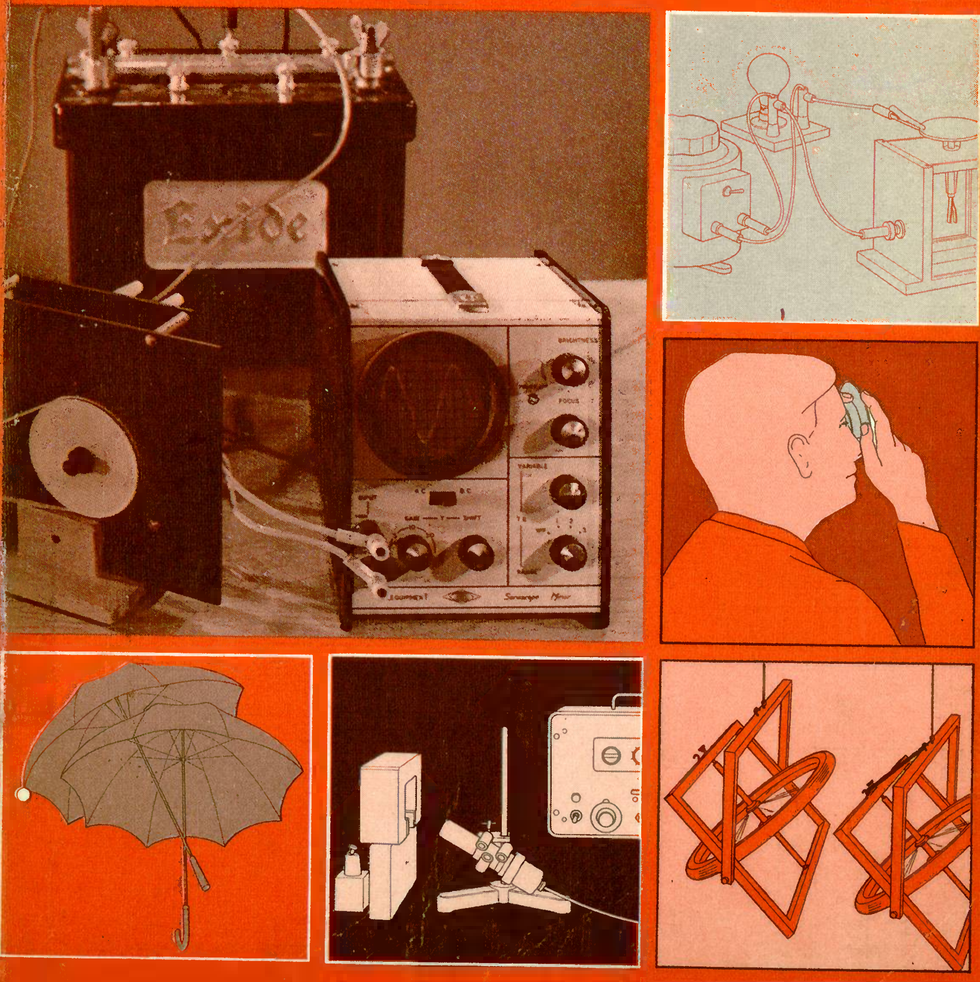
PHYSICS

Guide to experiments V



Nuffield Physics Guide to Experiments 5

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Nuffield Physics
Guide to Experiments
5

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Foreword

This volume is one of the many 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 fifth 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 V

Circular Motion and Electrons in Orbit

1	*Demonstration*	– CO_2 puck moving with constant velocity.
2	*Class Experiment/ Demonstration*	– The motion of the Moon around the Earth.
3	*Demonstration*	– Fine beam tube.
4	*Class Experiment*	– Whirling a small satellite.
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100	*Optional Class Experiment or Demonstration*	– Ripple tank experiment to illustrate measurements of wavelength frequency and speed.
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103b	*Class Experiment*	– Interference with corrugated cardboard wave model.
103c	*Class Experiment*	– Diffraction of light.
104	*Demonstration*	– Young's fringes with visible light.
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147	*Film*	– 'Matter Waves.'

Appendices

I Operating instructions for the demonstration oscilloscope.

II Operating instructions for the class oscilloscope.

III Details on the operation of the scaler as a timing device.

IV Electron diffraction.

V Experiments with a turntable.

1 *Demonstration*

CO_2 puck moving with constant velocity

Apparatus

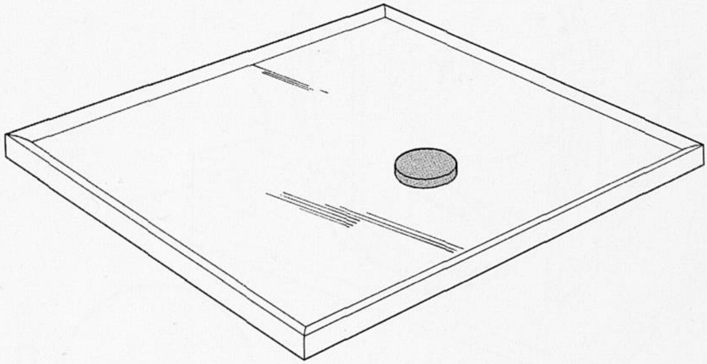
1 magnetic ring puck	– item 95C
1 glass plate	– item 95A
4 wedges	– item 95B
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2

Procedure

The glass plate is cleaned carefully with methylated spirit or window cleaning fluid and polished with a duster. It is carefully levelled with the wedges.

A small quantity of dry ice is made in the usual way using the CO_2 cylinder and dry ice attachment. It is put under the puck on the glass plate. The puck is given a gentle push.

It should be watched travelling *both* ways.



2 *Class experiment/demonstration*

The motion of the Moon around the Earth

Procedure

The pupils should realize that the Moon is going round the Earth. They should be encouraged to locate the Moon with reference to the star pattern. If possible they should follow its motion at different times on the same night and also at the same time on consecutive nights.

3 *Demonstration*

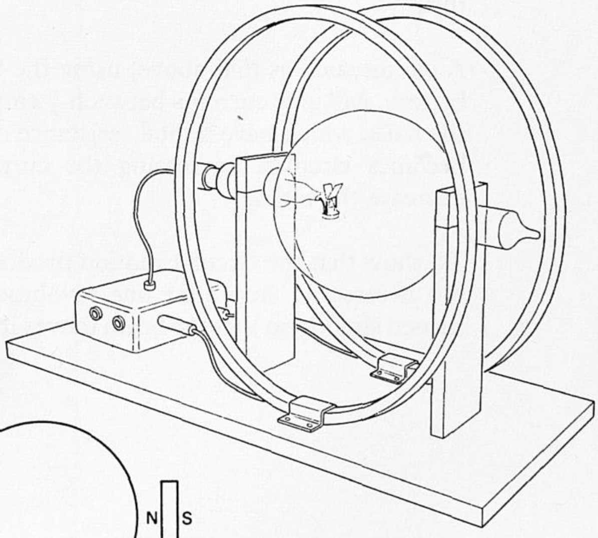
Fine beam tube

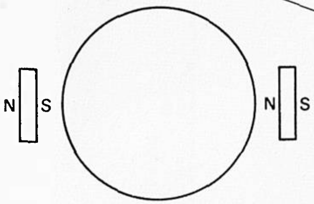
Apparatus

1 fine beam tube	– item 61
1 fine beam tube base	– item 62
1 H.T. power supply	– item 15
1 rheostat (10–15 ohms)	– item 541/1
1 battery	– item 176
2 magnadur magnets	– item 92B

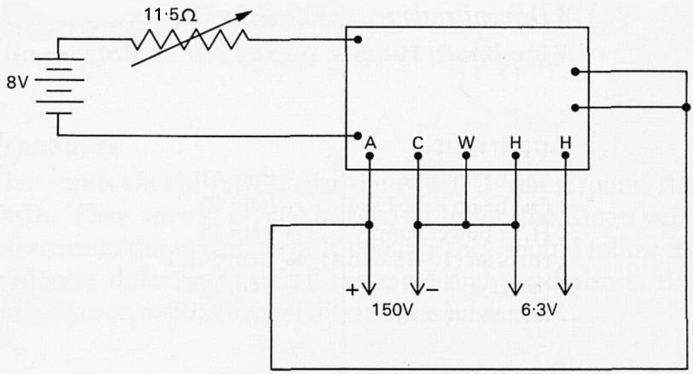
Procedure

This demonstration of the electron beam being deflected by a magnetic field into a circular path should be performed quickly to show an example of circular motion: measurements will be made later (see Experiment 24).





The fine beam tube is set up, as previously described (see Year IV Experiment 162). No voltage should be connected to the deflecting plates. These should both be connected to the anode. First a single bar magnet should be used to deflect the beam, then a pair of magnets as shown will give a bigger and more symmetrical deflection. (A pair of magnadur magnets give a good deflection.)



These demonstrations show that the beam is bent where the magnetic field is strongest – and that the bending is at right-angles to the motion of the beam. For steady bending a large uniform field is needed and the Helmholtz coils are used for this.

A circuit such as that above, using the 8 volt tapping on the battery, will give currents between $\frac{1}{2}$ amp and 2 amp through the coils, which have a total resistance of 4 ohms. The beam becomes circular. Increasing the current will be seen to decrease the radius.

To show that the circular motion produced by this field does not necessarily stop after one revolution, the tube may be turned slightly so that the beam moves in a spiral.

4 *Class experiment*

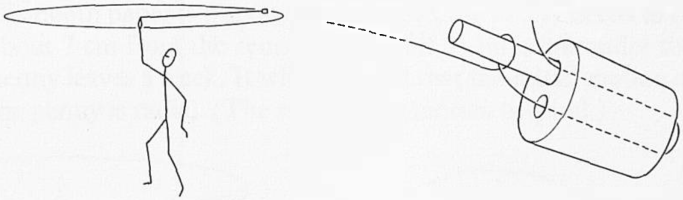
Whirling a small satellite

Apparatus

1 centripetal force kit – item 172
Also required: string

Procedure

The centripetal force kit includes a rubber bung which is convenient for this experiment and safer than whirling stones. With about 50 cm of string, the bung can be whirled round above the head.



5 *Demonstration*

Whirling a block and letting go

Apparatus

1 light wooden block
Also required: string

Procedure

A piece of string about 1 metre long is tied round the wooden block. It is swung round in a circle with a radius about 50 cm horizontally above the teacher's head. At the moment when it is nearest to the class it is suddenly released so that it travels tangentially towards the side of the room.

6 *Demonstration or home experiment*

Penny on a turntable

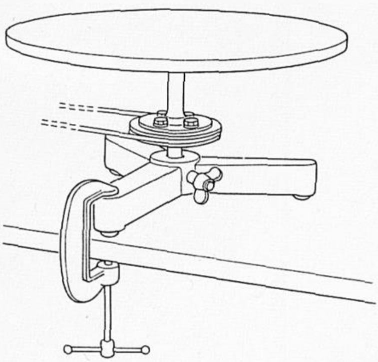
Apparatus

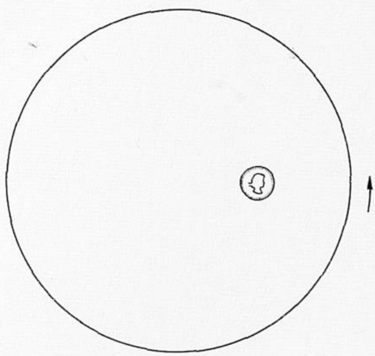
1 turntable – item 154/1
1 penny

Procedure

The penny is put near the centre of the turntable (a gramophone turntable is satisfactory; it need not be a special turntable) and the speed is increased to over 1 revolution per second – to, say, 78 rev/min.

If smooth paper is put on the turntable, the penny needs to be about 7 cm from the centre to slide off. A little ink under the penny leaves a track. It will be found that the initial motion of the penny is radial. (The subsequent motion is spiral.)





7 Class experiment

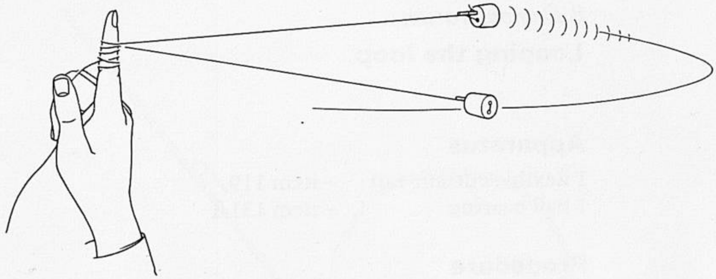
Whirling 'stone' with string winding up round finger

Apparatus

1 centripetal force kit – item 172
Also required: string

Procedure

The pupils attach the rubber bungs from the centripetal force kit to the string and whirl the bungs fairly gently above the head. The string is then allowed to wrap round a finger. If the bung is whirling slowly at first, the increase in speed is more apparent.



8 *Demonstration*

Looping the loop

Apparatus

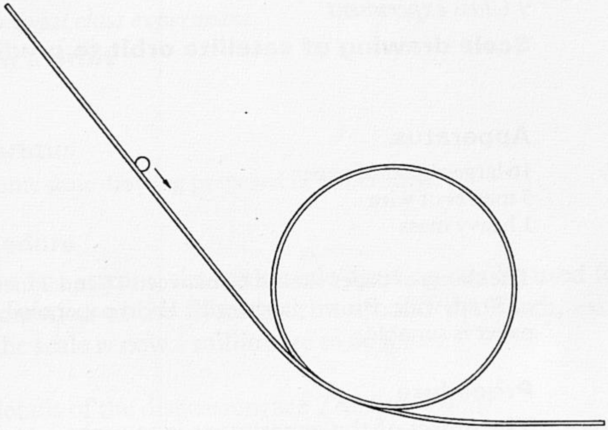
1 flexible curtain-rail – item 119
1 ball bearing – item 131A

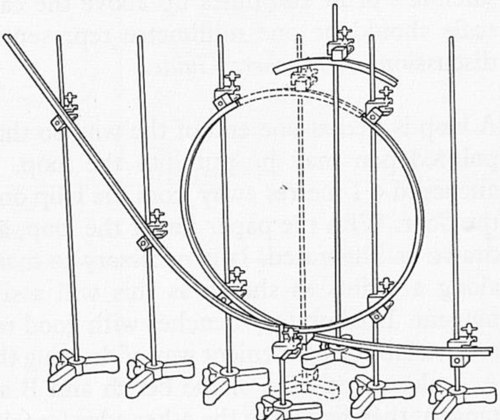
Procedure

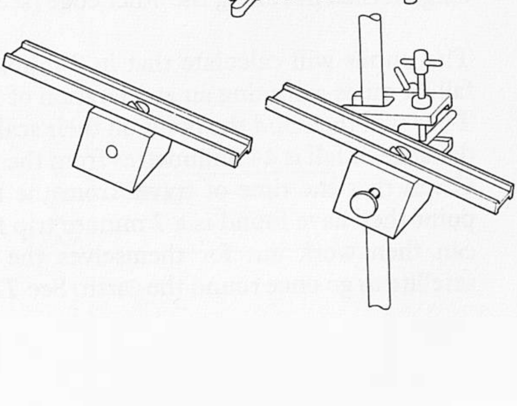
Bend the curtain-rail so that the ball bearing can 'loop the loop' after being released at the top of the rail. It can be done with a curtain-rail 8 ft long, but it is more effective with a 10 ft length, even a 12 ft one.

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 × $1\frac{1}{2}$ in × $1\frac{1}{2}$ 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-head as it goes round the rail). The blocks could be drilled so that the holes fit the end of clamps attached to retort stands with bosses (see illustration). Alternatively, 6 in nails can be put through the holes in the blocks.







9 *Class experiment*

Scale drawing of satellite orbit to predict period

Apparatus

16 large sheets of paper
5 metres of wire
1 heavy mass

The sheets of paper should be between $1\frac{1}{2}$ and 2 metres long and 20 to 30 cm wide. Brown paper, wide Hidri paper towelling, or lining paper is suitable.

Procedure

The object of the experiment is to make a scale drawing of a satellite's orbit 100 miles up above the earth's surface. The scale should be one millimetre representing one mile. For discussion see *Teachers' Guide*.

A loop is tied at one end of the wire so that a pencil or ball-pointed pen may be put into the loop. The wire is then anchored 4·1 metres away from the loop on a flat bench or on the floor. With the paper under the loop, an arc of a circle is drawn as illustrated. It is necessary to mark two points A A along a radius as shown as this will assist in drawing the tangent. If laboratory benches with good rectangular corners are available, a convenient way of drawing the tangent is to put A A along one edge of the bench and B at the corner. The tangent then lies along the other edge (see diagram opposite).

The pupils will calculate that in 2 minutes, the satellite will fall 44 miles assuming an acceleration of 32 ft/sec per second. They will then find the point on their scale drawing where the distance of fall is 44 millimetres from the tangent to the circle. Given that the time of travel from the tangent point to the point they have found is a 2 minute trip for the satellite, they can then work out for themselves the time taken for the satellite to go once round the earth. See *Teachers' Guide*.

10 *Optional class experiment*

Moon's orbit

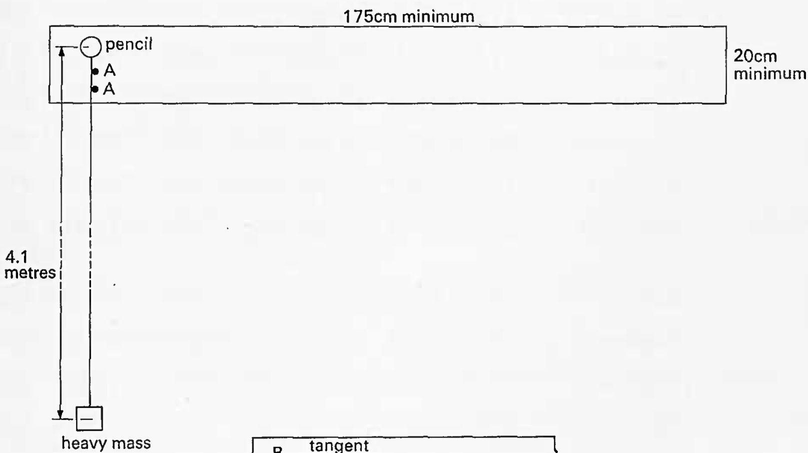
Apparatus

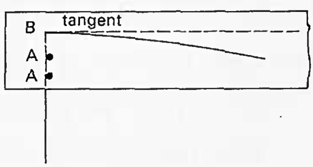
The same scale drawing prepared in Experiment 9.

Procedure

With a fast stream, the same scale drawing can be used for a consideration of the Moon's orbit around the Earth, except that the scale is now 1 millimetre to 60 miles.

For details of the discussion, see *Teachers' Guide*.





11 *Demonstration*

Data for Earth satellites

Procedure

The details in the following table should be displayed for the class to see.

Name	Launch date	Recovery date or estimated lifetime	Inclination of orbit to equator *(deg)*	Initial values *Period (min)*	*Lowest Point (km)*	*Highest Point (km)*
Sputnik 1	4 Oct 1957	4 Jan 1958?	65·1	96·2	215	939
Explorer 1	1 Feb 1958	10 years	33·2	114·8	356	2548
Luna 3	4 Oct 1959	29 Mar 1960?	73·8	22,700	40,300	476500
Tiros 1	1 Apr 1960	60 years	48·4	99·2	693	750
Discoverer 13	10 Aug 1960	14 Nov 1960	82·9	94·0	258	683
Echo 1	12 Aug 1960	7 years?	47·2	118·2	1524	1684
Sputnik 5	19 Aug 1960	20 Aug 1960	65·0	90·7	297	324
Samos 2	31 Jan 1961	15 years	97·4	95·0	474	557
Vostok 1	12 Apr 1961	12 Apr 1961	65·0	89·3	169	315
Mercury 6	20 Feb 1962	20 Feb 1962	32·5	88·6	159	265
Telstar 1	10 July 1962	10,000 years	44·8	157·7	952	5632
Syncom 2	26 July 1963	million years	33·1	1,454·0	35,584	36,693
Echo 2	25 Jan 1964	15 years?	81·5	109·0	1029	1,316
Nimbus 1	28 Aug 1964	20 years	98·7	98·4	429	937
Voskhod 2	18 Mar 1965	19 Mar 1965	64·8	90·9	167	475
Early Bird	6 Apr 1965	million years	0·1	1,437·0	35,003	36,606
Gemini 4	3 June 1965	7 June 1965	32·5	88·8	162	281
Asterix 1	26 Nov 1965	200 years	34·2	108·6	527	1,808
Gemini 7	4 Dec 1965	18 Dec 1965	28·9	98·8	215	321
Gemini 6	15 Dec 1965	16 Dec 1965	28·9	89·6	258	271

Acknowledgement is made to the Royal Aircraft Establishment for permission to use the data quoted above.

Notes

First Soviet artificial satellite. 83·6 kg. Transmitted for 21 days.

First U S satellite. 14·0 kg. Discovered inner Van Allen radiation belt.

Photographed hidden side of Moon during first orbit.

First weather satellite. Transmitted 22,952 cloud-cover photographs.

First successful recovery of ejected capsule. Landed in Pacific after 17 orbits.

First passive communications satellite. Inflated balloon, 30 metres diameter.

First Soviet recovery of satellite. Carried dogs for 18 orbits.

First retrograde orbit – launched against Earth's rotation.

First Soviet manned spaceflight. Yuri Gagarin. 1 orbit.

First U S manned orbital flight. John Glenn. 3 orbits.

First active repeater communications satellite.

First operating synchronous communications satellite; positioned over Indian Ocean.

Second balloon satellite; 41 metres diameter in near-polar orbit.

Second generation weather satellite.

First Soviet extra-vehicular activity. A. Leonov 'space-walk' for 10 minutes.

First commercial synchronous communications satellite; positioned over Atlantic midway between Africa and South America.

First U S extra-vehicular activity. Ed White 'space-walk' for 20 minutes.

France becomes third nation to launch its own satellite.

Longest manned spaceflight. F. Borman and J. Lovell. 330 hours 25 minutes.

Achieved rendezvous with Gemini 7, lasting for 4 hours. W. Schirra and T. Stafford.

12 *Class experiment*

Experimental test of $F=mv^2/r$

Apparatus

1 centripetal force kit	– item 172
16 stop watches or stop clocks	– item 507
string or cord	– item 10A

The kit contains sufficient to enable pupils to work in pairs.

Procedure

A piece of cord 1·5 metres long is tied to the wire hook. The other end is passed through the square indicator with two holes, through the glass tube and then through one hole of the bung. The end is then passed back through the other hole of the bung and anchored by plugging the hole with the wooden rod. Finally the string is hitched round the wooden rod. Alternatively, the string can be tied off.

Washers are slipped over the wire hook to provide the accelerating force. The square indicator is adjusted so that it will be just below the glass tube when the bung is at the required radius.

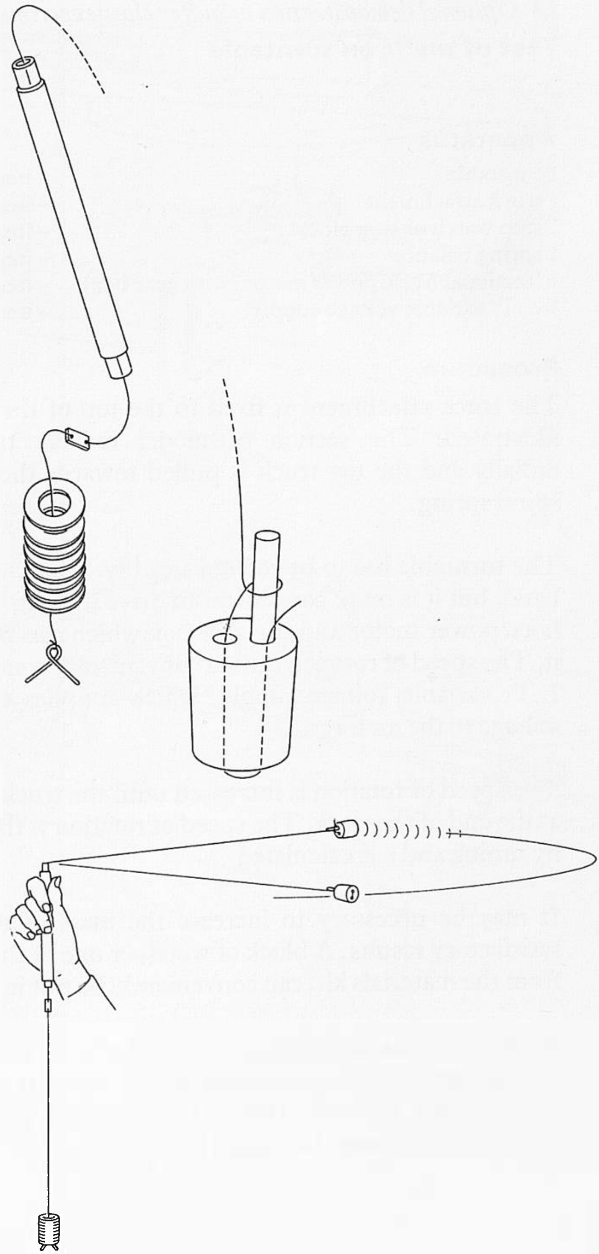
One pupil whirls the bung around his head, holding the glass tube in his hand and keeping the indicator just below the glass tube. The indicator will probably rotate when it is not touching the tube and this can be helpful in deciding whether it is clear of the tube or not. The other pupil times 50 revolutions with a stop watch.

The force F may be varied by adding more washers, up to 20 washers. The period T is deduced from the time for 50 revolutions. Knowing T and the radius r, v can be calculated. See *Teachers' Guide* for discussion.

Notes

1. In place of the square indicator, a paper clip can be used, but this is less convenient when rotating. The indicator is very inexpensive or can be easily improvised.

2. It is important to count 'nought' when starting counting revolutions (and not 'one').



13 *Optional demonstration or buffer class experiment*

Test of mv^2/r on turntable

Apparatus

1 turntable	– item 154/1
1 truck attachment	– item 154/2
1 stop watch or stop clock	– item 507
1 spring balance	– item 43
1 fractional horse power motor (with gear box)	– item 150
1 L.T. variable voltage supply	– item 59

Procedure

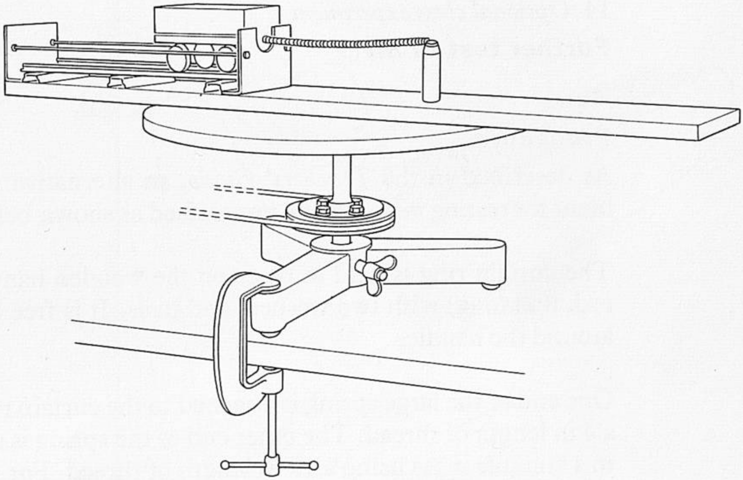
The truck attachment is fixed to the top of the turntable as illustrated. The section of model railway track extends radially and the toy truck is pulled towards the centre by a spiral spring.

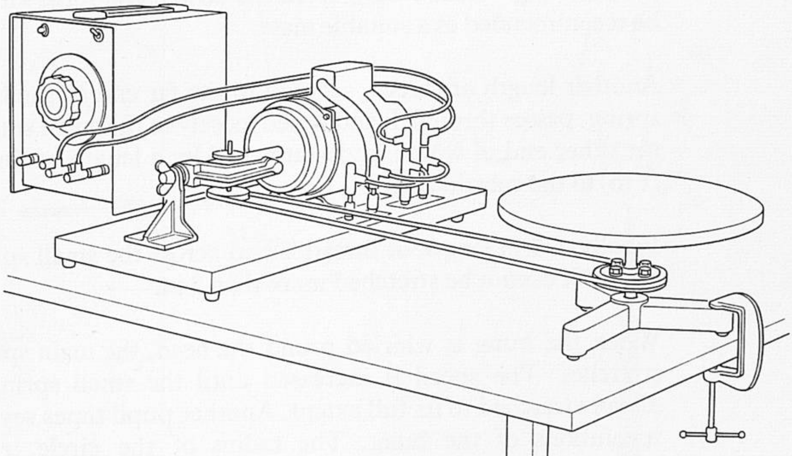
The turntable has to be rotated steadily. This can be done by hand, but it is more convenient to drive it using the fractional horsepower motor and the gear box which can be attached to it. The speed of rotation is then conveniently controlled by the L.T. variable voltage supply, which supplies the necessary voltage to the motor.

The speed of rotation is increased until the truck hits the stop at the end of the track. The speed of rotation is then measured by timing and v is calculated.

It may be necessary to increase the mass of the truck for satisfactory results. A block of wood, or one of the lead blocks from the materials kit, can conveniently be put in the truck.

With the turntable at rest, pupils measure the force which the spring applies when stretched to the full amount with the truck hitting the end. They do this using a spring balance. Then they compare that actual force with mv^2/r.





14 *Optional class experiment*

Further test of mv^2/r

Procedure

As described in the *Teachers' Guide*, an alternative arrangement for testing mv^2/r can be improvised as shown below.

The curtain ring is held in place on the wooden handle ($\frac{1}{2}$ in rod, 8 in long) with two washers and nails. It is free to rotate around the handle.

One end of the large spring is attached to the curtain ring with a 4 in length of thread. The other end of the spring is attached to a suitable mass using a 12 in length of thread. For safety, a rubber bung – item 172B – from the centripetal force kit can be recommended as a suitable mass.

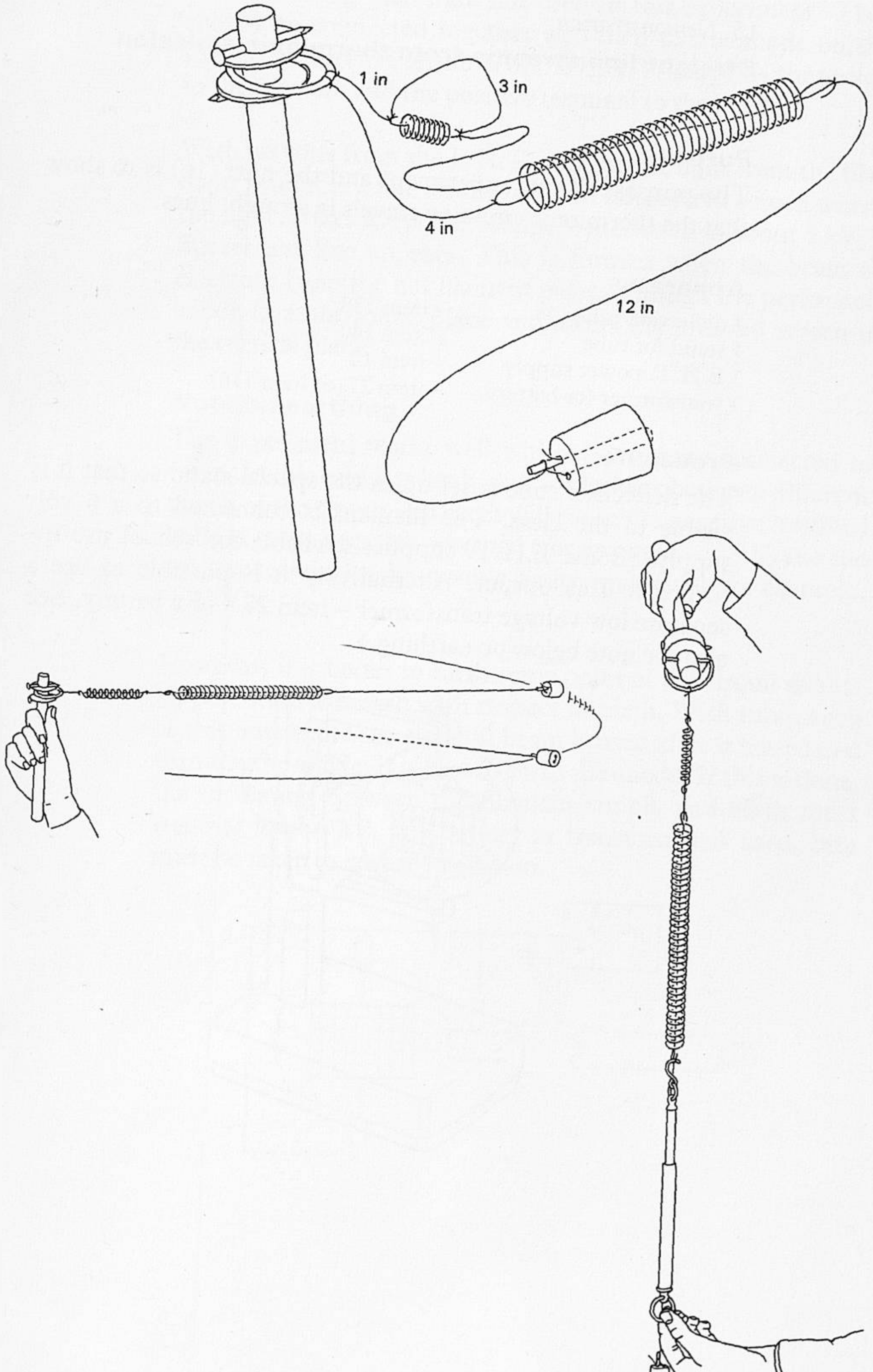
Another length of thread, secured to the far end of the large spring, passes through it and is tied loosely to the small spring, the other end of which is also attached by a length of thread (1 in) to the curtain ring.

Finally, a 3 in length of thread is tied across the small spring so that it cannot be stretched more than 3 in.

When the bung is whirled round the head, the main spring stretches. The speed is increased until the small spring is *almost* stretched to its full extent. Another pupil times several revolutions of the bung. The radius of the circle, r, is measured when the device is flat on the bench with the bung pulled outwards so that the small spring is stretched the same amount as when rotating. This enables v to be deduced.

By hanging the spring vertically – as in the diagram – and loading it with masses (or pulling on the spring with a spring balance) until the small spring is again stretched almost fully, the actual force F is found. And the radius of the circle, r, is measured in this position.

The mass of the bung is measured, and mv^2/r is calculated and compared with the measured value of F.


1 in
3 in
4 in
12 in

15 *Demonstration*

Straight line streams from thermionic emission

Purpose

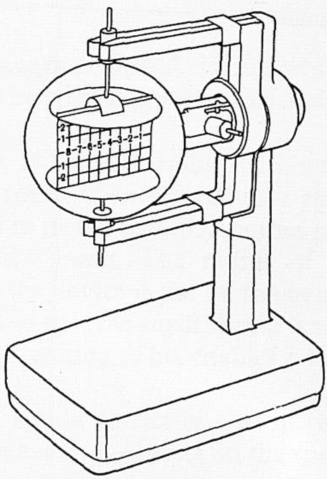
The purpose of this experiment and the next (16) is to show that the thermionic emission travels in straight lines.

Apparatus

1 deflection tube	– item 138
1 stand for tube	– item 140
1 E.H.T. power supply	– item 14
1 transformer (or battery)	– item 27 (or 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 volt supply. (Some E.H.T. supplies available for school use incorporate this output. Alternatively it is possible to use a separate low voltage transformer – item 27 – or a battery. See also the note below on earthing.)



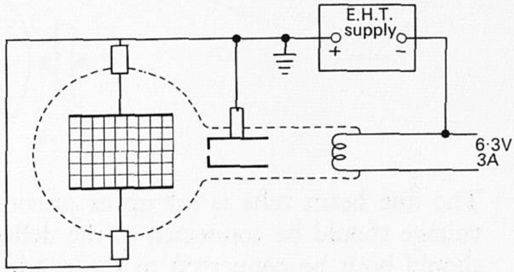
The deflecting plates are not used in this experiment. They should be connected together and then to the anode on the tube. The negative terminal of the E.H.T. supply is connected to the filament and the positive terminal to the anode.

With no volts from the E.H.T. supply, 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. This is formed when the beam of electrons from the hot filament passes through the perforated anode in a horizontal plane and meets the inclined screen in the vertical plane.

Note on earthing

The experiment works well without any point connected to earth. In this case it is likely that the leakage between different points of the circuit and earth will cause the negative terminal to be at some negative potential (for example, −1 kV) and the positive terminal to be at some positive potential (for example, +2 kV).

However, it is better to earth some point of the circuit so that all potentials are fixed with respect to earth. With tubes such as this one where the electron beam is used after it has passed through the anode, it is best to earth the anode. If this is done, the insulation between the filament supply and earth must stand at least 6 kV. If a battery or transformer is used, care must be taken to ensure insulation.



16 *Demonstration*

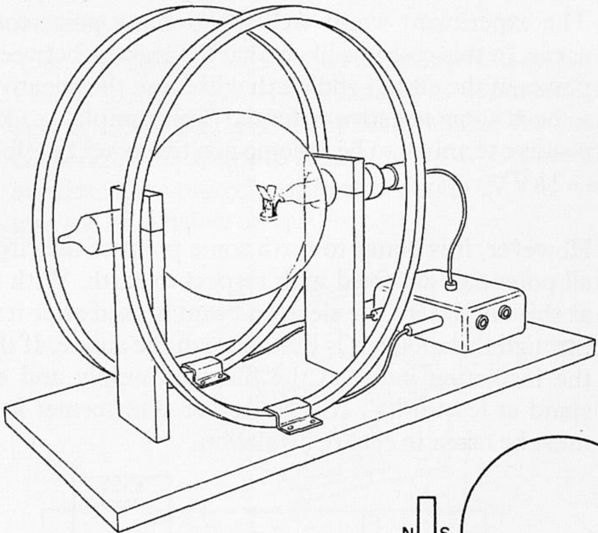
Fine beam tube

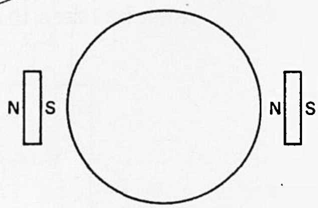
Apparatus

1 fine beam tube	– item 61
1 fine beam tube base	– item 62
1 H.T. power supply	– item 15
1 rheostat (10–15 ohms)	– item 541/1
1 battery	– item 176
2 magnadur magnets	– item 92B

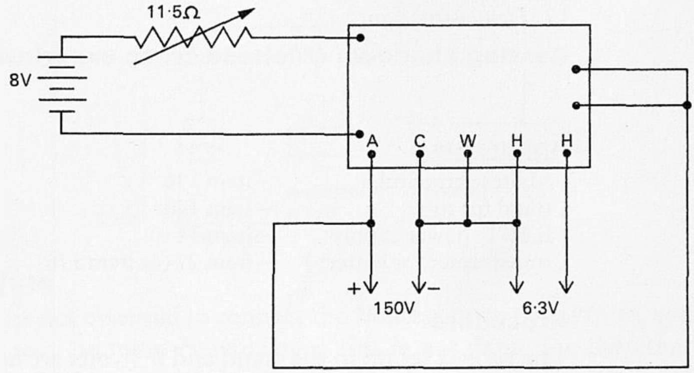
Procedure

This is a repetition of Experiment 3.





The fine beam tube is set up as previously described. No voltage should be connected to the deflecting plates. These should both be connected to the anode. First a single bar magnet should be used to deflect the beam, then a pair of magnadur magnets as shown will give a bigger and more symmetrical deflection.



For steady bending a large uniform field is needed and the Helmholtz coils are used for this.

A circuit such as that above, using the 8 volt tapping on the battery, will give currents between $\frac{1}{2}$ amp and 2 amp through the coils, which have a total resistance of 4 ohms. The beam becomes circular. Increasing the current will be seen to decrease the radius.

17 *Demonstration*

Casting shadows (Maltese cross experiment)

Apparatus

1 Maltese cross tube	– item 136
1 stand for tube	– item 140
1 E.H.T. power supply	– item 14
1 transformer (or battery)	– item 27 (or item 176)

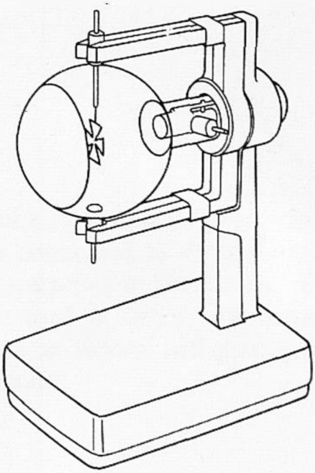
Procedure

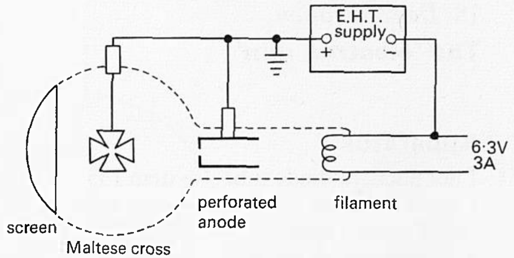
The tube is set up in the stand and 6·3 volts are applied to the filament to heat it. The positive terminal of the E.H.T. power supply is connected to the perforated anode and also to earth (see note on earthing in Experiment 15). The negative terminal of the supply is connected to the filament.

With no volts for 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.





Note

It is not essential to connect the Maltese cross to anything and it may be more convincing if this is not done. On the other hand, electrons hitting the cross will charge it negatively so that it repels electrons: this may even prevent the fluorescence from being seen at all. The fluorescence will reappear if the cross is momentarily connected to the anode. With some tubes, electrons hitting the cross cause other electrons to be emitted from the cross. These secondary electrons travel to the positive anode and keep the cross from becoming appreciably negative with respect to the anode.

If the cross is connected to the anode, the cross is at the same potential as the anode all the time. This arrangement may therefore be preferred.

Film

This experiment is demonstrated in the Esso-Nuffield film for science teachers *An Approach to the Electron*. This film is available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

18 *Demonstration*

The 'electron gun'

Apparatus

1 hot filament diode tube	– item 135
1 stand for diode	– item 140
1 H.T. power supply	– item 15
1 demonstration meter	– item 70
1 2·5–0–2·5 mA dial	– item 71/4

Procedure

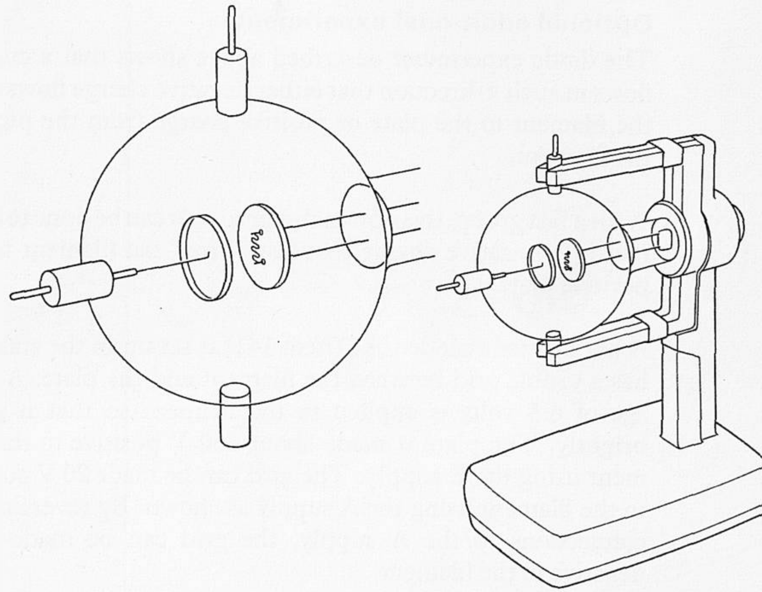
The purpose of this experiment is not to study the characteristics of a diode as was done in Year IV, but to explain the principle of an electron gun.

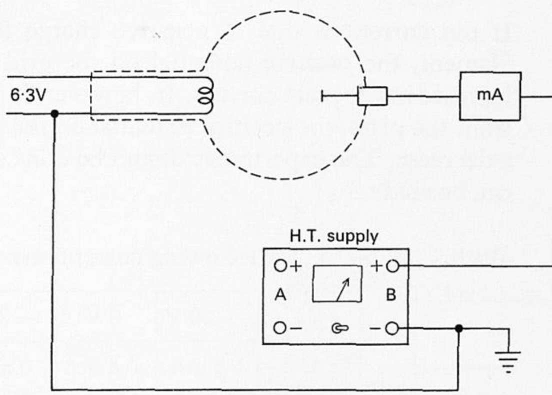
The diode tube is set up in the stand and 6·3 volts are applied to the filament.

The plate in the tube is connected through the demonstration meter (2·5–0–2·5 mA) to the H.T. power supply. The other terminal of the supply is earthed and connected to one of the filament terminals. The supply enables the plate to be at 400 volts either positive or negative relative to the filament.

It will be found that no current flows, whatever the p.d. across the tube, as long as the filament is not glowing. When the filament is glowing, a current flows if the plate is positive. If, however, the plate is negative, no charge flows.

With no p.d. across the tube a small current of about 50 A flows owing to the energy with which electrons are emitted from the filament (Edison effect). But this will probably not be noticed in the experiment described above.




6·3V
mA
H.T. supply
+
A
−
+
B
−

Optional additional experiment

The diode experiment described above shows that a current flows in such a direction that either negative charge flows from the filament to the plate or positive charge from the plate to the filament.

With a fast group, this optional experiment can be done to show that it is negative charge that flows from the filament to the positive plate.

A hot filament triode tube (item 141) is set up in the stand. It has a visible grid between the filament and the plate. A voltage of 6·3 volts is applied to the filament so that it glows brightly. The plate is made about 500 V positive to the filament using the B supply. The grid can be made 20 V positive to the filament using the A supply as shown. By reversing the connections to the A supply, the grid can be made 20 V negative to the filament.

If the current is due to negative charge flowing from the filament, the positive potential on the grid would cause an increase in the plate current. If, however, it is positive charge from the plate, the positive potential on the grid would cause a decrease. The experiment should be done so that a decision can be made.

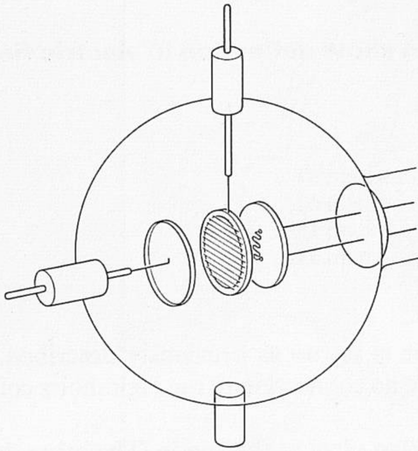
With $V_a = 500$ V, the following currents are typical:

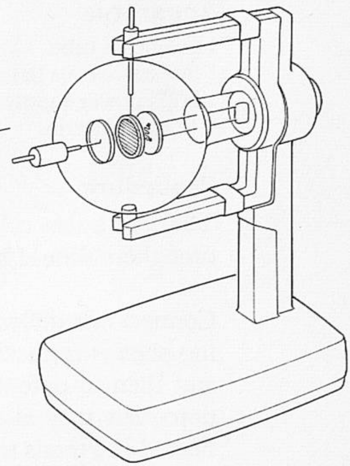
V_g	+ 20 V	0 V	− 20 V
I_a	1·5 mA	0·4 mA	0 mA

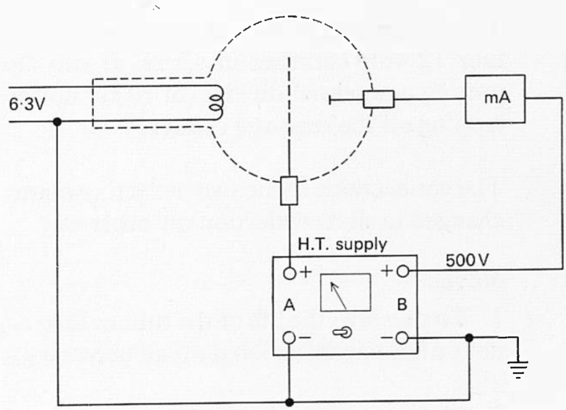
Note that if these experiments are done, they should be treated as a piece of detective work: looking for evidence and drawing conclusions. Millikan's experiment (by film, in Year IV) gave evidence of 'electrons', but *these* experiments do not say anything about the nature of charge, whether it is a fluid or whether it is particulate.

Esso-Nuffield Film

All the above experiments are shown in the Esso-Nuffield film for science teachers, *An Approach to the Electron*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.






6·3V
mA
H.T. supply
500 V
A
B
+
+
−
−

19a *Demonstration*

Fine beam tube to show deflection in electric field

Apparatus

1 fine beam tube	– item 61
1 fine beam tube base	– item 62
1 H.T. power supply	– item 15
4 12 volt batteries	– item 176

Procedure

The fine beam tube is set up as previously described. This time there should be no connection to the Helmholtz coils.

Connect one deflecting plate to the anode. The other deflecting plate is connected first to the anode to show no deflection and then to potentials up to —50 V to the anode. (Positive potentials may also be used but the beam is less easily deflected and tends to go out of focus.)

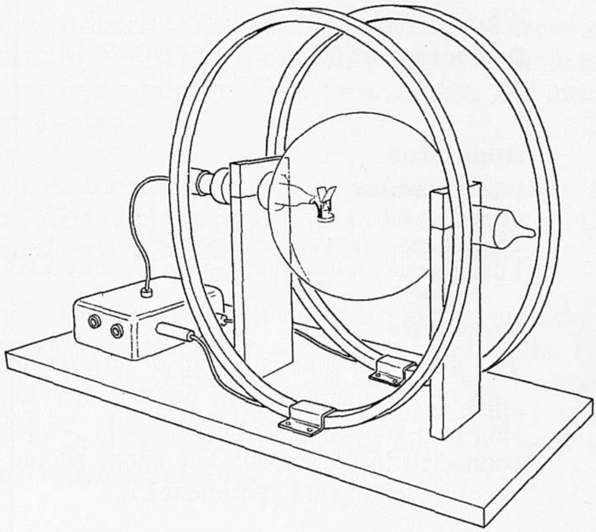
The deflecting voltage is most conveniently obtained from four 12 volt batteries in series. It can also be obtained by putting a potential divider (of 10 kΩ upwards) across AC and tapping off the required voltage.

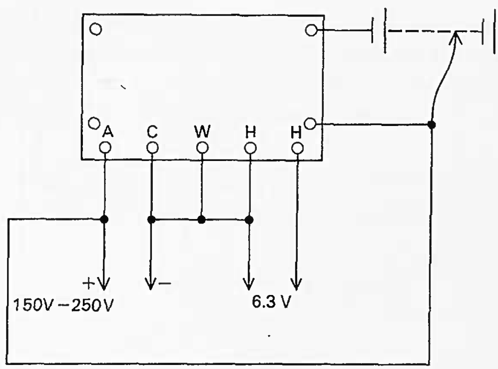
The connections to the two deflecting plates can then be interchanged to show deflection the other way.

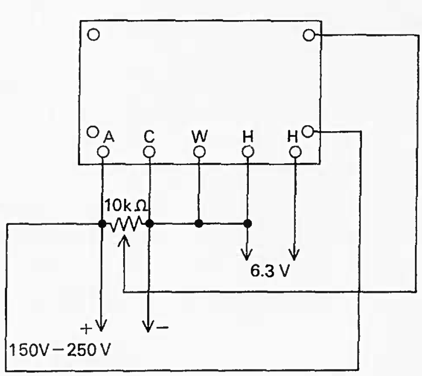
Notes

1. To preserve the life of the tube as long as possible, it should not be left operating longer than necessary.

2. Always switch the heater on first and only when it is glowing turn up the accelerating voltage on the anode.




A
C
W
H
H
+
−
150V − 250V
6.3 V


A
C
W
H
H
10kΩ
6.3 V
+
−
150V − 250 V

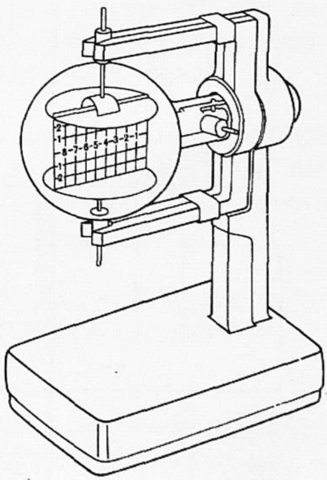
19b *Optional alternative demonstration*
Deflection of beam in electric field

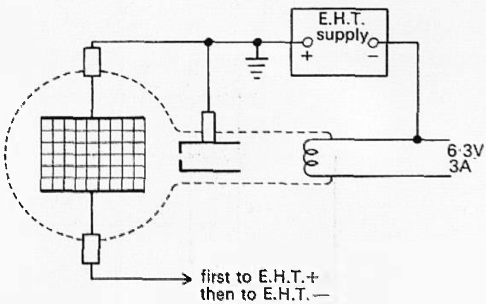
Apparatus

1 deflection tube	– item 138
1 stand for tube	– item 140
1 E.H.T. power supply	– item 14
1 transformer (or battery)	– item 27 (or item 176)

Procedure

The deflection tube is set up as in Experiment 15 with 6·3 volts on the filament. 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 (see note on earthing in Experiment 15).





With the E.H.T. supply turned off, 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.

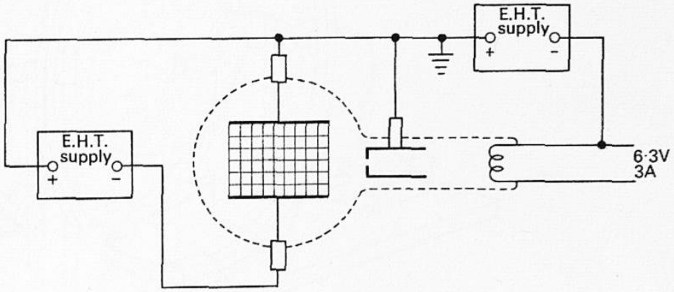
First both the deflecting plates should be connected to the anode. The beam will move in an enclosure at a uniform potential and the line on the screen will be straight.

Then, while one plate is left connected to the anode, the other plate is connected to the negative terminal of the E.H.T. supply. This produces a vertical electric field between the plates and consequently the beam is deflected into a parabolic path. Alternatively apply a potential difference from an insulated external source using a battery.

Note

With this simple arrangement, it is not possible to show 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 unaltered.

If two E.H.T. power supplies are available the following arrangement may be used to produce a variable deflection.



It is very important to earth the anode in this case. If the cathode were earthed, for example, there could be 10 kV between the positive terminal of the second power supply and the neutral side of its mains winding and this is likely to damage the insulation of the transformer.

The deflecting power supply can also be connected the other way round to make the deflecting plate negative to the anode.

20 *Demonstration*

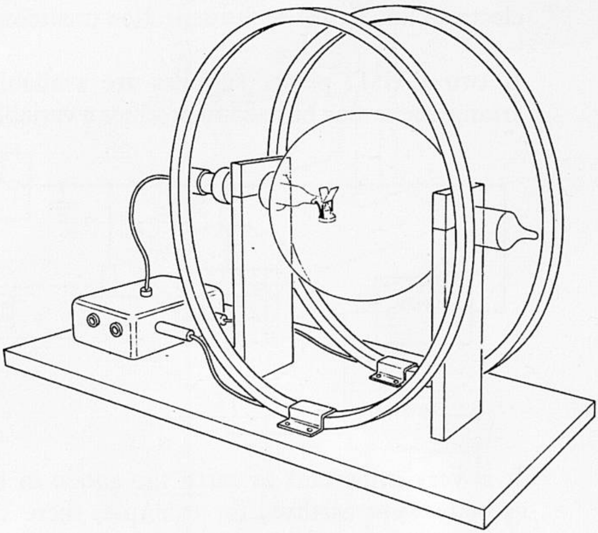
Fine beam tube to show deflection in magnetic field

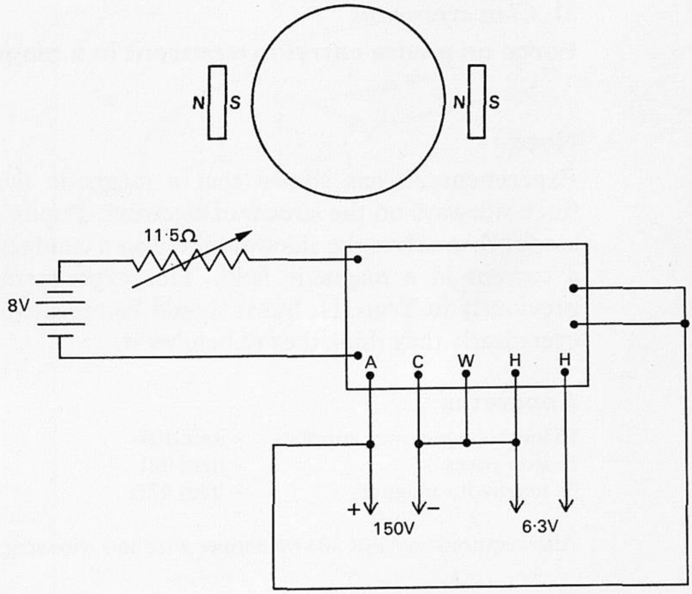
Apparatus

1 fine beam tube	– item 61
1 fine beam tube base	– item 62
1 H.T. power supply	– item 15
1 rheostat (10–15 ohms)	– item 541/1
1 battery	– item 176
2 magnadur magnets	– item 92B

Procedure

The fine beam tube is set up as previously described and Experiment 3 is repeated showing first the deflection of the beam when the magnadur magnets are brought near the tube. Then the battery is connected to the Helmholtz coils in series with the rheostat. This will send a current between $\frac{1}{2}$ amp and 2 amp through the coils which have a total resistance of 4 ohms. The beam will be seen to move in a circle.




N
S
N
S
11·5Ω
8V
A
C
W
H
H
+
−
150V
6·3V

21 *Class experiment*

Force on a wire carrying a current in a magnetic field

Note

Experiment 20 has shown that a magnetic field exerts a force sideways on the stream of electrons. Pupils should now see for themselves the sideways force on a conductor carrying a current in a magnetic field. This experiment was done previously in Year III, but it should be repeated here, however clearly they think they remember it.

Apparatus

16 low voltage power supplies	– item 104
16 iron yokes	– item 92I
32 magnadur magnets	– item 92B

Also required: reels of 26 swg copper wire and wire strippers

Procedure

Two lengths of 26 swg wire are stripped and attached to the low voltage power unit so that they project three inches from the unit and are parallel to each other.

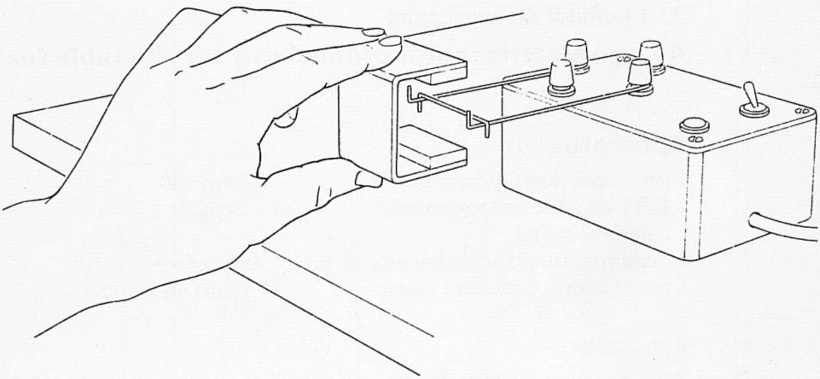
A 3 in length of stripped wire is laid across the projecting wires, as illustrated. It will help if the ends are turned down, as shown.

When the yoke with magnadur magnets attached is brought up, the wire lying across the fixed projecting wires will be projected along the rails. Repeat with the magnetic field reversed.

Alternatively, position the magnets first and then note the movement when the current is switched on.

Film

This experiment can be seen in the Esso-Nuffield film for science teachers *The Electromagnetic Kit*. This film is available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1. It is not suitable for showing to a class.



22 *Optional demonstration*

A large electric motor producing a considerable force

Apparatus

1 fractional horse-power motor	– item 150
1 L.T. variable voltage supply	– item 59
1 length of string	
1 demonstration spring balance (5 Kg)	– item 85
1 retort stand, boss, and clamp	– items 503–506

Procedure

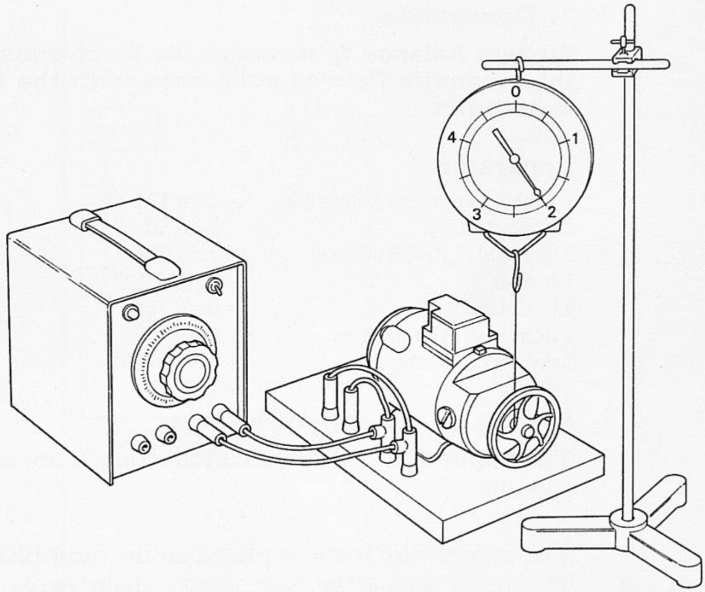
The purpose of the demonstration is to show that the rather small 'catapult' force seen in Experiment 21 is not trivial, but of great practical use, and that it can produce large forces.

A large commercial motor should be shown, or, failing that, the fractional horse-power motor could be shown operating with 12 volts d.c. from the L.T. variable voltage supply (or the 12-volt battery – item 176). The same voltage should be applied to both the armature and field terminals.

The demonstration of the motor can be made more vivid by showing the force it can exert when stalled. The string is anchored to the spindle of the motor by tying it to a spoke of the pulley wheel and wound several times round the spindle. The other end is attached to the demonstration spring balance which is suspended from a retort stand.

With a voltage of only 5 volts, the force on the spring balance is about $1\frac{1}{2}$ Kg wt.

Note that the motor should not be in this condition for long as it is being heated with about 50 watts of electrical power. Raise the voltage carefully to avoid overloading the power supply and the motor.


0
1
2
3
4

23 *Demonstration*

Current balance to measure the force constant for the magnetic field of coils used with the fine beam tube

Apparatus

1 Malvern current balance kit	– item 173
2 slotted bases	– item 30
2 rheostats (10–15 ohms)	– item 541/1
1 beaker	– item 512/2
2 batteries	– item 176
2 demonstration meters	– item 70
2 d.c. dials: 5 amp	– item 71/2

Setting up the current balance

The details of the Malvern current balance are as illustrated opposite.

The copper wire frame is placed on the razor blade contacts. The frame should be bent with a slight curve so that the fulcrums are about 5 mm above the ends of the wire.

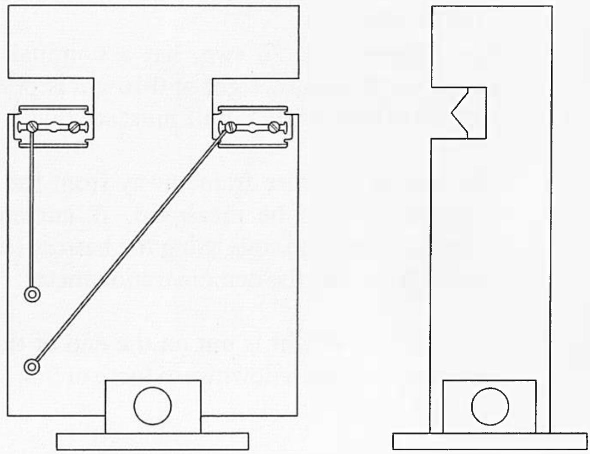
An O-BA washer is suspended by cotton from the end of the balance so that it hangs in water. This damps the balance. It is necessary to have a trace of Teepol in the water to reduce surface tension forces on the cotton.

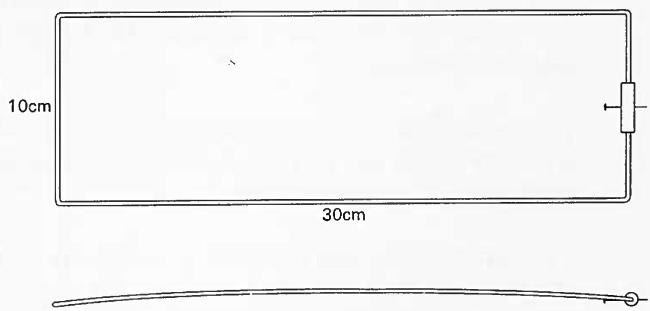
The wire frame is roughly balanced on the razor blades. A small rider of copper wire is then slid along the frame to bring the pin level with the point on the hardboard index.

Both the support for the frame and the support for the index are fixed in two of the slotted bases (item 30).

The end of the wire frame should be *inside* the gap so that the wire cannot move far from the horizontal: this will prevent the rider from slipping off.

It is helpful to push the wire frame sideways along each razor blade to cut a slight groove in the copper wire. This gives a better contact and prevents overheating of the thin knife edges of the blades.




10cm
30cm

Procedure

Bare copper wire, 26 swg, has a nominal mass of 1·46 gm per metre. A small weight of 0·10 gm is prepared from about 6·85 cm of such wire. Pupils must see that it is 0·1 gm.

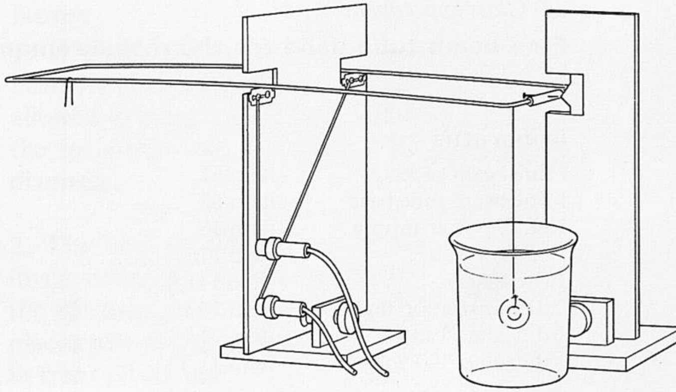
The end of the wire frame away from the pin is put in the magnetic field to be measured. A current of 2·5 amp is passed through the coils using the battery (item 176), rheostat (item 541/1), and the demonstration meter.

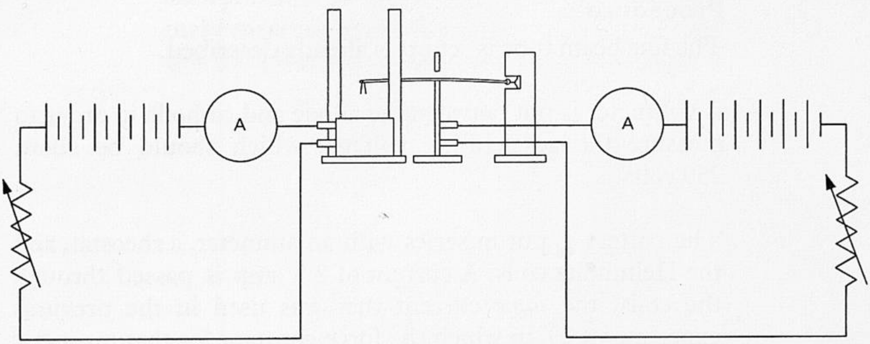
The 0·10 gm weight is put on the end of the wire frame at A and this produces a downward force of $9{\cdot}8 \times 10^{-4}$ newtons on the wire.

A second battery is connected in series with a second rheostat, another meter, and the terminals of the current balance. A current flows round the frame via the razor blade contacts. This current is increased until the upwards force on the wire just equals the downwards force of the weight so that the balance is restored.

The connections to the terminals may have to be changed over if the current in the wire produces a downward force on the frame and not an upwards one.

The current I through the frame is noted, the length l of the end of the frame is measured, and thus the force constant B is deduced for the given coils since $BIl = 9{\cdot}8 \times 10^{-4}$.




A
A

24 *Class experiment*

Fine beam tube used for the measurement of *e/m*

Apparatus

1 fine beam tube	– item 61
1 fine beam tube base	– item 62
1 H.T. power supply	– item 15
1 battery	– item 176
1 rheostat	– item 541/1
2 demonstration meters	– item 70
1 d.c. dial: 5 amp	– item 71/2
1 d.c. dial: 300 volts	– item 71/11

Procedure

The fine beam tube is set up as already described.

A voltmeter is put between the anode and cathode in order to measure the accelerating voltage, which should be about 250 volts.

The battery is put in series with an ammeter, a rheostat, and the Helmholtz coils. A current of 2·5 amp is passed through the coils, the *same* current that was used in the previous experiment, 23, in which the force constant for that magnetic field was determined. The beam will be bent into a circle.

Each group of pupils should measure the diameter D and then deduce a value for e/m.

To measure D, simply hold a ruler outside the tube. In the darkened room, the ruler should be illuminated. (A Perspex ruler with a small electric lamp taped to one end – and covered with masking tape so that no direct light emerges – works well.)

Theory of the experiment

See the *Teachers' Guide*.

Experiment 23 will have found a value for B and using $Bev = mv^2/r$ and $eV = \frac{1}{2}mv^2$, e/m is deduced.

Notes

1. It is helpful if pupils practise measuring the diameter of the beam by measuring the diameter of a wire loop without being allowed to bring the wire loop near to the rule. Practice with the loop will save time when they all measure the beam diameter.

2. The best modification so far produced forms a *virtual* image of an illuminated scale inside the tube, in the plane of the electron stream. A vertical sheet of clean plate glass is placed just in front of the tube. An illuminated scale is placed in front of the sheet at such a distance that the image of the scale, behind the sheet, is in the middle of the tube. This does make measurements easier; but we do not recommend adding this complication except with a very fast group.

25 *Demonstration*

Measurement of *e*/M for hydrogen ions

Apparatus

1 Worcester gas voltameter kit	– item 54
1 L.T. variable voltage supply	– item 59
1 demonstration meter	– item 70
1 d.c. dial: 1 amp	– item 71/1

Alternatively a 12 V battery (item 176) and a rheostat (item 541/1) can be used for the voltage supply.

Procedure

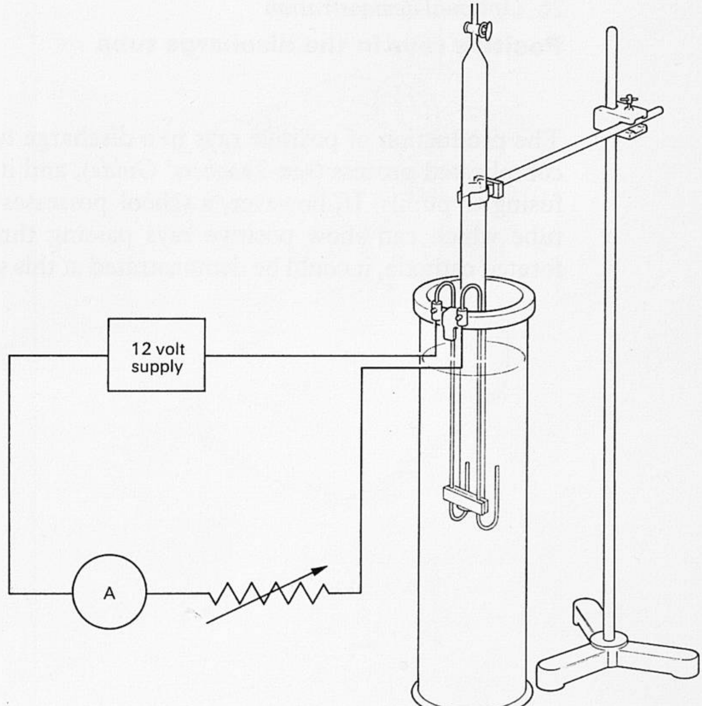
The circuit is connected as shown.

The gas jar is filled with acidulated water and one of the two 250 ml burettes is placed over the cathode (the second burette is not necessary in this experiment and only complicates it unnecessarily). The burette is filled with acidulated water using the plastic bottle provided. (The bottle is squeezed empty, connected to the top of the burette. The tap on the burette is then opened and water is drawn up. The tap is closed. Repeat this process until the burette is full.)

The current is switched on and adjusted to 1 ampere. (Note that the position of the burette relative to the electrode has a marked effect on the current. It should not be moved once the current is adjusted.)

The burette is then refilled with water as before. Then the current is allowed to flow for, say, 20 minutes.

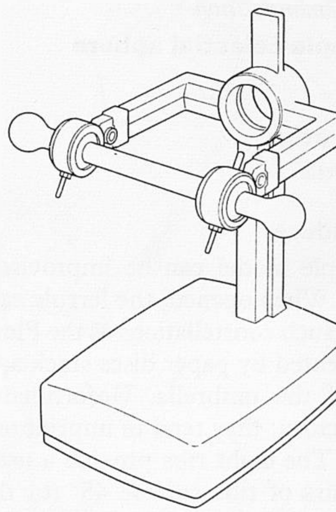
After switching off, the burette is slid in its holding clip until the levels of the water inside and outside the tube are the same. The pressure is then atmospheric. The volume of hydrogen gas is then read. Since the density of hydrogen is about 10^{-4} gm cm^{-3}, the mass liberated in 20 minutes can be calculated. Hence the mass liberated by one coulomb can be found, from which *e*/*M* is deduced in coulombs per kilogram.


12 volt
supply
A

26 *Optional demonstration*

Positive rays in the discharge tube

The production of positive rays in a discharge tube is a very complicated process (see *Teachers' Guide*), and it can be confusing to pupils. If, however, a school possesses a discharge tube which can show positive rays passing through a perforated cathode, it could be demonstrated at this stage.



27a *Demonstration*

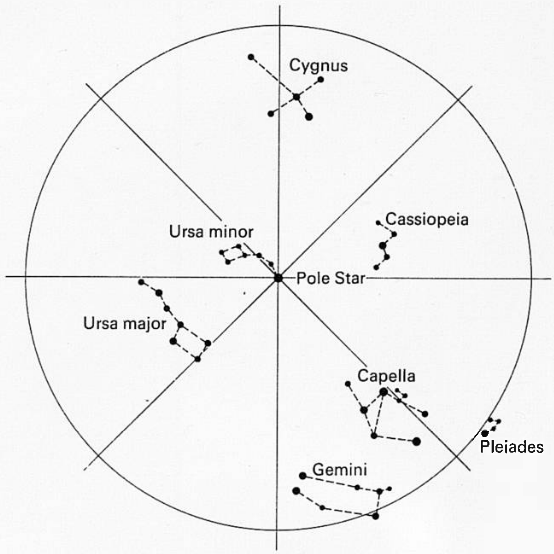
A simple celestial sphere

Apparatus

1 umbrella

Procedure

A simple model can be improvised from an ordinary umbrella. When opened, the ferrule can represent the Pole Star, whilst such constellations as the Plough and Cassiopeia can be represented by paper discs stuck appropriately to the underside of the umbrella. Unfortunately chalk marks are not satisfactory: they tend to imprint once the umbrella is closed again. The eight ribs provide a useful guide in the marking up. Pairs of ribs enclose 45° (or three hours of time). The surface can include the circumpolar stars visible from about latitude 45° and may be marked as shown.



27b *Home experiment*

Observation of the night sky during the course of one evening

Procedure

Pupils are asked to observe the sky at least twice in one evening, with an interval of, say, two hours between observations.

27c *Demonstration or home experiment*

Photograph of the night sky

Procedure

A photograph of the night sky taken by exposing a film in a rigidly fixed camera for several hours should be available for discussion.

Pupils who are interested should be encouraged to make a photograph themselves. To take such a photograph, a simple camera with an ordinary lens (not telephoto) is attached to a firm stand or tripod. It should be pointed towards the Pole Star. Open the shutter, having set the aperture (say, f/3·5 for Pan film – though the correct aperture will usually have to be found by trial), and leave undisturbed for the period chosen (at least 2 hours, preferably 4 to 8 hours).

The film may be developed in the traditional way or using the technique described in detail in Appendix II of the Year IV *Guide to Experiments*.

Note

The photograph will be more impressive if the picture includes the silhouette of the school building or of well-known trees near by.

28a *Home experiment*

Observation of the Moon: daily motion

Procedure

Pupils are asked to watch the Moon and to note its position relative to the stars. Then, one or two hours later, they should look again and note the new position of the Moon relative to the stars.

28b *Home experiment*

Observation of the Moon: monthly motion

Procedure

The previous experiment should be extended over the period of a month. The position of the Moon should be noted at the same hour on each possible night for a month. The observations should relate to the stars, and also to the position in the sky relative to the horizon.

28c *Home experiment*

Observation of the Sun

Procedure

Pupils should watch the Sun and its daily movements, if possible from month to month, so that the changes in the height of the Sun's daily arc are revealed.

They might also note over a period of time, the star pattern which is revealed immediately after sunset and before sunrise.

28d *Home experiment*

Observation of the planets

Procedure

Pupils should be shown the brightest planets – Venus, Jupiter, and, possibly, Saturn.

Information on where to look for these can be found in the monthly articles published in such newspapers as *The Times*, *The Daily Telegraph*, or *The Guardian*. Or from such annual publications as *The Sky at Night* (*The Times* Publishing Co.), *The Yearbook of Astronomy* (Eyre and Spottiswoode), *Whitaker's Almanack*, or *The Astronomical Ephemeris* (HMSO).

29 *Demonstration*
Model of the celestial sphere

Apparatus

1 large flask (for example, 2 litre, bolt-head)
1 bung to fit flask
1 long knitting needle
1 polystyrene sphere (1 in diameter)
2 retort stands, bosses, and clamps – items 503–506

Procedure

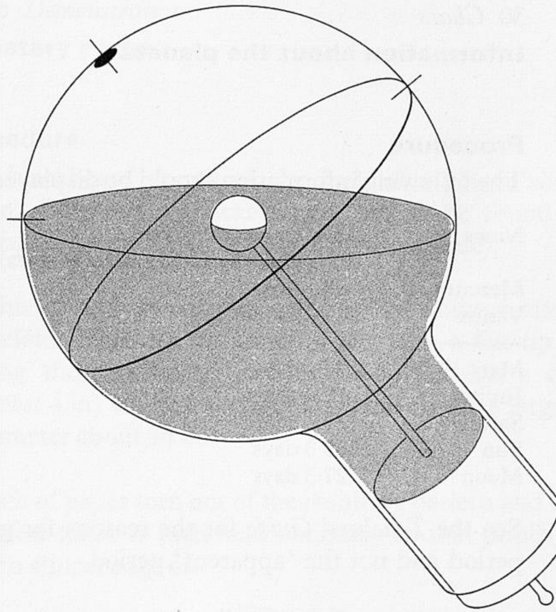
The polystyrene sphere is mounted on the point of the knitting needle, which has been pushed through the bung, so that the sphere is at the centre of the flask. The flask is then partially filled with water so that, when it is inverted, the water level passes through the centre of the flask so that the plastic sphere is half immersed. A circular piece of coloured Sellotape is stuck on to the 'bottom' of the flask, marking the end of the axis through the neck of the flask and the sphere. This also represents the Pole Star.

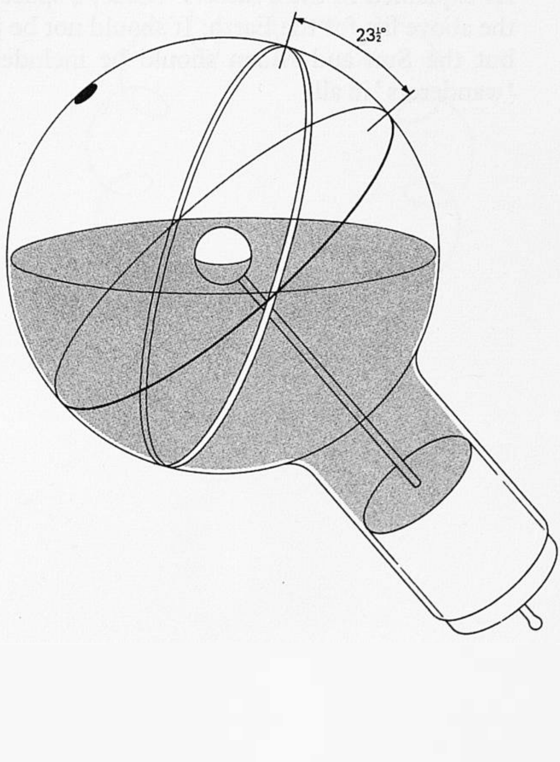
The celestial equator should be marked. The flask is then placed, with its neck slanting downward, in a chemistry tripod with round (instead of triangular) top; or in a horizontal ring on a retort stand. Failing that, it may be supported in a clamp (it may be necessary to use a second boss to prevent the clamp turning under the weight of the model) so that the polar axis is inclined at about 50° to the horizontal.

The level of the water provides a horizon whilst the small sphere represents the earth at the centre of the celestial sphere.

A band of coloured tape should then be added to represent the Zodiac, within which the ecliptic path will be included. This band should be at $23\frac{1}{2}°$ to the equatorial plane of the model.

Simple rotation of the model about its axis will provide a model of the repetitive, daily motion of the stars. But it does not permit a description of the lagging and wandering motion of the Sun, the Moon, and the planets. These are best explained when this diurnal rotation can be ignored.




23½°

30 *Chart*

Information about the planets

Procedure

The following information should be displayed:

Name	*Time for complete orbit* (judged against *background* of stars)
Mercury	87 days
Venus	225 days
———	———
Mars	687 days
Jupiter	12 years
Saturn	30 years
Sun	365·3 days
Moon	27·3 days

See the *Teachers' Guide* for the reasons for giving the 'true' period and not the 'apparent' period.

As explained in the *Teachers' Guide*, a space has been left in the above list for the Earth. It should not be placed there yet, but the Sun and Moon should be included making seven 'wanderers' in all.

31a, b *Demonstration*

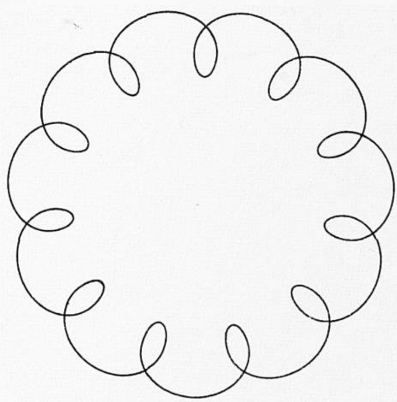
Planetary paths

Procedure

a. A blackboard sketch of the path of a planet should be drawn. Currently applicable ones are to be found in *The Yearbook of Astronomy* (Eyre and Spottiswoode).

b. This should be supplemented by an oblique view of an epicycloid. This can be drawn freely with a felt-tip pen by moving the pen round in a small circle (say, a circle of diameter 4 in) whilst sweeping the hand round a larger circle of diameter about 30 in.

A patch of paper torn out of the resulting pattern and containing a few loops is then held obliquely so that pupils see the pattern almost edge on.



31c *Demonstration*

Model of planetary path

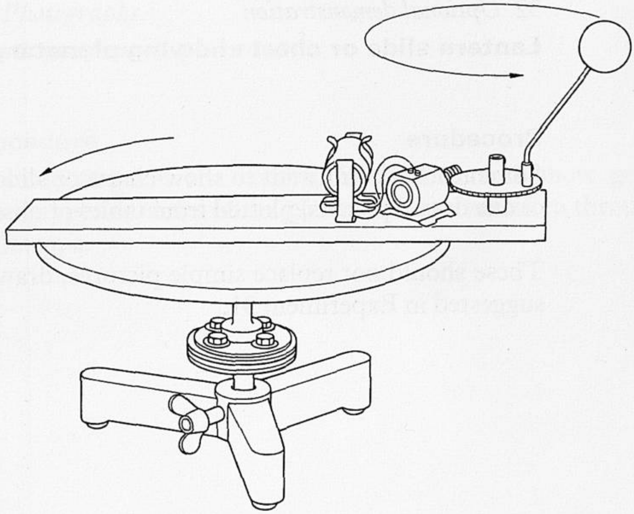
Apparatus

1 turntable – item 154/1
1 small motor on base plate – item 154/3

Procedure

The base plate is attached to the turntable. The dry cell drives the motor, which rotates a polystyrene sphere in a small circle as illustrated opposite. At the same time the turntable is rotated slowly by hand.

The epicyclic motion of the small sphere is observed edgewise by the class.



32 *Optional demonstration*

Lantern slide or chart showing planetary paths

Procedure

Some teachers will want to show charts or slides of the paths of one or two planets, plotted from tables of observations.

These should not replace simple pictures, drawn by hand, as suggested in Experiment 31.

33 *Photographs*

Photographs of planets

Procedure

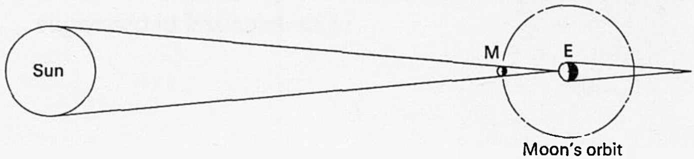
At some stage of the course, teachers should show good photographs or slides of the planets themselves taken through a telescope.

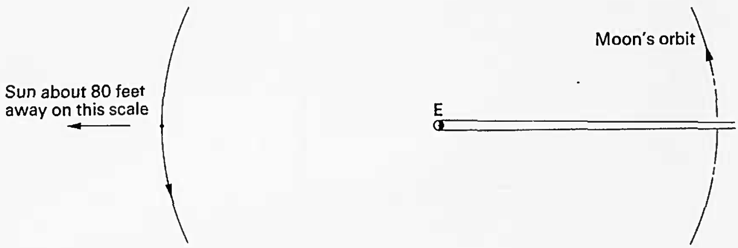
34 *Demonstration*

Eclipses

Procedure

Simple sketches of eclipses of the Sun and Moon should be shown to the pupils. See *Teachers' Guide*, which urges that the usual details of umbra and penumbra should not be given.





35 *Optional demonstration*

Precession of the equinoxes

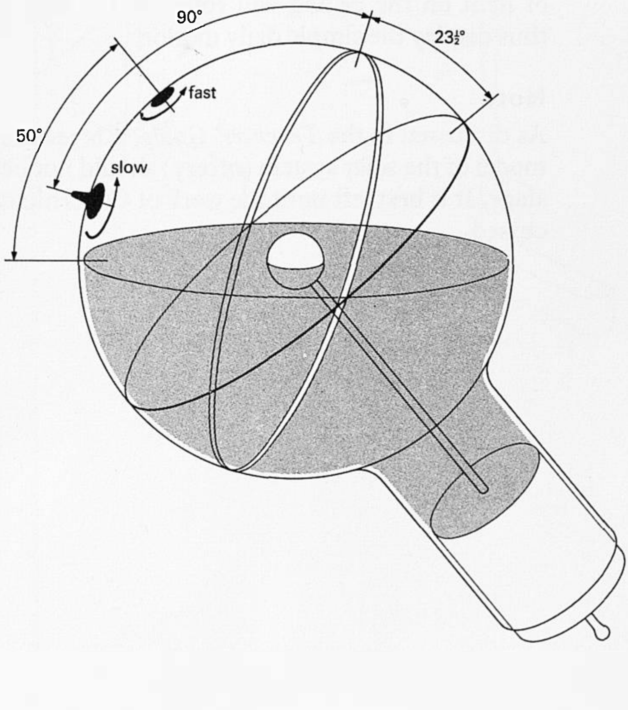
Apparatus

Simple flask model of the celestial sphere, as in Experiment 29.

Procedure

A new axis, perpendicular to the ecliptic, can be established on the flask with small circles of coloured Sellotape indicating where the axis meets the surface. (An ideal arrangement is to fix two small suction caps at these points.)

The model is then held so that it can revolve very, very slowly about that axis, whilst the whole model is imagined to be spinning very rapidly (10 million times faster) round the Pole Star axis.



36 *Demonstration*

Planetarium

Procedure

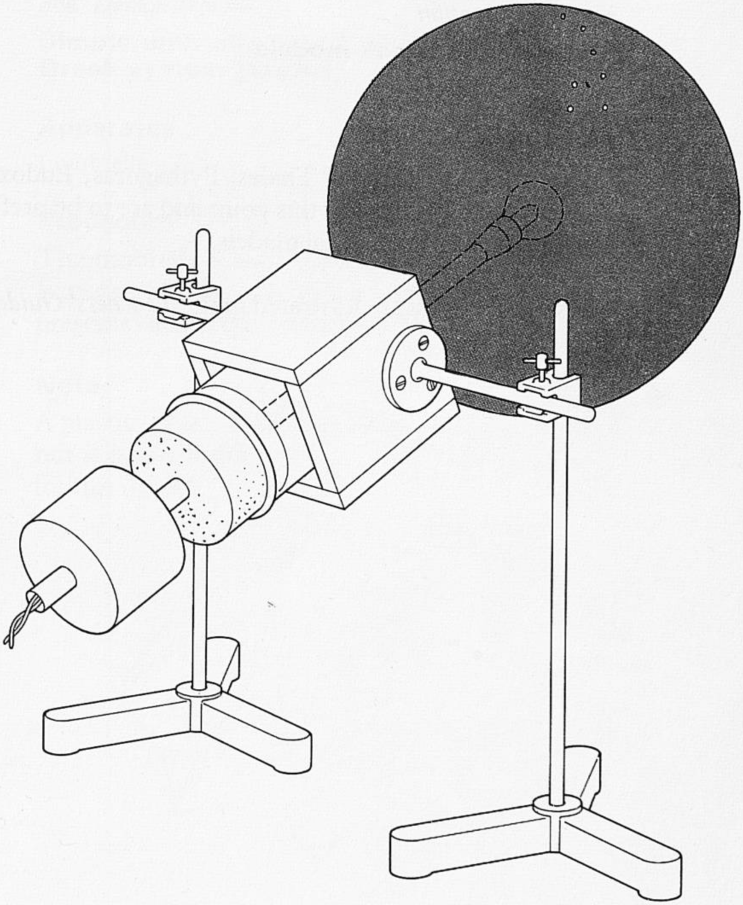
Where a visit to a planetarium can be arranged, this can be a valuable part of the teaching, especially if a special programme is arranged as discussed in the *Teachers' Guide*.

A simple 'toy' planetarium can be improvised using a two litre round-bottomed flask (preferably bolt-head type with a wide neck). A 12 V, 36 W lamp is supported at the centre of the flask. The surface of the flask is coated with Aquadag. Holes are then scratched in this surface to represent the pattern of some of the major constellations.

When the lamp is switched on in a darkened room, the spots of light on the ceiling will rotate as the flask is rotated and thus display the simple daily motion.

Note

As discussed in the *Teachers' Guide*, it is recommended that a model of the solar system (orrery) should not be shown at this stage. It is best left until the work of Copernicus has been discussed.



37 *Demonstration*

Slides of the Greek models

Procedure

Slides of the systems of Thales, Pythagoras, Eudoxus, and Ptolemy are useful aids at this point and are to be preferred to complex three-dimensional models.

These systems are all illustrated in the *Teachers' Guide*.

38a *Demonstration*

Simple umbrella model of the early Greek system (Thales)

Apparatus

1 umbrella

Procedure

The umbrella – with some constellations marked on it as in Experiment 27a – is rotated over a flat disc E (which represents the Earth) as illustrated below.

Note

A plastic sphere with a flat disc at the centre is a luxury model, but it is not worth buying. A celestial sphere is not suitable for this model.

38b *Demonstration*

Simple flask model of early Greek scheme

Apparatus

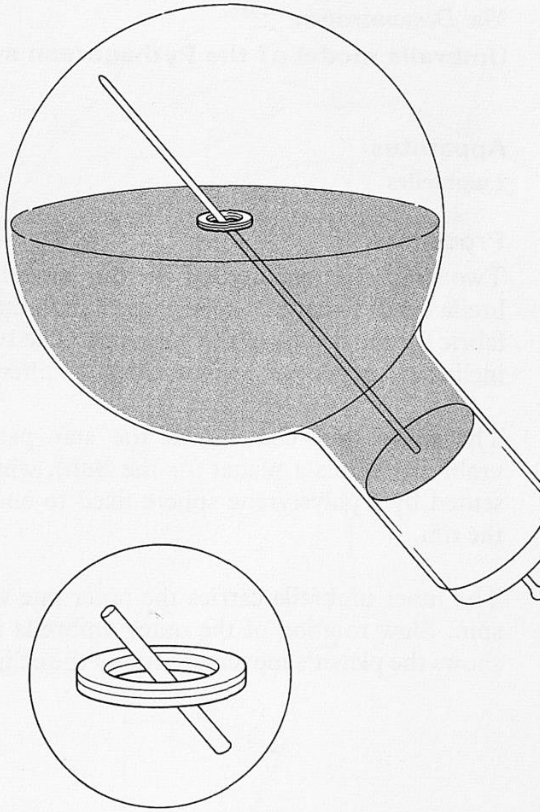
1 large flask (2 litre, bolt-head)
1 bung to fit flask
1 long knitting needle
1 wooden 'washer' (about 1 in diameter)
1 retort stand, boss, and clamp – items 503–506

Procedure

The wooden 'washer' is slipped over the knitting needle, over which it rides freely. The needle should be pushed through the bung so that the point of the needle will almost reach the bottom of the flask when the bung is inserted.

The flask is then half filled with water and the bung carefully inserted so that the wooden 'washer' floats centrally on the water surface. The whole is turned upside down and placed in a ring on a tripod or attached to a retort stand so that it is inclined.

The round globe represents the heavens, the flat wooden 'washer' the flat Earth. The 'heavens' can then rotate about the Earth.



39a *Demonstration*

Umbrella model of the Pythagorean system

Apparatus

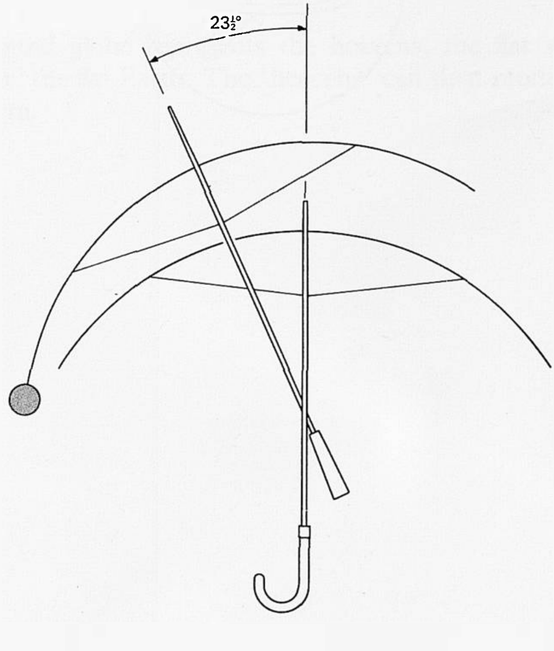
2 umbrellas

Procedure

Two umbrellas are needed for this model. The inner umbrella needs to have its spike cut off short and a hole cut in its fabric for the handle of the outer one. The two axes should be inclined to each other to show the $23\frac{1}{2}°$ difference.

The inner umbrella carries the star pattern. The outer umbrella carries a planet (or the Sun), which can be represented by a polystyrene sphere fixed to one of the spokes at the rim.

The inner umbrella carries the outer one with it in its daily spin. Slow rotation of the outer umbrella from west to east shows the planet's movement round the ecliptic.



39b *Demonstration*

Flask model of Pythagorean system

Apparatus

1 large flask (2 litre, bolt-head)
1 bung to fit flask
1 long knitting needle
1 small polystyrene sphere

Procedure

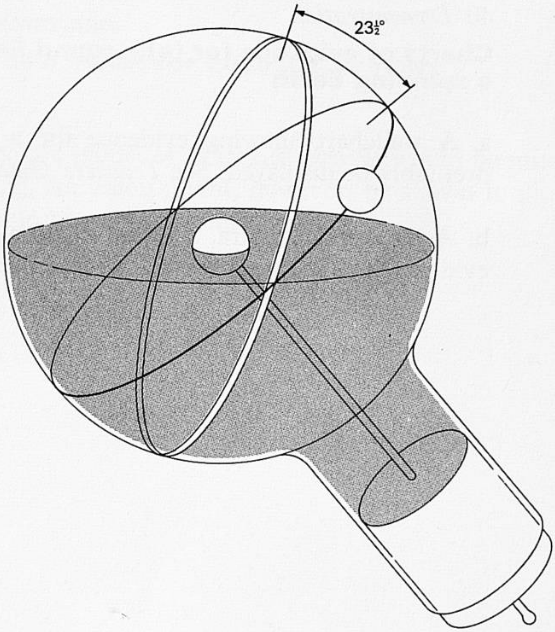
The sphere is mounted, instead of the wooden washer, on the needle which is inserted into the flask, which is half full of water.

The position of the sphere and the volume of water are adjusted so that the sphere is at the centre of the flask and in the water surface when the flask is inverted. The whole assembly is tilted and placed in a ring on a tripod or attached to a retort stand.

The sphere represents a round Earth. The ecliptic is marked on the flask with a greasy pencil or a band of coloured Sellotape (at $23\frac{1}{2}°$ to the equatorial plane of the model).

A yellow disc to represent the sun is stuck temporarily at various points on the ecliptic.

The daily motion is shown by rotating the flask about its own axis. The progress of the Sun through the seasons of the year can be shown by moving it from place to place round the ecliptic whilst the flask is spun for each position.


23½°

40 *Demonstration*

Charts of evidence for (a) a round Earth (b) a spinning Earth

a. A wallchart showing evidence for a round Earth can profitably be displayed. See *Teachers' Guide.*

b. As an optional extra, teachers might also show a chart of evidence for a spinning Earth – see *Teachers' Guide.*

41 *Demonstration*

Onion as a model for Eudoxus' system

An elaborate model of Eudoxus' system would be much too confusing. An onion might, however, be shown to illustrate his scheme of many concentric spheres.

42 *Demonstration*

Simple model of Aristarchus' system

Apparatus

1 umbrella
1 small Earth globe – see below

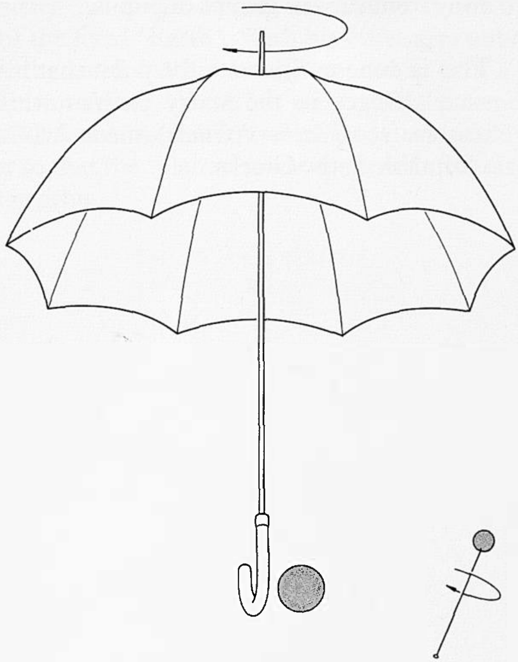
Procedure

As in previous experiments, a star pattern should be put on the umbrella.

The small Earth globe can be readily improvised with a 2 in polystyrene or wooden sphere mounted on a thin knitting needle driven half into the sphere.

The small globe is held just at the crook of the umbrella as illustrated below. Each is spun in turn to show the various motions.

Secondly, the Earth sphere is moved out a short distance, and another sphere is placed at the crook of the umbrella to represent the Sun. Then the Earth sphere is carried round the Sun, in an orbit, by hand. That is easier if the teacher dispenses with the umbrella and just holds the Sun and Earth in his hands, or places them on a table. He must move the Earth round the Sun with its spin-axis always pointing in the same direction.



43 *Demonstration*

Simple demonstration of parallax

Procedure

As the teacher walks round the laboratory, he can point out how an observer, moving in an orbit, sees the pattern of the pupils seated in the class change as he moves nearer or farther away from various groups of pupils.

This is done to illustrate the point that it was the absence of such changes in the starry pattern which, amongst other reasons (see *Teachers' Guide*), made Aristarchus' scheme unacceptable to the Greeks.

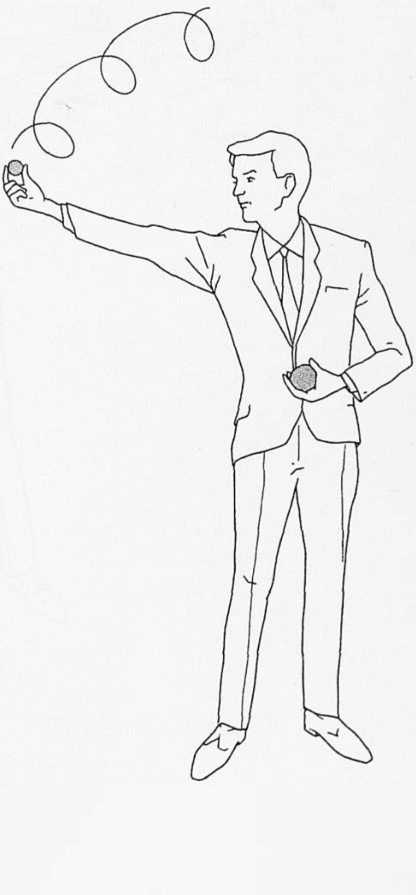
44 *Demonstration*

Simple models of epicycle system for planets

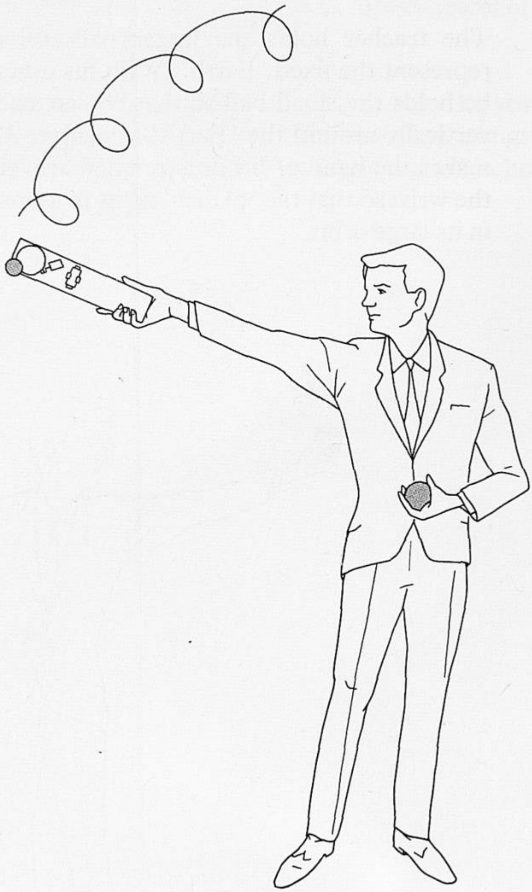
Procedure

a. A large ball (say, 3 in diameter) and a small one (say, $\frac{1}{2}$ in or 1 in diameter) are needed.

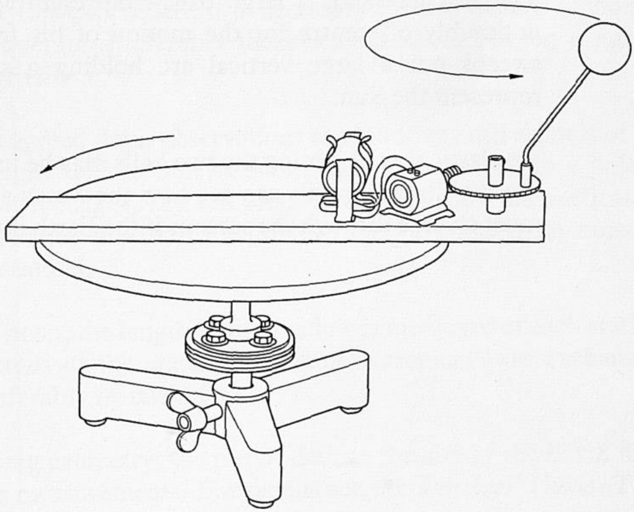
The teacher holds the larger ball still in front of him to represent the fixed 'Earth'. With his other arm outstretched, he holds the small ball so that he can sweep it in a large arc vertically around the 'Earth' as centre. At the same time he makes the hand of his outstretched arm turn quickly around the wrist so that the 'planet' turns in a small circle as it moves in its large orbit.



b. The small electric motor assembly used in Experiment 31 may be used to represent the 'planet' moving in its epicycle. The whole assembly is swept in a large vertical arc, as described in (a) above, about the fixed 'Earth' whilst the motor drives the 'planet' in its small circle. Alternatively it may be found easier for the teacher to use a clockwork motor suitably adapted.



c. Show again the electric motor assembly (used in Experiment 31c) mounted on a rotating turntable. The turntable is rotated slowly by hand whilst the sphere on the electric motor assembly rotates. The epicyclic motion will be observed. The motor may be tilted a little.



45 *Demonstration*

Simple model of an eccentric scheme for the Sun

Procedure

The teacher holds a large ball – representing the Earth – noticeably off centre for the motion of his free arm which sweeps out a large vertical arc holding a second ball to represent the Sun.

An elastic thread joining the two balls may be used. By watching the thread, pupils can see how the Sun's apparent speed must change through the seasons if the Earth is off-centre.

46 *Optional experiment*

Estimating the size of the Earth

Procedure

For this experiment it is necessary for two distant schools to co-operate. Preferably these schools should lie on a north–south line.

On agreed days, observations are made at both schools of the 'height' of the Sun at noon. Each school sets up a pole of known height, say ten feet. The poles must be vertical, as shown by a plumb line, and ground around them must be horizontal.

At noon, the length of the shadow is measured at each station. Details of the apparatus and measurements are exchanged, preferably by telephone.

Using geometry, the pupils deduce the size of the Earth from the measurements. For details see the *Teachers' Guide*. They will also need to know the distance between the two schools (in miles or kilometres) and this can be found from a map or railway timetable.

47 *Class experiment*

Estimate the ratio of the distance away of the Moon to its diameter

Procedure

Pupils hold a very small coin at arm's length and adjust its distance from the eye until the disc of the coin just obscures the disc of the moon. Their partners then measure the distance from the eye to the coin.

A similar technique can be applied to the Sun – preferably when the Sun is somewhat veiled by mist or cloud. Great care must be taken *not* to look directly at the Sun.

It will be found that in each case the coin is approximately 110 coin-diameters away. Thus the Moon's distance is about 110 moon-diameters away.

48 *Optional experiment*

Estimate of distance of the Moon from eclipse photograph

Procedure

An enlarged photograph of a partial eclipse of the Moon is needed for this experiment. It is clearly preferable for this to be taken by the pupils themselves. Details of forthcoming eclipses can be obtained from *Whitaker's Almanack*, *Astronomical Ephemeris* (HMSO), *Year Book of Astronomy* (Eyre and Spottiswoode). Fast film should be used for this with the camera lens opened to its widest aperture and an exposure of, say, $\frac{1}{10}$ second. The camera should be firmly secured to a stand during the exposure and great care taken to avoid camera shake.

As a poor substitute, a printed photograph can be used.

An estimate is made of the radius of the shadow-bite on the Moon. The radius of the image of the Moon is also measured. As explained in the *Teachers' Guide*, the ratio

$$\frac{\text{Radius of image of Moon}}{\text{Radius of shadow on Moon}} = \frac{\text{Moon diameter}}{\text{Earth diameter} - \text{Moon diameter}}$$

From the value obtained for the Moon's diameter from this and using the result obtained in Experiment 47, the distance of the Moon is estimated.

49 *Demonstration*

Simple model of Copernicus' explanation of the looped path of the planets

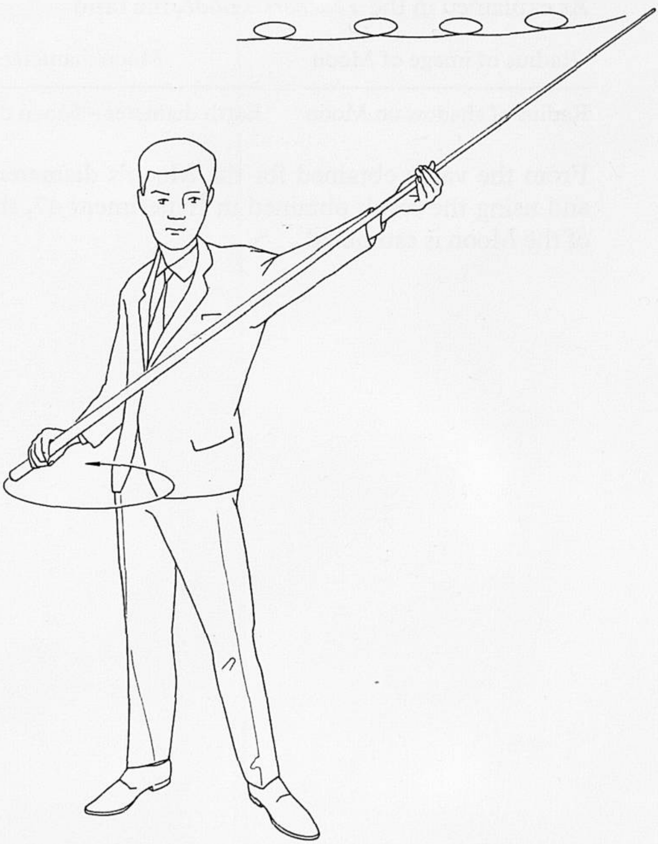
Procedure

The teacher holds a light smooth pole of bamboo or light metal (about 6 to 8 ft long) as a 'sight line' from the Earth to, say, Jupiter.

He holds one end in his right hand (representing the Earth), letting the pole run loosely through a ring made by finger and thumb of his left hand. The right hand is held close to the body with the left arm extended sideways from the shoulder.

The line of the pole runs on out to the 'stars' imagined to be on the walls and ceiling of the room.

The Earth (right hand) is moved quickly in a tight circle whilst Jupiter (left hand) moves slowly. The pole wags to-and-fro as well as making general progress across the sky.



50 *Wallchart*

Chart of the planets in order as determined by Copernicus

Procedure

The teacher should prepare a chart of the following detail and display it.

Copernicus' system	*Modern planetary data* Radius of orbit (*R miles*)	Time of revolution (planet's year) (*T days*)
Sun, stationary at centre	—	—
Mercury, nearest to Sun	$3{\cdot}596 \times 10^7$	86·96
Venus	$6{\cdot}716 \times 10^7$	224·7
Earth, with the Moon travelling round it	$9{\cdot}290 \times 10^7$	365·3
Mars	$14{\cdot}16 \times 10^7$	687·1
Jupiter	$48{\cdot}33 \times 10^7$	4323
Saturn, farthest of the planets then known	$88{\cdot}61 \times 10^7$	10760

51 *Demonstration*

Demonstration of precession of the equinoxes

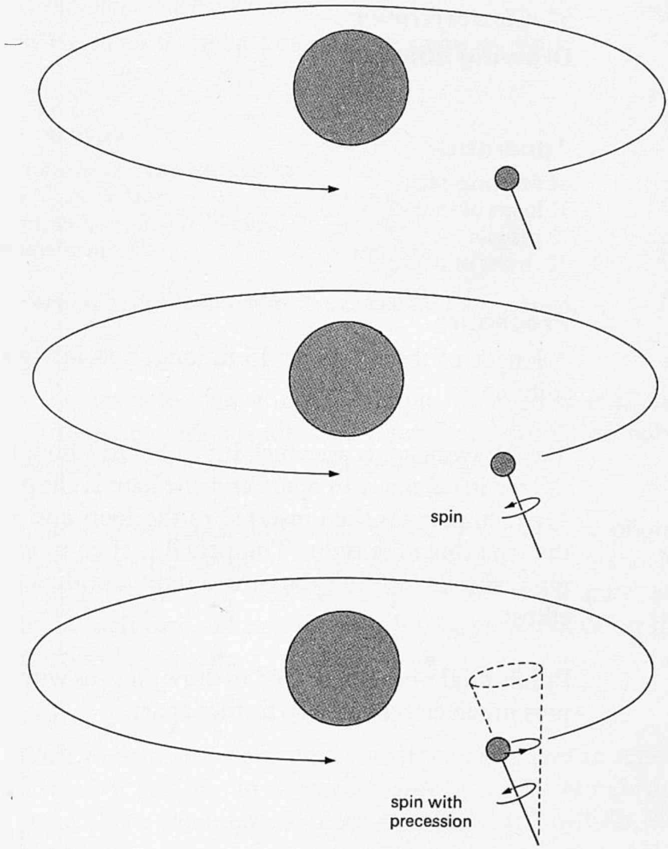
Procedure

A large ball (for example, a football) to represent the Sun is placed at the centre of the table.

A small globe mounted on an axis making about $23\frac{1}{2}°$ with the vertical will represent the Earth. This may be a mounted Earth globe, as used in geography teaching. Failing that, it may be improvised from a large polystyrene or wooden sphere drilled along a radius to a depth of about $\frac{3}{4}$ diameter and supported on a knitting needle so that it will spin freely.

This globe is set spinning and moved round the Sun in a circle with the axis always pointing in a constant direction. This represents the yearly motion of the Earth.

Precession is then shown by making the spin axis of the ball revolve in a slow conical motion round an axis perpendicular to the Earth's orbit as the assembly is held in the hand and taken again round the Sun. The real conical motion is, of course, a very slow one with a period of 26,000 years.


spin
spin with
precession

52 Class experiment

Drawing ellipses

Apparatus

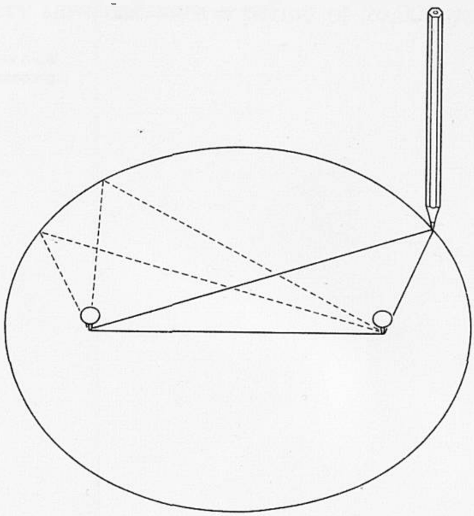
64 drawing-pins
32 loops of thread
32 pencils
32 sheets of paper

Procedure

A length of thread about 15 in long, tied into a loop, is very suitable.

Two drawing-pins are stuck into a board (though not pressed too far in) about 4 in apart and the loop is slipped over them. A pencil point is then inserted in the loop and positioned so that the thread is tight. The pencil is then moved round the pins, always keeping the thread tight and thus tracing out an ellipse.

Pupils might be encouraged to draw ellipses with the drawing-pins much closer and also farther apart.



53 *Optional demonstration*

The Inverse Square Law in the case of light

Apparatus

1 photoelectric exposure meter	
1 12 V, 24 W lamp	– item 72
1 lampholder (SBC) on base	– item 74
1 transformer	– item 27

The exposure meter should be borrowed for the occasion.

Procedure

This is intended as a quick simple demonstration, and measurements with a traditional photometer would probably defeat this object and might even be confusing.

The lamp is switched on in a darkened room and the photoelectric exposure meter is directed towards it from distances of 1, 2, 3 . . . ft. The meter readings (in arbitrary units) are noted in each case. The readings will be seen to fall off in the proportion $1:\frac{1}{4}:\frac{1}{9}$, etc.

Notes

1. With some exposure meters it may be necessary to reflect back some of the light to the reverse side of the meter in order to make these readings: a piece of white card will do this effectively.

2. Some exposure meters have scales marked so that adjacent markings represent light values increasing by a factor of 2 for each stop. Care must then be taken when interpreting.

54 *Wallchart*

Chart of the historical development

Procedure

A tall chart showing the historical development of astronomy is a useful visual aid for the class – and a helpful *aide-mémoire* for the teacher.

Suggested details for such a chart are given in the *Teachers' Guide*.

55 *Demonstration*

Illustration of an elliptical orbit

Note

As explained in the *Teacher's Guide*, simple demonstrations of elliptical orbits are difficult to arrange. Probably the best that can be done are those described here, but neither are very convincing. The orbit precesses and shows the effect of friction. Furthermore, in neither case do the pupils know that the force must be an inverse square one. They are at the best merely qualitative illustrations of oval orbits.

Procedure

a. Roll a small steel ball (say, $\frac{1}{4}$ in diameter) on a slanting path in a large glass funnel (at least 20 cm diameter) which is firmly held vertically. Friction will affect the orbit which will, in consequence, precess.

b. A thin rubber sheet can be used, but the equipment is not easily set up and, again, a precessing orbit occurs. The rubber sheeting is stretched over a rigid circular frame and secured tightly with string. A vertical rod, which can be held in a retort stand, is pushed down onto the centre of the sheet, deforming the rubber into a reasonable model of the potential well of an Inverse Square Law force. The steel ball is then rolled on a slanting path in this well.

Film

The P.S.S.C. film referred to in the *Teachers' Guide* is *Elliptic Orbits* and is obtainable in the United Kingdom from Sound Services Ltd, Wilton Crescent, London, S.W.19.

56 *Optional weather-dependent demonstration*

Illustration of Kepler's Second Law: pupils on ice

Procedure

If a safe, frozen pond is available, two pupils can provide a good illustration of Kepler's Second Law.

The lighter pupil holds a light rope as he skates or slides in a circle around the heavier pupil, firmly fixed in the centre of the pond, who holds the other end of the rope. The heavier stationary pupil, who represents the Sun, then pulls the rope in.

As the moving 'planet' moves closer, so his speed will increase.

57 *Class experiment or demonstration*

Illustration of Kepler's Second Law: whirling bung

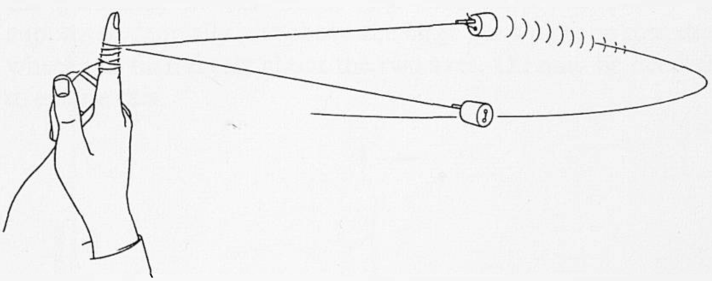
Apparatus

16 rubber bungs – item 172B
16 lengths of twine – item 172F

Procedure

A length of twine is securely attached to the rubber bung. It is whirled round in a circle.

After a few revolutions, the twine is allowed to wind itself up around the finger. As the length shortens, so the 'planet' moves faster and faster.



58 *Optional demonstration*

Illustration of Kepler's Second Law: ball in funnel

Procedure

The large funnel (at least 20 cm diameter) and steel ball ($\frac{1}{4}$ in diameter), already used in Experiment 55a, may also be used as an illustration. It is not, however, a true example of Kepler's Second Law and this demonstration is not therefore recommended.

The ball is started in a circular orbit within the glass conical funnel. As friction acts, the orbit moves lower whilst the time for each trip round the funnel gets less and less.

59 *Optional demonstration*

Illustration of Kepler's Second Law: using a dry ice puck

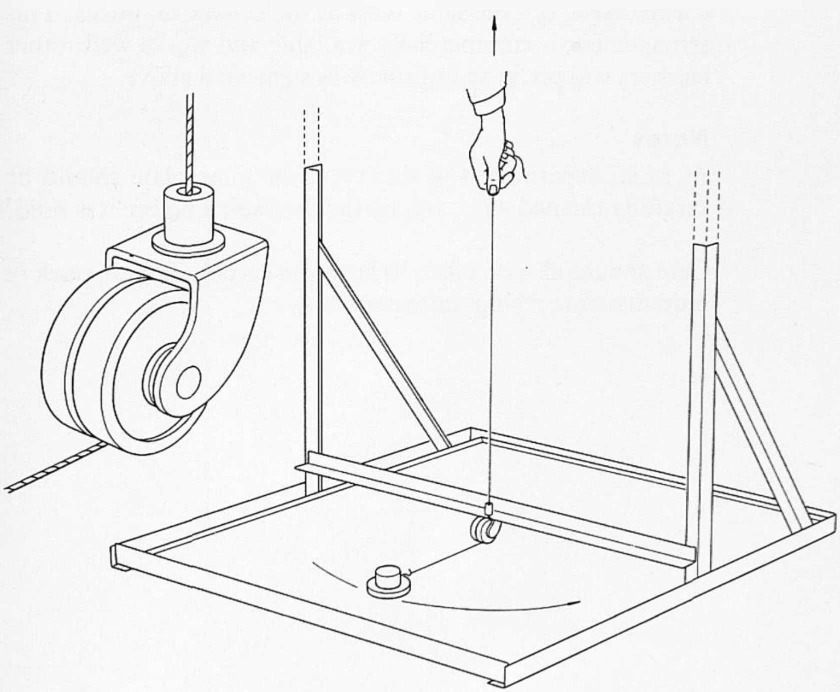
Apparatus

1 Edinburgh CO_2 pucks kit	– item 95
1 freely swivelling pulley	– see below
1 block of solid CO_2	

Procedure

A rough, but useful, demonstration can be improvised with the Edinburgh CO_2 pucks kit.

The simplest technique employs a swivelling furniture castor. A hole is drilled through the shank and a groove is cut around the periphery of the wheel (see diagram). The pulley is supported centrally just above the large glass plate so that the wheel can turn freely about the two axes. Oil may be needed to ensure this.



A puck is made up from a mass of about a kilogram which carries a cup hook, or other device, enabling a length of light string to be fastened to its side. The puck is placed on the glass plate, supported on a block of solid carbon dioxide about half an inch thick and of external diameter an inch or two larger than the metal block. The string is passed over the groove and through the pulley shank to the hand.

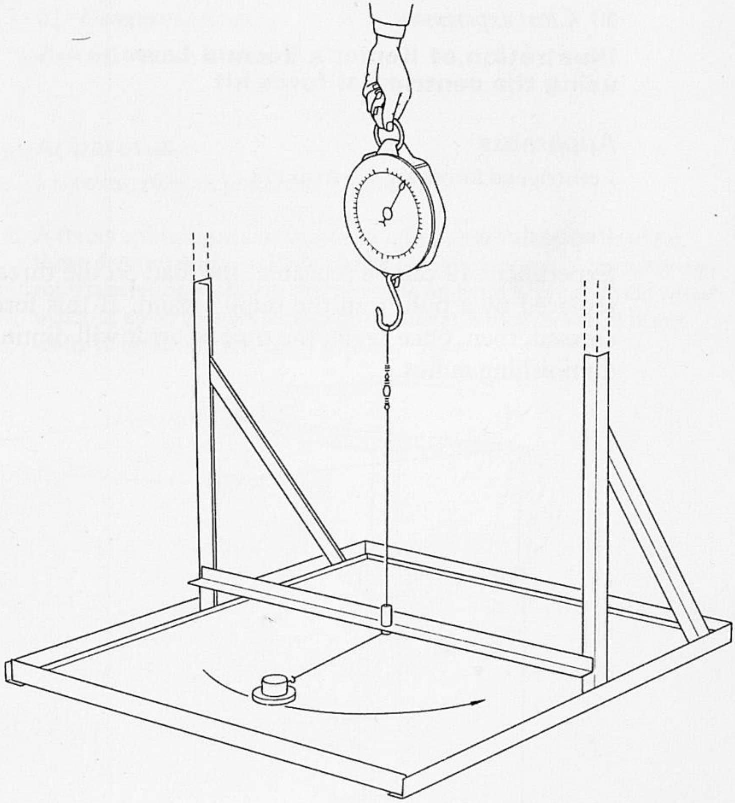
The puck is started moving in a circular orbit on the glass plate, the centrally directed force being applied through the string. Then this force is increased and the effect observed.

An alternative arrangement is illustrated opposite. The additional bar across the gantry (item 161) supports the glass tube which acts as the flexible pulley, one end of the twine is connected to a specially shaped puck, and the other end is connected to a fisherman's swivel which enables the twine to rotate freely. This in turn is connected to a spring balance which is held by hand. The puck is specially shaped to give it a wider base, but the same mass as the usual CO_2 pucks. This arrangement is commercially available and works well: other teachers will prefer to improvise as suggested above.

Notes

As in all experiments of this type, the glass plate should be carefully cleaned with, say, methylated spirit before it is used.

Care should also be taken to keep the carbon dioxide puck in motion before trying the experiment.



60 *Class experiment*

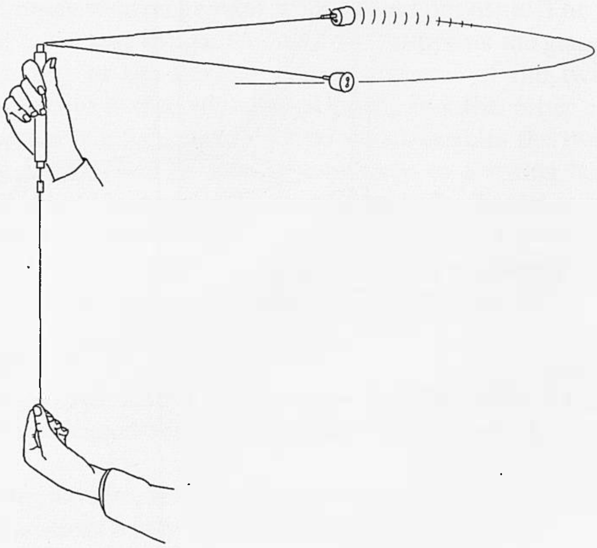
Illustration of Kepler's Second Law: using the centripetal force kit

Apparatus

1 centripetal forces kit – item 172

Procedure

Experiment 12 can be repeated, the load on the thread being replaced by a pull from the pupil's hand. If this force is increased, then, once again, the time of orbit will diminish with diminishing radius.



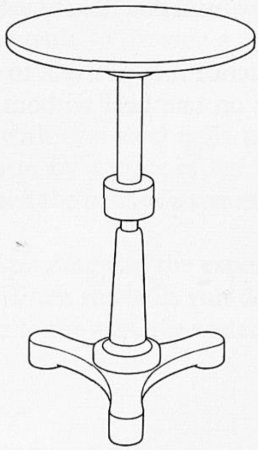
61 *Demonstration*

Rotation on a stool

Apparatus

1 rotating stool or platform – item 187

A freely spinning music stool – or office chair – may be used for these demonstrations. It should be oiled before use. Alternatively a robust rotating platform can be made up from a motor-cycle wheel which is covered with a blockboard disc. (A bicycle wheel is not likely to be strong enough.)

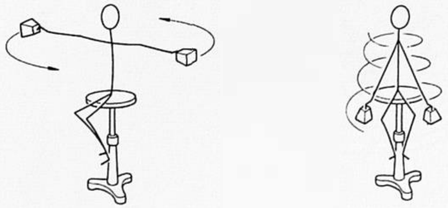


Procedure

A pupil sits on the stool, holding a massive object in each hand, his arms being stretched out sideways. The stool is turned by another pupil so that it rotates fairly rapidly.

The pupil on the stool then draws in his arms holding the 'planets' tightly to his chest.

Finally he stretches his arms out again.



62 *Class experiment*

Pupils spinning on their heels

Procedure

A simpler version of the previous experiment which each pupil should try for himself requires him to spin on his heel for a short time.

If, in this time, he remains as upright as he can and holds a heavy book in his hand, he can feel the effect of moving the book away from and then towards his body.

With practice it is possible to make two or more revolutions spinning on one heel without the other foot coming to the rescue.

63 *Optional demonstration*

Spinning demonstration with V-channel

Apparatus

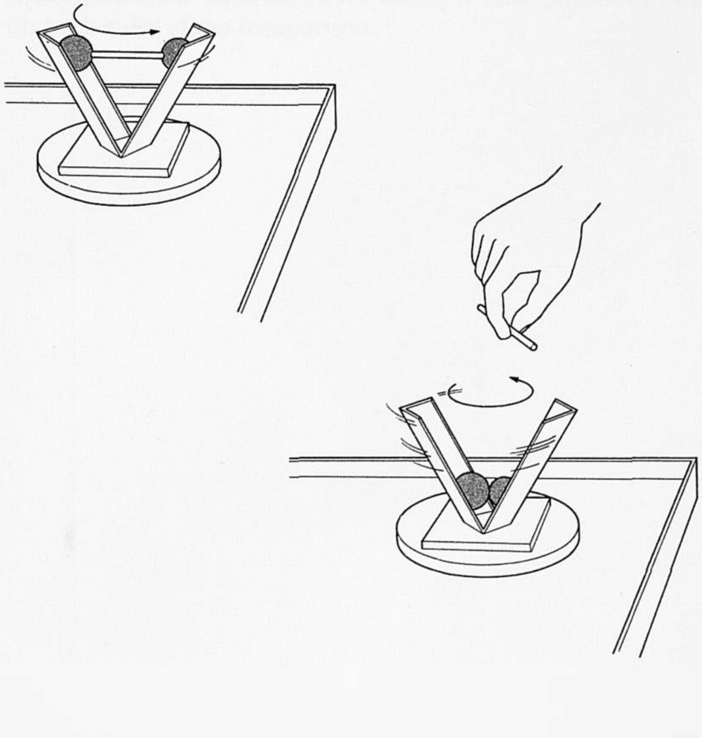
The teacher who wishes to do this experiment can construct the special apparatus with two pieces of V-channel, arranged in a V. They are mounted on a base.

Procedure

The mounted channel is placed on the glass plate from the Edinburgh CO_2 pucks kit with a small block of solid CO_2 between it and the table to provide a frictionless bearing for spinning.

The V is loaded with two steel balls to act as planets, held high up on each arm by a piece of light metal tubing placed horizontally between the balls as a spacer.

The device is set spinning and the experimenter snatches the metal tube away. When the balls run down to the bottom of the V, much closer to the axis, the system spins much faster.



64 *Wallchart*

Planetary data and Kepler's Third Law

Procedure

The teacher should prepare a chart of the following information and display it.

Planet	Radius of planet's orbit R (miles)	Time of revolution (planet's year) T (days)	R^3 (miles)^3	T^2 (days)^2	$\frac{R^3}{T^2}\frac{(\text{miles})^3}{(\text{days})^2}$
Mercury	$3{\cdot}596 \times 10^7$	86·96	$46{\cdot}49 \times 10^{21}$	7,734	$6{\cdot}009 \times 10^{18}$
Venus	$6{\cdot}716 \times 10^7$	224·7	$303{\cdot}3 \times 10^{21}$	50,490	$6{\cdot}008 \times 10^{18}$
Earth	$9{\cdot}290 \times 10^7$	365·3	$801{\cdot}7 \times 10^{21}$	133,500	$6{\cdot}009 \times 10^{18}$
Mars	$14{\cdot}16 \times 10^7$	687·1	$2{,}836 \times 10^{21}$	472,100	$6{\cdot}008 \times 10^{18}$
Jupiter	$48{\cdot}33 \times 10^7$	4323	$112{,}900 \times 10^{21}$	18,780,000	$6{\cdot}012 \times 10^{18}$
Saturn	$88{\cdot}61 \times 10^7$	10,760	$695{,}800 \times 10^{21}$	115,800,000	$6{\cdot}011 \times 10^{18}$

65 *Optional wallchart*

Jupiter's moons and Kepler's Third Law

Procedure

The teacher might also prepare a chart of the following information and display it.

Name of Satellite	Distance from Jupiter: in Jovian diameters	in miles (R)	Time of revolution in hours (T)	R^3 (miles)^3	T^2 (hours)^2	$\frac{R^3}{T^2}$
Io	3·02	262,220	42·36	$1{\cdot}803 \times 10^{16}$	1,802·8	?
Europa	4·80	417,190	85·23	$7{\cdot}261 \times 10^{16}$	7,264	?
Ganymede	7·66	665,490	171·71	$29{\cdot}473 \times 10^{16}$	29,484	?
Callisto	13·48	1,170,700	400·54	$160{\cdot}440 \times 10^{16}$	160,430	?

Note

It is simplest to measure the moon's orbits in terms of Jupiter's diameter. The radii could remain in those units for a test of Kepler's Law III; but, if these data are to be used in gravitational theory (e.g. to compare Jupiter's mass with the Sun's), then the same units, for example miles, must be used on both sides of the comparison.

66 *Optional wallchart*

Earth satellites and Kepler's Third Law

Procedure

The teacher might prepare a chart of the following information and display it.

Name of Satellite	*Average distance from centre of Earth* (R) *km*	*Time of revolution* (T) *mins*	R^3 (*km*)^3	T^2 (*mins*)^2	$\frac{R^3}{T^2}$
Gemini 6	6,632	89·6	29·3 × 10^{10}	8·04 × 10^3	?
Tiros 1	7·092	99·2	35·7 × 10^{10}	9·83 × 10^3	?
Echo 2	7,539	109·0	42·8 × 10^{10}	11·9 × 10^3	?
Echo 1	7,967	118·2	50·6 × 10^{10}	13·9 × 10^3	?
Early Bird	42,173	1,437	7,510 × 10^{10}	2,060 × 10^3	?
Moon	386,000	39,343	574,000 × 10^{10}	1,540,000 × 10^3	?

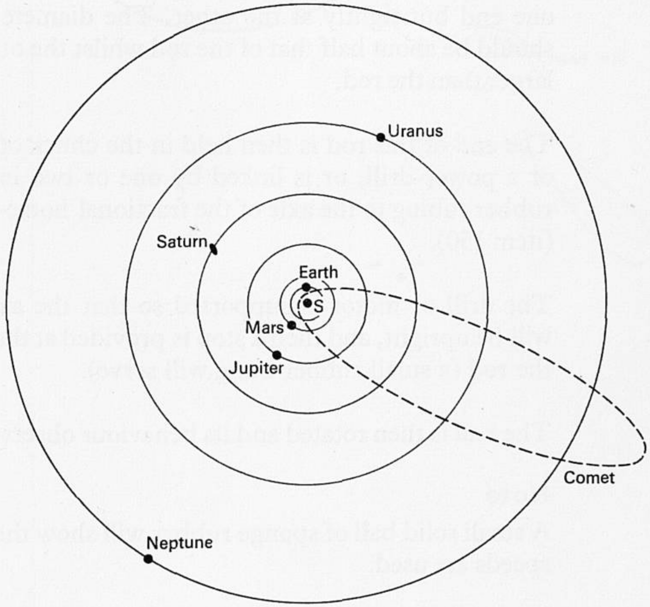
67 *Photograph and wallchart*

Comets

Procedure

a. The teacher should show a photograph of a comet, and display it for the pupils to look at.

b. A chart should be displayed – as shown below – giving a sketch of a comet's orbit against the background of the planets' orbits in the solar system.



68 Demonstration

Model of the oblate Earth

Apparatus

1 large hollow rubber ball	– see below
1 metal rod	– see below

Procedure

A large, hollow rubber ball from a toyshop provides the best model. Small holes are drilled through the rubber at each end of a diameter and a metal rod is slid through the ball, freely at one end but tightly at the other. The diameter of one hole should be about half that of the rod whilst the other is slightly larger than the rod.

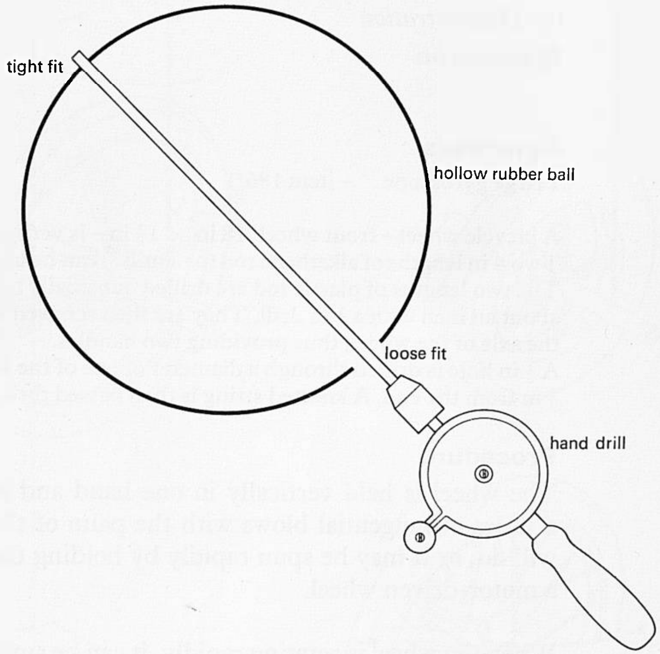
The end of this rod is then held in the chuck of a hand-drill, or a power-drill, or is linked by one or two inches of stout rubber tubing to the axle of the fractional horse-power motor (item 150).

The drill or motor is supported so that the axis of rotation will be upright, and then a stop is provided at the upper end of the rod (a small rubber bung will serve).

The ball is then rotated and its behaviour observed.

Note

A small solid ball of sponge rubber will show the effect if high speeds are used.


tight fit
hollow rubber ball
loose fit
hand drill

69 *Demonstration*

Precession

Apparatus

1 large gyroscope – item 186/1

A bicycle wheel – front wheel, 18 in × $1\frac{3}{8}$ in – is very satisfactory. Two 4 in lengths of alkathene rod (or similar) can be used for handles. The two lengths of plastic rod are drilled out axially to a depth of about an inch with a $\frac{1}{4}$ in drill. They are then screwed firmly on to the axle of the wheel, thus providing two handles.
A $\frac{1}{8}$ in hole is drilled through a diameter of one of the handles about $\frac{1}{2}$ in from the end. A knotted string is then passed through this hole.

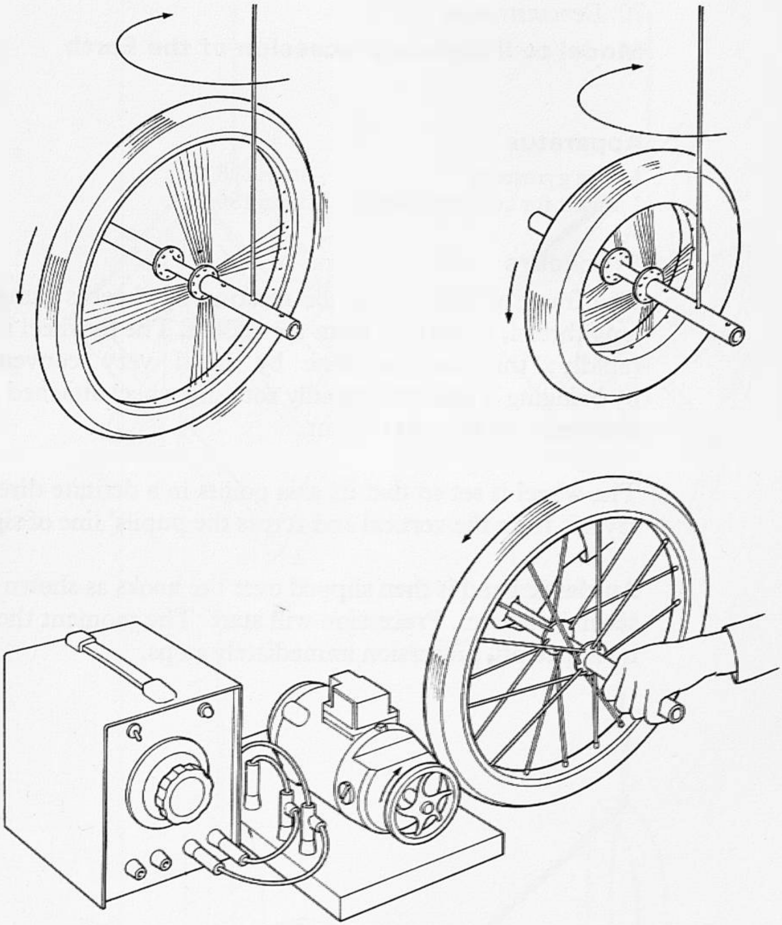
Procedure

The wheel is held vertically in one hand and set rotating – a series of tangential blows with the palm of the other hand will do, or it may be spun rapidly by holding the rim against a motor-driven wheel.

When the wheel is rotating rapidly, it can be supported by the string. It remains vertical and precesses.

Note

If the large gyroscope is not available, a toy gyroscope should be shown.



70 *Demonstration*

Model to illustrate precession of the Earth

Apparatus

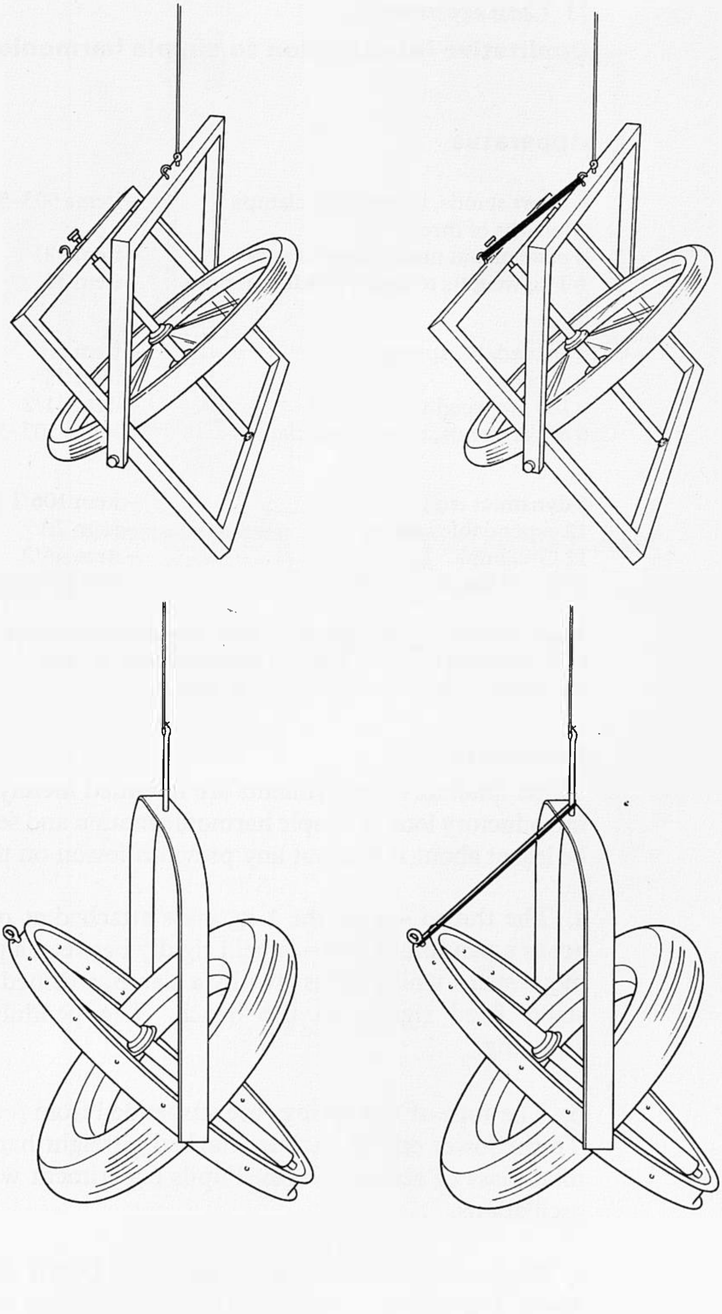
1 large gyroscope – item 186/1
1 mount for large gyroscope – item 186/2

Procedure

The frame which carries the rotating flywheel is hung on a long thread, preferably from the ceiling. The flywheel is spun rapidly: this can be done by hand very conveniently by bringing it against a rapidly rotating wheel attached to the fractional horse-power motor.

The wheel is set so that its axis points in a definite direction, say 45° from the vertical and across the pupils' line of sight.

An elastic band is then slipped over the hooks as shown in the second diagram. Precession will start. The moment the band is slipped off, precession immediately stops.



71 *Class experiment*

Qualitative introduction to simple harmonic motion

Apparatus

a.

6 retort stands, bosses, and clamps	– items 503–506
6 lengths of thread	
6 pairs of 2 in metal strips as jaws	– item 121
6 1 kg weights to use as pendulum bobs	– item 32

b.

6 expendable springs	– item 2A
6 S-hooks	– item 35
6 100 gm weight hangers	– item 31/2
6 retort stands, bosses, and clamps	– items 503–506

c.

6 dynamics trolleys	– item 106/1
12 expendable springs	– item 2A
12 G-clamps	– item 44/2
12 retort stands	– items 503–504

These should be sufficient to enable pupils to investigate each in turn, working in pairs. For this investigation, the above items should not become demonstration experiments.

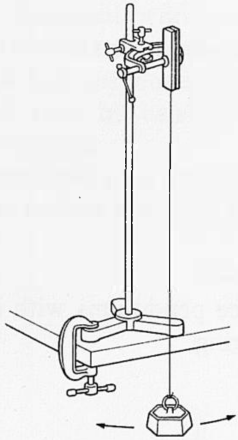
Procedure

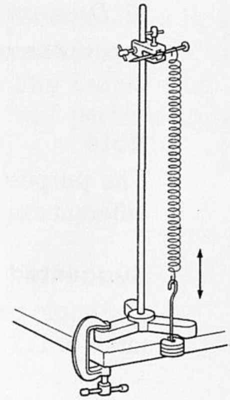
These qualitative experiments are intended merely to give an introductory look at simple harmonic motion and see what can be learnt about it without any previous lesson on the subject.

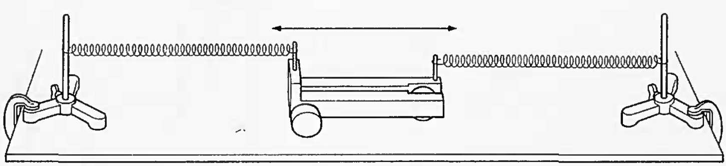
a. The thread – with the 1-kg mass attached at one end to act as a pendulum bob – is held rigidly between a pair of 2 in metal strips which act as jaws by a clamp, attached to a retort stand fixed rigidly to the bench. The pendulum is set swinging.

b. The tops of the springs are suspended from retort stands. To the lower end of each is attached a weight hanger with a total mass of about 400 gm. Pupils experiment with vertical oscillations.

c. Pupils clamp two retort stands to the bench about 60 cm apart. The trolley in between them is connected to the retort stands with expendable springs. The pupils make the trolley oscillate between the stands.







72 Demonstration

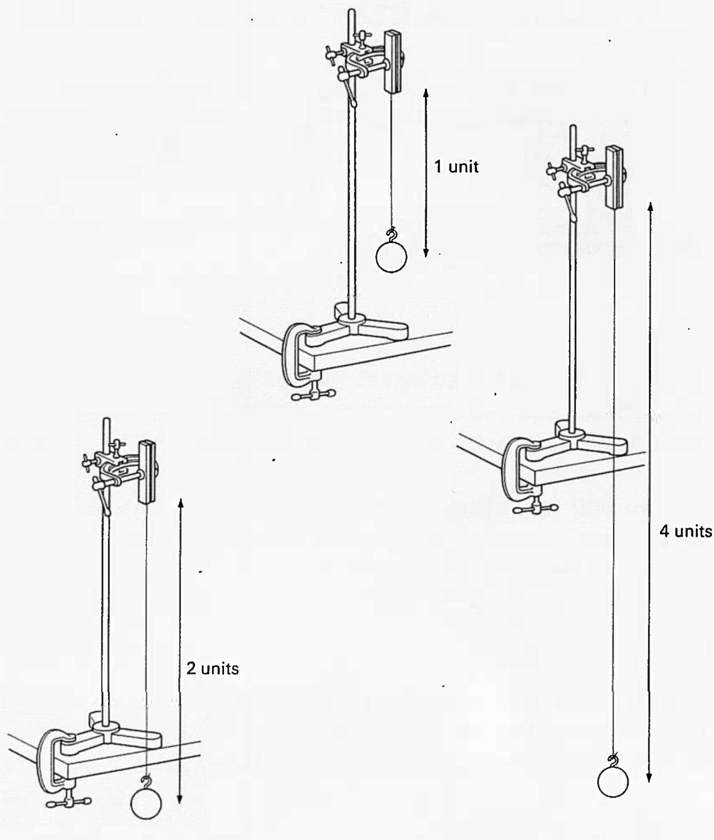
Examples of simple harmonic motion

Note

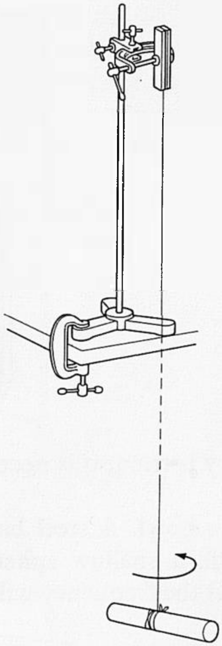
The purpose of this experiment is to demonstrate as many different examples of simple harmonic motion as possible.

Suggested demonstrations

a. Simple pendulum. Three pendulums with lengths in the ratios of 1 : 2 : 4 are set swinging.

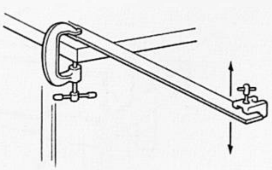


b. Torsional pendulum. A torsional pendulum can be made with a wooden rod (for example, item 90J from the ripple tank kit) suspended by 50 cm of 26 swg Eureka wire. The rod must be balanced and then it will perform torsional oscillations.



Two rods fastened together with elastic bands or a shorter length of wire may also be tried.

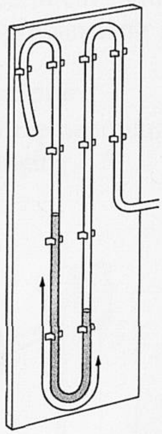
c. Lath with load. One end of a metre rule is clamped to the bench. The other end carries a boss-head. The metre rule will perform vertical oscillations.



(The effect of increasing the load with a second boss-head can be shown.)

d. A huge model of the balance wheel of a watch.

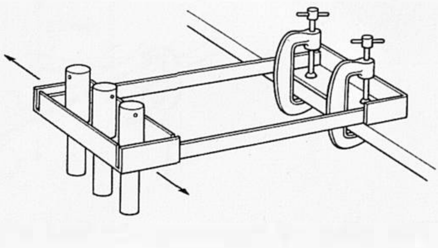
e. U-tube of water. Either the 8 ft mounted U-tube or the 4 ft mounted U-tube from the Bristol pressure kit is filled half way up the tube. The levels are altered by blowing into the tube and the water will then perform damped harmonic motion.



(If mercury is tried, it is necessary to use the small U-tubes.)

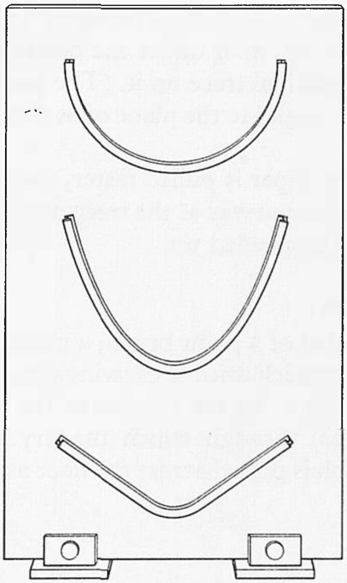
f. Ball in a bowl. A steel ball or marble is rolled back and forth inside a shallow spherical bowl. The amplitude decreases, but the frequency will seem to be unaltered.

g. Inertia balance (the wig-wag). One end of the inertia balance is clamped to the bench. The other end is loaded and the balance oscillates sideways.



h. Optional. Three 2 ft lengths of curtain rail are connected to a vertical board as shown. The upper one in the form of a circle, the middle one in the form of a parabola, and the third one V-shaped with a short curve at the bottom. A steel ball or a marble is rolled to and fro in each in turn.

The pupils should listen to the difference in each case. (In fact – though they should not be told this – the first will give what sounds like an isochronous motion; the second a frequency that changes while the amplitude dies down; the third is not isochronous at all. In the second case pupils will notice that the frequency changes while the amplitude decreases, but few will notice that the motion becomes almost isochronous at small amplitudes. Give them a second chance, without prompting, and more will discover it.)



73 Demonstration

Pendulum with ink or sand to show sinusoidal motion

Apparatus

1 broomstick pendulum – item 10F
1 roll of paper
1 paint brush

Procedure

The massive broomstick pendulum is set up as used in previous years.

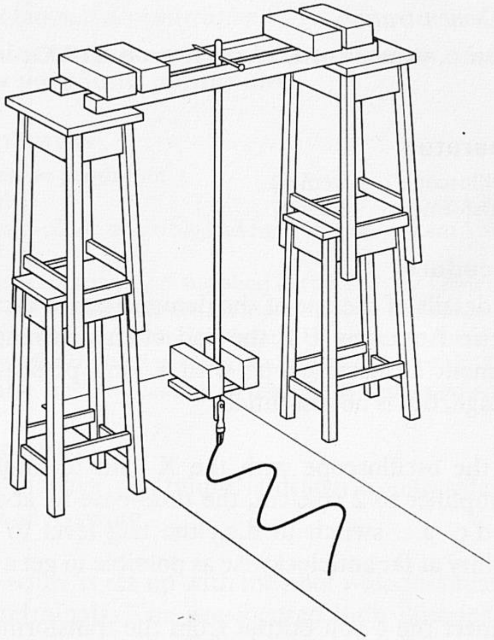
To the lower end of the broomstick is attached a paint brush dipped in ink.

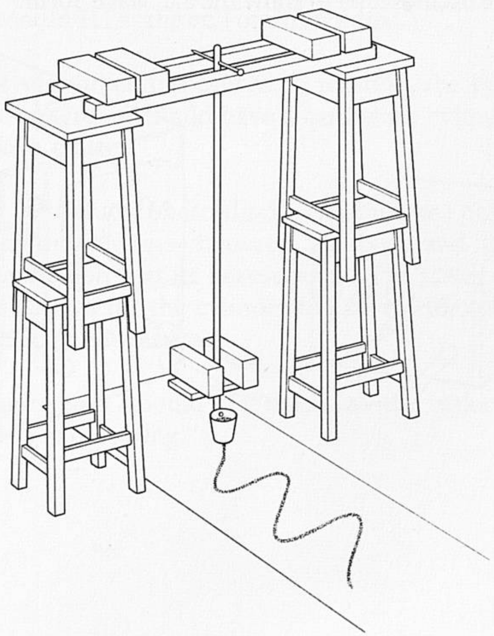
The pendulum is set swinging and the paper is pulled steadily across the floor under the pendulum so that the brush makes a sinusoidal trace on it. (The paper is pulled in a direction at right angles to the plane of oscillation.)

If the paper is pulled faster, the sine wave is spread out more in the same way as the trace on an oscilloscope when the time-base is speeded up.

Note

Instead of a paint brush, a plastic cup can be attached to the broomstick with a drawing-pin. The cup is filled with fine dry sand. In the bottom of the cup is a hole (2–3 mm diameter) through which the dry sand flows onto the paper, which is pulled across the floor as described above.





74 *Demonstration*

The a.c. wave form shown on a C.R.O.

Apparatus

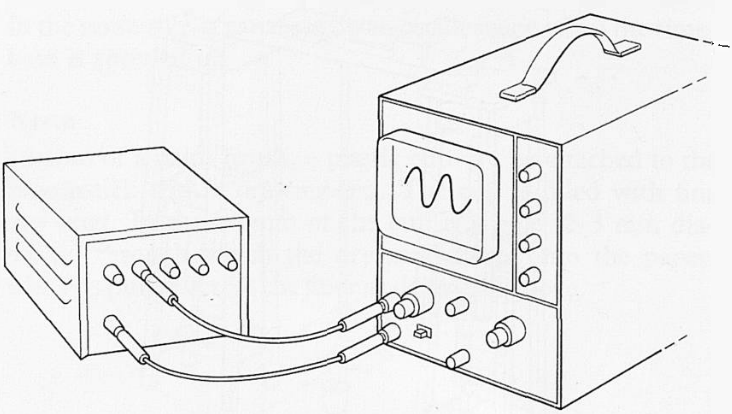
1 oscilloscope – item 64
1 transformer – item 27

Procedure

For details of the use of the demonstration oscilloscope (item 64) see Appendix I at the end of this volume. For this experiment an oscilloscope with a long persistence is an advantage, but is not essential.

Set the oscilloscope with the X gain to minimum and the Y-amplifier to 2 volt/cm, the time-base to about 10 ms/cm, the d.c.–a.c. switch to d.c., the trig level to auto, and the stability as far anticlockwise as possible to get a trace.

Connect the 4 volt output from the transformer to the input of the oscilloscope to show the a.c. wave form.



75 *Optional demonstration*

Scaler used to make measurements of the velocity of a very long pendulum

Apparatus

1 massive pendulum
1 scaler – item 130/1
1 photo-diode assembly and light source – item 130/2

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

The massive pendulum is drawn to one side, released, and allowed to swing.

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 III at the end of this volume.)

To avoid difficulties caused by rotation, the bob should be a large sphere or should have a cardboard cylinder fixed round it like a collar.

The pendulum, photo-diode, and bulb are positioned so that the cylinder passes between the bulb and the photodiode 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.

Measurement should be made of the velocity at several regions in the swing.

76 *Optional demonstration*

Vibrating tuning fork and rotating mirror

This is a worthwhile demonstration, rewarding if the teacher spends the time setting it up. It should be attempted if the apparatus is available.

Apparatus

1 tuning fork (256 c/s or more)	– item 520
1 fractional horsepower motor	– item 150
1 small piece of mirror (5 mm × 2 mm)	
1 compact light source	– item 21
1 converging lens (+ 7D)	– item 112
1 screen	– item 102
1 L.T. variable voltage supply	– item 59

Also required: a small strip of mica and a piece of mirror or a small piece of aluminized Melinex (gauge 25).

Procedure

A small piece of thin plane mirror (less than 5 mm square) is secured to the end of a strip of mica about 5 mm wide and 2 or 3 cm long with a contact adhesive (for example, Evo-stik). The mica strip is then itself carefully secured by the other end to one limb of the tuning fork.

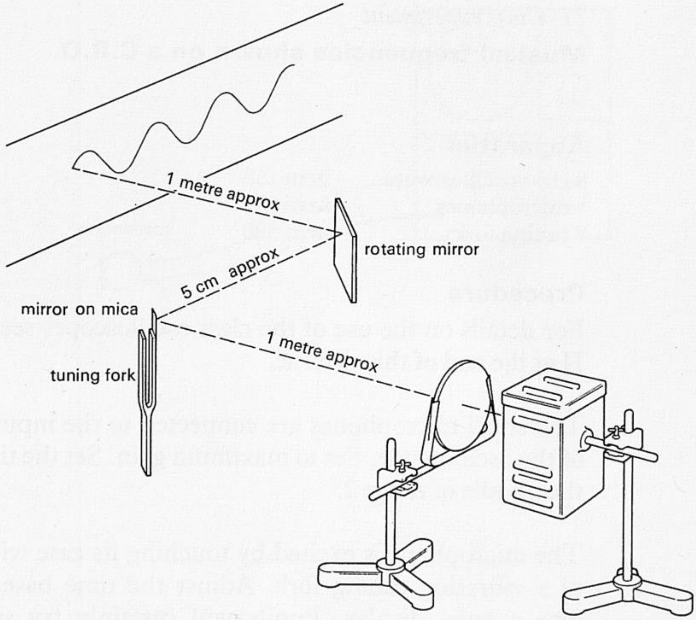
Alternatively a small strip of aluminized Melinex (as used in the demonstration electroscope described in Experiment 99b of the Guide to Experiments III) may be secured to the fork. This can act as its own mirror.

The fork is firmly clamped in the vertical position.

Light from the lamp filament is converged to an image about 2 m away using the lens, and the tuning fork mirror is placed in this beam about a metre from the lens.

A single plane mirror, mounted so that it can rotate about a vertical axis when driven by the fractional horsepower motor, is placed as near as possible to the fork where it can intercept the reflected beam. The image is received on a screen about a metre away.

The motor is then driven at about 600 r.p.m. The light spot will be seen to travel across the screen. If now the fork is plucked vigorously, the light spot will trace a wave form.


1 metre approx
rotating mirror
5 cm approx
mirror on mica
1 metre approx
tuning fork

77 Class experiment

Musical frequencies shown on a C.R.O.

Apparatus

8 class oscilloscopes	– item 158
8 microphones	– item 157
8 tuning forks	– item 520

Procedure

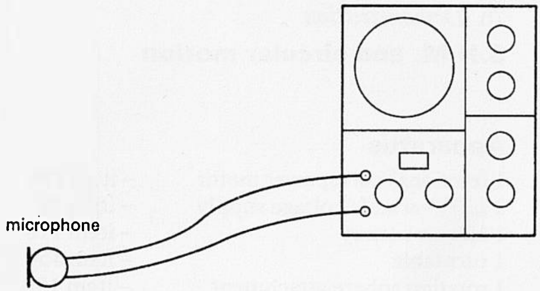
For details on the use of the class oscilloscopes see Appendix II at the end of this volume.

The small microphones are connected to the input terminals of the oscilloscope. Set to maximum gain. Set the time-base to the middle of range 2.

The microphone is excited by touching its case with the base of a vibrating tuning fork. Adjust the time base control to give a good display. Pupils will certainly try singing and whistling across the microphone.

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.


microphone

78 *Demonstration*

S.H.M. and circular motion

Apparatus

1 fractional horsepower motor	– item 150
1 L.T. variable voltage supply	– item 59
1 12 volt battery	– item 176
1 turntable	– item 154/1
1 rotating sphere attachment	– item 152
2 expendable springs	– item 2A
1 1 lb mass	– item 36
1 S-hook	– item 35
1 simple pendulum	– item 527
2 retort stands, bosses, and clamps	– items 503–506
1 compact light source	– item 21
1 translucent screen	– item 46/1
2 G-clamps (4 in)	– item 44/1

Procedure

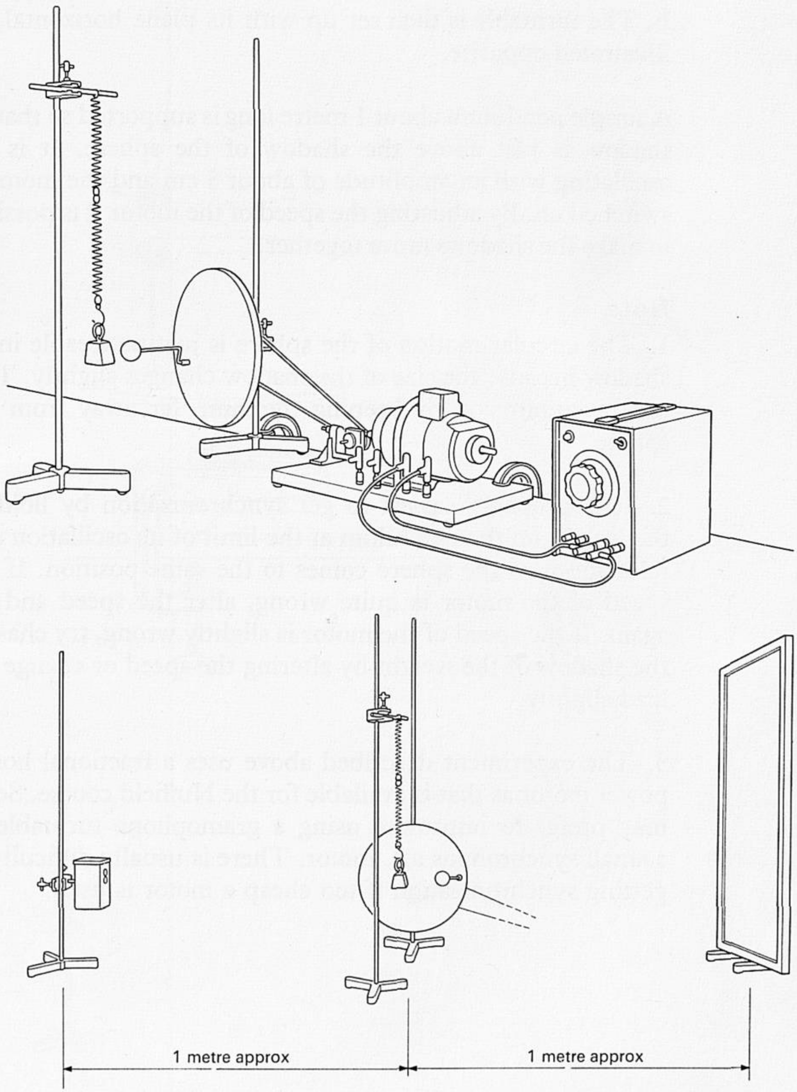
a. Two expendable springs should be joined together and suspended from a retort stand. To the lower end is attached a 1 lb mass using an S-hook.

The turntable is attached to a retort stand so that its plane is vertical, as illustrated opposite. The rotating sphere attachment is connected to the turntable, which is rotated slowly, driven by the fractional horsepower motor through its gearbox attachment.

Set the spring oscillating vertically and adjust the speed of the motion so that the two motions synchronize.

The tungsten iodine lamp is put at least 1 metre behind the 1 lb mass and the sphere, so that two shadows are projected on the screen at least 1 metre farther away.

The field and armature windings of the motor should be connected in parallel to the d.c. terminals of the L.T. variable voltage supply. If fine adjustment of the motor speed is difficult, it may be helpful to connect the field terminals to the 12 volt battery and only connect the armature winding to the L.T. variable voltage supply.


1 metre approx
1 metre approx

b. The turntable is then set up with its plane horizontal, as illustrated opposite.

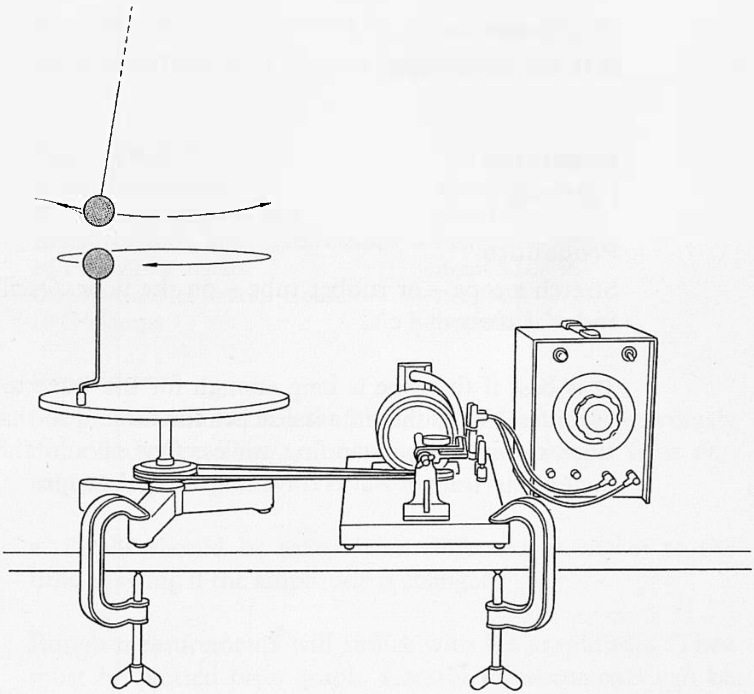
A simple pendulum about 1 metre long is supported so that its shadow is just above the shadow of the sphere. It is set oscillating with an amplitude of about 5 cm and the motor is switched on. By adjusting the speed of the motor it is possible to make the shadows move together.

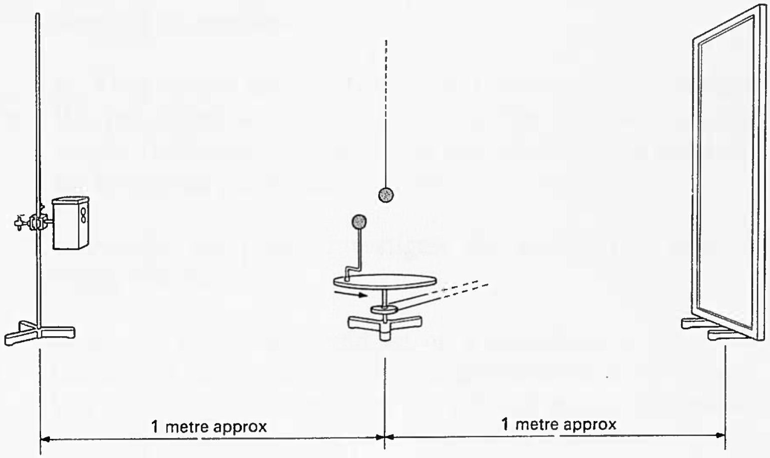
Note

1. The circular motion of the sphere is just noticeable in its shadow because the size of the shadow changes slightly. This can be minimized by keeping the lamp far away from the sphere.

2. It is probably easiest to get synchronization by holding the weight on the pendulum at the limit of its oscillation and releasing it as the sphere comes to the same position. If the speed of the motor is quite wrong, alter the speed and try again. If the speed of the motor is slightly wrong, try chasing the shadow of the weight by altering the speed or change the load slightly.

3. The experiment described above uses a fractional horse-power motor as that is available for the Nuffield course. Some may prefer to improvise using a gramophone turntable or a small synchronous a.c. motor. There is usually difficulty in getting synchronization if too cheap a motor is used.




1 metre approx
1 metre approx

79 *Demonstration*

S.H.M. on a rope

Apparatus

1 20 ft rope

Procedure

Stretch a rope – or rubber tube – on the floor. Oscillate one end of it at about 4 c/s.

It is best if the rope is long enough for the wave to die out considerably by the time it reaches the far end so that reflections do not cause standing waves. One should then see a continuous train of waves travelling along the rope.

80 *Optional class experiment*

Investigation of a simple pendulum

Apparatus

16 pendulum bobs	– item 527
32 2 in metal strips as jaws	– item 121
16 retort stands, bosses, and clamps	– items 503–506
16 1 lb or 1 kg masses	– items 32 or 36
16 stop-watches or stop-clocks	– item 507
16 G-clamps	– item 44/1

Procedure

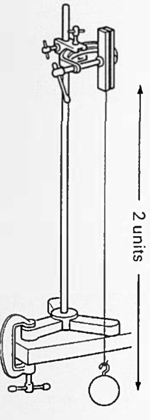
Simple pendulums at least 30 in long are set up as previously described. See *Teachers' Guide* for discussion of aims and procedure.

a. Pupils should be asked what difference it makes to the time of swing if the amplitude is changed.

Rough measurements will suffice with big amplitudes. They must be plotted on a graph. Careful measurements can be made at small amplitudes once it is apparent that the period does not change rapidly.

b. They should investigate the effect of changing the mass of the pendulum to a much more massive bob, keeping the length, from support to centre of bob, the same. In this case, the longer the pendulum the better.

c. Finally, the pupils investigate the variation of time of swing with length.



Each pair of pupils should set up a pendulum of a definite length and make one or two measurements of it. If various lengths are assigned amongst the pairs of pupils, the results of all the readings can be incorporated in a communal graph plotted by the teacher on the blackboard. Pupils may also plot their own communal graphs.

See *Teachers' Guide* for a discussion on how the first graph might be used to lead pupils to a graph of T^2 against L.

81 *Class experiment*

Simple d.c. and a.c. generators

Apparatus

1 Westminster electromagnetic kit – item 92
16 galvanometers – item 180
8 class oscilloscopes – item 158

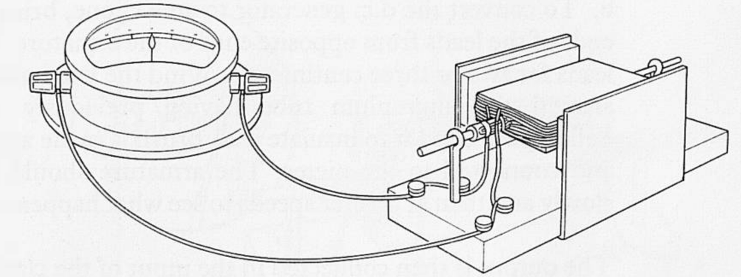
Procedure

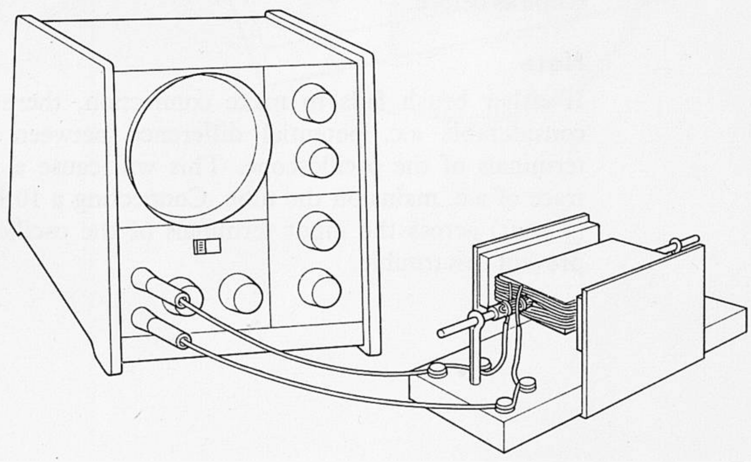
a. The pupils should make again a d.c. generator using the electromagnetic kit – for full details see Year III *Experiment Guide*, Experiments 85 and 87a.

The leads are connected to the galvanometer. On spinning the armature, a deflection is observed. The direction of spin should be reversed to see what difference this makes. (The armature can conveniently be spun with a finger on the aluminium tube.)

The output of the generator should then be connected to the class oscilloscope, using maximum gain. For details of the class oscilloscope, see Appendix II at the end of this volume. The time-base should be set at about 20 ms/cm.

A convenient way of turning the generator when connected to the oscilloscope is to wrap a thread round the aluminium tube and to pull the ends.



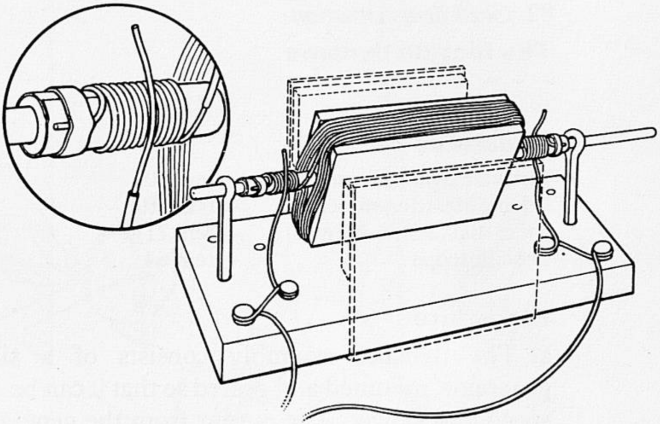


b. To convert the d.c. generator to an a.c. one, bring out the ends of the leads from opposite ends of the armature. Bare the leads for two or three centimetres. Wind the bare ends tightly around the aluminium tube having previously wrapped Sellotape around it to insulate it. A brush is made at each end and connected to the meter. The armature should be spun slowly and then at greater speeds to see what happens.

The output is then connected to the input of the class oscilloscope as before.

Note

If either brush fails to make connection, there will be a considerable a.c. potential difference between the input terminals of the oscilloscope. This will cause a misleading trace of a.c. mains on the tube. Connecting a 10 kΩ resistor ($\frac{1}{2}$ watt) across the input terminals of the oscilloscope will prevent this trouble.



82 *Class demonstration*

The bicycle dynamo

Apparatus

1 bicycle dynamo assembly	– item 103
1 demonstration meter	– item 70
1 d.c. dial (2·5–0–2·5 mA)	– item 71/4
1 oscilloscope	– item 64

Procedure

a. The dynamo assembly consists of a simple bicycle generator, mounted and geared so that it can be driven both at speed and slowly. The output from the generator should be connected to the large demonstration meter with a d.c. dial 2·5–0–2·5 mA and the handle turned slowly so that the deflection is clearly visible. Pupils should increase the speed of rotation and note how, at higher speeds, the pointer merely vibrates over a very small range about the zero position.

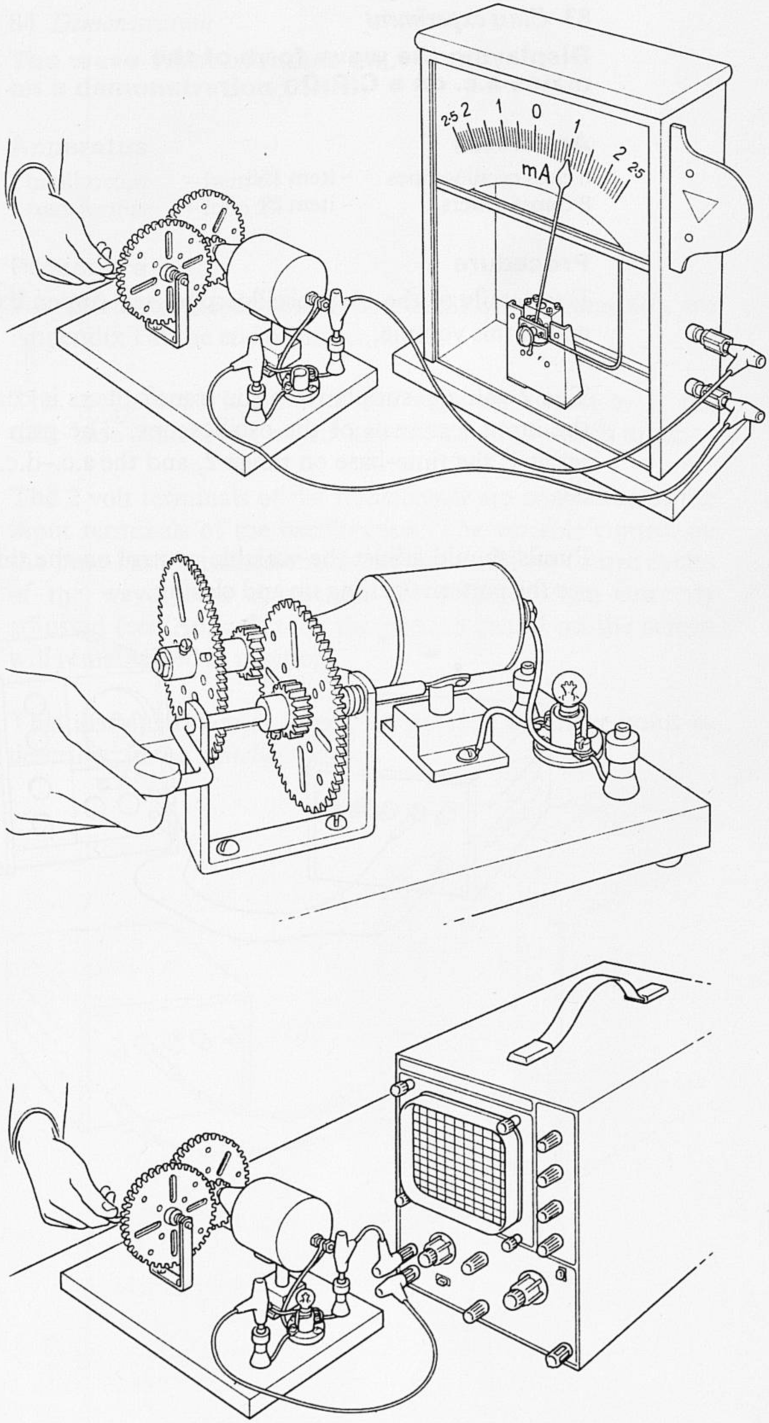
The dynamo may also be driven at high speed using the other gears provided. The output will be sufficient to light the pea lamp across it. Remember to disconnect the meter first.

b. The output from the bicycle dynamo is applied to the Y-plates of the demonstration oscilloscope. The time-base should initially be switched off and there should be maximum gain on the Y-amplifier. The dynamo should be driven at the slow speed and the spot will move up and down.

The time-base should then be switched to slow speed and the trace centred with the X-shift with the gain still at maximum. The dynamo is again driven at the slow speed. (A long persistence screen would be an asset for this part of the experiment, but is not essential.) Gradually speed up the time-base.

Cut down the gain on the oscilloscope to about 2 volts/cm and drive the dynamo at the high speed. With the time base set at 10 ms/cm the wave-form will be seen.

The wave-form will not be sinusoidal; the bicycle dynamo was designed for efficiency and not for teaching purposes. Other generators can be found which give a more nearly sinusoidal wave-form, but there is greater value here in using a generator as familiar as the bicycle dynamo.


2·5 2 1 0 1 2 2·5
mA

83 *Class experiment*

Displaying the wave form of the mains a.c. on a C.R.O.

Apparatus

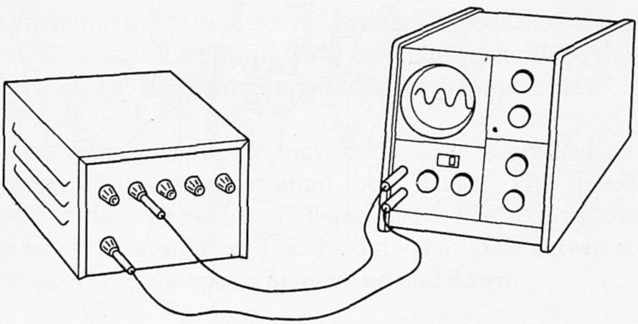
8 class oscilloscopes	– item 158
8 transformers	– item 27

Procedure

For details of the class oscilloscope, see Appendix II at the end of this volume.

The 2 volt a.c. supply from the transformers is connected to the input terminals of the 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.



84 *Demonstration*

The wave-form of mains a.c. on a demonstration C.R.O.

Apparatus

1 oscilloscope – item 64
1 transformer – item 27

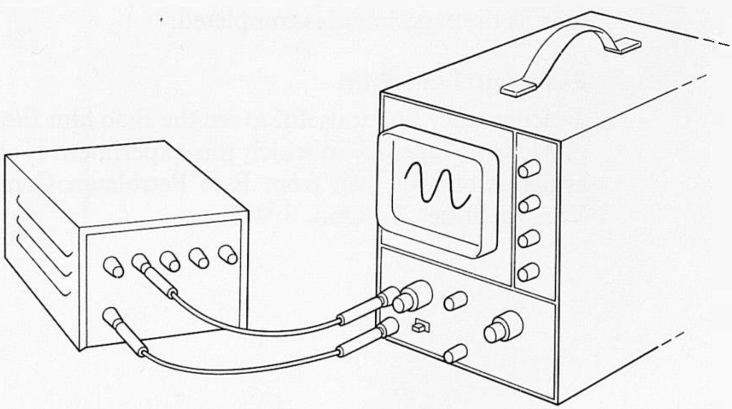
Procedure

For details of the demonstration oscilloscope (item 64), see Appendix I at the end of this volume.

The oscilloscope is set with the volts/cm switch to 1, the time-base control to 1 ms/cm and the a.c.–d.c. switch to a.c.

The 2 volt terminals of the transformer are connected to the input terminals of the oscilloscope. The variable control on the time-base is turned anticlockwise until four or five cycles of the wave form appear on the screen. When correctly adjusted (see Appendix I), the pattern traced on the screen will remain fixed in position.

This demonstration is largely to provide a talking point as described in the *Teachers' Guide*.



85 *Demonstration*

An electroscope as a voltmeter

Apparatus

1 electroscope	– item 51A and B
1 H.T. power supply	– item 15
1 1-kΩ safety resistor	– item 132H
1 variable a.c. supply ('Variac')	– item 78
1 mains lamp (240 V, 60 watt)	
1 lampholder (BC) on base	– item 162

Procedure

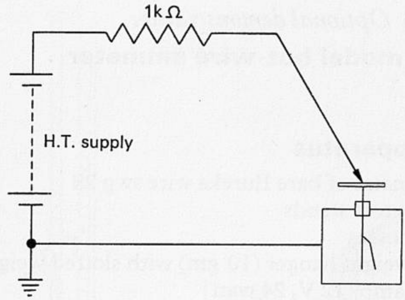
The H.T. power supply is set to full output. It is connected through a safety resistor of, say, 1 kΩ, to the electroscope, first with the positive lead to the plate and the negative to the case, then the other way round.

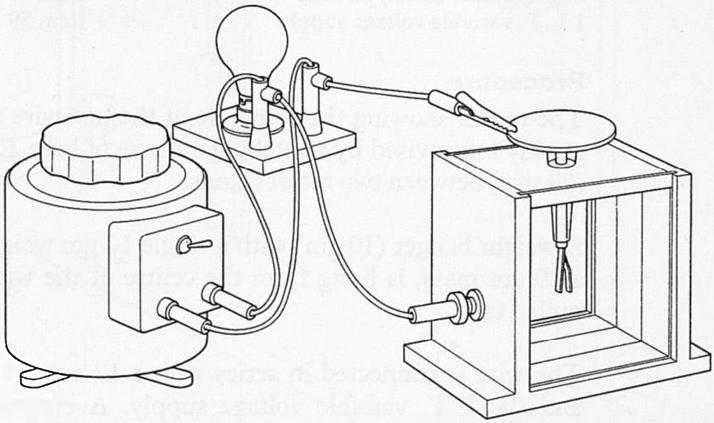
The experiment is repeated with the a.c. supply. Perhaps the simplest method is to connect the variable a.c. supply ('Variac' type) across a mains lamp and to connect the electroscope as a voltmeter in parallel with the lamp.

Care must obviously be taken only to switch on when all connections have been made and to switch off and disconnect as soon as the experiment is completed.

Esso-Nuffield Film

Teachers may find it useful to see the Esso film *Electrostatics: A Modern Approach* in which this experiment is shown. It is available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.


1kΩ
H.T. supply



86 *Optional demonstration*

A model hot-wire ammeter

Apparatus

1 metre of bare Eureka wire swg 28	– item 98
2 retort stands	– items 503–504
2 bosses	– item 505
1 weight hanger (10 gm) with slotted weights	– item 31/1
1 lamp (12 V, 24 watt)	– item 72
1 lampholder (SBC) on base	– item 74
1 L.T. variable voltage supply	– item 59

Procedure

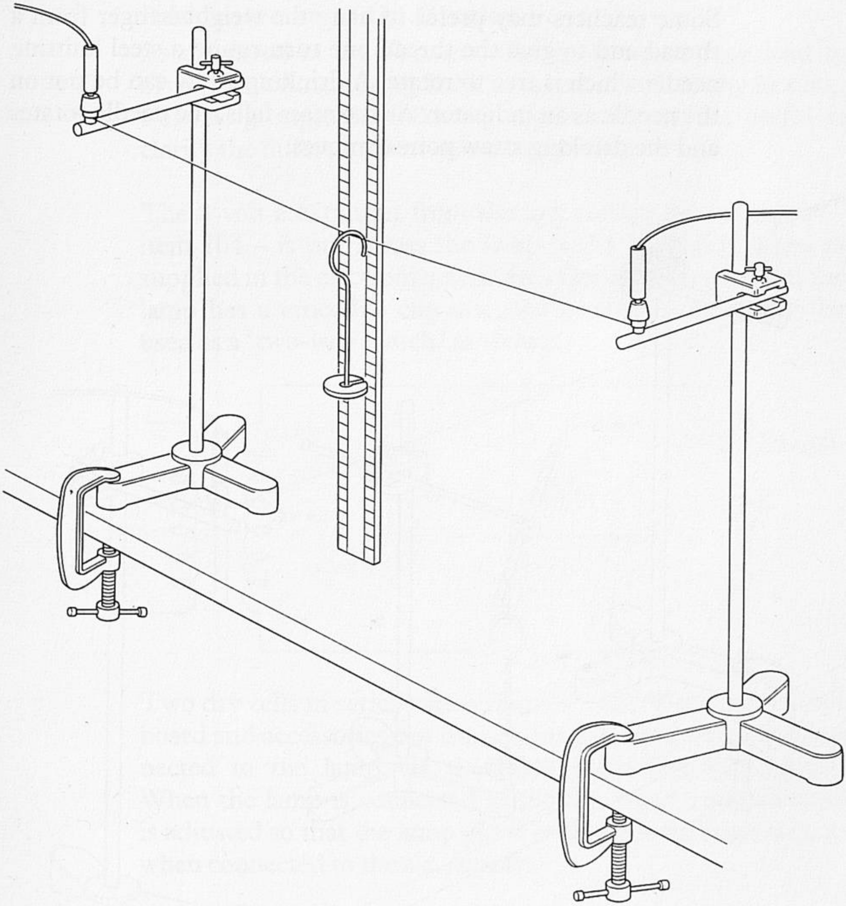
The model showing the principle of the hot-wire ammeter is readily improvised by stretching a metre of bare Eureka wire (28 swg) between two retort stands.

A weight hanger (10 gm) with a single 10 gm weight, making a 20 gm mass, is hung from the centre of the wire which is pulled taut.

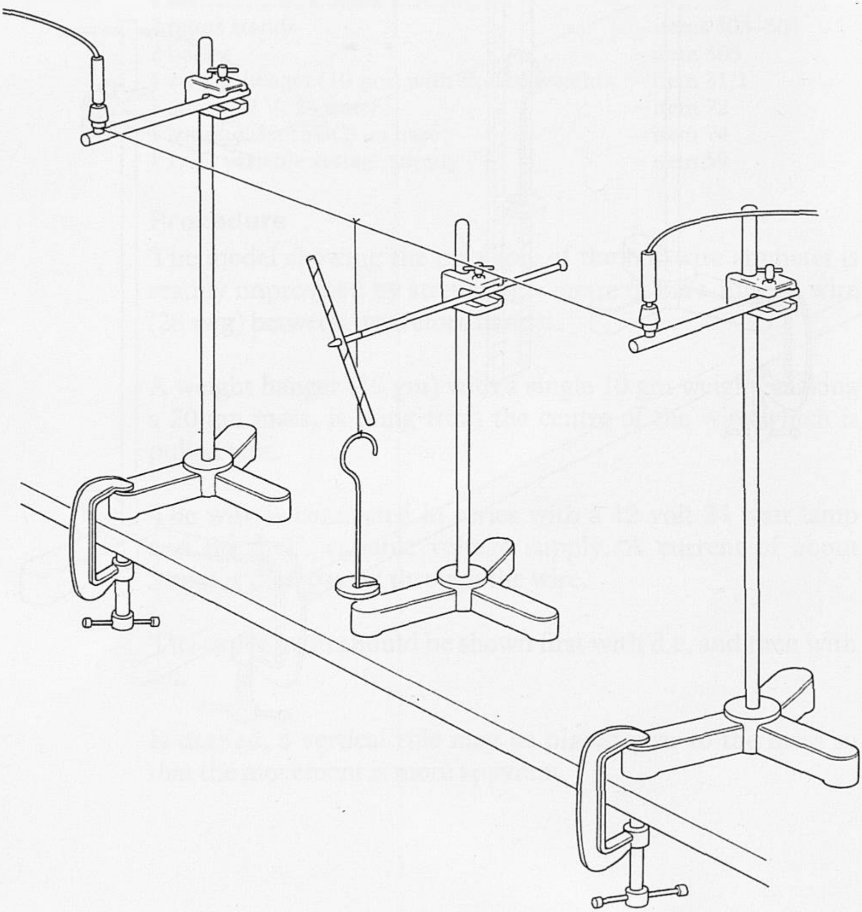
The wire is connected in series with a 12 volt 24 watt lamp and the L.T. variable voltage supply. A current of about 2 amp is then passed through the wire.

The experiment should be shown first with d.c. and then with a.c.

If desired, a vertical rule may be placed near to the mass so that the movement is more apparent.



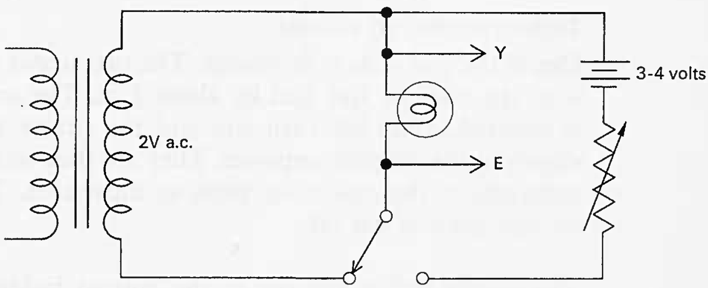
Some teachers may prefer to hang the weight hanger from a thread and to give the thread one turn round a steel knitting needle which is free to rotate. A drinking straw can be put on the needle as an indicator. As the mass falls, the needle rotates and the drinking straw pointer moves.



Peak value and R.M.S. value

As discussed in the *Teachers' Guide*, the above may lead to discussion of measuring R.M.S. values of current by heating. For fast groups, the following experiment may be useful to clarify the difference between the two values.

The 2 volt a.c. output from the low voltage power supply – item 104 – is put across the lamp (a 2·5 V M.E.S. lamp, as supplied in the electromagnetic kit). One of the leads from the lamp has a crocodile clip attached to enable the lead to be used as a 'two-way switch' as shown.



Two dry cells in series with a rheostat – the Worcester circuit board and accessories can conveniently be used – are also connected to the lamp via the home-made two-way switch. When the lamp is connected to the d.c. supply, the rheostat is adjusted so that the lamp glows with the *same* brightness as when connected to the a.c. supply.

Leads across the lamp are connected to the input of the class oscilloscope.

In the d.c. case, the spot will be seen to be deflected a definite amount. In the a.c. case, a line is obtained the length of which is $2\sqrt{2}$ times the deflection of the spot.

The time-base should be switched on. In the d.c. case, the line trace is merely deflected. In the a.c. case, the wave form is seen.

87 *Optional demonstration*

A model moving iron meter

Apparatus

1 600 turn transformer coil	– item 147E
1 L.T. variable voltage supply	– item 59
1 rheostat	– item 541/1
2 3 in nails	
2 drinking straws	

Also required: pins.

Construction of model

One of the 3 in nails is beheaded. The two straws are slipped over the ends of this nail by about $\frac{1}{4}$ in. The arrangement is inserted in the 600 turn coil and the straws are bent as shown in the diagram opposite. They are then secured to the terminals of the coil using pins, as illustrated. The excess on one straw is cut off.

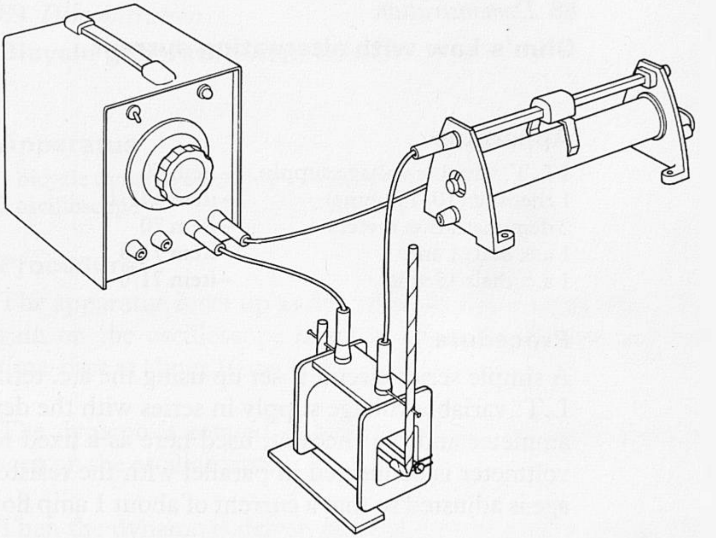
The second nail is secured to the bottom inside corner of the coil, at the same level as the nail held by the drinking straws.

The whole coil is then tipped until the beheaded nail swings to a position which brings it very close to the fixed nail.

Procedure

The coil is then connected in series with a rheostat to the d.c. output of the L.T. variable voltage supply. When the current is switched on the nails repel each other and there is a deflection of the pointer. Increase the current to increase the deflection.

Repeat using the a.c. output of the L.T. variable voltage supply.



88 *Demonstration*

Ohm's Law with alternating current

Apparatus

1 L.T. variable voltage supply	– item 59
1 rheostat (10–15 ohms)	– item 541/1
2 demonstration meters	– item 70
1 a.c. dial: 1 amp	– item 71/8
1 a.c. dial: 15 volts	– item 71/6

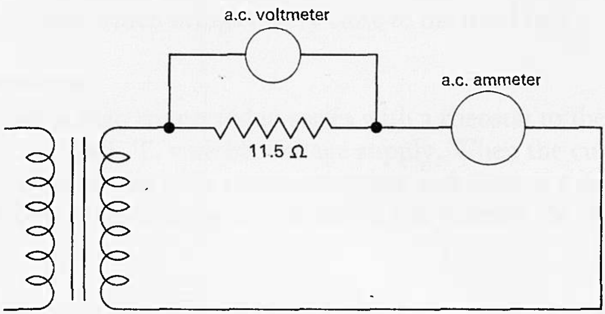
Procedure

A simple series circuit is set up using the a.c. terminals of the L.T. variable voltage supply in series with the demonstration ammeter and the rheostat, used here as a fixed resistor. The voltmeter is connected in parallel with the resistor. The voltage is adjusted so that a current of about 1 amp flows.

A series of values of the current and potential difference is recorded as the voltage applied is gradually reduced.

Note

This should be a quick demonstration, as explained in the *Teachers' Guide*, to show that the ratio of the (R.M.S.) meter readings is constant.



89 *Demonstration*

Bicycle generator with C.R.O.

Apparatus

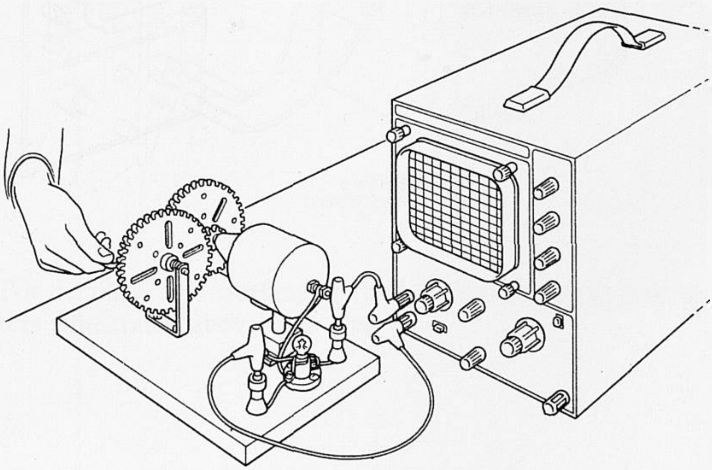
1 bicycle dynamo assembly – item 103
1 oscilloscope – item 64

Procedure

The apparatus is set up as described in Experiment 82b. The gain on the oscilloscope is set at about 2 volts/cm and the time-base at about 10 ms/cm.

The dynamo is rotated at high speed and the wave form is seen on the oscilloscope.

Then the dynamo is driven more and more slowly so that the lower voltage and lower frequency are evident.



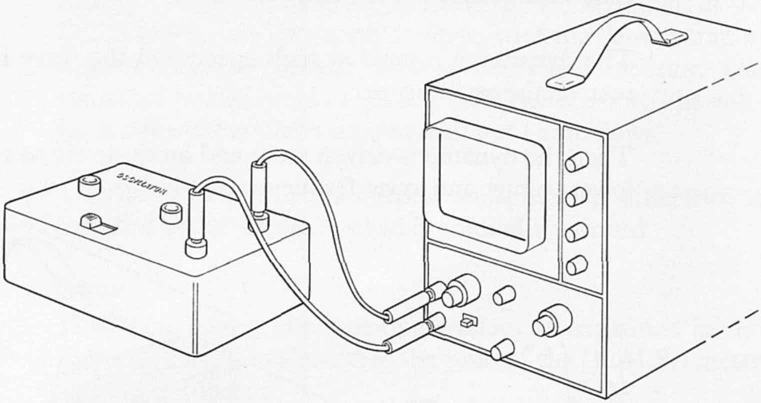
90 *Optional demonstration*

Slow a.c. with transistor oscillator

Procedure

If a school possesses a suitable transistor oscillator providing a.c. at frequencies of 1 or 2 cycles per second, the teacher might wish to demonstrate it.

This should never replace a simpler, more obvious slow a.c. generator as used in the next experiment.

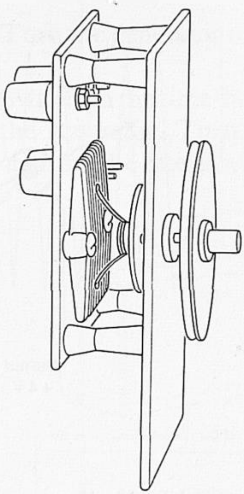


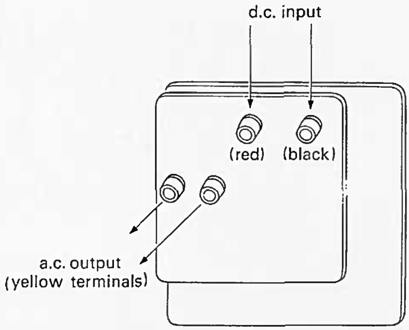
91a *Class experiment*

Slow a.c. with low frequency generator-I

Apparatus

8 class oscilloscopes	– item 158
8 low frequency a.c. generators	– item 170
8 batteries	– item 176

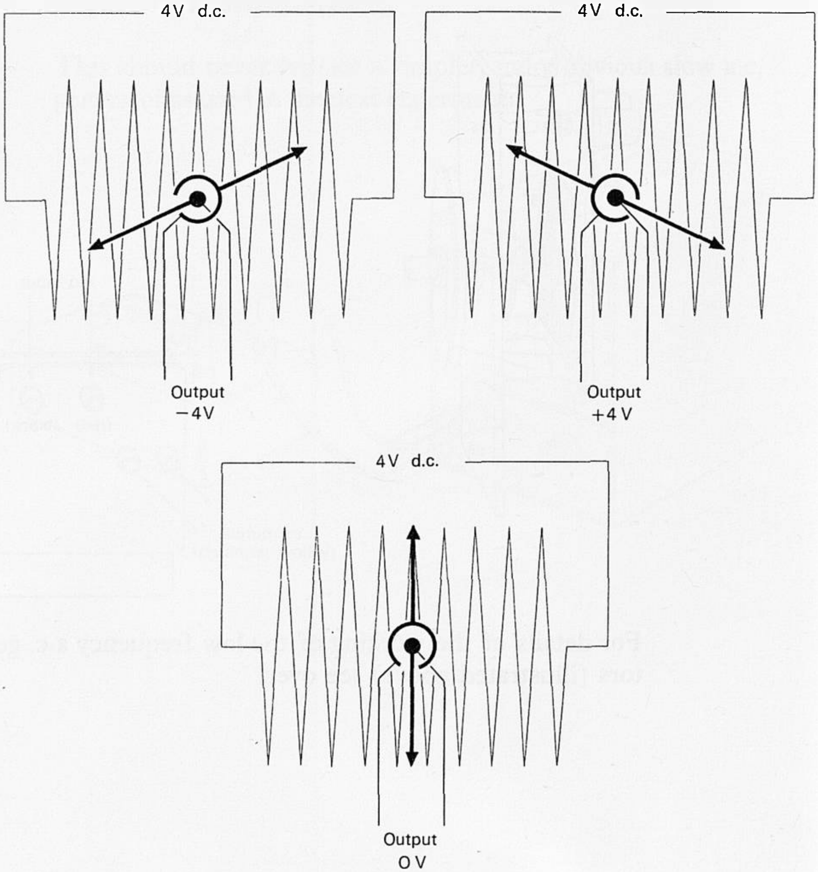




For details of the working of the low frequency a.c. generators (illustrated above) see over.

Low frequency A.C. generators

A d.c. 4 volt supply is connected across the coil of the generator. The metal brushes rotate in contact with the coil and are connected to the a.c. output terminals. See the film *Oscilloscopes and Slow A.C.* mentioned on the next page.



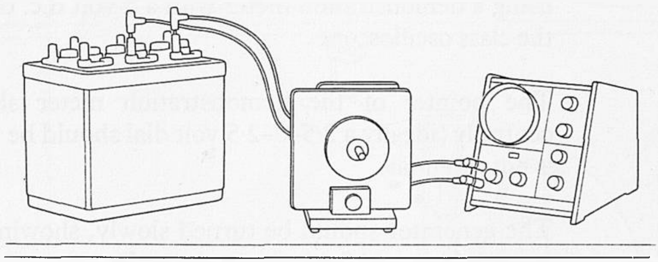
Procedure

For details of the class oscilloscopes see Appendix II at the end of this volume.

Set the a.c.–d.c. switch on the oscilloscope to d.c., the time-base off, and the Y-gain to about 1. Put 2–4 volts across the low frequency a.c. generator. Connect the output terminals to the input of the oscilloscope.

Turn the generator to show the spot moving up and down.

Switch on the time-base to its slowest speed on range 1 and turn the generator. Turn up the time-base speed and repeat increasing the rate at which the generator is turned.



Esso-Nuffield Film

It is recommended that teachers might see the Esso film for science teachers *Oscilloscopes and Slow A.C.* The above experiment is shown in it. The film is available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

Note

The low frequency generator works well, but if it is found that it has got dirty, a few drops of thin oil (Three-in-one oil is suitable) on the brushes will ensure continuous contact.

91b *Demonstration*

Slow a.c. with low frequency generator-II

Apparatus

1 low frequency a.c. generator	– item 170
1 battery	– item 176
1 demonstration meter	– item 70
1 d.c. dial: 5 volts	– item 71/3
1 a.c. dial: 5 volts	– item 71/5
1 class oscilloscope	– item 158

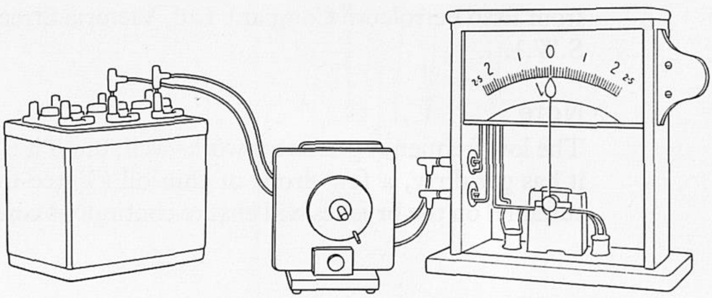
Procedure

After the pupils have seen slow a.c. for themselves on the class oscilloscopes, the teacher should show the same thing using a demonstration meter with a 5 volt d.c. dial in place of the class oscilloscope.

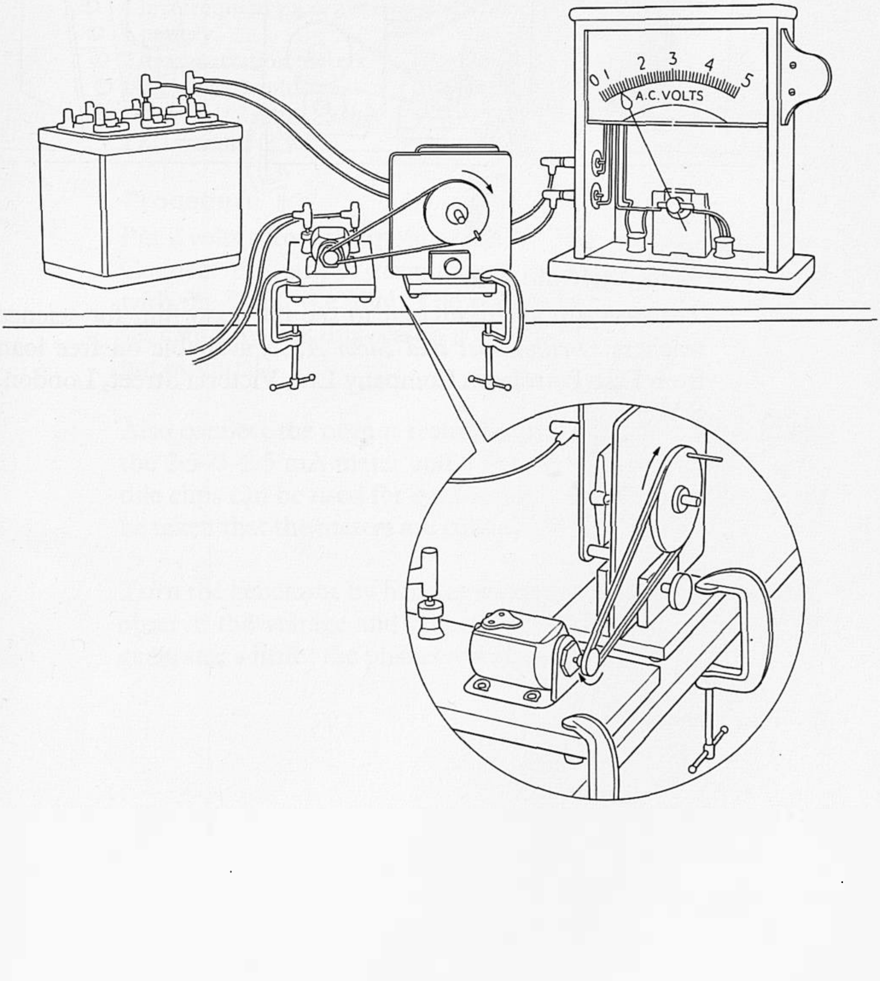
The pointer of the demonstration meter should be set centrally (ideally a 2·5–0–2·5 volt dial should be used, but this is not essential).

The generator should be turned slowly, showing the pointer moving back and forth across the scale.

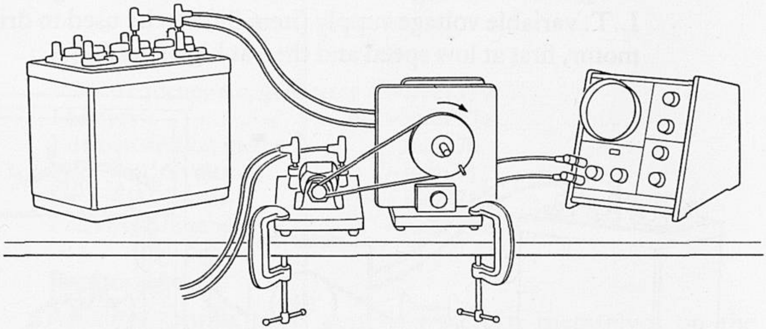
The generator is then turned faster and faster, so that the amplitude of the pointer's movement gets less and less. Then replace the d.c. dial with an a.c. dial.



If the motor from the Malvern Energy Conversions Kit (item 9A) is put beside the motor generator, it can be used to drive the generator using an elastic band as the driving belt. The L.T. variable voltage supply (item 59) can be used to drive the motor, first at low speed and then at high speed.



Finally the output from the a.c. generator, driven by the small motor, can be shown on the oscilloscope.



Esso-Nuffield Film

Teachers are again advised to see the Esso film for science teachers *Oscilloscopes and Slow A.C.*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

91c *Demonstration*

Slow a.c. with low frequency generator-III

Apparatus

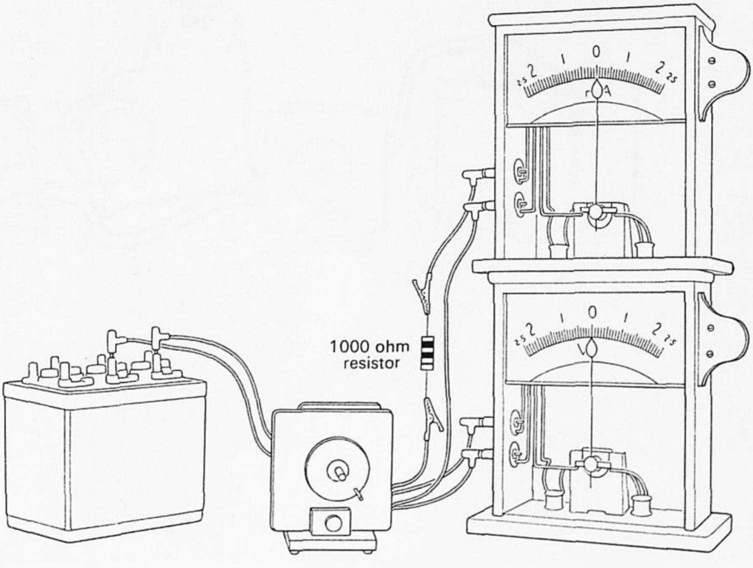
1 low frequency a.c. generator	– item 170
1 battery	– item 176
2 demonstration meters	– item 70
1 d.c. dial: 5 volts	– item 71/3
1 d.c. dial: 2·5–0–2·5 mA	– item 71/4
1 kΩ resistor ($\frac{1}{2}$ watt)	– item 132H

Procedure

Put 2 volts across the input of the low frequency a.c. generator. Connect the output terminals to the demonstration meter with the 5 volt d.c. dial. The pointer of the meter should be set centrally (for this reason a 2·5–0–2·5 volt dial is ideal, but not essential).

Also connect the output from the generator in series through the 2·5–0–2·5 mA meter and a resistor of 1000 ohms. Crocodile clips can be used for connecting the resistor. Care should be taken that the meters are connected with the same polarity.

Turn the generator by hand at about 1 turn per 5 seconds and observe the voltage and current phases. Then speed up the generator a little; the phases remain the same.



91d *Optional class experiment*

Slow a.c. with low frequency generator-IV

Note

With a fast group, the teacher might like to repeat the previous experiment 91c as a class experiment.

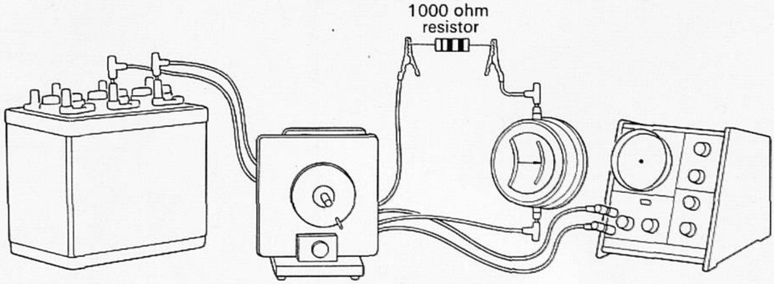
Apparatus

8 low frequency a.c. generators	– item 170
8 class oscilloscopes	– item 158
8 1000 ohm resistors ($\frac{1}{2}$ watt)	– item 132H
8 galvanometers (centre zero)	– item 180
8 batteries	– item 176

Procedure

Put 2 volts across the input of the low frequency a.c. generator. The output is connected to the input terminals of the class oscilloscope. Also across the output terminals is put the centre-zero galvanometers in series with the 1000 ohm resistor.

The time-base of the oscilloscope is switched off, the a.c.–d.c. switch put in the d.c. position, the gain set to 5 div/volt, and the Y-shift adjusted so that the spot is in the centre when the galvanometer reads zero.



The generator is turned by hand at speeds of $\frac{1}{2}$ to 1 rev/sec and the phase difference is observed.

It is easier to see the phase difference if the face of the galvanometer is put side by side with the oscilloscope screen. The galvanometer should be turned so that the needle moves up and down parallel to the spot.

Notes

1. The component values have been chosen to give a good deflection when a centre zero galvanometer, 3·5–0–3·5 mA, is used. Other galvanometers may need different component values.

2. 4 mm crocodile clip leads (as used on the circuit board) are useful in making connections to the wire ended resistance.

3. By putting the circuit board rectifier in series with the lead to the C.R.O. a delightful demonstration of rectification is obtained.

4. Increasing the speed of rotation of the generator shows the effect of the inertia of the galvanometer needle compared with that of the electron beam.

5. The brilliance control should be kept as low as possible and the spot defocused to avoid screen burn.

92a *Optional buffer demonstration*

Slow a.c. with a capacitor and an inductor

Apparatus

1 low frequency a.c. generator	– item 170
1 battery	– item 176
2 demonstration meters	– item 70
1 d.c. dial: 5 volts	– item 71/3
1 d.c. dial: 2·5–0–2·5 mA	– item 71/4
1 demountable transformer kit	– item 147
1 electrolytic capacitor (500 μF, 15 V working)	– item 132C

Procedure

Put 2 volts across the input of the low frequency a.c. generator as in Experiment 91c. Connect the voltmeter across the output. Put the output also through the 2·5–0–2·5 mA meter in series with the 500 μF capacitor. Set the pointers of the meters to the centre positions.

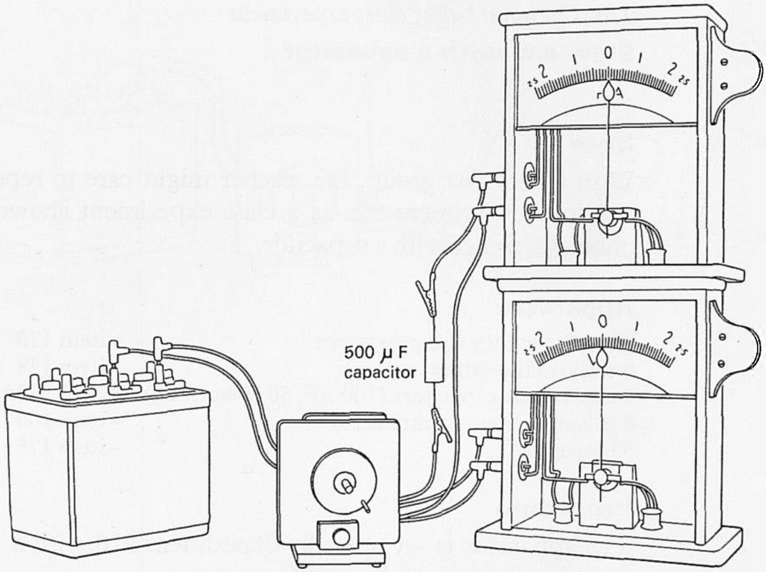
Turn the generator slowly and show the phase difference.

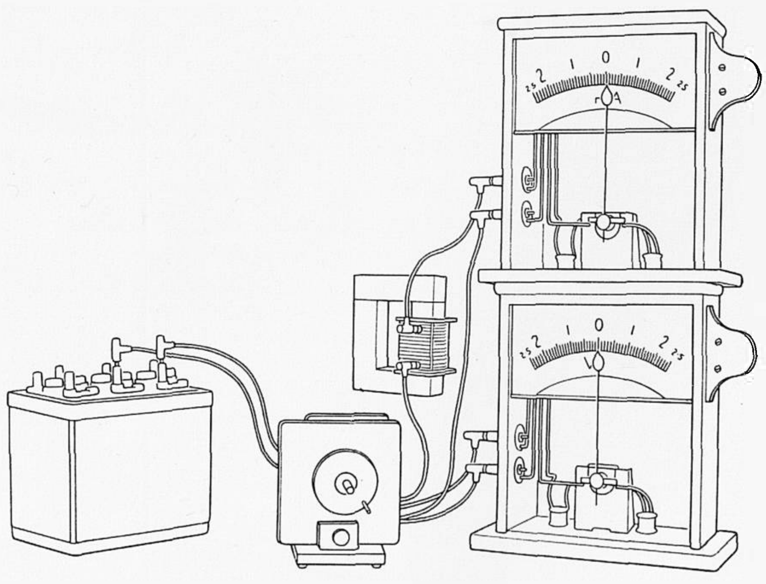
Repeat with an inductor, consisting of the 12,000 turn coil on the laminated U-core of the demountable transformer, in place of the capacitor. Observe the phase difference.

Electrolytic capacitors should normally be used only on direct voltages of the correct polarity. However, it has been found that they work well in these slow a.c. experiments. The lack of any direct polarizing voltage may cause some deterioration of the dielectric in these capacitors and it is a wise precaution to 'form' the plates before and after use. This is done by connecting the capacitors to d.c. with a voltage less than or equal to the working voltage of the capacitor and of the correct polarity.

Esso-Nuffield Film

Teachers are advised to see the Esso film for science teachers *Oscilloscopes and Slow A.C.* in which all the above experiments are demonstrated. It is a film for teachers and is not suitable for showing to pupils because the pace of the film covers a large number of important experiments much too rapidly for pupils.





Note

The low frequency generator works well, but if it is found that it has got dirty, a few drops of thin oil (Three-in-one oil is suitable) on the brushes will ensure continuous contact.

92b *Optional buffer class experiment*

Slow a.c. with a capacitor

Note

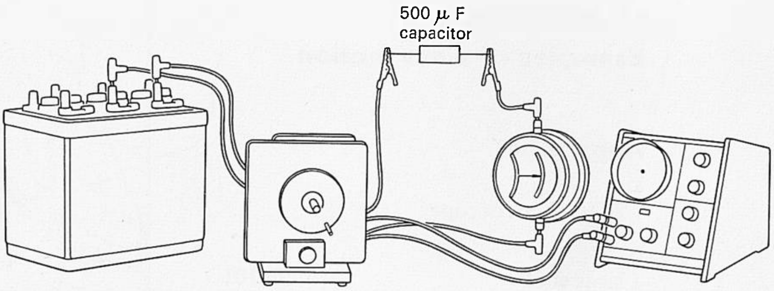
With a very fast group, the teacher might care to repeat the previous experiment 92a as a class experiment showing the phase difference with a capacitor.

Apparatus

8 low frequency a.c. generators	– item 170
8 class oscilloscopes	– item 158
8 electrolytic capacitors (100 μF, 50 V working)	– item 132A
8 galvanometers (centre zero)	– item 180
8 batteries	– item 176

Procedure

The apparatus is set up as in Experiment 91d with a 100 μF capacitor in place of the 1000Ω resistor.


500 μ F
capacitor

93 *Demonstration*

Examples of wave motion

Apparatus

a.
1 20 ft length of rope

b.
1 large slinky – item 101

c. (optional)
1 rectangular tank – item 100/2

d. (optional)
1 Edinburgh CO_2 pucks kit – item 95
4 extra CO_2 pucks – item 169

e. (optional)
20 dynamics trolleys – item 106/1
40 expendable springs – item 106/1
40 expendable springs – item 2A
60 trolley pegs
1 4 in G-clamp – item 44/1

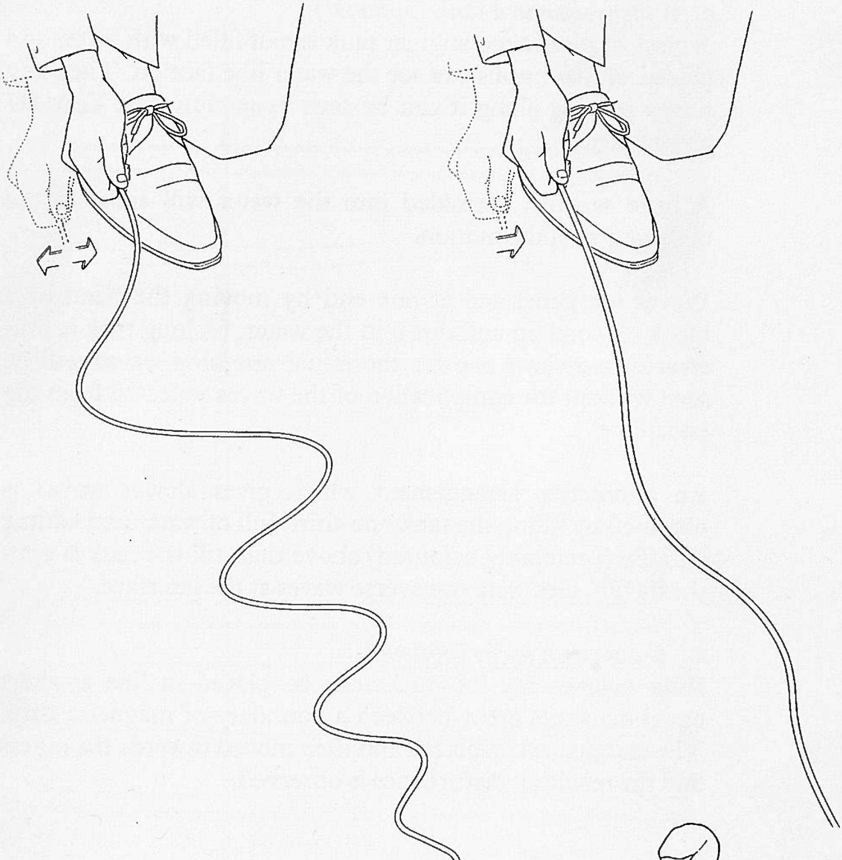
Procedure

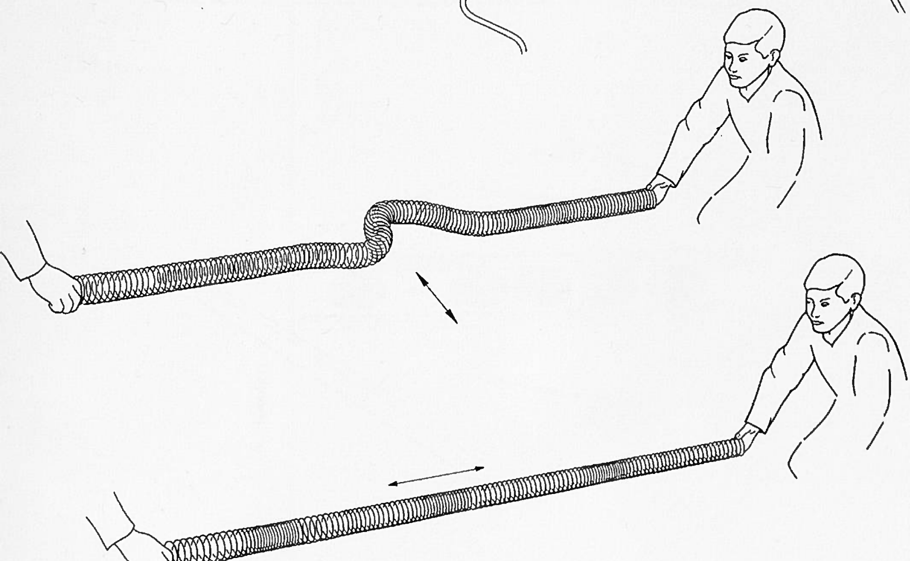
a. *Waves on a rope*

Stretch a rope – or rubber tube – on the floor or bench top. Oscillate one end of it at about 4 c/s, keeping the other end fixed. It is best if the rope is long enough for the wave to die out considerably by the time it reaches the far end so that reflections do not cause standing waves. One should then see a continuous train of waves travelling along the rope.

b. *Waves in a slinky*

The large slinky is stretched across the floor or along the bench top. First a transverse pulse and then a continuous transverse wave is shown travelling down it. Longitudinal pulses travelling down the slinky should also be shown.





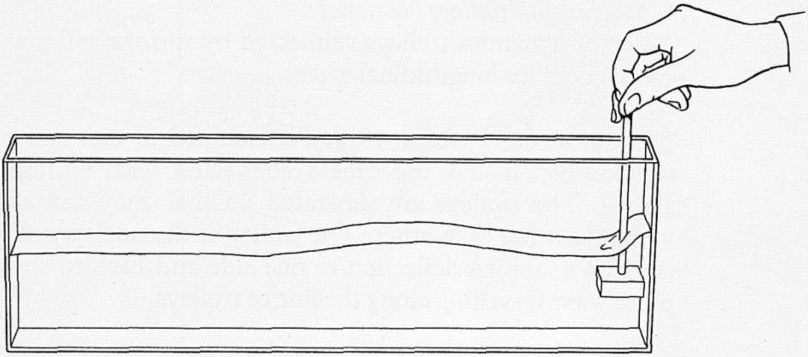
c. *Water waves in a tank (optional)*
A glass or plastic rectangular tank is half filled with water and placed so that pupils can see the water line face on. Then any waves passing along it can be seen in section. See Year III experiment 3.

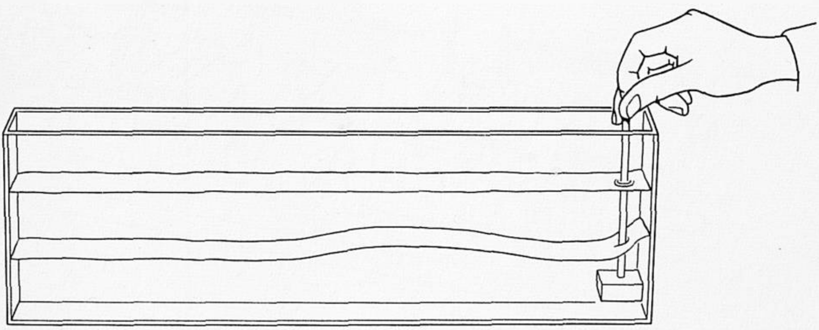
A little sawdust sprinkled into the water will assist in the observation of the motion.

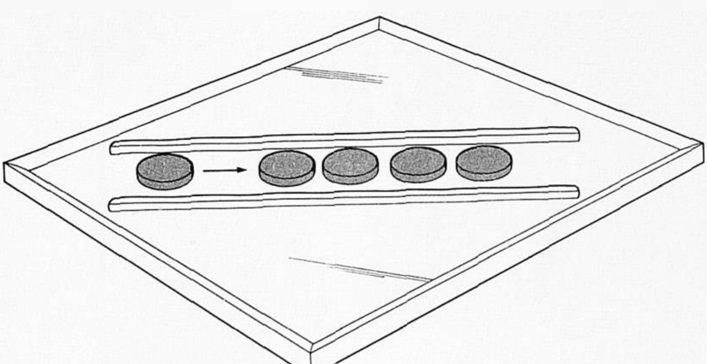
Waves are generated at one end by moving the hand or a block of wood up and down in the water. (A long tank is preferable to a short one for the initial outgoing waves will be seen without the complication of the waves reflected from the end.)

An alternative arrangement which gives slower waves is obtained by filling the tank one-third full of water and adding paraffin (preferably coloured) above that, till the tank is two-thirds full. Generate transverse waves at the interface.

d. *Waves with pucks (optional)*
Ring magnet dry ice pucks can be placed in line at short equal distances apart between a boundary of magnetic strip. The end puck is displaced and then moved towards the others and the resulting disturbance is observed.



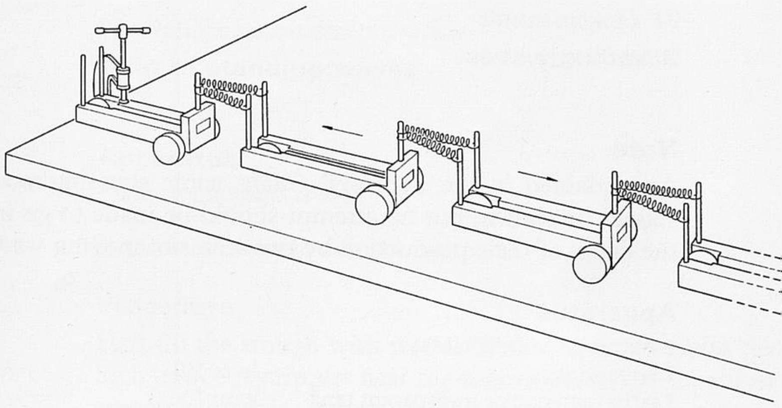


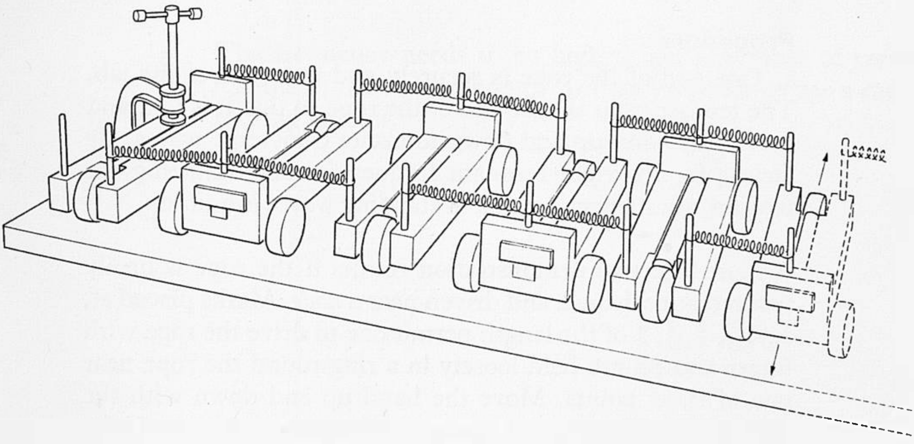


e. *Waves with trolleys (optional)*
A line of dynamics trolleys connected by springs will make a good model for longitudinal waves.

For transverse waves, a trolley is clamped to one end of a smooth bench and the others connected with springs as shown. The trolleys are separated so that they can move without hitting each other. The trolley at the unclamped end is given a sudden deflection to one side and back to show a pulse wave travelling along the line of trolleys.

The end trolley can then be oscillated continuously to show continuous waves. (Unless the bench is very rough reflections from the clamped end are likely to cause standing waves.)





94 *Demonstration*

Standing waves

Note

As explained in the *Teachers' Guide*, some standing waves should be shown, but no attempt should be made to go into the detail of their production by two trains of moving waves.

Apparatus

1 20 ft rope (soft, flexible)	
1 large slinky	– item 101
1 large rectangular transparent tank	– item 100/2

Procedure

a. One end of the rope is securely tied at a wall of the lab. The teacher pulls the far end of the rope so that it is taut and moves his hand up and down to excite transverse waves. By feeling for the right resonant frequencies and adjusting the tension, a stationary pattern of standing waves is built up.

A more effective demonstration results if the rope is firmly secured at both ends and driven near a *node*. Marks placed at, say, $\frac{1}{5}$, $\frac{2}{5}$, $\frac{3}{5}$, $\frac{4}{5}$ of the length permit one to drive the rope with finger and thumb held loosely in a ring round the rope near one of these points. Move the hand up and down with the rope loose in the ring and change the frequency until the 5 loop motion builds up.

b. Build up a longitudinal standing wave on a slinky. This is most easily done by clamping both ends of the stretched spring and exciting it by hand.

c. Standing waves should also be shown in the transparent tank – item 100/2 – and viewed from the side as discussed in Experiment 93c.

d. Optional home experiment. Pupils might be encouraged to set up standing waves in a bath half full of water: a messy but valuable experiment.

95 *Optional extra demonstration*

Ring of standing waves

Apparatus

1 large round glass trough

A pneumatic trough is suitable for this.

Procedure

Half fill the trough with water. With the hand excite fairly high frequency ripples near the edge and establish a pattern of standing waves.

The frequency needs to be high to get a number of wave-lengths in the circumference. It may be better to use a rapid rocking motion.

96 *Optional demonstration*

Experiments with a monochord

Apparatus

1 monochord
1 tuning fork
1 violin bow

Procedure

The monochord is stretched taut and excited by plucking or bowing near one end. Then, just as the wire is plucked or bowed for a second time at the same point, it is touched with a finger *very lightly* at its mid-point. This procedure is followed by touching it very lightly (when plucking or bowing near the end) at $\frac{1}{3}$, $\frac{1}{4}$ and so on of its length.

The existence of nodes and loops can be made plain by the use of small paper 'riders' placed at the requisite positions, after which the wire is bowed and touched gently.

This procedure needs practice. An easier procedure is to tune the wire before the lesson so that it vibrates in, say, three loops with exactly the frequency of a tuning fork. Then, in class, the riders are placed in position and the wire excited by bringing the shank of the vibrating tuning fork onto the bridge at one end of the wire.

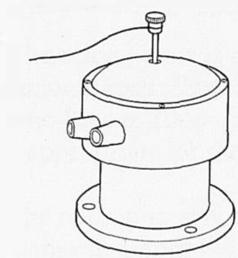
97 *Optional demonstration*

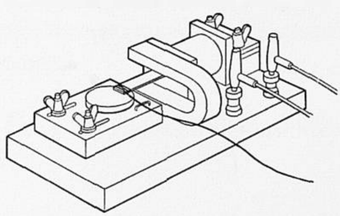
Melde's experiment

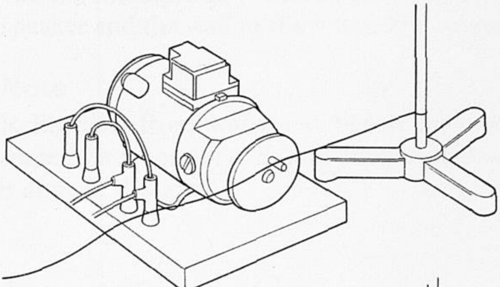
Apparatus

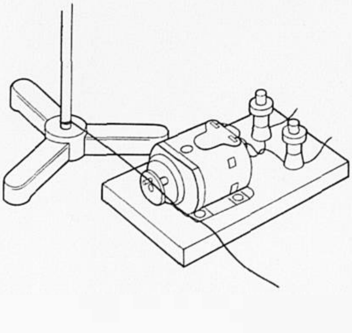
1 single pulley on clamp	– item 40
3 metres of thread	
1 weight hanger with slotted weights	– item 31/2
32 hand stroboscopes	– item 105/1
1 vibrator	– see below

A commercially available vibrator can be used for this experiment. Alternatively the end of the thread can be attached to the vibrating strip in a ticker tape vibrator. Another suitable arrangement is to attach a wheel to either the fractional horse-power motor or one of the small motors from the Energy Conversions Kit: the thread is then attached to an eccentric screw.





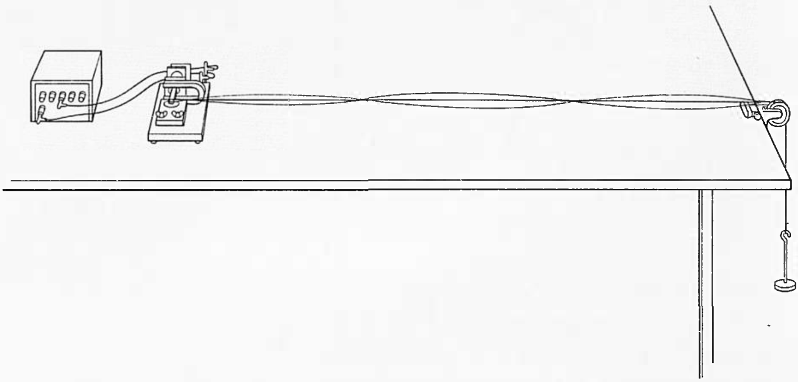




Procedure

The vibrator is set up so that one end of the long thread is excited, whilst the other end passes over the pulley to the weight hanger. The load is adjusted until several loops are clearly seen.

Pupils should observe the thread through hand stroboscopes. Alternatively the thread can be illuminated intermittently by light from the compact light source (item 21) immediately in front of which is placed the motor driven stroboscopic disc (item 134/1). If the school possesses a Xenon flasher (item 134/2), this can also be used.



98 *Optional buffer demonstration*

Demonstrations with sound waves

Apparatus

1 L.F. signal generator	– item 182
1 loudspeaker	– item 183
1 microphone	– item 157
1 oscilloscope	– item 64

Procedure

If a school has the necessary apparatus, some demonstrations with sound waves might be shown as a buffer option.

a. The loudspeaker is connected to the signal generator and driven at a suitable frequency (2,000 to 4,000 cycles/sec).

The microphone is connected to the input of the oscilloscope by long leads. The a.c.–d.c. switch should be set to a.c., the time-base to 100 μs/cm and the gain to maximum or whatever is appropriate for the microphone used.

The microphone is moved away from the speaker to show the change in amplitude with distance.

b. The loudspeaker and the microphone are set facing a wall and the microphone is moved about in the space between the speaker and the wall to show standing waves.

Note

Reflections from walls and bench tops are always troublesome in a laboratory. Sound experiments will be much better if done in the open.

99a *Optional buffer demonstration*

Demonstrations with centimetre waves

Apparatus

1 3 cm wave transmitter	– item 184/1
1 3 cm wave receiver	– item 184/2
1 amplifier	– item 181
1 loudspeaker	– item 183

Also required: various aluminium barriers – see below.

Procedure

If a school possesses suitable equipment, a series of demonstrations using centimetre waves might be shown.

The cm waves can be unmodulated in which case the receiver is connected to a meter. If they are modulated, it is possible to detect them using an amplifier and loudspeaker.

Esso-Nuffield Film

Suggested demonstrations can be seen in the Esso film for science teachers *Use of Centimetre Waves in the Teaching of Optics*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

At the time that film was made, the emphasis was more on how centimetre waves could be used for demonstration purposes in conventional optics teaching; in the context of this course it would be more appropriate to consider them as waves in their own right. They do of course have a very convenient wavelength for demonstration purposes.

99b *Optional buffer demonstration*

Demonstrations of electrical oscillations

Procedure

Where a school possesses suitable equipment, teachers might wish to show a series of demonstrations of electrical oscillations ranging from very low frequencies to the very high frequency of the centimetre wave generator. Most teachers will consider that these demonstrations are more relevant to A-level, where detailed treatment will be expected.

Suitable experiments are included in the *Modern Physical Science Reports* published by the Association for Science Education.

Esso-Nuffield Film

Suggested demonstrations can be seen in the Esso film for science teachers *Electrical Oscillations and the Electromagnetic Spectrum*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

100 *Optional class experiment or demonstration*

Ripple tank experiment to illustrate measurements of wavelength frequency and speed

Apparatus

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

Procedure

These experiments will already have been done in Year III. The teacher may care to repeat them here or merely refer to them or show them as a demonstration.

a. *Estimating wavelength*
Pupils should freeze the pattern and measure a batch of wavelengths (say, ten) on the paper on the floor. It should be made clear that the idea is to get a rough estimate quickly, and not to try to achieve precision with a technique which cannot really support it.

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

It is difficult to measure frequency accurately, but rough measurements are possible. (The vibrator can be driven either slowly or fast and a different technique is necessary in each case. For high speeds, the hand stroboscopes can be used.) Note that in estimating wavelength the stroboscopes were used *only* to freeze the pattern for easy measurement. Their frequency need not be known for that.

c. *Estimating velocity*

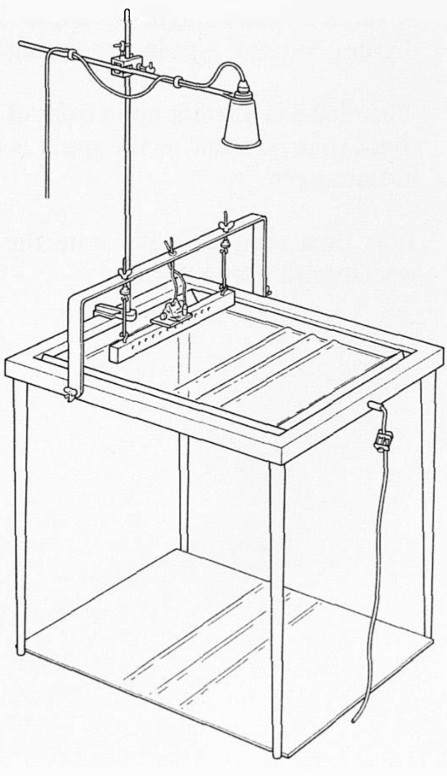
The speed may be judged by running a pencil along the paper keeping it level with one wave. Another pupil measures the time taken to travel between the two points marked on the paper. (The velocity of pulses is easier to measure but they do not travel at the proper wave speed, so they should not be used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

Note

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

Test of V=nL

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



101 *Optional 'advanced' demonstration*

Model to illustrate group velocity

Apparatus

1 mechanical model	– see below
1 compact light source	– item 21
1 translucent screen	– item 46/1

Procedure

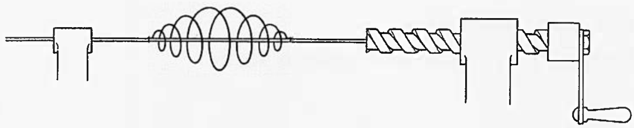
The model is best improvised from a length of stiff wire, which is bent into a spiral shaped as shown.

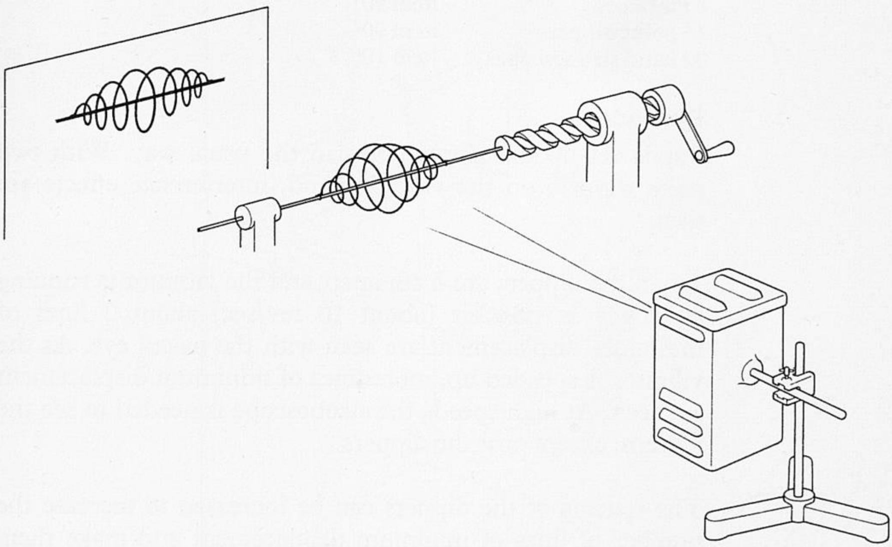
This spiral, which should be about 8 in or 9 in long and 2 in to 3 in wide at its maximum, is mounted on a straight thin rod. One end of the rod is supported in a simple, free bearing, the other is fixed to a thicker rod carrying a screw thread of very large pitch. The screw thread passes through a suitable nut, fixed stationary, so that, as the rod is turned by hand, the whole moves forward.

A suitable screw might be improvised from a spiral screw-driver ('Yankee' type incorporating an Archimedean screw).

The model is then set up in front of a compact light source so that a sharp shadow of the spiral is projected onto the translucent screen.

It is then rotated to illustrate the contrast between group velocity and wave velocity.





102 *Class experiment*

Young's fringes in a ripple tank

Apparatus

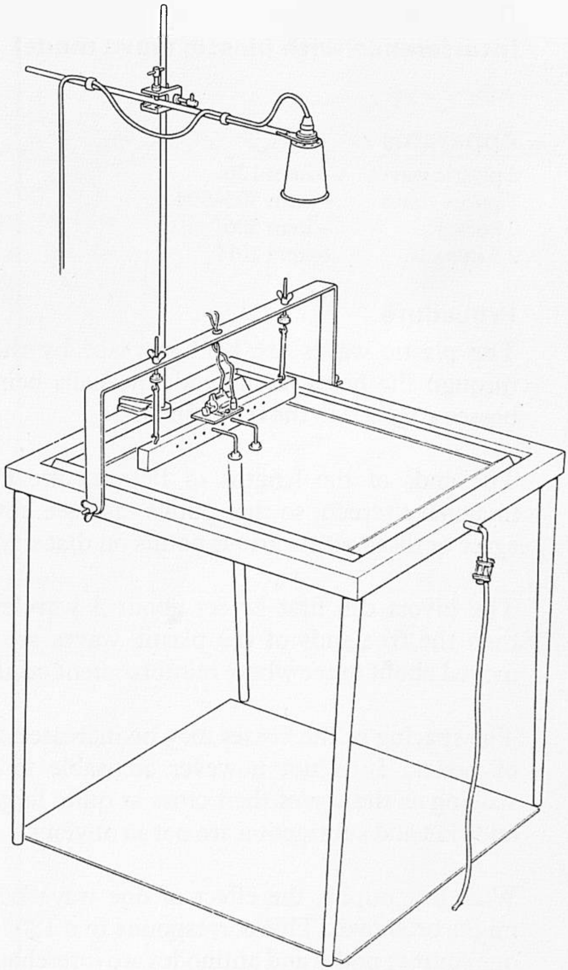
8 ripple tanks	– item 90
8 illuminants	– item 47
8 vibrators	– item 90L
16 point dippers	– item 90G
32 hand stroboscopes	– item 105/1

Procedure

Pupils set up the ripple tanks in the usual way. With two point dippers on the vibrating rod, interference effects are seen.

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

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



103a *Demonstration*

Interference with plastic wave model

Apparatus

2 plastic waves	– item 126
1 retort stand	– item 503–504
2 bosses	– item 506
2 6 in nails	– item 10H

Procedure

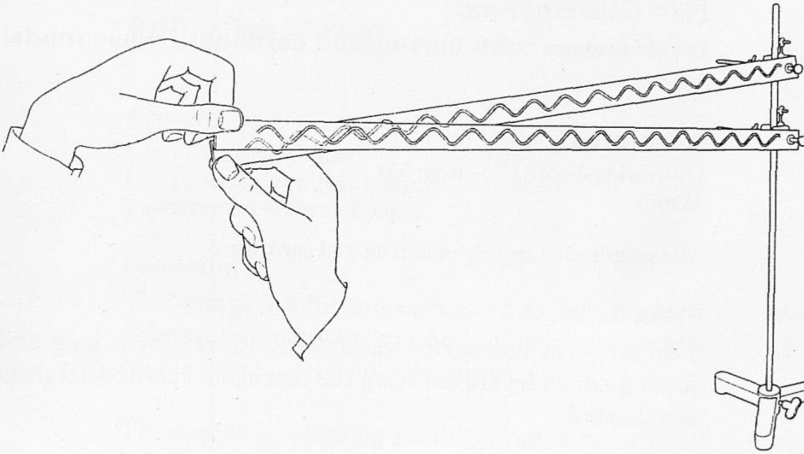
The plastic waves are held in place by the 6 in nails put through the holes in the end, the nails being supported by bosses attached to the retort stands.

The ends of the lengths of Perspex are moved across an imaginary screen, so that pupils may see how the two waves agree or disagree at various points on that screen.

The pivots can first be set about 3 wavelengths apart and then the free ends of the plastic waves are overlapped and moved about to see where reinforcement occurs.

The spacing of the bosses may be increased to get more lines of nodes. It is not however advisable to start with wide spacing as the waves then cross at quite large angles and the addition and subtraction are not so obvious.

With fast pupils, the effect of one wave being turned over might be shown. This corresponds to a 180° phase change of one source: nodes and antinodes are interchanged.



103b *Class experiment*

Interference with corrugated cardboard wave model

Apparatus

16 drawing-boards – item 551
32 pins

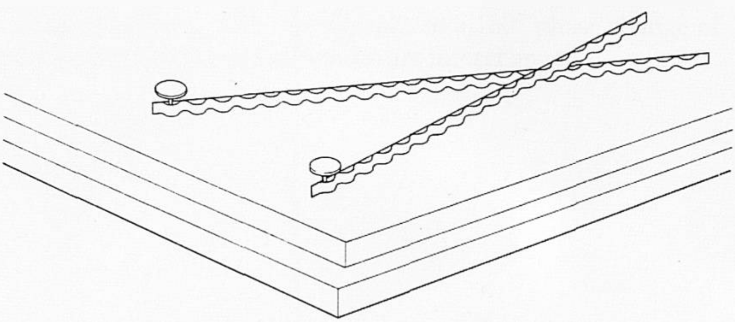
Also required: a supply of corrugated cardboard.

Procedure

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

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

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



103c *Class experiment*

Diffraction of light

Apparatus

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

Procedure

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

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

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

104 *Demonstration*

Young's fringes with visible light

Apparatus

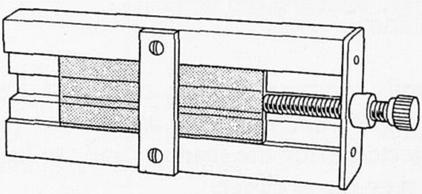
1 compact light source	– item 21
1 double slits kit	– item 97
1 screen of greaseproof paper	
1 L.T. variable voltage supply	– item 59

Note

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

Ruling the slits

The slits are made by coating one side of a microscope slide with Aqaudag. The slits are ruled by hand, or the slide is inserted in the holder and a slit ruled on the Aquadag with a blunt needle or pin held up against the brass cross-piece. A fine ball-point pen works well.



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

The separation of the double slits

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

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

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

This arrangement will give three bright fringes with two dark fringes between them, and little illumination in regions beyond that.

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

The light source

The simplest demonstration of Young's fringes requires a lamp with a line filament. A 48 watt 12 volt lamp over-run does well. The 100 watt tungsten-iodine lamp in the compact light source (item 21) is also very good for this.

The lamp must be shielded so that no stray light reaches the screen: such a housing is provided. It is also very important to avoid illumination by light reflected by the surface of the table. (Any fairly smooth surface becomes an excellent mirror at very oblique incidence.) It is necessary to install limiting screens and place black cloth on the table to prevent that.

The screen

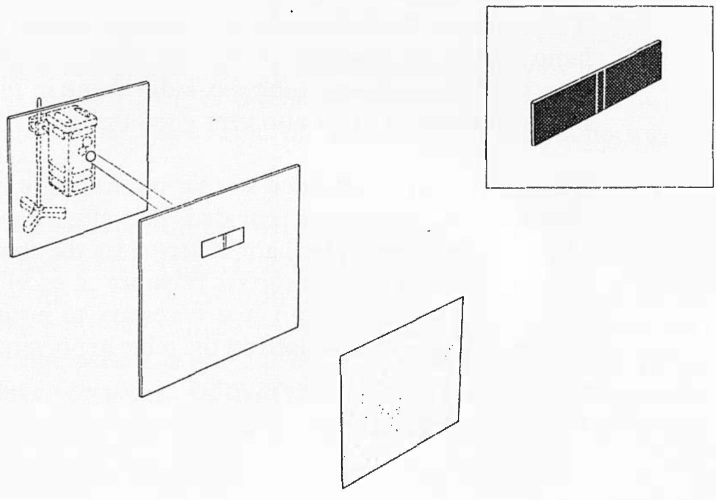
Even with the best of slits and a very bright lamp, the fringe pattern is not so bright that pupils looking at an unfamiliar picture can see it easily. Therefore, although the teacher can see the pattern clearly on a white wall or screen, he should arrange a translucent screen for pupils to view the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

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

Procedure

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

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



105 *Class experiment*

Young's fringes

Apparatus

1 double slits kit	– item 97
8 small screens of greaseproof paper	
4 lamps, holders, and stands	– item 94A
4 transformers	– item 27
8 metre rules	– item 501
8 $\frac{1}{2}$ mm graticules	– item 7E
8 lenses (+ 14D)	– item 113/1

In almost any room one lamp will serve for several pairs of pupils. The fewer lamps the better, to minimize stray light.

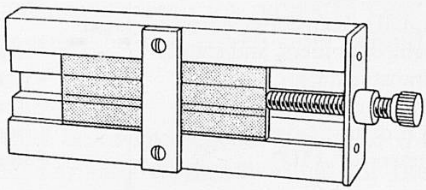
Preparation of double slits

To make the slits, a microscope slide from the double slits kit (item 97) is painted quickly with Aquadag (colloidal graphite) using a soft brush. Allow the slide to dry. Before ruling the slits, hold the slide up to a bright light to make sure it is thoroughly opaque.

As a tool for ruling each slit, a ball-point pen is easiest, preferably one with a fine ball-point. A blunt needle, or pin is not quite so easy to handle. (A darning needle, with the end of its eye broken off, can be used as an ingenious tool to rule both slits at once, but this is not recommended for general use.)

If pupils rule the slits, each should place a ruler across the coated slide and run the tool along the edge of the ruler to make one slit. To make the second slit, the tool should be tilted slightly and run along the ruler *which is kept in the same position.* (Shifting the ruler for the second slit is likely to make the slits too far apart.) If pupils are shown this technique, they soon learn to use it quickly and successfully, provided they are told that they may make many pairs of slits and then choose the best.

If the teacher wishes to prepare slits beforehand, he will find that a special device, the slide holder, will be a great help in mass production. The slide is inserted in the holder and a slit is ruled. Then displace the slide slightly by turning the screw at the end of the holder and rule the second slit.



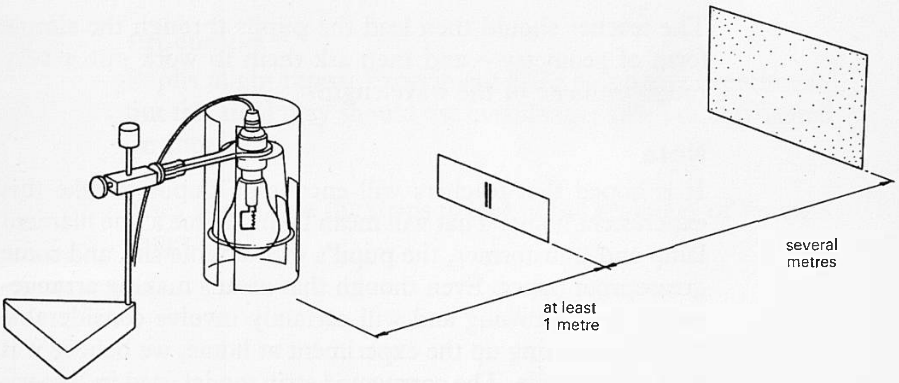
In a large classroom, slits $\frac{1}{2}$ mm apart, centre to centre, will give fringes that are wide enough for pupils to see easily if the screen is several yards from the double slits. If each of the slits is itself about $\frac{1}{4}$ mm wide, only two or three bright fringes will be visible – because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

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

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

Procedure

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



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

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

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

Measurements

Seeing the fringes – 'light + light' making 'more light' in some places but making 'no light' in other places – is the most important thing.

However, a fast group should certainly try making measurements. They should first measure the fringe spacing. If that is a few millimetres, it is probably best to ask pupils to make marks on the screen with a pencil while they are looking at the fringes with the naked eye. Later, in daylight, they can measure the spacing between the marks.

It will now be necessary to measure the distance from the slits to the screen with a metre rule and then to measure the separation of the slits. The simplest method is to compare the slits with a $\frac{1}{2}$ mm scale (as used in Year I), using a magnifying glass to help.

The teacher should then lead the pupils through the simple form of geometry – and then ask them to work out a very rough estimate of the wavelength.

Note

It is hoped that teachers will encourage pupils to take this experiment home. That will mean taking home a line filament lamp and transformer, the pupil's own double slit, and some greaseproof paper. Even though that means making arrangements for borrowing and will certainly involve considerable trouble in setting up the experiment at home, we believe it is well worth while. The corrugated strip model used in Experiment 106, which they should also take, will be found very useful in 'explaining' the phenomenon of interference at home.

106 *Home experiment*

The geometry of Young's fringes

Apparatus

Pins and supply of corrugated cardboard

Procedure

Pupils might repeat Experiment 103b as a home experiment, but this time they should use even longer strips of corrugated cardboard.

They should use the strips to look at the geometry of Young's fringes.

107a *Optional demonstration*

Young's fringes with sound waves

Apparatus

1 L.F. signal generator – item 182
2 loudspeakers – item 183

The two loudspeakers must be similar to each other.

Procedure

This experiment is best done in the open air. Any reflecting buildings should be behind the loudspeakers.

The two loudspeakers are driven by the audio frequency signal generator. The output of the signal generator should be set at about 2000 c/s. The loudspeakers should be 50 cm apart in the first instance.

The pupils walk across in front of the loudspeakers and listen for loud and quiet places. It may help them if they block one ear with a finger.

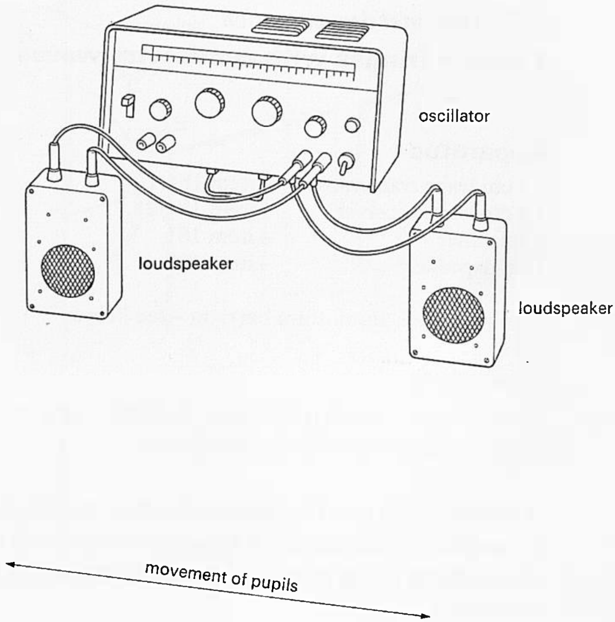
If told to stand where the sound is loudest, they should be found to be standing on hyperbolae with the two loudspeakers as focuses. If this is done, the loudspeakers in this case should be high up so that the pupils do not stand in each other's way.

They are then asked to move to positions where the sound is a minimum. If one loudspeaker is then covered with something absorbent (for example, a cushion) the sound immediately gets louder. (It is better not to switch off one of the loudspeakers as the power to the other speaker might change.)

Notes

1. If the central position turns out to be a minimum, reverse the connections to one of the speakers. This will make the central position a maximum.

2. If the demonstration has to be done indoors, it helps to keep the sound as quiet as possible so that the reflected sound is not too obtrusive.


oscillator
loudspeaker
loudspeaker
movement of pupils

107b *Optional demonstration*

Young's fringes with centimetre waves

Apparatus

1 3 cm wave transmitter	– item 184/1
1 3 cm wave receiver	– item 184/2
1 amplifier	– item 181
1 loudspeaker	– item 182

Also required: aluminium barriers – see below

Procedure

In a school which possesses suitable equipment, a teacher might wish to show this experiment.

The cm waves can be unmodulated in which case the receiver is connected to a meter. If they are modulated, it is possible to detect them using an amplifier and loudspeaker attached to the receiver.

The transmitter is set up symmetrically behind the two gaps, each of which is 1·5 cm ($\lambda/2$) wide.

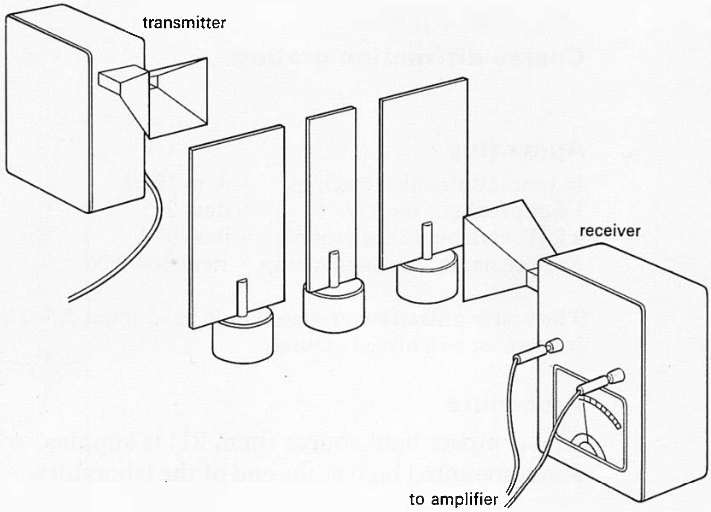
As the receiver is moved around, always the same distance from the gaps, the current through the meter rises and falls to show about five maxima.

If there is no risk of pupils thinking that the sound waves which they hear are interfering with each other, it is worth modulating the transmitter and connecting the receiver to an amplifier and loudspeaker. The system then shows the change very clearly.

Perhaps the most important part of this demonstration is to show that, when either gap is covered with a metal plate, the received signal diminishes when the receiver is at a maximum but *increases* when the receiver is at a minimum.

Esso-Nuffield film

The above experiment is shown in the Esso film for science teachers *Use of Centimetre Waves in the Teaching of Optics*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.


transmitter
receiver
to amplifier

108a *Class experiment*

Coarse diffraction grating

Apparatus

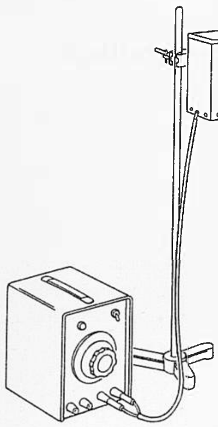
16 coarse diffraction gratings	– item 191/1
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 retort stand, boss, and clamp	– item 503–506

The coarse diffraction grating should have about 2,500 lines/inch. It must *not* be a blazed grating.

Procedure

The compact light source (item 21) is supplied with 12 volts and is mounted high at the end of the laboratory.

Pupils are asked to hold the grating near to the eye and to look through it at the distant light source.



For Experiment 108b, see page 212.

109 *Demonstration*

Projection of spectrum with diffraction gratings

Apparatus

1 coarse diffraction grating	– item 191/1
1 fine diffraction grating	– item 191/2
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 cylindrical lens	– item 94H
2 lens holders	– item 124/1
1 red filter	– item 192/1
1 green filter	– item 192/2
2 retort stands, bosses	– item 503–505

The coarse diffraction grating should have about 2,500 lines/inch. The fine grating should have about 7,500 lines/inch. They must *not* be blazed gratings.

Procedure

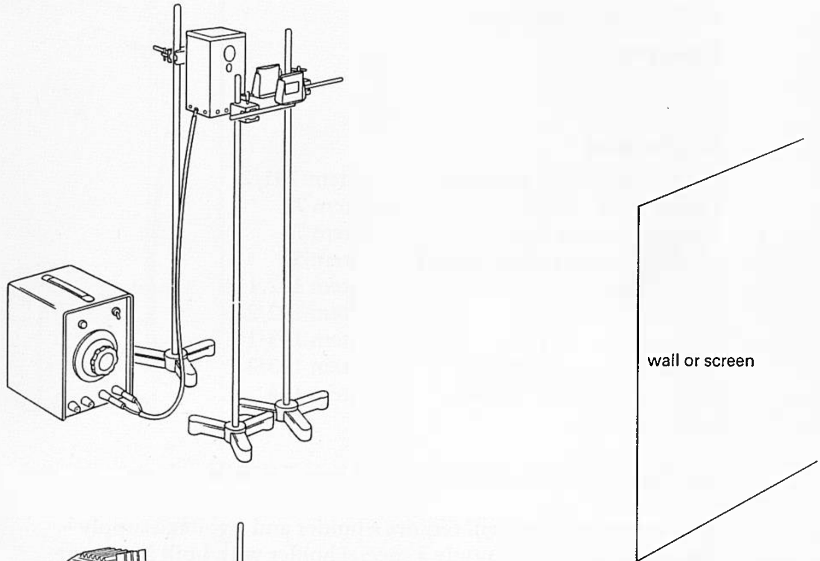
As explained in the *Teachers' Guide*, as soon as pupils have tried the coarse grating for themselves, they should be shown a demonstration in which white light passes through a lens.

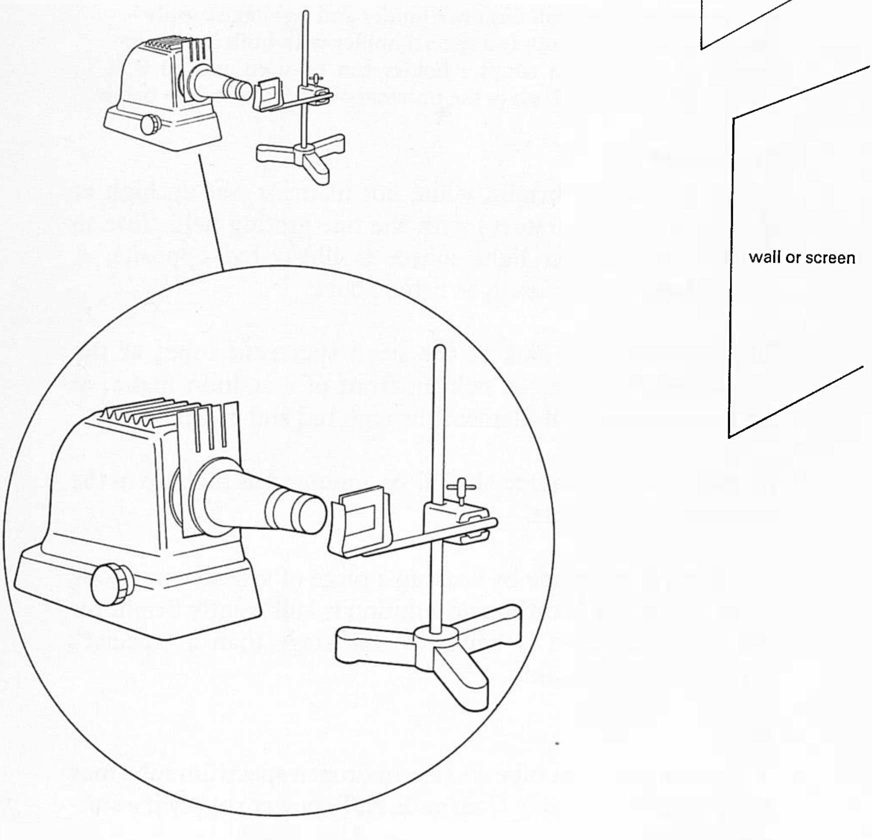
The lamp and lens are set up at one end of the darkened laboratory so that a sharp image of the filament is obtained on a screen at the other end. The screen should be a long one – perhaps a 10 to 15 foot roll of white kitchen paper. A white wall is good.

The coarse grating is placed in the beam just beyond the lens. Then red or green filters are placed in the beam. Finally the coarse grating is replaced by a finer one.

Alternative arrangement

A slide projector can conveniently be used, instead of the compact light source, as illustrated opposite. In this arrangement a single slit (item 94c from the ray optics kit works well) must be inserted in the projector as shown.





For Experiment 110, see page 214.

108b *Class experiment*

Spectra

Apparatus

16 fine diffraction gratings	– item 191/2
1 lamp (12 V 24 W)	– item 72
1 lampholder on base	– item 74
1 L.T. variable voltage supply	– item 59
16 red filters	– item 192/1
16 green filters	– item 192/2
1 neon spectrum tube	– item 193/1
1 hydrogen spectrum tube	– item 193/2
1 holder for spectrum tube	– item 194
1 sodium flame	

The fine diffraction gratings should have 7,500 lines/inch.

The spectrum tubes will require a holder and a voltage supply – some manufacturers supply a special holder with built in voltage supply, alternatively a simpler holder can be used and an E.H.T. power supply (item 14) gives the necessary voltage. See note below.

Procedure

Pupils look at the bright, white hot filament (set up high at the end of the laboratory) with the fine grating held close to the eye. A compact light source is illustrated opposite. A 12 volt lamp can be used, as listed above.

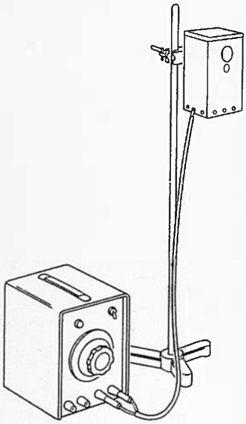
They should then look at the neon spectrum tube; at the hydrogen tube; at a slit held in front of a sodium flame; at the bright, white hot filament through red and green filters.

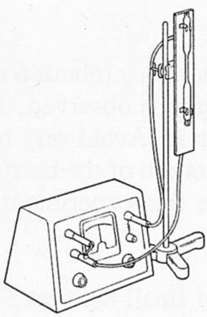
In each case the source should be mounted as high up in the laboratory as possible.

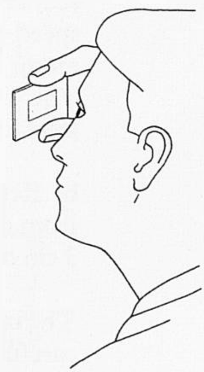
A sodium flame made by soaking a piece of asbestos in strong brine or sodium bicarbonate solution is sufficiently bright for this experiment. It is better at this stage than a 'special', expensive sodium lamp.

Note

The neon spectrum tube and the hydrogen spectrum tube may be operated very easily from an E.H.T. power supply if a suitable resistor is included in series. This should be about 1·5 megohms (at least 2 watt rating and preferably higher). A voltage of $2\frac{1}{2}$ to $3\frac{1}{2}$ kV is needed to trigger the tube and the discharge current is about $\frac{1}{2}$ mA.







For Experiment 109 see page 210.

110 *Demonstration*

Diffraction of a plane wave by multiple slits

Apparatus

1 ripple tank	– item 90
1 illuminant	– item 57
1 vibrator	– item 90L
1 transformer	– item 27
2 dry cells for vibrator	– item 52B
1 rheostat (10–15 ohms)	– item 541/1
2 large barriers	– item 90D
6 small barriers	– item 90E

Procedure

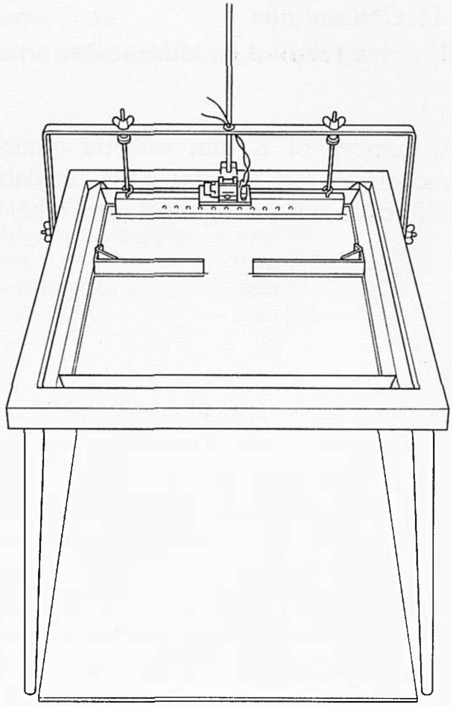
a. First set up the ripple tank with about 1 cm depth of water. Place two long barriers 2 to 3 cm apart and 5 cm away from the vibrator.

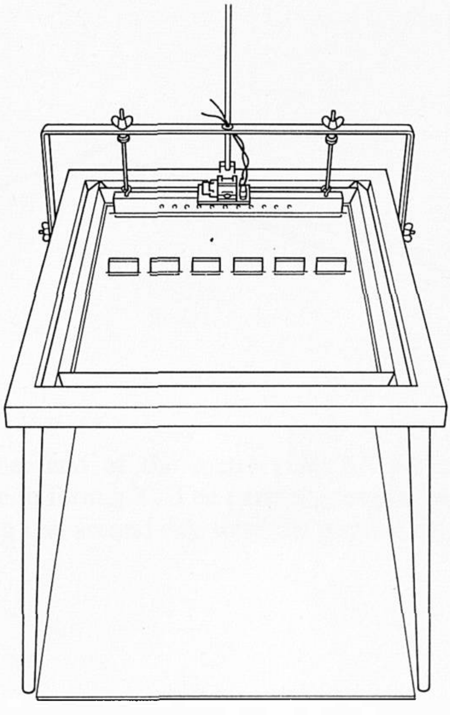
The motor should be started at a low frequency (about 6 rev/sec) and the wave passing through the gap is observed. The speed of the motor should then be increased. Avoid very high motor speeds which cause unwanted vibration of the barriers. The slit width is best kept constant for this experiment, at least for this first experiment.

b. Replace the long barriers by a line of small barriers 5 cm from the vibrator as illustrated. There should be a gap of 2 to 3 cm between each.

The motor is started at a low speed (4 rev/sec) and the pattern carefully observed with and without the stroboscope.

The motor speed is then increased and the changes in pattern are noted.





111 *Optional film*

Spectra formed by diffraction in a ripple tank

A number of 8 mm cassette films showing ripple tank phenomena are commercially available and one showing diffraction at a grating might profitably be shown here.

112 *Class experiment*

Estimation of the wavelength of light

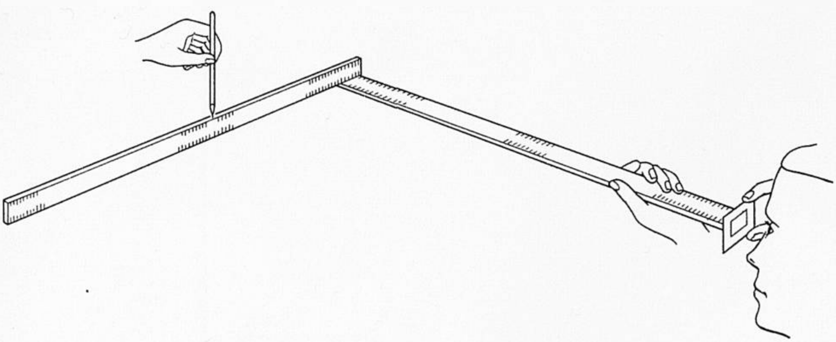
Apparatus

1 12 V, 36 W lamp	– item 73
1 lampholder (SBC) on base	– item 74
1 L.T. variable voltage supply	– item 59
16 green filters	– item 192/2
16 fine diffraction gratings	– item 191/2
32 metre rules	– item 501

Procedure

The 12 V 36 W line filament lamp is set up at one end of the laboratory so that it is clearly visible to the pupils. A green filter is placed in front of the lamp and, if necessary, the voltage applied is increased steadily to 14 or 15 volts so that the light is sufficiently bright.

The pupils work in pairs. One pupil observes the lamp through the fine grating (7,500 lines/inch). He holds the grating against one end of a metre rule, which is aimed directly at the line source.



At the other end of the metre rule, his partner places a second rule to form a T. The partner moves a vertically held pencil along that second rule until the pupil at the grating sees the pencil in line with the first order spectrum. The distance moved along the ruler enables the pupil to calculate tan A and hence sin A. This leads to an estimate of the wavelength of the light used.

It is a good enough approximation to take 1 metre to be 40 inches, so that the slit separation is $1/7{,}500 \times 40$ or $1/150{,}000$ metres.

Note

In discussing the value given for the grating spacing, it is worth while to examine the surface of the grating and of a $\frac{1}{2}$ mm glass scale (item 7E) under a microscope and to make a comparison.

113 *Optional home experiment*

A gramophone record as a grating

Procedure

Pupils might like to look at the grating spectra formed by reflection when light falls obliquely on a gramophone record.

The rulings are too coarse to be useful at direct incidence, so the observer must take an oblique view.

The grating spacing can be determined by playing the record, counting the number of turns. A ruler is used to measure the part of the radius of the grating that is used, so that the spacing can be calculated.

114 *Demonstration*

Spectrum formed by a prism

Apparatus

1 high dispersion prism	– item 69
1 convex lens	– item 113/3
1 lens holder	– item 124/1
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
2 retort stands, and bosses	– item 503–505

Also required: a selection of colour filters

Procedure

The light source is set up at one end of the laboratory so as to produce an intense line of light. (If a 12 V 36 W lamp is used in place of the compact light source, it should be overrun at 14 to 16 volts.)

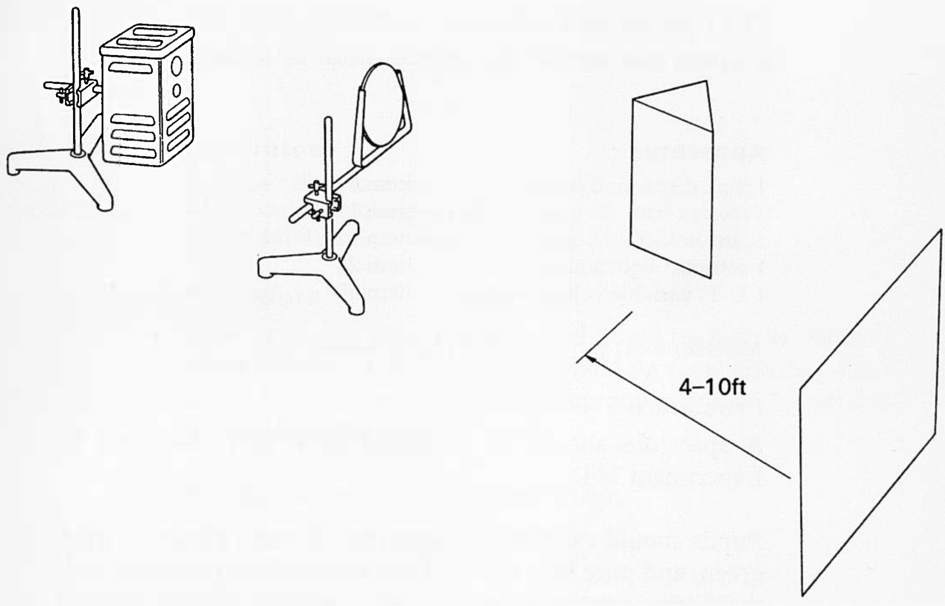
The lens is placed so that a sharp image is produced on a distant screen.

The glass prism is placed in the beam, just beyond the lens, and rotated to show how the prism swings the rays round. The screen is moved to a suitable spectrum: this need not be at minimum deviation.

Pupils should then look at the spectrum through a selection of coloured filters.

Coloured materials – a sheet of stamps, for example – should also be looked at when held in different parts of the spectrum.

Pupils should also look at coloured objects in pure yellow light from a sodium flame.


4–10ft

115 *Optional class experiment*

Colour mixing

Apparatus

1 high dispersion prism	– item 69
1 convex lens	– item 113/3
1 lens holder	– item 124/1
1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59

Also required: various filters as listed below

Procedure

A spectrum should be produced as already described in Experiment 114.

Pupils should examine the spectrum through pure red, pure green, and pure blue filters. They should also investigate with the filters: turquoise ('minus red'), magenta ('minus green') and yellow ('minus blue') and then pairs of these.

If the teacher or pupil has a special interest in 'colour mixing' some further experimental work might be done at this stage if time allows. Teachers are referred to such literature as Sir Graham Savage, *The Teaching of Colour in Elementary Courses of Science*, a Modern Science Memoir published by the Association for Science Education, and obtainable from the A.S.E., 52 Bateman Street, Cambridge.

116 *Class experiment*

A second look at spectra formed by gratings

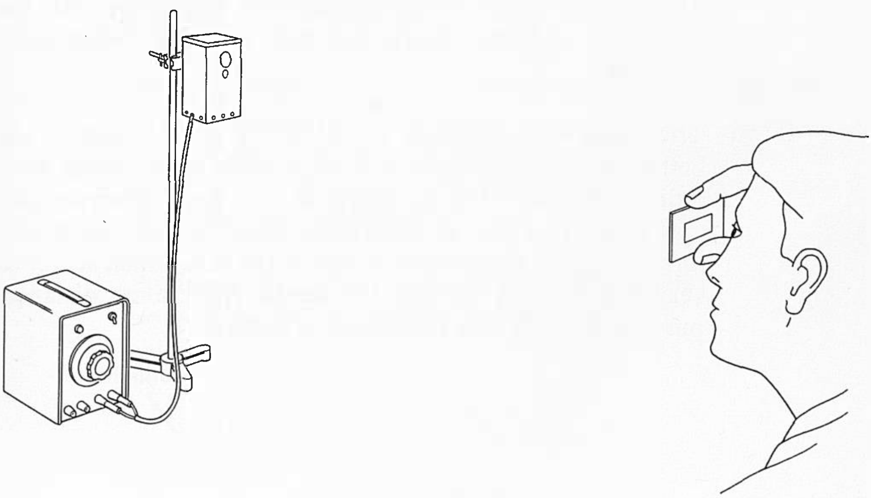
Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
16 fine diffraction gratings	– item 191/2

Procedure

Once again the light source should be set up high at one end of the laboratory and the pupils, holding their gratings close to the eye, look at the distant lamp and examine the several orders of spectra seen.

For discussion see the *Teachers' Guide*.



117 *Optional class experiment*

Simple spectrum of sunlight

Apparatus

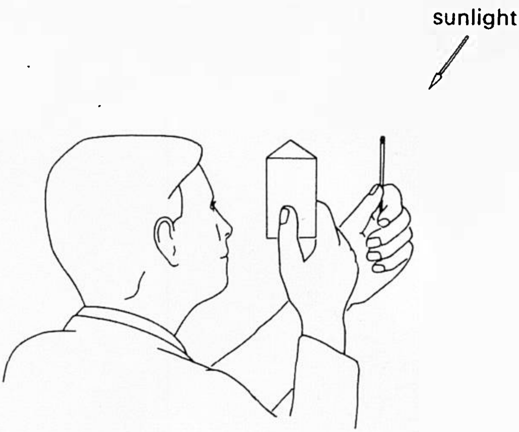
16 60° prisms – item 111
16 needles

Procedure

The pupil is given a bright needle and a prism. He holds the needle at arm's length in one hand and the prism in the other hand, close to his eye. The needle should be parallel to the refracting edge of the prism. He twists the prism until he can see the needle by refraction through the prism. The needle should be brightly illuminated by sunlight.

The needle, which would appear as a bright line but for dispersion, appears drawn out into a bright, white-light spectrum.

The higher the dispersive power of the prism material, the better, but it will usually only be possible to let pupils have ordinary prisms. Even so, they will see a good spectrum and may even see a hint of absorption lines. In this, the needle forms a bright, narrow line-image of the sun, which serves as slit; and the eye, viewing the needle from some distance, provides the only lens system that is needed.



118 *Demonstration*
Absorption lines in the spectrum of sunlight

Apparatus

1 spectrometer (if available)	
1 high dispersion prism	– item 69
1 convex lens	– item 113/3
1 lens holder	– item 124/1

Procedure

The prism spectrometer is set up in the usual way to give a good spectrum of white light.

With the slit narrowed down very considerably, sunlight is directed into the slit with a plane mirror. A 10–15 cm lens is used to converge the light to a focus an inch or so in front of the slit.

This experiment should be done in a partially darkened room so that the spectrum does appear to be a bright one. Arrangement of the apparatus will have to depend on the laboratory layout and may require very careful thought before a satisfactory set up is achieved.

Pupils view the spectrum one at a time. Arrangements have to be made to ensure that the sunlight continues to fall on the slit.

119 *Optional extra demonstration*

Absorption spectrum of sodium

Apparatus

1 lamp (12 V 24 W)	– item 72
1 lampholder on base	– item 74
1 L.T. variable voltage supply	– item 59
2 convex lenses	– item 112
2 lens holders	– item 124/1
2 retort stands, bosses, and clamps	– items 503–506
1 spectrometer with high dispersion prism	

Also required: a spectrometer with high dispersion prism and a Bunsen flame with brine impregnated asbestos wad.

Procedure

It is essential to provide an intense sodium flame. A wad of asbestos which has been dipped into concentrated brine and held in the Bunsen flame by a stout length of wire will provide this.

The spectrometer is focused in the usual way and the slit is left so that it is fairly narrow.

The source of white light is a line filament lamp. The two converging lenses are arranged to make sure that *all* the white light entering the collimator passes through the flame on the way to it. One lens forms a real image of the filament in the flame; the other lens forms a real image of that first real image on the slit of the spectroscope. It is easiest to make each distance from filament to lens, lens to image, image to lens, and lens to slit, twice the focal length of the lens.

The intense sodium flame is then placed midway between the two lenses, where the lens closer to the lamp also produces a sharp image. This arrangement ensures that all the white light passes through the flame in the region where it is rich in sodium.

It may be necessary to adjust the voltage applied to the lamp, as well as the slit width, to get the best conditions for seeing the dark line. Pupils should also see the effect of dimming the lamp as well as the absorption spectrum itself.

Alternative large experiment

An alternative experiment using the vapour produced when metallic sodium is burnt is discussed in detail in the *Teachers' Guide* for those teachers who want a large demonstration.

120 *Demonstration*

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

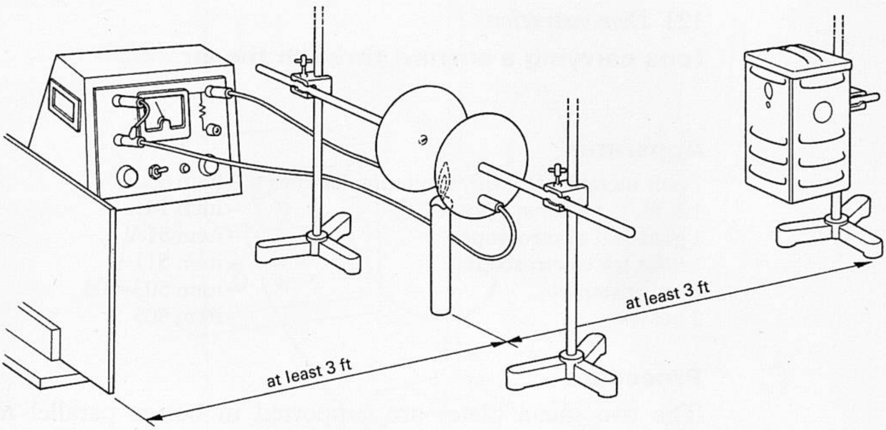
Apparatus

1 pair of metal plates with insulating handles	– item 65
1 E.H.T. power supply	– item 65
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.

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

121 *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
2 retort stands	– item 503–504
2 bosses	– item 505

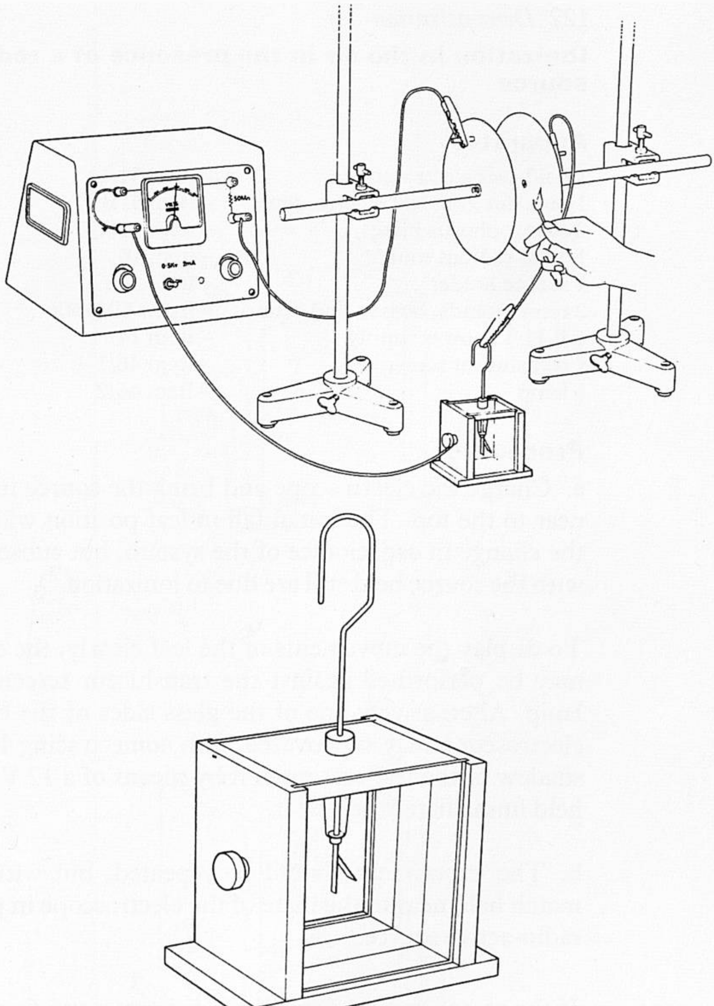
Procedure

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.



122 *Demonstration*

Ionization in the air in the presence of a radioactive source

Apparatus

1 gold-leaf electroscope	– item 51A
1 plate for gold leaf electroscope	– item 51B
2 electrophorus plates	– item 51K
1 5 μC radium source	– item 16
1 source holder	– item 196
2 retort stands, bosses, and clamps	– items 503–506
1 E.H.T. power supply	– item 14
1 translucent screen	– item 46/1
1 lamp	– item 46/2

Procedure

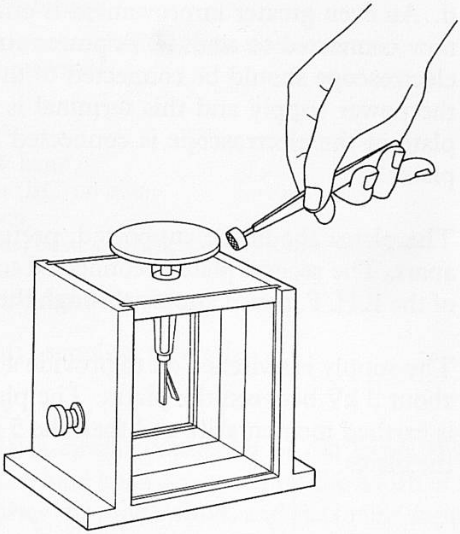
a. Charge the electroscope and bring the source in its holder near to the top. The initial fall in leaf position will be due to the change in capacitance of the system, but subsequent falls with the source held still are due to ionization.

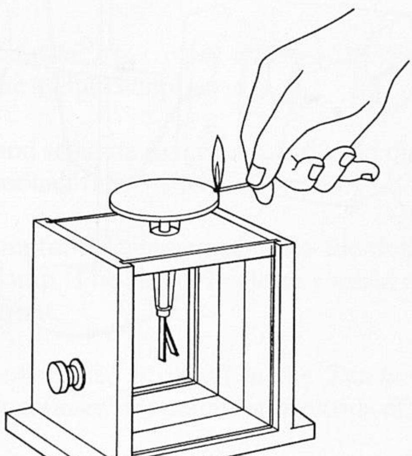
To display the movements of the leaf clearly, the experiment may be performed against the translucent screen using the lamp. Alternatively one of the glass sides of the body of the electroscope may be covered with some tracing linen and a shadow of the leaf cast upon it by means of a 12 V 24 W bulb held immediately behind it.

b. The experiment should be repeated, but with a lighted match held near to the plate of the electroscope in place of the radio-active source.

If the match is held some little distance away from the plate and the teacher blows across the top of the flame, the discharge will be seen to continue.

c. If an earthed plate is supported on a stand about 1 cm above the plate of the charged electroscope and the electroscope is recharged, the discharging action due to the radioactive source held nearby (or placed on the lower plate) will be even more effective. Item 51K from the electrostatics kit can be used for this.

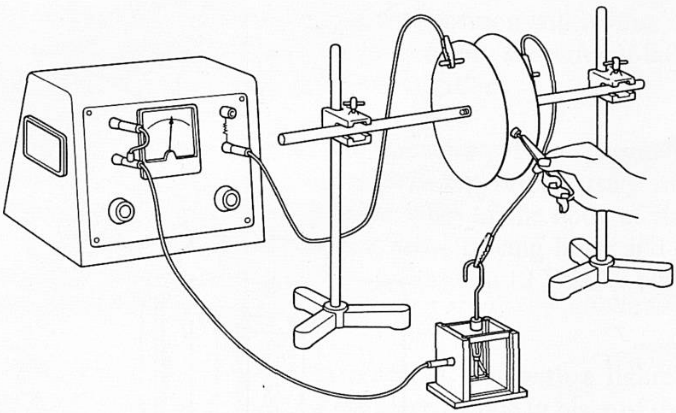




d. An even greater improvement is effected if two plates are now connected to an E.H.T. power supply. The case of the electroscope should be connected to the negative terminal of the power supply and this terminal is in turn earthed. The plate of the electroscope is connected to one of the pairs of plates.

The plates should be supported, preferably vertically, 1 cm apart. The second plate is connected to the positive terminal of the E.H.T. power supply through the safety resistor.

The supply is switched on to provide a potential difference of about 3 kV between the plates. The plate of the electroscope is earthed momentarily and then the 5 μC source is held near the plates.



123a *Demonstration*

Introduction to the Geiger counter: 'the salt counter'

Apparatus

1 240 V 40 W lamp
1 lampholder (BC) on base – item 162
1 mains switch
2 retort stands, bosses, and clamps – items 503–506
1 1 litre beaker
2 well insulated copper wires

Also required: a supply of table salt

Procedure

Set up a series circuit consisting of the lamp, the 2 copper wires with the bare ends separated by the width of the beaker into which they dip, the switch, and the mains supply. Switch on.

Switch off and let the copper wires touch. Switch on again to display the lighted lamp.

Switch off and separate the wires again. Add distilled water to fill the beaker half full. Switch on.

Throw a handful of common salt into the water and display the lighted lamp. The beaker has to be washed out and refilled after each count.

Explain, as discussed in detail in the *Teachers' Guide*, that this is a 'salt counter' for counting handfuls of salt.

123b *Demonstration*

Introduction to the Geiger Counter: 'the match counter'

Apparatus

1 EHT power supply	– item 14
2 insulated metal spheres	– item 188
2 retort stands, bosses, and clamps	– item 503–506
1 capacitor (0·001 μF, 20 kV)	– item 132E

Procedure

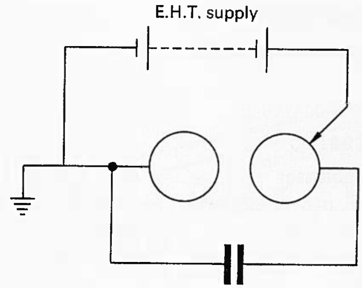
Set up two metal spheres a cm or so apart, fixing the insulated handles to retort stands using a boss.

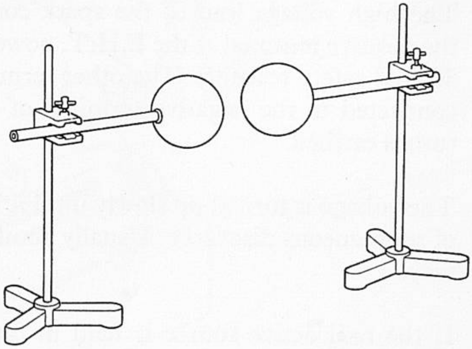
Connect the capacitor, well insulated from earth, across the gap and apply about 5 kV between the spheres using the E.H.T. power supply (item 14). This is readily done by earthing one of the spheres to the negative terminal of the power supply (which itself is earthed) and making momentary contact between the other sphere and the positive terminal of the power supply. This should be done with a thoroughly insulated flying lead.

The separation between the spheres should be adjusted so that the arrangement *just* fails to spark. Some previous rehearsal will be necessary if the optimum conditions are to be found.

When the spheres are charged, a match struck just beneath the gap will trigger off the spark.

For a full discussion of this 'match flame' counter see the *Teachers' Guide*. It is not a demonstration of a spark, but a 'match counter': the teacher lights the matches, the pupil counts the sparks.


E.H.T. supply



123c *Demonstration*

The spark counter

Apparatus

1 spark counter	– item 17
1 E.H.T. power supply	– item 14
1 radium source	– item 16
1 source holder	– item 196

Procedure

The high voltage lead of the spark counter is plugged into the positive terminal of the E.H.T. power supply (without the 50 MΩ safety resistor). The other terminal on the counter is connected to the negative terminal of the supply, which in turn is earthed.

The voltage is turned up slowly until it is just below the point of spontaneous discharge. Usually about 4,500 volts is necessary.

If the radioactive source is held in forceps over the gauze, sparks will be seen and heard. The random nature of the process should be appreciated.

By moving the source slowly away from the gauze, the finite range of the radiation becomes apparent.

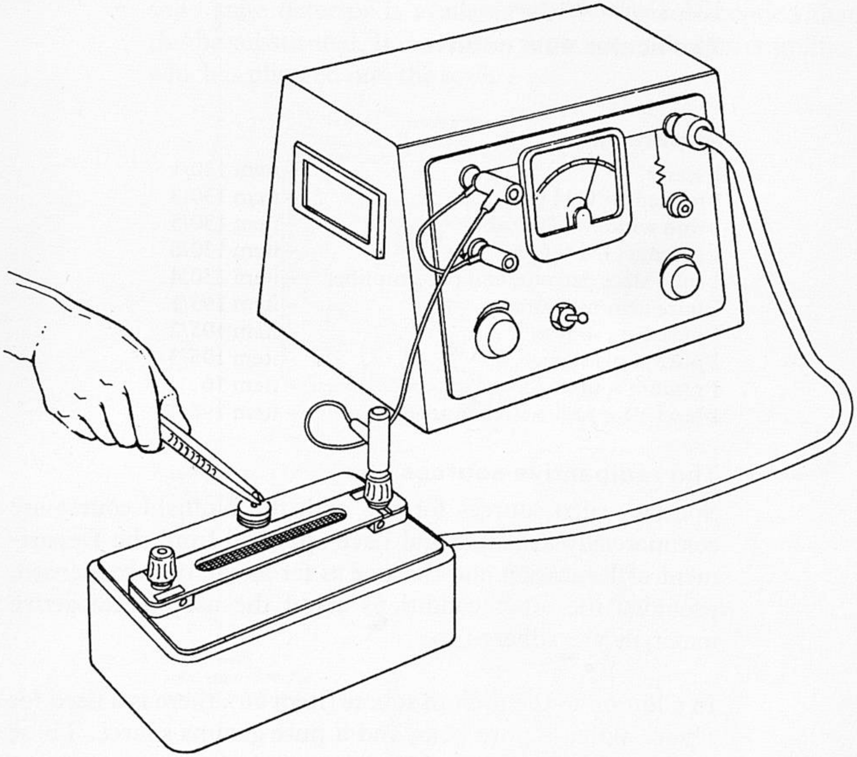
For full discussion of this counter, see the *Teachers' Guide*.

Notes

1. Any kink or bend in the wire in the counter is liable to cause a spark discharge at that point. If that happens the wire should be replaced.

2. A continuous spark (which will very soon damage the wire) shows the voltage is too high.

3. The counter should be dust free. Dust around the stretched wire can often be blown away.



124 *Demonstration*

The scaler as a counter

Apparatus

1 scaler	– item 130/1
1 holder for GM tube	– item 130/3
1 thin window GM tube	– item 130/5
1 gamma GM tube	– item 130/6
1 solid state detector and pre-amplifier	– item 130/4
1 pure gamma source	– item 195/1
1 pure beta source	– item 195/2
1 pure alpha source	– item 195/3
1 radium source	– item 16
1 holder for radioactive sources	– item 196

The radioactive sources

Special sealed sources for use with the Nuffield course are commercially available and have approval from the Department of Education and Science as far as safety is concerned, provided the other conditions about the use of radioactive materials are adhered to.

In addition to the radium source (item 16), there is a need for a pure alpha, a pure beta, and a pure gamma source. Those recommended for use, which most nearly meet these requirements, are:

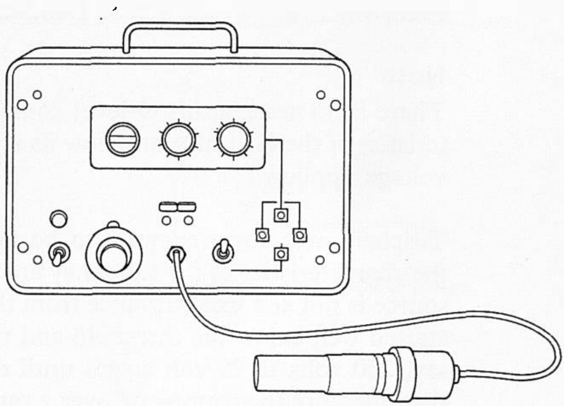
Cobalt 60 (Co60)	– pure gamma
Strontium 90 (Sr90)	– pure beta
Plutonium 239 (Pu239)	– pure alpha

Each of these sources is available with 5 microcurie strength.

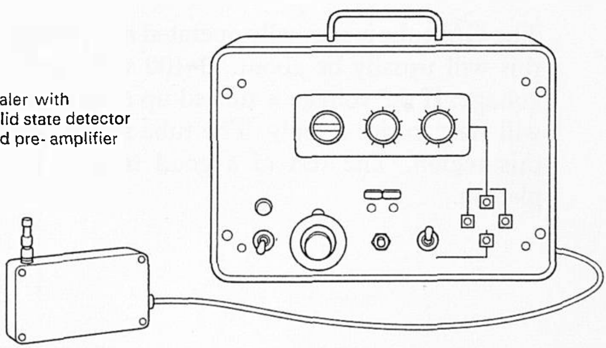
The plutonium source is somewhat expensive. An almost satisfactory source is Americium 241, though this does emit some weak gamma radiation as well. It is however much cheaper.

Alpha-particle detector

The *Teachers' Guide* refers to the use of a very thin window tube for detecting alpha particles. Unfortunately no suitable tube is commercially available in England, which can be used at the voltages available for school experiments or with the standard GM tube socket used in school work. However a solid state detector is available and it is recommended that this be substituted. It is necessary to use it with a pre-amplifier which is plugged into the scaler.



scaler with
G M tube



scaler with
solid state detector
and pre- amplifier

Procedure

The four sources are presented in turn to each of the GM tubes and to the solid state detector, connected to the scaler. The scaler responds by counting the ionizing events which occur.

In each case, absorbers may be put between the source and the detecting device. It may be shown that paper stops alpha radiation, a sheet of Perspex, an exercise book, or thin aluminium stops beta radiation, but thick lead or very thick aluminium is necessary for gamma radiation.

Esso-Nuffield Film

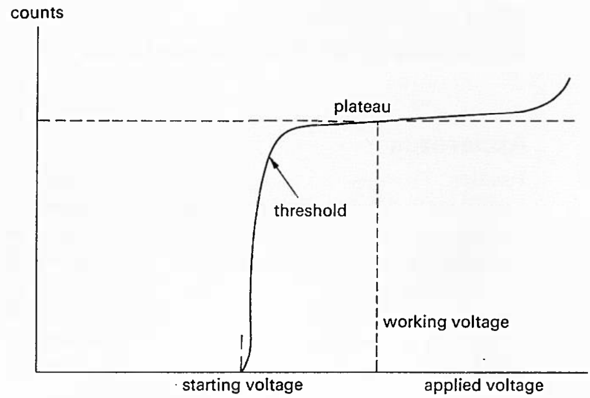
Teachers may like to see the film *Further Experiments in Radioactivity*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

Note

There is no need in this O-level course to show the characteristics of the GM tube and how its response depends on the voltage applied.

Teachers will, however, want to be familiar *themselves* with the characteristics of the tube they are using. To plot these, a source is put at a fixed distance from the tube. The voltage is started well below the threshold and turned up slowly from, say, 250 volts in 25 volt stages until counts start. They can then measure the count-rate over a range of applied voltages and then will obtain a plot like this.

The GM tube is normally operated at a voltage on the plateau; this will usually be about 50–100 volts above the threshold voltage. If the voltage is turned up even more, the count-rate will start to rise steeply. The tube should *not* be operated in this region. The test of a good tube is the length of the plateau.


counts
plateau
threshold
working voltage
starting voltage
applied voltage

125 *Demonstration*

Experiments with alpha particles

Apparatus

1 scaler	– item 130/1
1 solid state detector and pre-amplifier	– item 130/4
1 alpha source	– item 16 or 195/3
1 holder for radioactive sources	– item 196
1 spark counter	– item 17
1 EHT power supply	– item 14
1 expansion cloud chamber	– item 18
1 HT power supply	– item 15

Procedure

a. *Range of alpha particles*

The solid state detector is plugged into the pre-amplifier which in turn is connected to the scaler. The alpha source is presented to the detector from a distance of about 10 cm. It is then moved slowly towards the detector until counting starts. This is repeated several times to show the short range of the alpha particles.

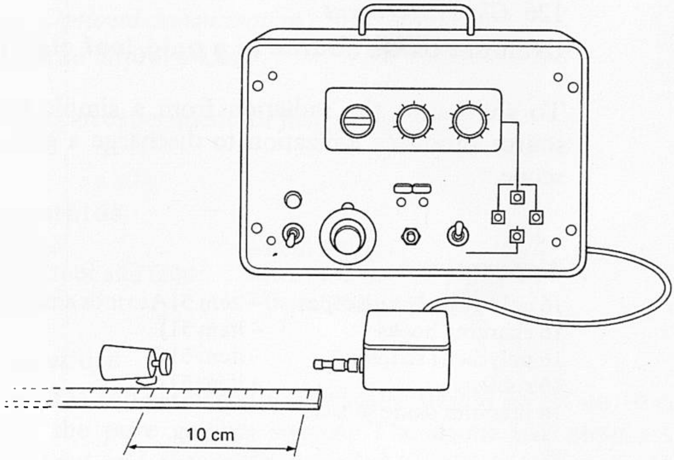
The same effect can be shown using the spark counter used earlier in the course. The voltage applied to the counter is turned up until it is just on the point of discharge. The source is held 10 cm above the counter and then lowered slowly until sparks are obtained.

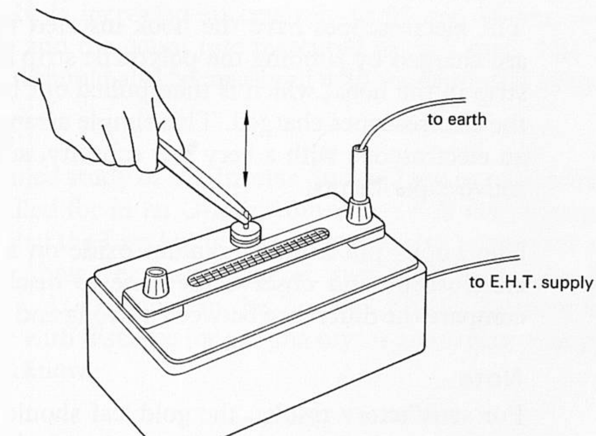
The limited range of the alpha particles should also be shown using an expansion cloud chamber with an alpha source inside.

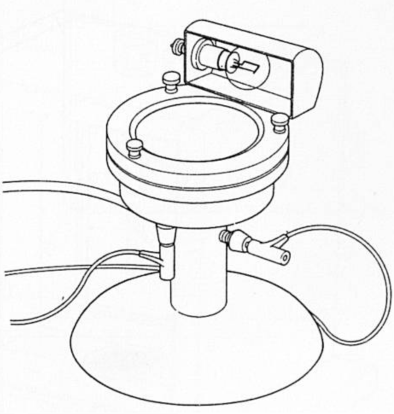
b. *Shielding of alpha radiation by paper*

The source is set up just in front of the solid state detector so that a good count-rate is obtained. First a piece of thin cigarette paper should be put between the source and the detector and then a piece of ordinary paper.

The same effect can be shown using the spark counter.


10 cm


to earth
to E.H.T. supply



126 *Class experiment*

Uranium oxide source in a gold-leaf electroscope

To show how the radiation from a simple uranium oxide source produces ionization to discharge a gold-leaf electroscope.

Apparatus

16 gold-leaf electroscopes	– item 51A
16 charging hooks	– item 51J
16 polythene strips	– item 51G
16 rubbers	– item 51I
16 uranium oxide sources	

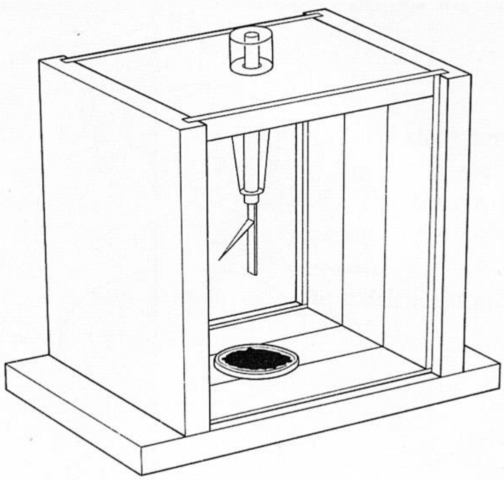
Procedure

The electroscopes have the hook inserted in the top. They are charged by rubbing the polythene strip and inserting the strip in the hook, which is then pulled out by it. This leaves the electroscopes charged. This simple arrangement provides an electroscope with a very low capacity, suitable for radioactive experiments.

The pupils put a little uranium oxide on a dish inside the electroscope and observe the time to discharge. They can compare the difference between a strong and a weak source.

Note

For satisfactory results, the gold leaf should be as narrow as possible. A thin strip almost pointed at the lower end is ideal.



127 *Optional demonstration*

Inverse Square Law

This is an experiment for fast groups only.

Apparatus

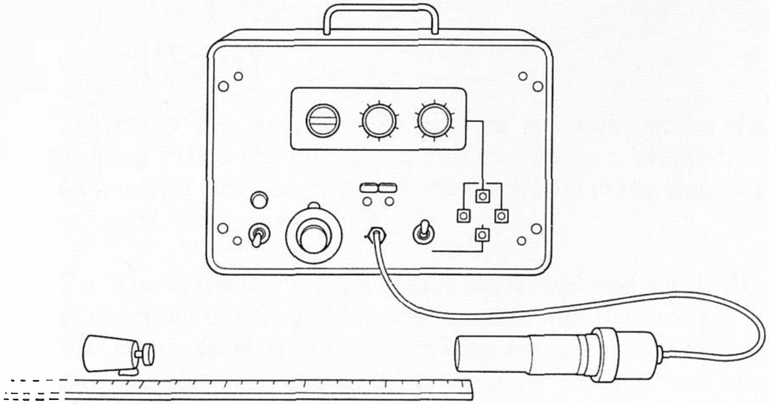
1 scaler	– item 130/1
1 GM tube and holder	– item 130/3
1 gamma source	– item 195/1

Procedure

The GM tube attached to the scaler should be set up 10 cm from the pure gamma source. The count rate should be measured and the result recorded on the blackboard. The distance is increased successively to 20 cm, 30 cm, 40 cm, 80 cm and the count rate measured in each case. The background should also be measured with the source far away.

Note

A detailed study of the Inverse Square Law in radioactivity is not called for in an O-level course and it is *not* necessary to show that the Law holds for a gamma source but not for a beta source, however interesting or significant this may be at A-level. As explained in the *Teachers' Guide*, the mere fact of fall off with distance for gamma rays is something that pupils should know.



128a *Demonstration*

Expansion cloud-chamber

Note

The pupils will have had a first glimpse of cloud-chambers in Year I, but will not have seen them since then. They will now watch tracks for themselves in Taylor cloud-chambers, but first they should see tracks in an expansion cloud-chamber.

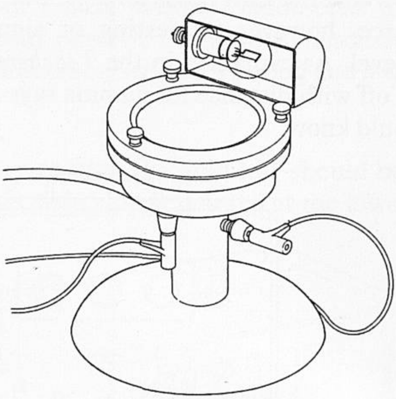
Apparatus

1 expansion cloud-chamber – item 18

The expansion cloud-chamber will require its own alpha particle source.

Procedure

Various types of expansion cloud-chamber are available and in each case the manufacturer's instructions should be followed carefully. Some cloud-chambers require special alcohol, some operate from methylated spirit or even water: the latter are to be preferred.



128b *Class experiment*

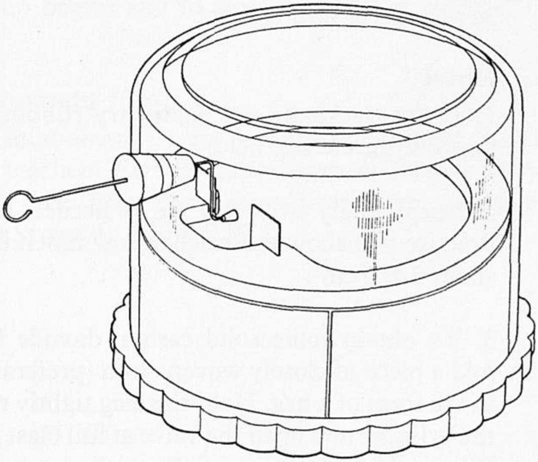
Taylor diffusion cloud-chambers

Apparatus

8 Taylor cloud-chambers	– item 28
8 illuminants	– item 47
1 CO_2 cylinder	– item 19/1
1 dry ice attachment	– item 19/2
8 transformers	– item 27

Procedure

The cloud-chambers should be distributed so that there is one for every four pupils. It is very important that they should have plenty of time for this experiment: it is something to be enjoyed and not hurried.



To set up the chambers, methylated spirit is put on the padding inside the top of the chamber using a dropper. A drop or two may also be put on the black base of the chamber and allowed to spread over it.

The base of the whole apparatus is unscrewed and a little dry ice from the CO_2 cylinder put in contact with the base plate. The plastic foam is put back to keep the dry ice in contact with the plate and the base cap screwed on again and the chamber inverted.

It is important that the cloud-chamber be level: it should be placed on the three wedges provided, which can be adjusted to get it level (if it is not level, convection currents moving in the chamber will be seen and these can be used as guides in levelling).

The top must be put back on the chamber. Rubbing it with a handkerchief will charge it sufficiently to provide an adequate electric field inside the chamber to sweep away old ions.

Illumination is important and the illuminants must be used and adjusted so that there is a layer of illumination a few millimetres above the base plate.

Alpha tracks will be seen coming from the weak radioactive source, inserted in the side of the chamber, usually within 30 seconds of setting it up.

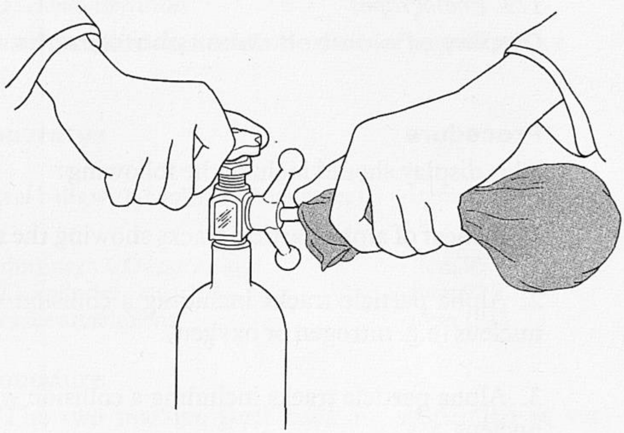
Notes

1. If the tracks are not sharp, try rubbing the top again to improve the electric field.

2. Surprisingly little dry ice is needed in these chambers. Practice will show the teacher how much is required, usually about 5 or 6 cm^3.

3. To obtain some solid carbon dioxide from the cylinder, fold a piece of closely woven cloth (preferably of dark colour) in the form of a bag. Hold this bag tightly round the nozzle of the cylinder and open the valve at full blast for 5 to 10 seconds. Where the cylinder is of the syphon type it should be kept upright. If it is an ordinary cylinder it should be held upside down during this process. See also Note 4.

4. In schools where several classes are following the Nuffield programme, it may not be feasible to manufacture the supply of solid carbon dioxide from the cylinders. It will be necessary to order a block from the suppliers. Such blocks are easily obtainable, delivered by railway. See Section C of the Nuffield *Physics Guide to Apparatus* for details on the availability of solid carbon dioxide in block form for use in schools.



5. It is possible to make the solid 'snow' by expansion before the lesson begins and to store it in a wide-necked Thermos flask.

Esso-Nuffield film

These cloud chambers are demonstrated in the Esso film for science teachers *Further Experiments in Radioactivity*, available on free loan from Esso Petroleum Company Ltd, Victoria Street, London, S.W.1.

129 *Photographs*

Display of cloud-chamber photographs

Procedure

This display should include the following:

1. A sheaf of alpha particle tracks showing the short range.

2. Alpha particle tracks including a collision with a massive nucleus (e.g. nitrogen or oxygen).

3. Alpha particle tracks including a collision with a hydrogen nucleus.

4. Alpha particle tracks including a collision with a helium nucleus.

5. Beta particle tracks.

6. A beam of gamma or X-rays showing secondary electrons ejected.

7. Alpha particle tracks bent in a very strong magnetic field.

8. Beta particle tracks bent in a much weaker magnetic field.

130 *Demonstration*

Elastic collisions with bodies of equal mass

Apparatus

a.

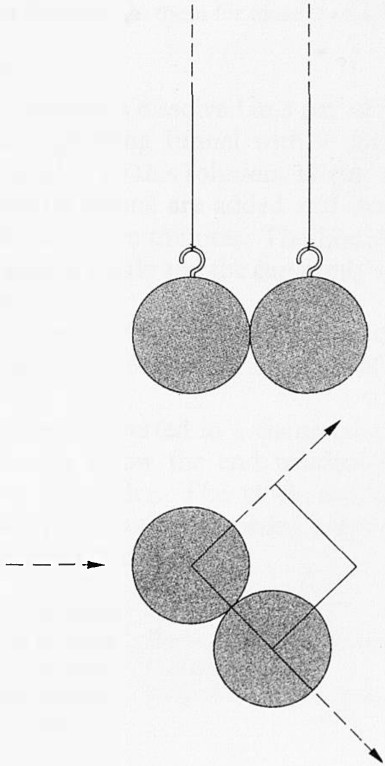
2 steel balls with hooks (2 in diameter)	– item 131B

b.

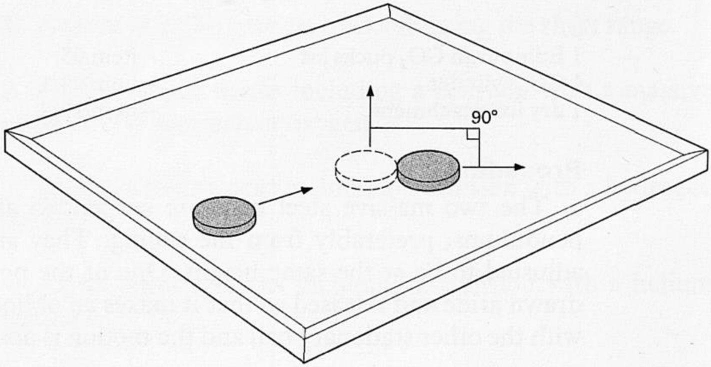
1 Edinburgh CO_2 pucks kit	– item 95
1 CO_2 cylinder	– item 99/1
1 dry ice attachment	– item 19/2

Procedure

a. The two massive steel balls are suspended as very long pendulums, preferably from the ceiling. They are carefully adjusted to be at the same height. One of the pendulums is drawn aside and released so that it makes an oblique collision with the other stationary ball and the motion is observed.



b. Two equal magnetic pucks are floated on dry ice in the usual way. One is placed at the centre of the glass plate and the other is allowed to coast towards it so that an oblique collision occurs. The motion is observed. It could perhaps be photographed using one of the multiflash techniques. In both the experiments, the right-angled fork should be apparent.



131 *Optional demonstration*

Exponential decay of a radioactive substance

This experiment shows the exponential decay of a 'grand-daughter' of uranium (protactinium 234).

Apparatus

1 scaler	– item 130/1
1 holder for GM tube	– item 130/3
1 thin window GM tube	– item 130/5
1 stop-clock	– item 507
1 retort stand, boss, and clamp	– item 503–506
1 small polypropylene bottle (30 ml capacity)	

Chemicals required: uranyl nitrate, concentrated hydrochloric acid, and amyl acetate or iso-butyl methyl ketone.

A polypropylene bottle is somewhat more resistant to attack by the acid and ketone than is polythene and is to be preferred. Nevertheless, polythene bottles can be used, provided no attempt is made to store the liquid in them for more than a few weeks.

Procedure

1 g of uranyl nitrate is dissolved in 3 cm^3 of water and washed into a small separating funnel with 7 cm^3 of concentrated hydrochloric acid. To this solution, 10 cm^3 of amyl acetate or iso-butyl methyl ketone are added and the whole is shaken together for about five minutes. The liquid is then run into the polypropylene bottle and the cap firmly screwed on.

The organic layer which separates out contains the protactinium 234 which decays with a half life of some 68 seconds.

The bottle is held inverted in a clamp (the organic layer on top) immediately below the end window of the GM tube connected to the scaler. The clock and the counting are started together and counts recorded every other ten second interval. The procedure is:

0–10 seconds	Count
10–20 seconds	Record reading and reset scaler
20–30 seconds	Count
30–40 seconds	Record reading and reset scaler
and so on.	

This should be followed for about five minutes, ample time to reveal the meaning of the term half life and to illustrate the decay process.

Allowance must be made for background radiation. After the activity in the organic layer has died down by many half lives (say after 10 minutes, when it is down to $\frac{1}{4}$ of 1 %), the scaler is set counting for, say, 5 minutes with the bottle still in position, to obtain an average value of the background, some of which comes from the lower liquid.

The experiment can, of course, be repeated at will provided a few minutes are left in between each attempt. In 5 minutes the activity of the protactinium in the aqueous layer grows to 15/16 of its equilibrium value.

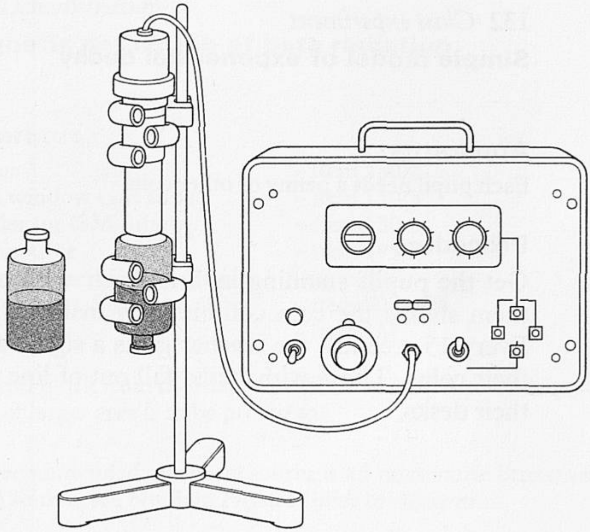
It is possible to record this growth to equilibrium by moving the GM tube so that the aqueous layer at the bottom of the bottle is immediately above the end window of the tube.

The chemistry of the experiment

The first steps of the Uranium 238 series are involved in the experiment.

$$U^{238}_{92} \xrightarrow{\alpha} Th^{234}_{90} \xrightarrow{\beta} Pa^{234}_{91} \xrightarrow{\beta} U^{234}_{92}$$

Thorium does not form anionic chloride complexes as do uranium and protactinium. At high hydrogen ion concentrations, these complexes can be extracted into the organic layer. Since U^{238}_{92} has a very long half life and is an alpha emitter, it makes no detectable contribution to the count rate.



132 *Class experiment*

Simple model of exponential decay

Apparatus

Each pupil needs a penny or other coin.

Procedure

Get the pupils standing in line, each with a coin. Each of them shakes the coin continuously inside his cupped hand. Every 15 seconds, the teacher gives a signal and they look at their coins. Those with 'tails' fall out of line and sit down at their desks.

133 *Demonstration*

Magnetic deflection of beta radiation

Apparatus

1 scaler	– item 130/1
1 thin window GM tube	– item 130/5
1 holder for GM tube	– item 130/3
1 beta source	– item 195/2
1 large magnet (Eclipse major)	– item 50/3
1 retort stand, boss, and clamp	– item 503–506
1 lead block	– item 1M

The lead block from the materials kit (item 1M) is just adequate. A block of larger area is to be preferred.

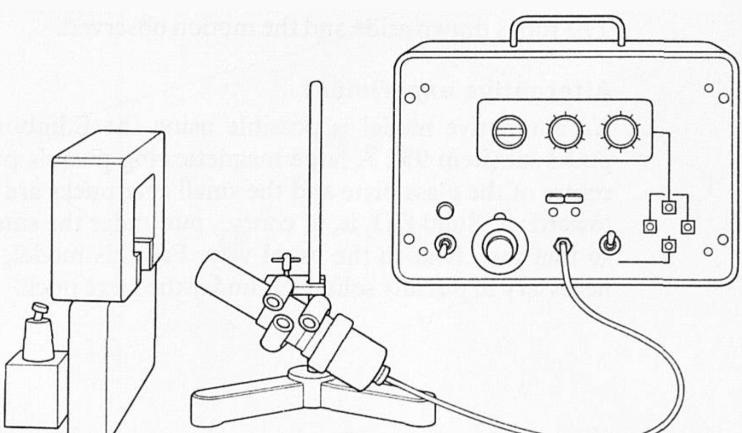
The recommended pure beta source is a 5 microcurie Strontium 90 sealed source, see Nuffield *Physics Guide to Apparatus.*

Procedure

Connect the GM tube to the scaler and hold it in a retort stand, as illustrated below, on one side of the lead block. Put the beta source on the other side of the block : it may be convenient to fix it into a cork. It should be directed upwards as illustrated. The block shields the source and only a low count-rate is observed.

Bring up the magnet above the lead block. The beta particles follow a curved path in the magnetic field and now reach the GM tube. The count-rate increases.

Finally remove the magnet, turn it round, and replace. This time there will be only the low count-rate.



134 *Demonstration*

Magnetic model of alpha particle scattering

Apparatus

3 retort stand rods	– item 504
2 retort stand bases	– item 503
2 bosses	– item 505
1 clamp	– item 506
1 G-clamp	– item 44/1
2 cylindrical magnets	
3 bar magnets	
1 light rod	– see below
6 in thin-walled rubber tubing	

The light rod should be about 1 metre long, either wood or aluminium tube, about 1 cm diameter.

The cylindrical magnets should be 3 cm long and 1 cm in diameter. The bar magnets at least 6 × 1·5 × 0·5 cm.

Procedure

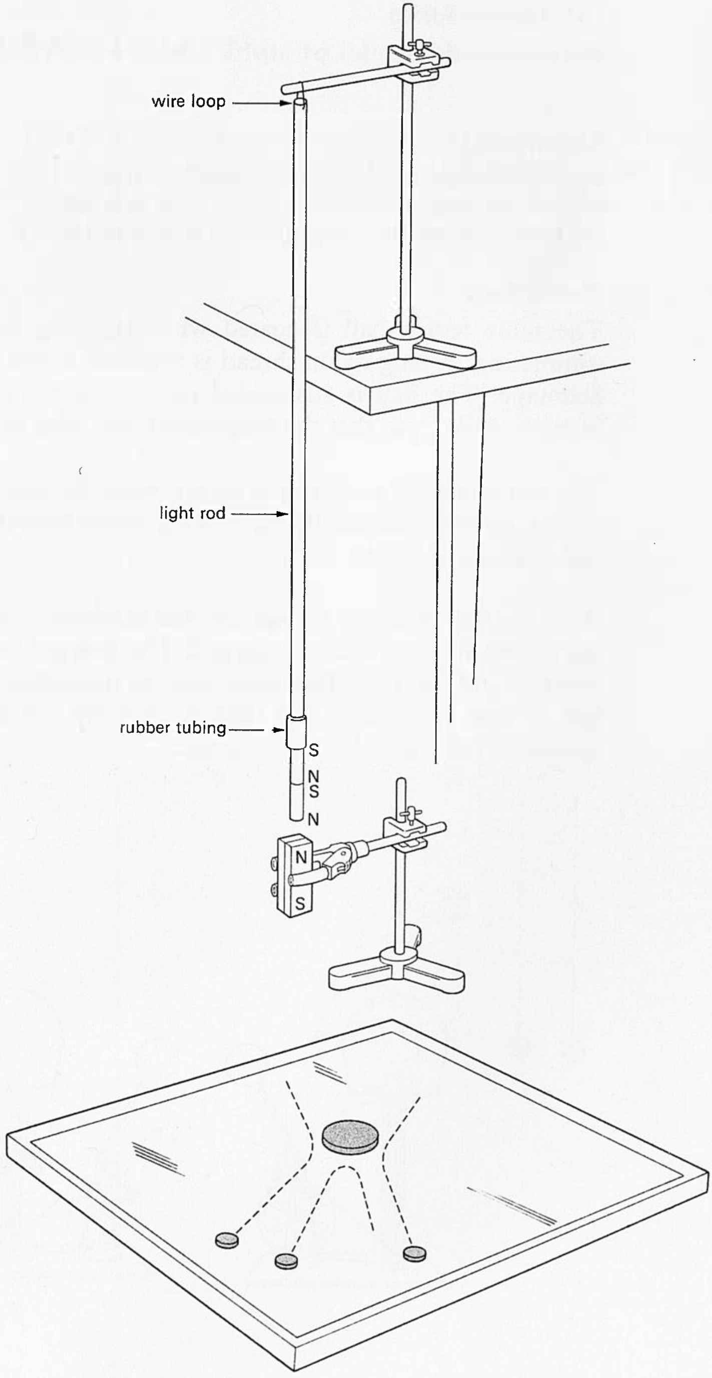
An inch of the rubber tubing is used to secure the cylindrical magnet to the end of the light rod. The second cylindrical magnet is held to the first by their mutual attraction. The rod is suspended by a short loop of flexible thread (a 1 or 2 inch loop is enough) from a rod held out from a retort stand so that it can swing freely as a pendulum with the magnet at the lower end. It is advisable to clamp the base of the retort stand.

The two or three bar magnets are secured in a clamp so that similar poles are together directly beneath and very slightly below the similar pole of the suspended cylindrical magnet.

The rod is drawn aside and the motion observed.

Alternative experiment

An alternative model is possible using the Edinburgh CO_2 pucks kit (item 95). A large magnetic ring puck is put at the centre of the glass plate and the small ring pucks are directed towards it. Solid CO_2 is, of course, put under the small pucks so that they float in the usual way. For this model, it is not necessary to put any solid CO_2 under the large puck.


wire loop
light rod
rubber tubing
S
N
S
N
N
S

135 *Demonstration*

Electrostatic model of alpha particle scattering

Apparatus

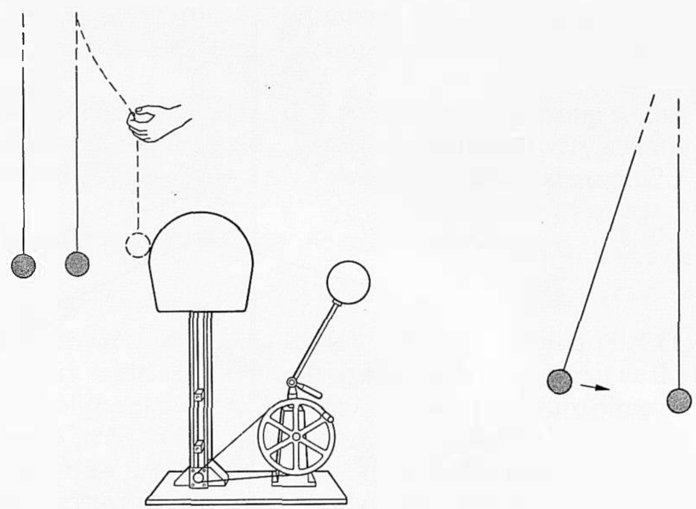
1 table tennis ball coated with Aquadag	– item 131E
1 van de Graaff generator	– item 60/1
fine nylon suspension	– item 51E

Procedure

The table tennis ball is coated with Aquadag to make it conducting. A long nylon thread is attached to the ball with Sellotape. The ball is suspended by the thread, preferably from the ceiling, so that the suspension is as long as possible.

The van de Graaff generator is set up below the suspension in such a position that the ball can swing freely near the sphere and at the same height.

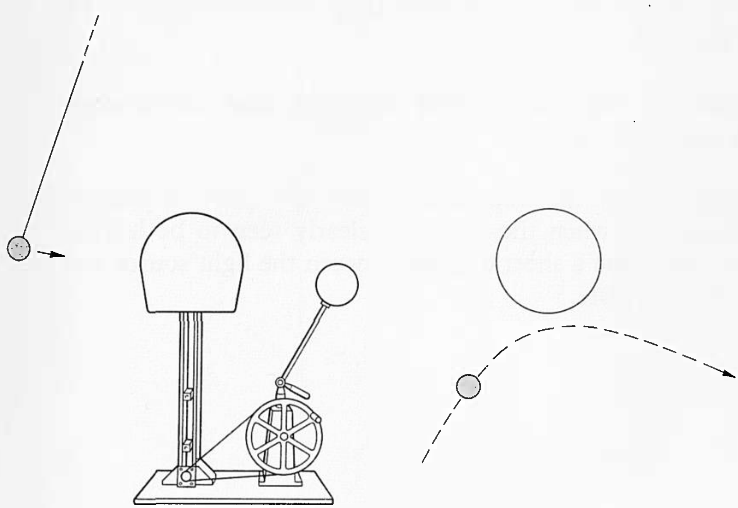
With the ball touching the sphere, the machine is set operating so that the two become charged. The charged ball will be repelled and can be pulled aside with an insulating rod. The ball is then allowed to fall back towads the sphere of the generator and the motion is observed.



136 *Film*

Rutherford Atom

This P.S.S.C. film, made by Dr Robert Hulsizer, University of Illinois, is available in the United Kingdom on hire from Sound Services Ltd, Wilton Crescent, London, S.W.1. Duration of film: 40 minutes.



137 *Demonstration*

'Wholesale' photoelectric effect

Apparatus

1 gold-leaf electroscope	– item 51A
1 zinc-plate attachment	– item 190
1 wire mesh	
1 EHT power supply	– item 14
1 piece of fine emery cloth	
1 sheet of glass	– item 58F
1 ultra-violet lamp	– item 189

Procedure

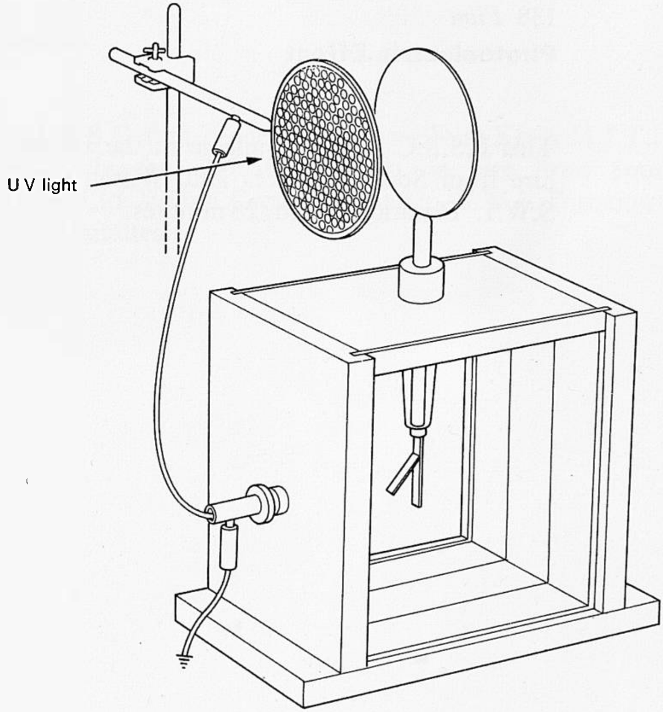
Set up the gold-leaf electroscope so that the pupils have a clear view of the leaf. (This may be shadowed onto a ground glass window in the electroscope using a 12 volt 24 watt lamp.)

Thoroughly clean the zinc plate with the emery cloth and attach it to the electroscope. Support the wire mesh a few inches away from the zinc plate. This mesh is connected to the case of the electroscope which is earthed.

Charge the plate on the electroscope negatively. Then illuminate the plate with the ultra-violet lamp. Observe the effect on the gold leaf.

Repeat the experiment with the plate and electroscope charged positively.

Finally repeat the experiment with the plate negatively charged, but when the charge is clearly seen to be leaking away, interpose a sheet of glass between the light source and the charged plate.


U V light

138 *Film*

Photoelectric Effect

This P.S.S.C. film is available in the United Kingdom on hire from Sound Services Ltd, Wilton Crescent, London, S.W.1. Duration of film: 28 minutes.

139 *Film*

Photons

This P.S.S.C. film, made by Professor John King, M.I.T., is available in the United Kingdom on hire from Sound Services Ltd, Wilton Crescent, London, S.W.1. Duration of film: 19 minutes.

140 *Demonstration*

Photoelectric effect with GM tubes

Suitable apparatus is not yet readily available in the United Kingdom for this experiment using standard school scalers.

Because some GM tubes do have sufficiently thin glass windows to enable this experiment to be done, teachers might like to experiment with their stock of tubes (including any liquid counter tubes).

To do this, set the tube about an inch from, say, a candle flame and observe the count rate with and without a piece of glass in between the flame and tube.

141 *Optional demonstration*

Photoelectric effect using X-rays

Suitable apparatus is not yet available in the United Kingdom for this experiment using standard school scalers.

142 *Class experiment*

Two-dimensional diffraction grating

Apparatus

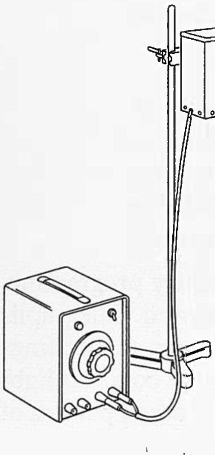
1 compact light source – item 21
1 L.T. variable voltage supply – item 59
16 coarse diffraction gratings – item 191/1
16 pieces of finely woven cloth
8 rotating devices – item 198

Procedure

a. The compact light source is placed fairly high up at one end of the laboratory and pupils hold the grating near to the eye and look through it at the distant light source. (This repeats experiment 108a.)

They should then look at the same source holding a tightly stretched piece of finely woven cloth near the eye. A silk handkerchief is very suitable. This acts as a two-dimensional grating.

b. The pupils are then asked what they would see if the woven cloth were rotated. They should try the special rotating device (item 198).



143 *Optional class experiment*

Two-dimensional grids from Nuffield Chemistry programme

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
1 set of diffraction grids	– item 191/3

Procedure

If the school is following the Nuffield chemistry programme, the Nuffield diffraction grids should be borrowed. The pupils examine the diffraction patterns produced when the gratings are held near to the eye so that light from the compact light source passes through. The sets included a random pattern of dots as well as regular two-dimensional arrays.

144 *Wallchart*

Chart of the electromagnetic spectrum

A simple chart should be prepared by the teacher as suggested in the *Teachers' Guide*. It should show the full range from gamma rays, through X-rays, ultra-violet, visible light, infra-red, radio waves, to low frequency radiation, giving approximate wavelengths for each.

145 *Film*

Interference of Photons

This P.S.S.C. film, made by Professor John King, M.I.T., is available in the United Kingdom on hire from Sound Services Ltd, Wilton Crescent, London, S.W.1. Duration of film: 13 minutes.

146 *Class experiment*

Two-dimensional diffraction grating

Apparatus

1 compact light source	– item 21
1 L.T. variable voltage supply	– item 59
16 coarse diffraction gratings	– item 191/1
16 pieces of finely woven cloth	
8 rotating devices	– item 198

Procedure

Before considering matter waves (electron diffraction), the teacher might care to repeat experiments 142a and b.

147 *Film*

Matter Waves

This P.S.S.C. film, made by Alan Holden and Lester Germer at Bell Telephone Laboratories, is available in the United Kingdom on hire from Sound Services Ltd, Wilton Crescent, London, S.W.1. Duration of film: 28 minutes.

Appendices

Appendix I

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.

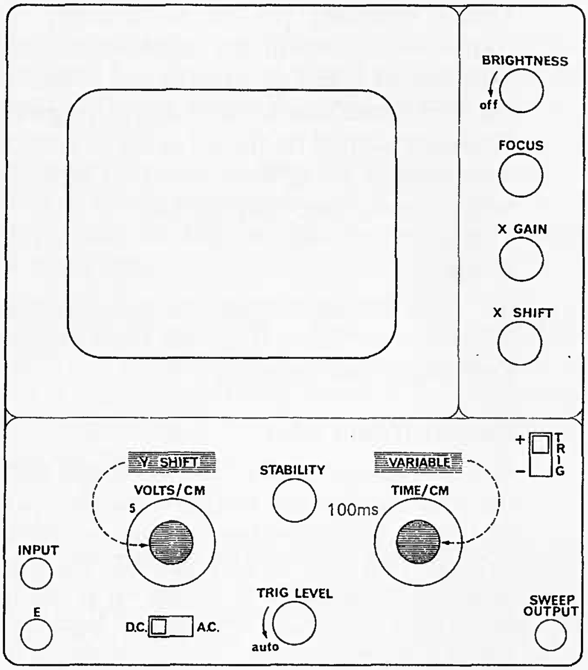
To prepare the oscilloscope for use, plug into the mains supply and set the controls as follows:

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 100μS, 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

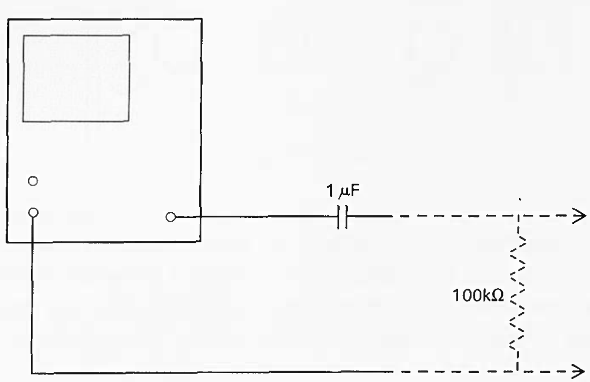
If a sine wave or square wave input is connected between the Z-INPUT and E sockets on the back of the oscilloscope, the brightness of the trace may be varied by these inputs.

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 makes it easier 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 II

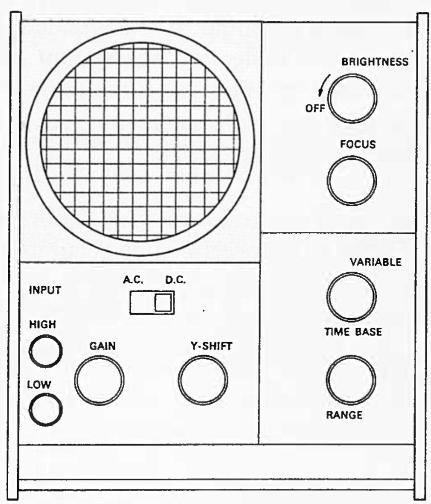
Operating instructions for the class oscilloscope*

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.)

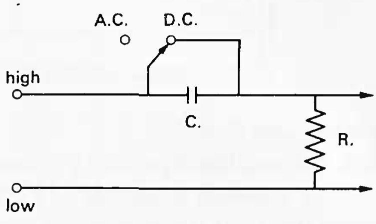
It may be found impossible to obtain a sharp focus when the brightness control is set near maximum and, if this is the case, the brightness control should be turned anticlockwise until a sharp focus is obtained.

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.)

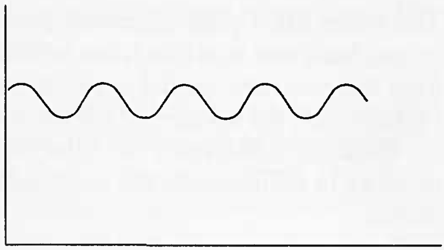
The 'Gain' control is roughly calibrated; the markings are not intended to be precise. For accurate readings of voltage, the calibration should be set with a moving-coil voltmeter connected in parallel to the terminals. The numbers on the 'Gain' control indicate approximately 'scale divisions per volt'.



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

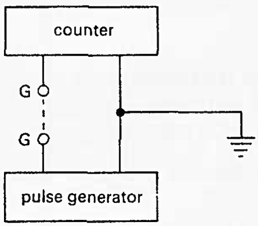
It is recommended that teachers might find it helpful to see the film for science teachers *Oscilloscopes and slow A.C.* in which the operation of this oscilloscope is demonstrated. This film is only suitable for teachers and is not intended for showing to pupils. It is available on free loan from Esso Petroleum Company, Victoria Street, London S.W.1.

Appendix III

Details on the operation of the scaler as a timing device*

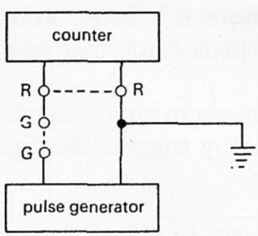
The scaler has a pulse generator producing 1,000 pulses per second built into it so that it can be used as a timer. The pulses from the generator are led out to an external switch and back to the scaler; the number of pulses received are recorded. As the oscillator's frequency is 1 kilocycle/second, 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:



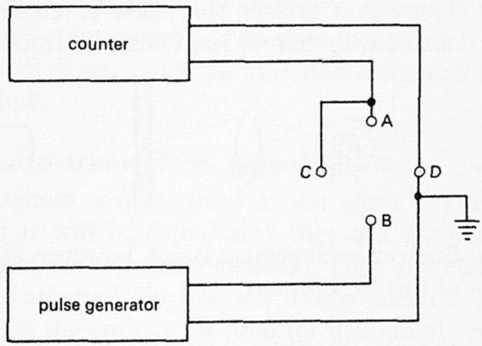
* The details given here refer to the Panax scaler SA 102 ST which was used in the Nuffield trials. Other scalers can be used – see item 130/1 in the Nuffield Physics *Guide to Apparatus*. The details given should be applicable to all the scalers appearing in the list of approved apparatus, though there 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

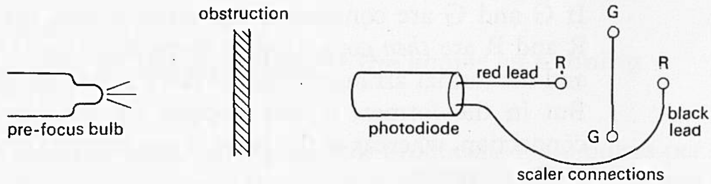
It is probably helpful to teachers to appreciate that points A and C are connected internally to each other and to the counter. D is connected to the earth and the chassis, while B is connected to the oscillator.



Timing accessories

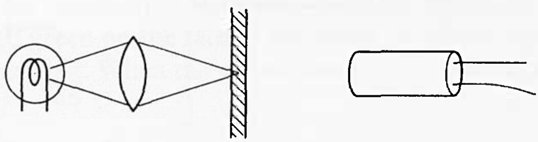
To measure trolley speeds with the scaler we use small photodiodes illuminated by light from small pre-focused torch bulbs. The bulbs operate from a 2·2-volt a.c. supply (which can be obtained from the rear of the scaler).

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.

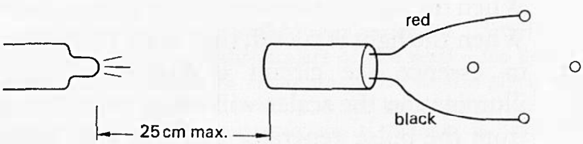


Such an arrangement is not, however, essential for the success of this experiment.

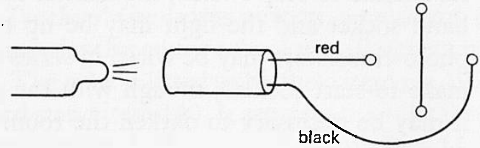
It is also possible to use two photo-diodes in series each with its own lamp. (See below.)

Use of Photo-diodes

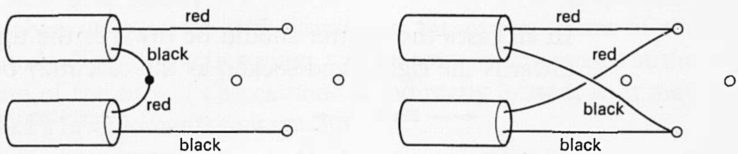
When a photo-diode is used as a make-to-start switch, the red lead should go to the top socket and the 2·2-volt lamp should not be more than 25 cm away:



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.



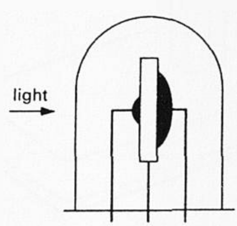
When the two photo-diodes are used together on the same pair of sockets they may be wired in series or in parallel but always with the red lead towards the top socket or towards the left-hand socket. Two photo-diodes in series used as a



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 photodiodes 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.



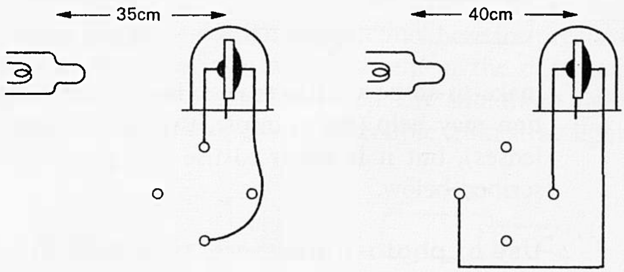
The emitter may be identified as the smaller of the two junctions.

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 below.)

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.



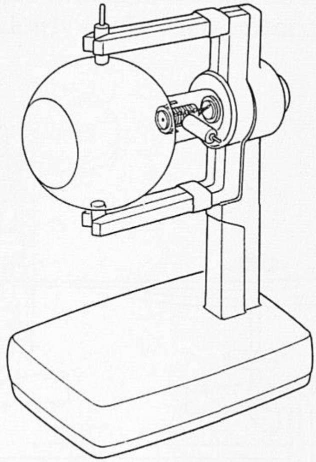
Make-to-start Make-to-stop

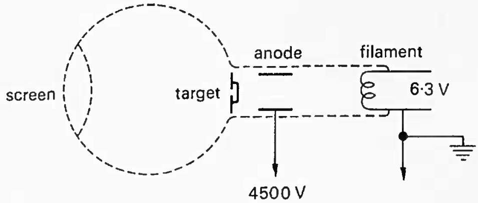
Appendix IV
Electron diffraction

Since the *Teachers' Guide* was written, an electron diffraction tube has been developed for school use. Teachers may care to show this. The tube is listed as Nuffield item no. 197 and it fits the standard stand item 140. It requires 6·3 volts for the heater and also requires the E.H.T. power supply item 14.

The heater supply of 6·3 volts is connected to the filament. The accelerating voltage of about 4,500 volts is connected between the filament and the accelerating anode. The electron beam then strikes a target of a thin deposit of graphitized carbon on a metal grid situated in the exit aperture of the anode. The diffraction rings will be seen on the screen at the end of the tube. (The cathode is indirectly heated, so it may take a few moments to warm up.)

The teacher should show the effect of bringing up a strong magnet. He should also show how the rings change as the voltage is varied between 3,500 and 5,000 volts.





Appendix V

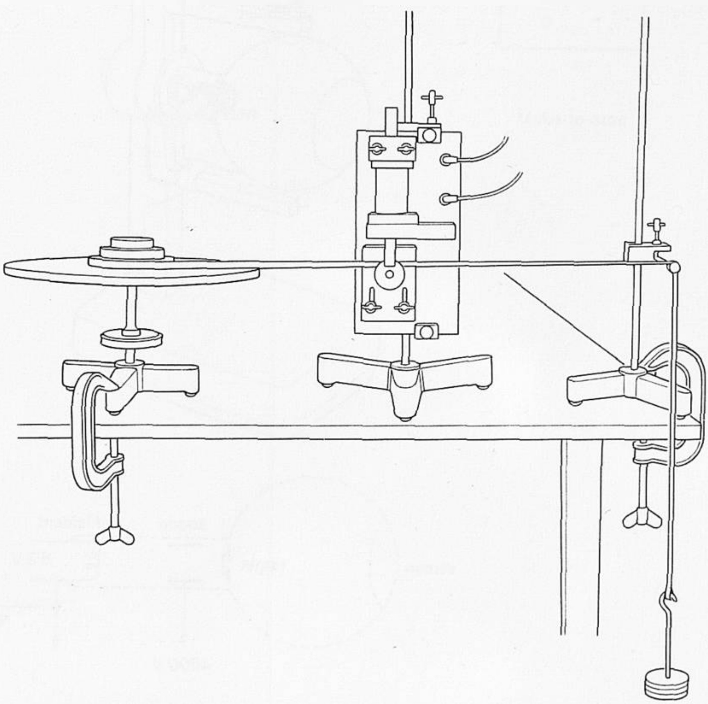
Experiments with a turntable

The turntable, illustrated in this volume, was developed for use with the Nuffield O-level physics course, but at the same time the needs of possible A-level experiments have been born in mind. These further experiments are certainly *not* part of the O-level course, but it might be helpful to teachers to know the further uses for which the turntable has been designed.

The turntable is used for demonstration purposes at O-level, but the design has been kept simple so that it could be used for class experiments at A-level.

Experiments in circular motion

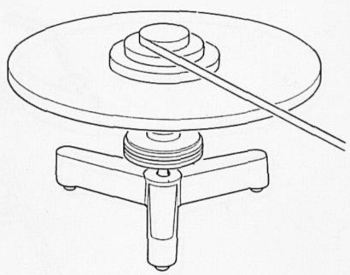
A wooden multiple pulley can be attached to the turntable as illustrated below. Ticker-tape is attached to this with Sellotape and wound round the pulley. The other end of the tape passes through a ticker-tape vibrator, held on its side with special clamps as illustrated. The tape passes over a rotating pulley and a weight hanger is attached to the end.



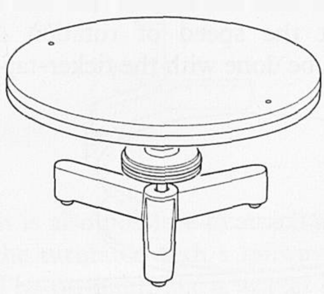
As in the linear motion experiments, compensation is first made for friction by adding a small load until the turntable continues to move without accelerating once set in motion. This is tested with the vibrator.

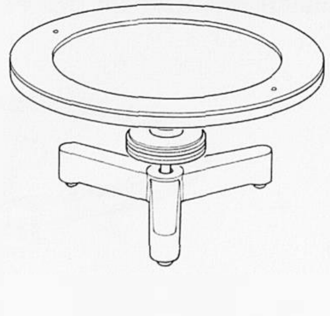
Loads are put on the weight hanger and the motion is recorded by the ticker-tape.

As well as changing the load, the couple can be varied by using a different radius on the wooden multiple pulley.

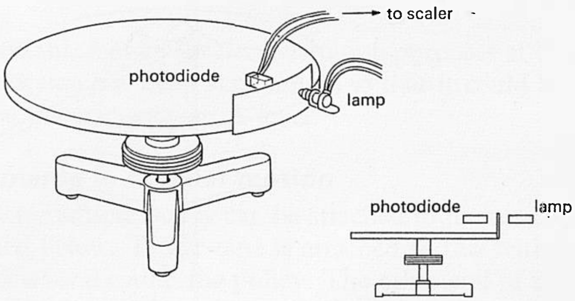


To change the moment of inertia of the turntable, a second wooden disc identical with the first can be added to the fixed top. A brass disc can be added: this has the same mass as the wooden disc, but clearly a different moment of inertia.



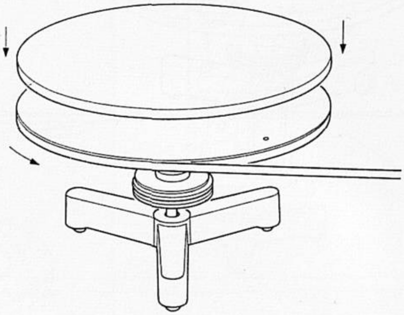


The above class experiments will establish the dependence of angular acceleration on the couple applied. The technique illustrated uses the ticker-tape vibrator. It would also be possible to do equivalent experiments using the scaler and photo-diodes. A card is attached to the rim of the turntable so that it interrupts the light to a photo-diode. The card should be, say, 10 cm long and using the scaler in the usual way, the velocity can be measured. This technique does not, however, give a record of the whole motion as is possible with the vibrator.



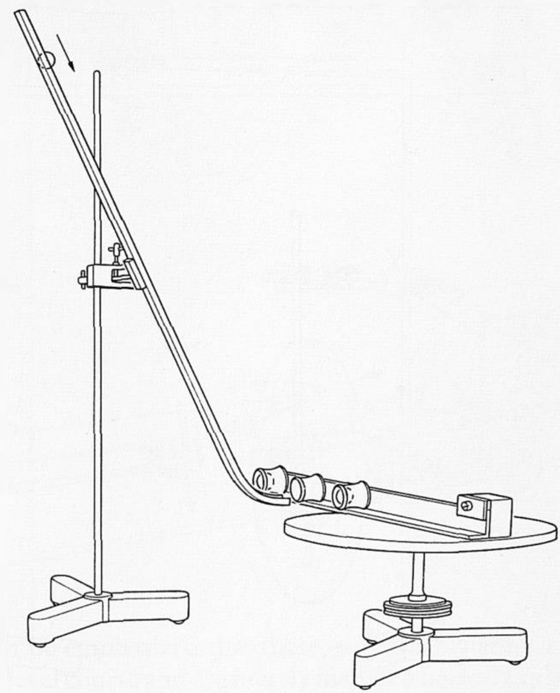
Collision experiments

The equivalent experiments in circular motion to those in linear motion can be done with the turntable. The turntable can be set rotating and then the second disc can be dropped onto the top so that the speed of rotation is reduced. Quantitative work can be done with the ticker-tape vibrators.

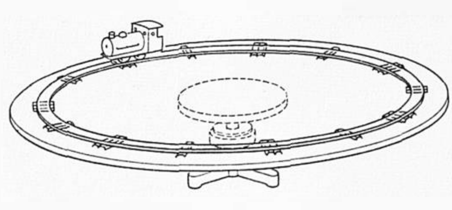


Collision processes can be investigated using the attachment illustrated. A ramp is set up so that a steel ball falls through a known height, is caught by the rubber stop, and starts the turntable moving. The motion is analysed with ticker-tape.

The ramp can be positioned so that the sphere goes successively into each stop. The end stop can be pivoted so that oblique impacts are possible.



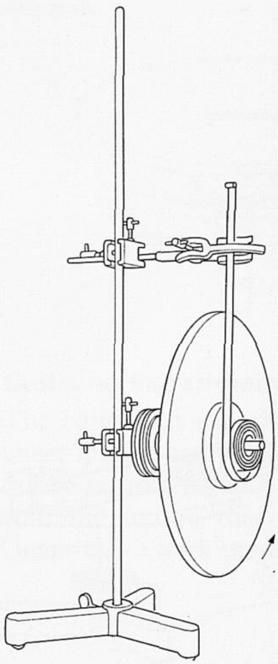
It is also possible to attach a large wooden disc to the top of the turntable with a railway track round the circumference. The turntable starts at rest and a clock-work train is put on the track: as the train moves forward, the turntable rotates backwards.

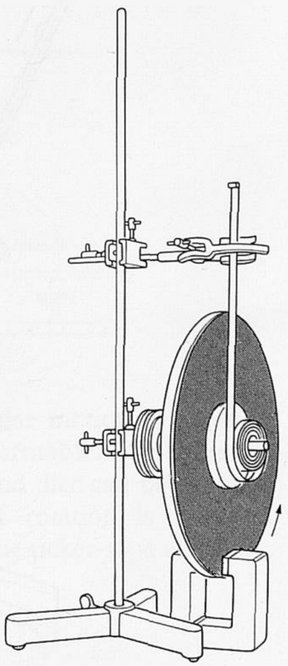


Oscillations

The turntable can also be used for studying mechanical oscillations. This time it is clamped on its side as illustrated below.

Damped oscillations can be considered by attaching the large spiral spring used early in the Nuffield O-level course. The damping can be increased by using two springs instead of one. The oscillations can be timed with a stop watch.

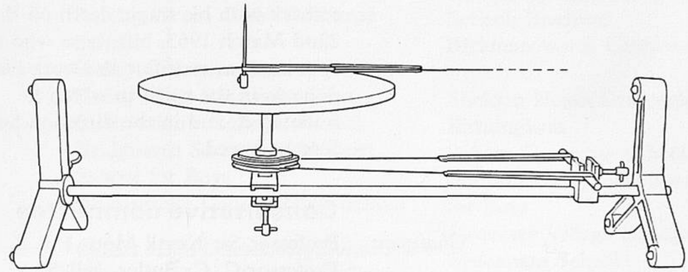


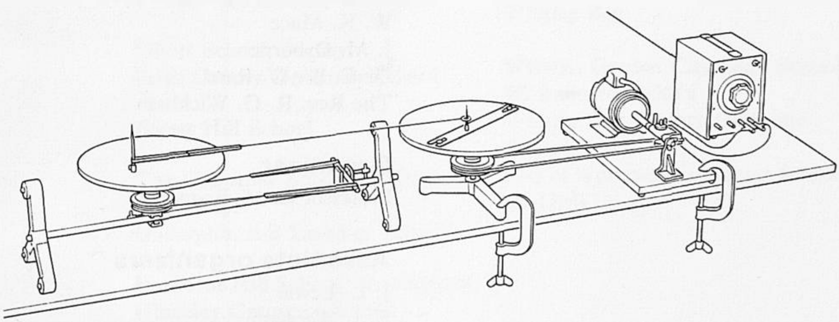


Eddy current damping can be studied by attaching the aluminium disc to the face of the turntable and bringing up a large horseshoe magnet.

Finally it is possible to investigate forced oscillations and resonance.

If the turntable is set up as illustrated below, it has a natural frequency of oscillation. If the turntable is driven by a second turntable, which is rotated at different speeds by the fractional horsepower motor, forced oscillations and resonance can be studied.





It must be emphasized that these experiments are *not* part of the O-level course and are merely included here to explain why the apparatus has been designed in a particular way and to show teachers some of its possible uses.

NUFFIELD FOUNDATION SCIENCE TEACHING PROJECT PHYSICS SECTION

The physics programme was inaugurated in May 1962 under the leadership of Donald McGill. It suffered a severe setback with his tragic death on the 22nd March 1963, but those who were appointed to continue the work have done so in the spirit in which he initiated it, and in the direction he foreshadowed.

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Organizer Professor E M Rogers
Associate organizers J L Lewis E J Wenham
Assistant organizer D W Harding

Other Nuffield Physics publications

Teachers' guide I
Teachers' guide II
Teachers' guide III
Teachers' guide IV
Teachers' guide V

Guide to experiments I
Guide to experiments II
Guide to experiments III
Guide to experiments IV

Guide to apparatus

Tests and examinations

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

Optical instruments and ray diagrams