an angle exceeding about 45 degrees from the vertical.

Probably the best object for illumination is a highly polished steel ball – at least $\frac{3}{4}$ inch in diameter and preferably larger. Such a ball can be secured to the top of a trolley to provide an indication of its position: or it can be allowed to roll freely down an inclined plane, or used as a projectile. The light reflected from the ball, which acts as a convex mirror, appears to come from an intense, diminished virtual image of the lamp; it is a point-object so far as the camera is concerned.

A golf ball is another useful object particularly for free fall; if it is dropped onto an iron anvil at a slight angle to the horizontal, it will enable the bounces to be photographed as well.

A simple pendulum may also be photographed with this arrangement: the camera being turned so that the frame is horizontal.

In some cases it will be found useful to provide a scale. This must be placed in, or near to, the plane in which the ball is moving. An ordinary metre rule is satisfactory, but it must be tilted so that it does not reflect light from the lamp directly to the lens.

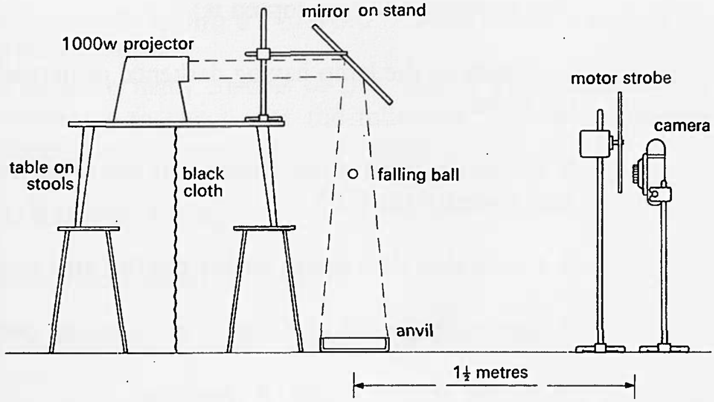
Chalk lines ruled on the blackboard, or on black paper, at 10-cm intervals are also useful. Alternatively a grid of white threads held in a frame with Sellotape may be used.

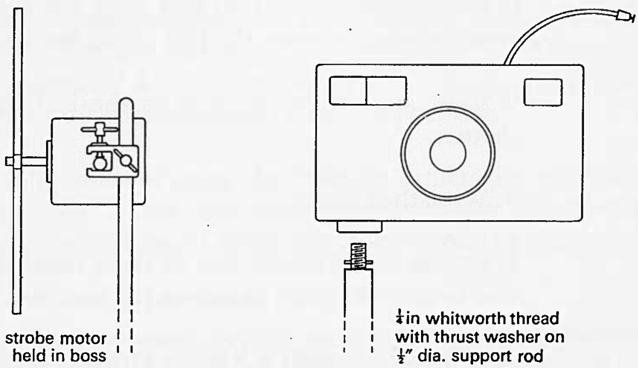
A steel rod 9 in long $\times$ $\frac{1}{2}$ in diameter, with a $\frac{1}{4}$-in Whitworth screw turned on one end makes an ideal support for the camera and allows it to be used with a normal stand, boss and clamp.

The frame of the film should be orientated to suit the motion being photographed. This is done by rotating the camera body to the required position.

The rod on the stroboscope motor is best gripped in an ordinary boss attached to a stand.

The stands used as supports should be as massive as possible (extra weights on the base will help) and extra height should be obtained by clamping the stands to laboratory stools, rather than by using taller stands.


mirror on stand
1000w projector
motor strobe
camera
table on stools
black cloth
falling ball
anvil
1½ metres


strobe motor held in boss
¼in whitworth thread with thrust washer on ½" dia. support rod

The procedure to be adopted is:

1. Switch on the lamp having darkened or partially darkened the room.

2. Check the focus of the camera lens and select the maximum lens aperture say f 3·5.

3. Check that the camera covers the full area required.

4. Put strobe motor and disc in position and switch on.

5. Set the shutter to the 'B' position.

6. Count down (3–2–1–0) and open the shutter just before your assistant releases the ball. Hold the shutter open.

7. Close the shutter as soon as the ball has completed its motion.

8. Wind the film on.

9. Repeat the exposure two or three times to ensure success and to provide spare negatives for later use.

Method 2: Using a Xenon stroboscope and a 35-mm camera

Sharper pictures than those taken with the motor stroboscope are possible if a Xenon stroboscope is used (item 134/2 – see Physics *Guide to Apparatus*).

The procedure is the same as for motor strobe photography except, of course, that the filmstrip projector and motor strobe are not needed. It is essential to have a good degree of blackout and to direct the beam from the Xenon stroboscope along the path of the ball. It should *not* be used as a general floodlight, this will produce pictures lacking contrast and showing too much background.

Method 3: Using a Polaroid* Camera and a motor stroboscope

There are many models of this camera available and it is important to check that the following facilities are incorporated on the one which you choose:

1. B shutter setting.

2. Focusing down to 3–4 ft.

The following remarks apply to the model 160.

The Polaroid camera combines photograph taking and print production, thus making the whole process simpler and faster but making the production of duplicates for the pupils more difficult. The film used is much faster (3,000 ASA) but this is counteracted to some extent by the comparatively small aperture (f 9 approximately) which is available.

The techniques of using the Polaroid camera for multiflash photography follow the same pattern as for the 35-mm camera any differences being due to the nature of the camera itself:

1. the camera is much heavier and needs substantial support (a special adaptor is necessary for using the Polaroid with a tripod).

2. a range-finder and view-finder are incorporated in the camera.

3. EV values are given, not conventional f numbers and shutter speeds. See next page.

* Polaroid cameras (for educational use) can be bought free of import duty: contact the Polaroid Company, Queensway House, Queensway, Hatfield, Herts, for details.

Details of exposure values (EV) on Model 160 Polaroid Camera

Exposure value 10 gives aperture f/9 at approx. 1/12 sec
Exposure value 11 gives aperture f/9 at approx. 1/25 sec
Exposure value 12 gives aperture f/9 at approx. 1/50 sec
Exposure value 13 gives aperture f/9 at approx. 1/100 sec
Exposure value 14 gives aperture f/13 at approx. 1/100 sec
Exposure value 15 gives aperture f/18 at approx. 1/100 sec
Exposure value 16 gives aperture f/26 at approx. 1/100 sec
Exposure value 17 gives aperture f/36 at approx. 1/100 sec

Procedure for multiflash prints of free fall with Polaroid camera

1. Set up the camera so that it covers the required field of view. If it is being placed on a support (for example, a laboratory stool) the front of the camera will need a block of wood so that the film plane is vertical. The focusing knob is covered in this case, but it can be operated with slight tilting of the camera and the focusing checked afterwards.

2. Illuminate the dropping area, either by light from the projector reflected down with a plane mirror held at a suitable angle or by light from a photoflood, taking care not to illuminate the background too strongly. Partial blackout is needed.

3. Focus on an object in the dropping plane.

4. Set the EV number to 14.

5. Set the selector switch to B (this must be done before *each* exposure).

6. Place the motor stroboscope (mounted on a stand) so that the slits cover the lens with the disc as close to the lens as possible.

7. Drop the ball after a count-down, opening the shutter on '1' and closing it when sufficient of the motion has been photographed.

8. Restore normal room lightning, develop the film according to the Polaroid instructions.

If the print is too light in colour, try a second shot at EV 15; should it be too dark, try EV 13, but remember that the aperture of the lens does not change after EV 13 for it is then fixed at f 9.

Above all, do not forget to switch to B each time.

If a scale is needed it can be incorporated in the original shot or it can be placed in position after the multiflash photograph has been taken and then on *the same negative* an instantaneous ('I' setting on selector switch) photograph at EV 14 can be taken, care being taken not to move the camera. The scale should be bold, carrying only main markings at, say, every 5 or 10 cm.

Method 4: Using a Polaroid camera and Xenon stroboscope

Sharper pictures than those taken with the motor stroboscope are possible if a Xenon stroboscope is used (item 134/2– see Nuffield Physics *Guide to Apparatus*).

The procedure is the same as for motor strobe photography, except, of course, that the projector and motor strobe are not needed. It is essential to have good blackout and to direct the beam from the Xenon strobe along the path of the ball. It should *not* be used as a general floodlight which will produce pictures lacking contrast and showing too much background.

Duplicate copies from Polaroid prints are difficult to produce and it would seem best to project the print by epidiascope and let the class make measurements (and copies) from this. If access to photographic copying is available, a negative of the print can be made and prints produced in the normal way.

Multiflash photography in general

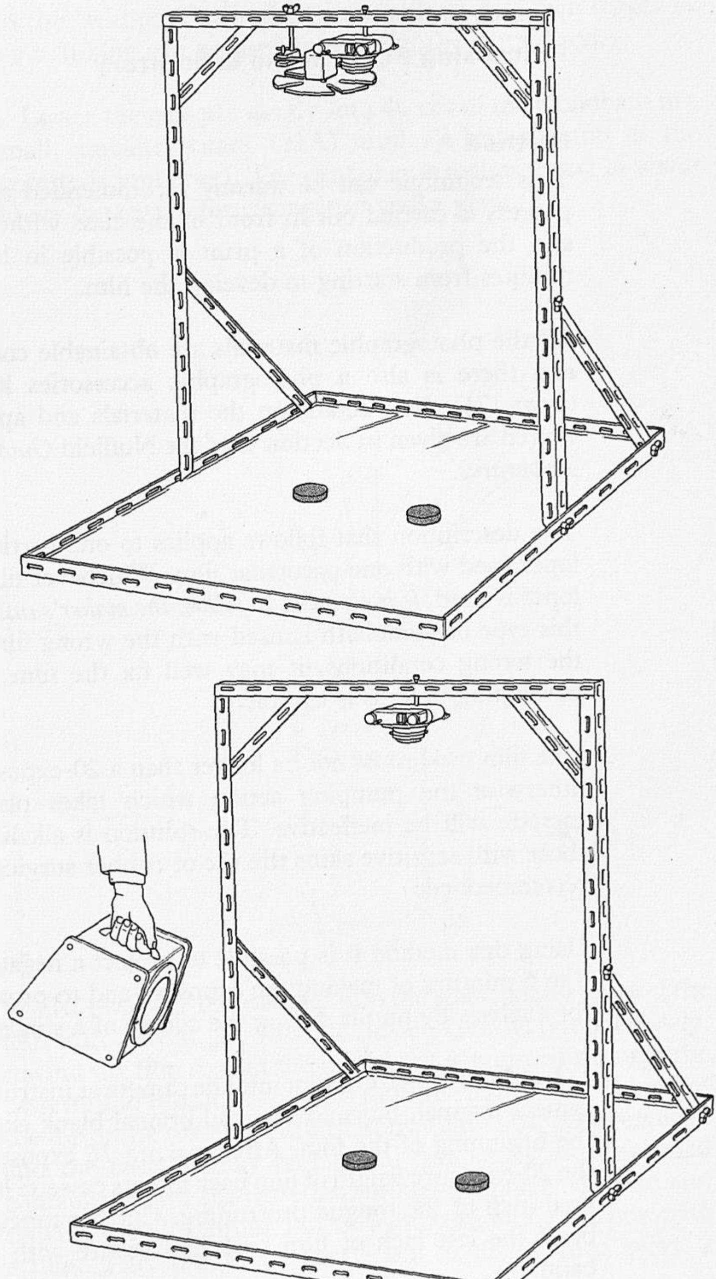
The techniques described so far have concentrated on free fall, but the general principles apply to all cases where it is desired to take multiflash photographs of some event.

In each case the highlighting of the body being photographed against a dark background is necessary to ensure good contrast in the picture. The successive photographs of the event at regular time intervals on the same negative frame are achieved either using constant illumination and strobing the camera with a motor-driven stroboscope or using intermittent illumination with a Xenon stroboscope.

The only differences lie in the disposition of the apparatus. For example, in multiflash photography of collisions in two dimensions the apparatus is set up as illustrated.

The gantry illustrated is item 161 (see Nuffield Physics *Guide to Apparatus*). Alternatively, a suitable gantry can be improvised from one or two trolley runways, laboratory stools and tables. The runways are supported as a bridge across the glass plate. Laboratory stools stood on laboratory tables make suitable supports. The camera and strobe disc are supported on retort stands clamped to the runways so that the photographs can be taken.

It is also possible to position the camera in the normal way and to use a small front surfaced mirror to reflect the light from the scene into the strobe disc/camera assembly.



Appendix II

Processing Films in the Laboratory

Method A

This technique can be warmly recommended as the whole process is carried out in front of the class without blackout and the production of a print is possible in less than 10 minutes from starting to develop the film.

All the photographic materials are obtainable commercially, and there is also a photographic accessories kit available (item 171). Full details on the materials and apparatus required are given in Section C of the Nuffield *Guide to Physics Apparatus*.

The description that follows applies to one particular developer used with one particular film. Whichever film or developer is used, *it is essential to follow the maker's instructions*. If this type of monobath is used with the wrong film or under the wrong conditions, it may well fix the film before the developing process is complete.

The film used must not be longer than a 20-exposure length otherwise the pumping action which takes place in the cassette will be ineffective. The solution is alkaline and for those with sensitive skins the use of rubber surgical gloves is recommended.

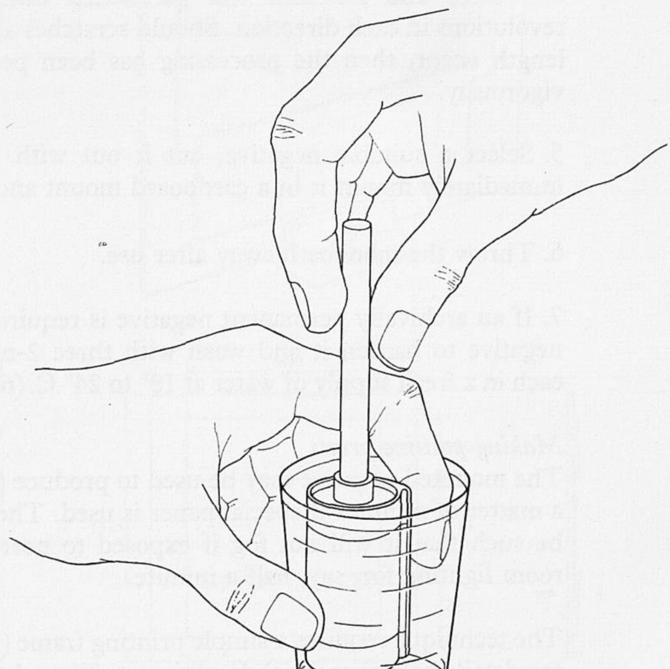
Using this method it is possible to project a negative within 5 to 6 minutes of making the exposure and to provide prints for analysis by pupils during the course of a single lesson.

1. Load the cassette of film into the camera as instructed in the camera manual, but make two additional blank exposures at the beginning of the film. After making *16* exposures, wind the 20-exposure length of film back into its cassette leaving the final inch of the tongue protruding. Cut the tongue off and bend the last inch of film back and secure with an elastic band.

2. Take the slotted rod (item 171B) which is about 3 in long, and fit the slot over the key in the cassette. Then wind the film

up (but without forcing) on its spool. (A 3 to 4-in length of p.v.c. tubing can be used in place of the slotted rod.)

3. Lower the cassette gently into 40 ccs of the monobath in a small container (item 171A) until all but the top of the cassette is immersed. The container is a glass vessel of about 70 ccs capacity – for example, a vodka glass.



Whilst lowering the cassette into the glass, gently unwind the film with the rod. Air will bubble out. Gently, but not slowly, rewind the film so that the monobath is pumped through the cassette and repeat the process until the liquid is forced out of the top of the cassette. All air bubbles have now been removed and the cassette may be lowered completely into the small container. With the cassette thoroughly immersed, wind and unwind the film through $1\frac{1}{2}$ turns so continuing the pumping action. This should be gentle but at about once every 2 seconds.

4. After the correct time had elapsed ($3\frac{1}{2}$ to 4 minutes at 20° to 23° C.), take the cassette from the container and plunge the whole into water. Open the cassette or unspool the film under water. (Should the film appear cloudy transfer it to a bath of an acid fixer containing a hardener.) Wash the film in water briefly (10 seconds, say) and inspect it. Should dark bands occur across the width of the film at its ends, then the rotating backwards and forwards was performed using too many revolutions in each direction. Should scratches along the film length occur, then the processing has been performed too vigorously.

5. Select a suitable negative, cut it out with scissors and immediately mount it in a cardboard mount and project it.

6. Throw the monobath away after use.

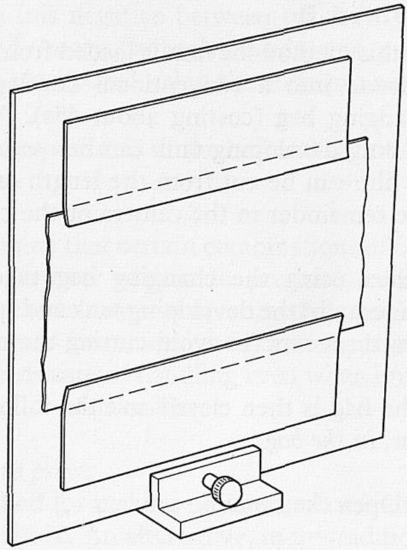
7. If an archivally permanent negative is required, re-fix the negative to harden it and wash with three 2-minute rinses each in a fresh supply of water at 18° to 24° C. (65° to 75° F.).

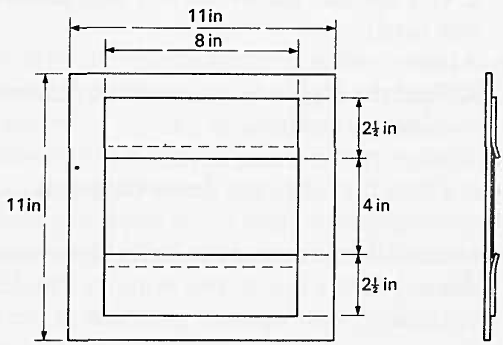
Making positive prints

The mounted negative may be used to produce prints within a matter of minutes if special paper is used. The paper must be such that it will not fog if exposed to normal tungsten room lighting for, say, half a minute.

The technique requires a simple printing frame (item 171 C – see details below) and a slide projector. The whole operation can be carried out in a room lit with tungsten lighting (or subdued daylight but not fluorescent). Project an image of the negative chosen on to the frame using the 500-watt projector. Switch the projector off and slip a piece of cut paper into the frame. A suitable size is 8 in by 5 in. Expose for about 5 seconds to the light from the projector, which should be about 1 metre away.

Develop the paper immediately (face down) in a dish of developer for half a minute and then transfer the paper print to a bath of fixing solution for 1 minute. Rinse the print briefly in clean tap water, preferably at about 20° C. to remove excess fixer salts. If it is intended to preserve the print, it should be more thoroughly washed for about 20 minutes in running water.





The printing frame is available commercially in the photographic accessories kit (item 171) or can be made from a sheet of hardboard about 11 in square, to which a piece of thin black card 8 in by $9\frac{1}{2}$ in is stuck. Double strips of black card 8 in long and $2\frac{1}{2}$ in wide are stuck to this leaving a strip 8 in long and $4\frac{1}{2}$ in wide across the centre. The double strips are stuck down with the inner edges left free so that a strip of the printing paper 8 in by 5 in can be held between them in the centre of the frame.

The whole frame is supported vertically in a slotted base (item 30).

Method B

In this method the film is loaded from the camera or from the cassette into a conventional developing tank in a daylight changing bag (costing about 45s). Alternatively, a daylight loading developing tank can be used. In either case a length of film can be cut from the length originally loaded, leaving the remainder in the camera or the cassette.

When using the changing bag take into the bag (a) the camera, (b) the developing tank and spiral, (c) a pair of round-nosed scissors (to avoid cutting the material of the bag).

The bag is then closed and the following operations carried out, *in the bag*:

1. Open the camera.

2. Cut the film across the last unexposed negative (if 35 mm was used).

3. Feed the exposed portion of the film into the spiral, *without touching the emulsion.*

4. Close the lid of the developing tank.

Once this has been done (after some private practice with a dummy film – one or two minutes should be allowed for this operation), development proceeds in the following steps:

5. Add the correct quantity of combined developer/fixer, and agitate the spool for 10 secs of each minute for 7 minutes.

6. Pour off the developer/fixer solution and wash in running tap water for 5 minutes. If time presses, this can be cut to 1 minute provided that the film is re-washed thoroughly later.

7. Rinse the film in water to which a few drops of wetting agent have been added.

8. Remove from the tank and inspect. Select a suitable negative for discussion and cut it from the film with scissors.

9. This negative can be rinsed in methylated spirit and dried over the exhaust from the projector to speed up the process.

10. Sandwich this negative between two 2-in glass slides or mount in ready mount adhesive cards, and project on to a screen or the blackboard using the slide projector.

11. Chalk in the positions of the ball and the scale for discussion.

It should be noted that certain combinations of film and combined developer/fixer appear to produce softening of the gelatine to such an extent that immediate projection is not possible. It should be remembered that the negative will still be soft and needs careful handling even when immediate projection appears to be possible.

Making positive prints

The best method for making positive prints is that described in Method A above. An alternative, more traditional method, is given below.

Copies for class use can be made by enlargement through the local chemist (postcard enlargements are suitable). If the teacher prefers to do the enlargement himself in the dark room, lightweight projection paper is very suitable (which is sold in packets of 100 sheets each 8 in $\times$ 10 in for about 35s). This paper is processed in the same way as any other bromide paper, costs roughly half as much and will take pen or pencil readily.

The procedure is:

1. Set up the enlarger to give a magnification of about 10.

2. Expose, after making the usual test strips, on to strips of the paper (about 2 in wide and 10 in long).

3. Develop for 1 minute.

4. Rinse in a stop bath and fix for 10 minutes.

5. Wash for at least 10 minutes and then dry.

Copies of not such good quality can be made using document paper and the 2-in slide projector.

This avoids the use of a dark room, providing that the laboratory can be blacked out to normal standards, because the paper is able to be handled in subdued tungsten lighting (not fluorescent lighting).

A simple paper holder is needed such as that described in Method A above. (See opposite.)

The procedure is:

1. Set up the slide projector and the paper holder so that the required size of final image is obtained on the white hardboard. Clamp a strip of wood behind the holder to act as a reference mark.

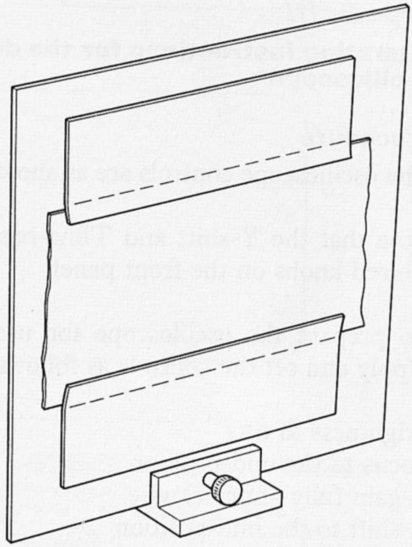
2. Switch off the projector, place the paper in the holder (shiny side facing glass) and hold the paper holder in correct position.

3. Cover the lens of the projector with card, switch on the projector and expose the paper for 1 second.

4. Remove the paper, develop and wash. If the print is suitable, fix it.

5. If the print is under-exposed, increase the exposure time until a satisfactory print is obtained.

6. If the negative is of a free fall, several copies may be made at once by masking the paper so that only the relevant strip falls on it, exposing in that position, then moving the paper (in its holder) about $1\frac{1}{2}$-in strip widths and exposing again, and so on.



Appendix III

Operating instructions for the demonstration oscilloscope*

Procedure

The oscilloscope controls are as shown in the diagram.

Note that the Y-shift and Time-base Variable controls are the red knobs on the front panel.

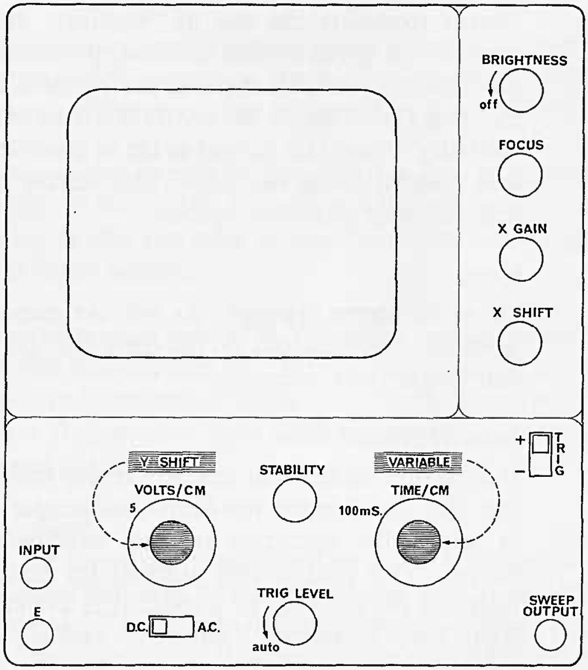
To prepare the oscilloscope for use, plug into the mains supply and set the controls as follows:

Brightness to OFF
Focus to the mid-position
X-gain fully anticlockwise
X-shift to the mid-position
Trig control to +
Time-base: time/cm control to 1 ms
Time-base: variable control fully clockwise
Stability control fully clockwise
Trig level control fully clockwise
Amplifier: volts/cm control to 0·5
Y-shift to the mid-position
Input switch to d.c.

Switch on by means of the Brightness control. After warming up for about 1 minute, turn 'Brightness' clockwise until a trace appears and set the control so that the trace is clearly visible but not excessively bright. If no trace appears, leave the 'Brightness' in the fully clockwise position, and adjust 'X-shift' and 'Y-shift' until the trace appears. This is best done by rotating 'X-shift' backwards and forwards whilst slowly advancing 'Y-shift' from the fully anticlockwise position. Immediately the trace is found, reduce 'Brightness' to a convenient level.

Now centre the trace with the 'X-shift' and 'Y-shift' controls, and adjust 'Focus' to give a sharp trace.

* 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 maker's instructions.



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 a 50-cps wave-form and then exploring the action of the various controls (excepting 'Stability' and 'Trig Level' controls which are set by the above procedure).

A possible routine for those unfamiliar with such instruments is to put 2–4 volts, 50 cps a.c. on the input – change volts/cm back to 5, turn variable time-base control (the red knob) fully anticlockwise and then back to the calibrated position (fully clockwise), change time-base to $100\mu S$, return to 1 ms, change Trig + to — (if the sine curve trace is not inverted by this, turn the Stability control very slightly anticlockwise until it is). Further work should bring increasing confidence.

Details regarding the use of 'Stability' and 'Trig Level' controls are given in the oscilloscope handbook. For most experiments – and all those in the Nuffield O level course – the 'Trig Level' can be left at AUTO. To give a steady trace, the 'Stability' should be turned as far as possible counter-clockwise without losing the trace. This setting may vary a little with different time-base speeds.

Note

To avoid screen damage, do not use excessive brightness. With the time-base off, do not leave the spot in a fixed position longer than necessary.

Esso-Nuffield Film

It is recommended that teachers might find it helpful to see the film for science teachers *Oscilloscopes and slow A.C.* in which the operation of this oscilloscope is demonstrated. This film is only suitable for teachers and is not intended for showing to pupils. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

Further details on the oscilloscope

X-input

The time-base should first be switched off by turning the Variable control fully counter-clockwise to the OFF position. A.C. inputs may then be connected to the X-input and sockets on the back of the oscilloscope. (*Note.* The socket on the back and the E terminal on the front are connected internally). The X-GAIN control will give a variation of 2:1 in the amplification. The spot will be deflected horizontally to the full screen width by a.c. voltages between 3 V r.m.s. and 6 V r.m.s. The sensitivity varies from 2 V/cm to 1 V/cm.

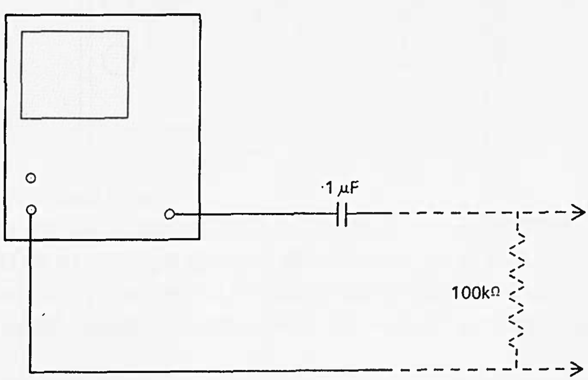
(There is no direct coupling between the X-INPUT socket and the cathode ray tube so that d.c. inputs will give only momentary deflections.)

Z-input
If a sine wave or square wave input is connected between the Z-INPUT and E sockets on the back of the oscilloscope, the brightness of the trace may be varied by these inputs.

With sine wave inputs at least 20 V r.m.s. is needed at a frequency of 50 c/s: this reduces to 1 V r.m.s. at 20 kc/s. It is necessary to dim the trace so that the variation in brightness may be easily noticed.

With square-wave inputs 30 V peak to peak is necessary at 50 c/s and this reduces to 2 V peak to peak at 20 kc/s. The variation in brightness is much clearer with square waves and with low frequencies, quite sudden increases or decreases in brilliance can be seen.

Sweep output
When the time-base is switched on a p.d. corresponding to the X deflection may be taken from the 'sweep output' and E terminals. The potential of the 'sweep output' terminal varies from about +40 V, when the trace is on the left of the tube, to about +20 V when the trace is on the right. Too much current should not be taken, unless distortion of the time-base is permissible. As a rough guide, the time-base will not be affected if a 0·1μF capacitor (to block the d.c. component) is connected in series with the sweep output and the load resistance is not less than 100 kΩ. At some sweep speeds, much more current may be taken.



It is easiest to see if the load circuit is distorting the time-base by unplugging it momentarily.

The sweep output may be used for triggering any transient effect repeatedly so that a steady pattern occurs on the tube. An example of this is the velocity of sound measurement in Experiment 93b.

It is also interesting, and helps to understand the operation of the time-base, to connect the sweep output of one oscilloscope to the Y-input of a second oscilloscope.

Appendix IV

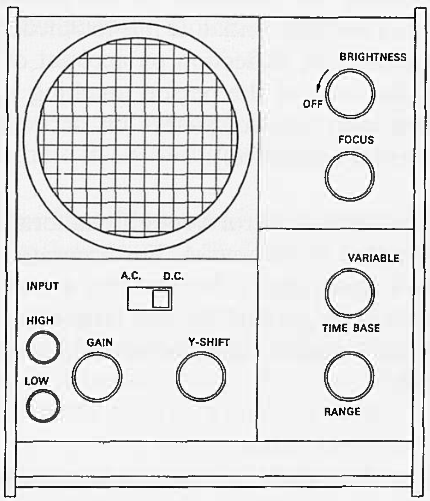
Operating instructions for the class oscilloscope*

Procedure

The oscilloscope controls are as shown in the diagram.

To prepare it for use, plug into the mains supply and set the controls as follows:

Brightness to OFF
Focus to the mid-position
Y-shift to the mid-position
Y-gain to 1 division/volt
A.C.–D.C. switch to D.C.
Time-base range switch to 2
Time-base switch to OFF



Brightness and focus

Switch the oscilloscope on by means of the brightness control. After allowing a quarter of a minute for the oscilloscope to warm up, turn the brightness control clockwise and move the Y-shift control gently about its central position until a

* The details and operating instructions given here refer to the Telequipment Serviscope Minor cathode ray oscilloscope, which was the instrument used in the Nuffield O-level Physics trials. For other instruments, these details should be read in conjunction with the maker's instructions.

trace appears. Then adjust the brightness and focus controls until a clear, sharply focused trace is seen. (With the time-base switched off, do not allow the spot to be too bright.)

It may be found impossible to obtain a sharp focus when the brightness control is set near maximum and, if this is the case, the brightness control should be turned anticlockwise until a sharp focus is obtained.

Input

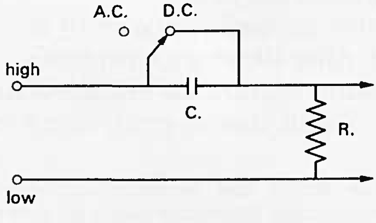
The input terminal labelled 'low' should normally be connected to the part of a circuit, if any, which is at earth potential. (As the terminal is not directly connected to earth it does not matter if it is connected to a point which is above earth potential.)

The input terminal labelled 'high' is sensitive and should normally be connected to the part of the circuit which is above earth potential. If it is touched, the spot will often show considerable deflection on account of the high a.c. potential of the body of the person touching it. (This is not normally seen with a.c. voltmeters on account of their much lower internal resistance.)

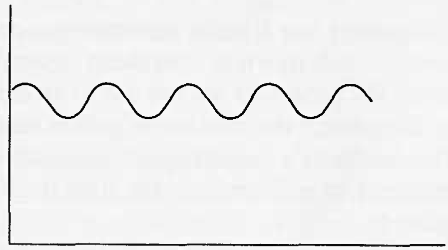
The 'Gain' control is roughly calibrated; the markings are not intended to be precise. For accurate readings of voltage, the calibration should be set with a moving-coil voltmeter connected in parallel to the terminals. The numbers on the 'Gain' control indicate approximately 'scale divisions per volt'.

A.C.–D.C. switch

The A.C.–D.C. switch should normally be set to D.C., even when the oscilloscope is used for a.c. work.



In the A.C. position there is a capacitor in series with the input and this will separate the a.c. component from a waveform such as:



The A.C. position of the switch should be used only for this purpose.

When the oscilloscope is used for pure a.c., setting the switch to 'A.C.' will cause a smaller deflection at very low frequencies because of C and R. This is another reason for not using it except for the purpose indicated above.

Time base

When the time-base is switched off the spot is automatically centred and there is no X-shift control.

When the time-base is switched on, the *speed* of the spot is determined by the setting of the 'Range' and 'Variable' controls. However, the *frequency* of repetition of the time-base is not much increased at the higher speeds and the time-base is often interrupted by slow changes of the input voltages. For these reasons it is better to have the time-base off when the oscilloscope is being used as a d.c. voltmeter.

When an alternating voltage is connected to the input, it automatically triggers the time-base and gives a very steady trace.

Esso-Nuffield Film

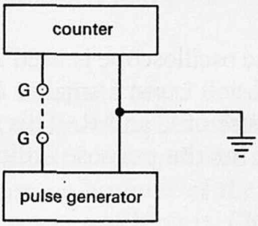
It is recommended that teachers might find it helpful to see the film for science teachers *Oscilloscopes and slow A.C.* in which the operation of this oscilloscope is demonstrated. This film is only suitable for teachers and is not intended for showing to pupils. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

Appendix V

Details on the operation of the scaler as a timing device*

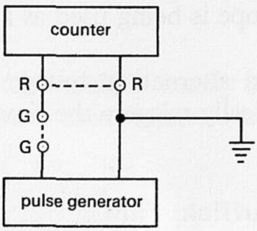
The scaler has a pulse generator producing 1,000 pulses per second built into it so that it can be used as a timer. The pulses from the generator are led out to an external switch and back to the scaler; the number of pulses received are recorded. As the oscillator's frequency is 1 kilocycle/second, the scaler will measure in milliseconds the time during which the switch is closed.

In essence, the scaler works as follows:



When the connection between the two terminals G, G (coloured green on the face of the scaler) is closed, the scaler starts counting. When the connection G, G is opened again, it stops.

On the scaler there are also two additional terminals R, R (coloured red) which in essence, if not in detail, operate as follows:



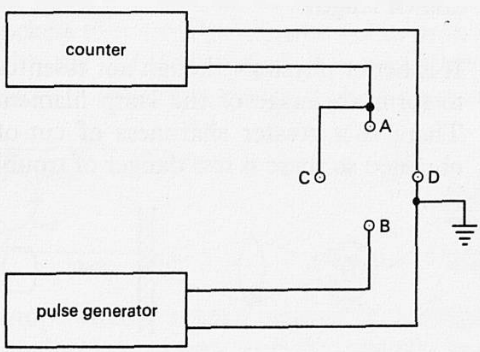
* The details given here refer to the Panax scaler SA 102 ST which was used in the Nuffield trials. Other scalers can be used – see item 130/1 in the Nuffield Physics *Guide to Apparatus*. The details given should be applicable to all the scalers appearing in the list of approved apparatus, though there may be some relatively trivial changes in such details as colour of terminals, etc.

If G and G are connected, the scaler counts the pulses. If R and R are *then* connected, it stops counting. In both this and the former arrangement, the clock is started on a 'make'. But in the former, it was stopped by *breaking* the G–G connection, whereas in the latter it was stopped by *making* the R–R connection.

If it is desired to start the clock on a break instead of a make, the G–G sockets are connected as are also the R–R sockets. Breaking the R–R connection starts the clock. It can be stopped either by breaking the G–G connection or making the R–R connection, There is thus considerable versatility in the instrument as a timing device.

Connections on the panel of the scaler

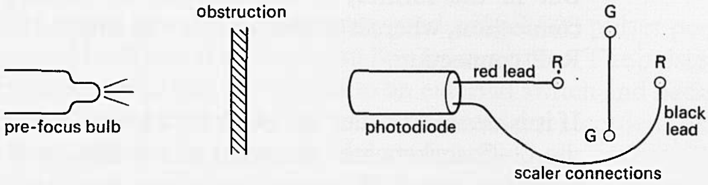
It is probably helpful to teachers to appreciate that points A and C are connected internally to each other and to the counter. D is connected to the earth and the chassis, while B is connected to the oscillator.



Timing accessories

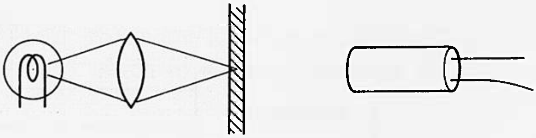
To measure trolley speeds with the scaler we use small photodiodes illuminated by light from small pre-focused torch bulbs. The bulbs operate from a 2·2-volt a.c. supply (which can be obtained from the rear of the scaler).

When the light is shone on to the photo-diodes, they conduct. When the light is cut off, they cease to conduct sufficiently and in essence the circuit is broken. (*Caution:* With weak illumination the scaler will count some but not all the pulses from the pulse generator and give false readings.)



If the photo-diode is set up with connections to the scaler as shown, an obstruction passing between it and the lamp breaks the R–R connection and the clock starts. When the obstruction is removed, the clock stops. Thus the time-of-passage of a trolley past the photo-diode can be measured by this 'clock' in milliseconds. In practice we do not make the trolley itself obstruct the light, but let it carry a sheet of cardboard of known length, to obstruct the light. Then the scaler gives the time in milliseconds taken by the trolley to travel that known length.

It is better physics – though not essential here for precision – to form an image of the lamp filament at the obstruction. There is a greater sharpness of cut-off and more light is obtained so there is less danger of trouble from stray light.

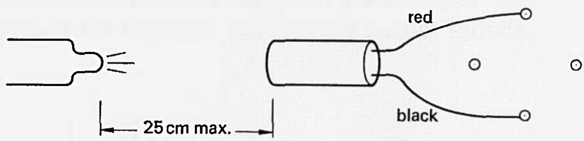


Such an arrangement is not, however, essential for the success of this experiment.

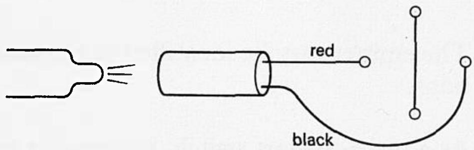
It is also possible to use two photo-diodes in series each with its own lamp. See below.

Use of Photo-diodes

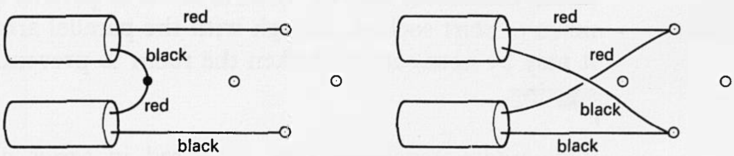
When a photo-diode is used as a make-to-start switch, the red lead should go to the top socket and the 2·2-volt lamp should not be more than 25 cm away:



When a photo-diode is used as a make-to-stop switch, the red lead should go to the left-hand socket. The 2·2-volt lamp should not be more than 5 cm away.



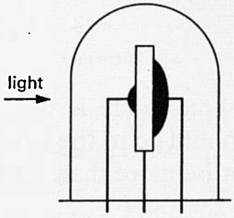
When the two photo-diodes are used together on the same pair of sockets they may be wired in series or in parallel but always with the red lead towards the top socket or towards the left-hand socket. Two photo-diodes in series used as a



make-to-stop switch are rather insensitive. Stronger illumination may help (for example, two illuminants, item 47, with lenses), but it is easier to use two photo-transistors as described below.

Use of photo-transistors, type OCP 71

Photo-transistors may be used in the same way as photo-diodes and it will be found that they are more sensitive, particularly as make-to-stop switches. Only the emitter and the collector are used; the base is left disconnected. The light should fall on the emitter junction for maximum sensitivity.



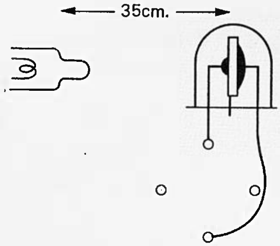
The emitter may be identified as the smaller of the two junctions.

As a make-to-start switch, the emitter goes to the top socket and the light may be up to 35 cm away. (See diagram opposite.)

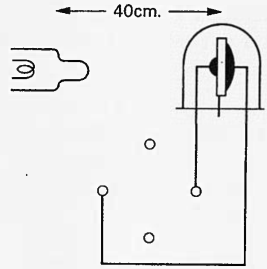
As a make-to-stop switch, the emitter should go to the right-hand socket and the light may be up to 40 cm away. Two photo-transistors may be wired in series or parallel across the make-to-start sockets, though with the parallel arrangement it may be necessary to darken the room to prevent spurious starting.

Two photo-transistors may be wired in series across the make-to-stop sockets but not in parallel. In the latter case, the photo-transistors will stop the counter even in the dark.

In all cases the emitter should be towards the top socket, or towards the right-hand socket, as the case may be.



Make-to-start



Make-to-stop

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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.

Consultative committee

Chairman Professor Sir Nevill Mott, F.R.S.
Professor C. C. Butler, F.R.S.
N. Clarke
Professor J. C. Gunn
Sister Saint Joan of Arc
Professor R. V. Jones, F.R.S.
W. K. Mace
J. M. Osborne
Dr C. W. W. Read
The Rev. R. G. Wickham

Organizer

Professor E. M. Rogers

Associate organizers

J. L. Lewis
E. J. Wenham

Assistant organizer

D. W. Harding

Area co-ordinators

Sister Saint Joan of Arc
Miss D. J. Alexander
Miss A. Lipson
Dr H. F. Boulind
B. R. Chapman
D. C. F. Chaundy
M. J. Elwell
L. Ennever
R. C. Hardwick
R. D. Harrison
V. J. Long
E. W. Tapper
C. L. Williams

Schools collaborating in the trials

The Abbey School, Ramsey
Ashfield County Secondary School

Banbury Grammar School
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Barnard Castle School
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Valley Gardens Modern School, Whitley Bay

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Westminster School
Whitley Bay County Grammar School
City of Worcester Grammar School for Girls

Organizer Professor E M Rogers
Associate organizers J L Lewis E J Wenham
Assistant organizer D W Harding

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