Physics

Apparatus construction drawings

Nuffield Advanced Science

Penguin Books Ltd, Harmondsworth, Middlesex, England
Penguin Books Inc., 7110 Ambassador Road,
Baltimore, Md 21207, U.S.A.
Penguin Books Ltd, Ringwood, Victoria, Australia

Design and art direction by Ivan and Robin Dodd
Illustrations designed and produced by Penguin Education

Filmset in 'Monophoto' Univers
by Keyspools Ltd, Golborne, Lancs.
and made and printed in Great Britain by
C. Tinling & Co. Ltd, Prescot and London

Contents

Introduction

In recent years, for a number of reasons, the cost of apparatus bought from manufacturers of equipment for schools has risen sharply. At the same time, the Nuffield Advanced Physics Project has thought it right to recommend for the course a fairly substantial increase in the range and quantity of apparatus to be used for teaching Advanced physics, taking the view that the course should be based on wide practical experience. Although some of the recommended items are complex and expensive, a substantial number are not, and it would be possible for many items to be built in a school.

This book is intended to provide enough additional information about the simpler items for a teacher working with a laboratory assistant to make them. For each item, drawings are provided, dimensions are given, and suitable materials are suggested. Very detailed specifications are not usually given, because the exact materials suggested may often not be available, and better alternatives will offer themselves. What is essential is that the teacher and laboratory assistant consult one another about the use the apparatus will have, so that it is made in a way which will be fitted to that use. Generally, simplicity and robustness matter more than appearance.

Not every school will find it practicable to make every item described. Some will prefer to make small simple items in quantity – two-terminal boxes, for example. Others will prefer to concentrate on larger, more expensive 'once off' items, such as the flat solenoid. Some will regard the construction of electronic items as easy, while others will lack the necessary experience and skill. It would be a great deal to expect to ask for as many as half the items described to be built in any one school.

As a matter of policy, we would regard a teacher's time as too valuable to be spent making pieces of apparatus, at a very high real cost both in money terms and in terms of the other demands on his time. A teacher without reasonable laboratory assistance ought not to be expected to undertake the construction of apparatus. In this connection, it should also be remembered that the first year or two of teaching the course, within which most of the constructional work would necessarily fall, will also be the time of greatest strain in other respects, as the teacher works through unfamiliar material with his classes for the first time. On the other hand, time spent building some items of apparatus in the period before the course is started could bring dividends, not only in releasing funds for other apparatus, but in making the teacher more familiar with the course itself.

1008 Ionization chamber *quantity* 1

The ionization chamber is essentially a hollow conducting can, provided with a central conducting electrode which is very well insulated from the rest of the can. Any metal can will serve, preferably one with a screw-on lid. An unwanted calorimeter can be used.

Figure 1 shows the parts added to the can. The essential feature is that the central electrode, insulated from the can, is to be connected directly to the input of an electrometer (item 1006), so that the chamber needs to be designed to fit the electrometer with which it will be used. Figure 1 shows a design suitable for an electrometer with an input of the coaxial UHF socket type. A second UHF socket is bolted to the inside of the base of the chamber, over a hole 17 mm in diameter cut in the base, so that the 4 mm pin which is part of the UHF socket projects below the chamber and can be inserted directly into the electrometer input socket.

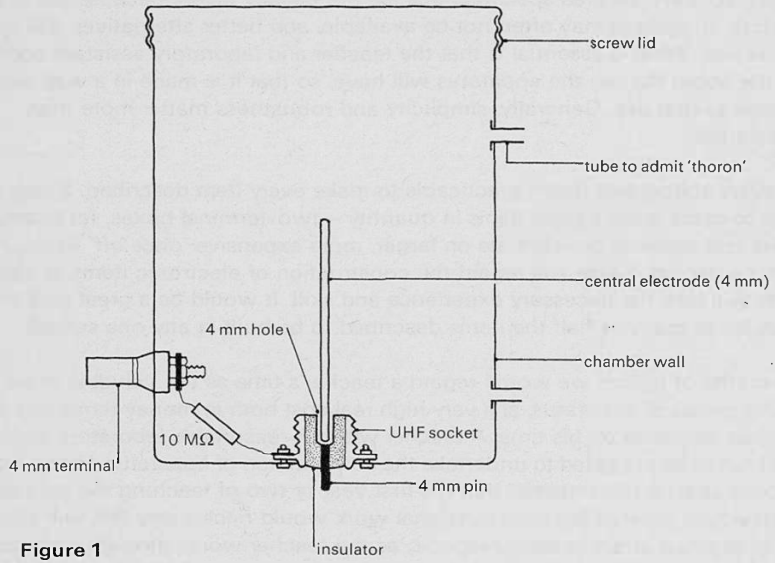


Figure 1
Item 1008. Ionization chamber.

It is essential that the metal chamber does *not* make contact with the earthed casing of the electrometer input socket. As shown in figure 2, the chamber is to be connected, via a built-in 10 MΩ safety resistor, to an h.t. supply, the other terminal of which is earthed. This mode of connection is essential so that the chamber can be made positive (or negative) with respect to earth. Ions collected by the central electrode then alter its potential, which is indicated by the electrometer.

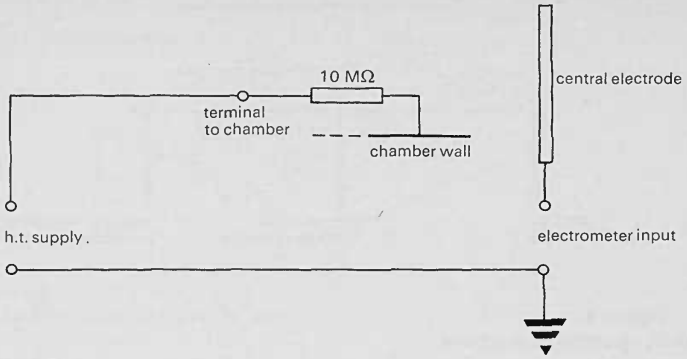


Figure 2
Electrical connections to ionization chamber.

The central electrode can be a brass rod, 4 mm in diameter and about 100 mm long, which plugs directly into the UHF socket mounted in the chamber. An insulated 4 mm terminal, mounted on the chamber wall but not in electrical contact with it, is connected via a 10 MΩ resistor to the chamber wall. Solder tags held by the terminal and one bolt fixing the UHF socket to the chamber make a convenient form of connection for this resistor.

It is best to provide the chamber with two small tubes, so that air carrying a little 'thoron' from the 'thoron' generator (item 1066) can be admitted to the chamber without removing the lid. A solid lid and a gauze lid will be required.

Special items required

From RS Components Limited

UHF socket SO239
Insulated terminal (4 mm)
10 MΩ resistor

1010 Reed switch

quantity 4

The reed switch is a dry-reed magnetic change-over switch. When placed inside a coil (as shown in figure 3), it may be driven by passing a fluctuating current from an oscillator through the coil. If the coil has a diode in series with it, the switch operates at the supply frequency. The circuit is shown in figure 4.

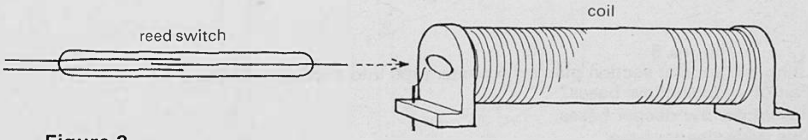


Figure 3
Reed switch and coil.

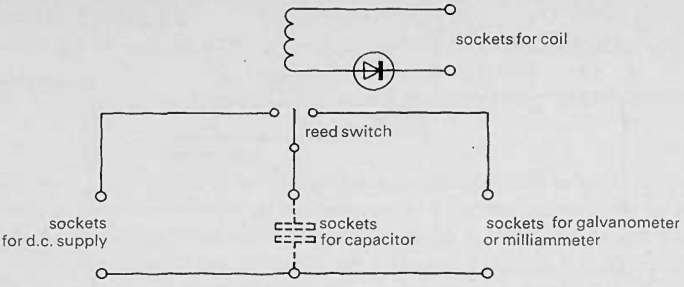


Figure 4
Reed switch, electrical connections.

Reed switch, type 13-RSR-A, from RS Components Limited, is suitable. This switch can carry a maximum current of 500 mA, has a maximum loading of 10 W, a contact resistance not exceeding 0.1 Ω, a resonant frequency greater than 900 Hz, and an open-contact capacitance of 3 pF. 100 ampere-turns are needed to operate it. The RS Components Limited coil type 1, driven by the signal generator, item 1009, will not operate the switch unless additional power amplification is provided. Osmor Limited coil SD3, 175 ampere-turns at 3 V, will operate the reed switch without an amplifier being needed.

The components can be mounted on an insulating base, which can be cut from rectangular section plastic rainwater pipe as shown in figure 5. Insulating bases made in the same way are suitable for items 1017, 1018, 1033, 1034, 1040, 1041, 1047, 1048, 1049, and 1081 and possibly for items 1031, 1035, and 1075. Components are mounted below the upper face of the base, which must be cut deep enough to accommodate the largest component. Figure 5 shows several ways of cutting bases from the pipe. 4 mm sockets are adequate and these are mounted on the upper face, through holes drilled in it, as in figure 6.

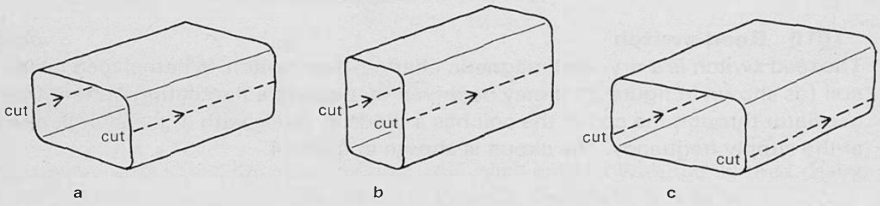


Figure 5
Cutting rectangular section plastic rainwater pipe into insulating bases.
a Pair of wide shallow bases.
b Pair of narrow deeper bases.
c One wide deeper base.

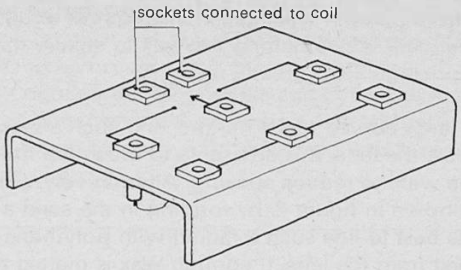


Figure 6
Base showing sockets mounted on upper face.

Special items required

From Osmor Limited

Coil, type SD3, 175 ampere-turns at 3 V

From RS Components Limited

Dry-reed switch type 13-RSR-A
Diode, type IN4001, for example
4 mm insulated sockets *8*

1014 Wax lens

quantity 2

A pair of plano-convex wax lenses, diameter 0.3 m, is required. The radius of curvature of the curved face should be about 0.25 m; thus the lens needs to be about 35 mm thicker at the centre than at the edges.

Each lens can be mounted in a simple wooden frame, as indicated in figure 7. The frame may have recesses cut in it to secure the lens at four places, or four simple chocks can be used, as in figure 7, to hold the lens against a lip on the inside of the frame.

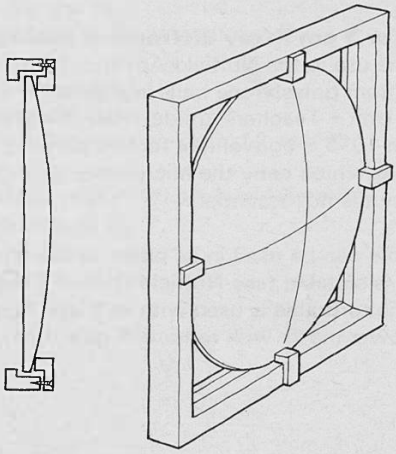


Figure 7
Item 1014. Wax lens.

The lenses are cast from paraffin wax. Each lens requires about 2 kg of wax. It is essential to take great care when melting the wax to ensure that there is no fire hazard. The wax takes a surprisingly long time to melt.

Many schools have large curved metal mirrors, and such a mirror can be used as a mould in which to cast the lens. It is advisable to brush the mirror with cooking oil before pouring in the wax, to reduce sticking. Alternatively, a mould can be made in a tray of fine sand as shown in figure 8, by rotating in the sand a template cut to a circle of radius 0.25 m. It is best to line such a mould with polythene sheet, which can afterwards be stripped from the lens. If enough wax is melted to form the lens in one casting, there is no need to press the polythene sheet into the mould beforehand, the weight of wax being sufficient by itself. It is likely that the curved wax surface will have minor irregularities which need to be filled with a little more wax after casting, or may need to be scraped away.

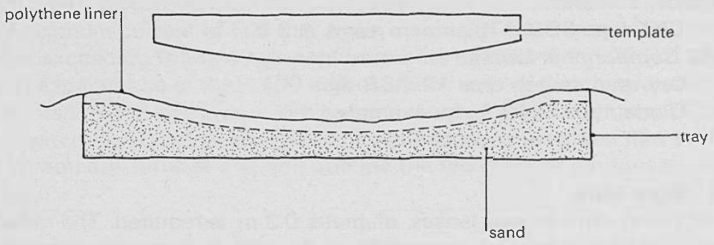


Figure 8
Sand mould for wax lens.

Wax contracts when it solidifies. To achieve a plane surface on the upper side of the casting, one or two further pourings of wax are needed to fill the hollow when the wax solidifies.

1015 Turntable for 3 cm X-ray diffraction analogue *quantity* 1

Item 1015 has only one use in the Nuffield Advanced Physics Course, that of rotating a model crystal made from polystyrene balls in a beam of microwaves, to simulate X-ray diffraction. See Unit 1 Teachers' guide, *Materials and structure,* experiment 1.4, for further details. Item 1015 is convenient for this purpose, as it has an angle scale and means of attaching rods which carry the microwave transmitter and receiver and keep them aligned, but it is not essential.

A gramophone turntable can be used in its place, or the Nuffield O-level Physics turntable, item 154/1, is suitable (see Nuffield O-level Physics, *Guide to apparatus*). For this application, the turntable is used with its plane horizontal, and is driven by the fractional horse power motor with reduction gear, item 150.

1017 Resistance substitution box

quantity 8

The resistance substitution box is a box which enables resistors covering a range from about 10 Ω to 10 MΩ to be brought into circuit. The circuit shown in figure 9 provides a satisfactory box, though fewer components can cover the range if more complex switching is employed. Twelve values covering a rather smaller range (say 100 Ω to 1 MΩ) would be enough for many purposes, and would require only one multiway switch and no range switch.

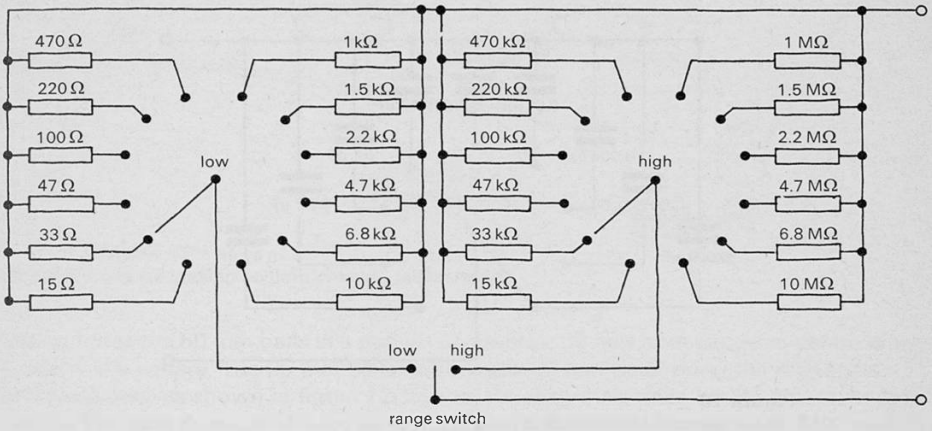


Figure 9
Item 1017. Resistance substitution box circuit.

In figure 9, the two multiway switches can be simple one-pole multiway wafer switches, and the range switch can be a slide switch.

The insulating base to carry the switches and components may be cut from rectangular section plastic rainwater pipe, as shown in figure 5.

Special items required

From RS Components Limited

Miniature wafer switches, one-pole, 12-way *2*
Slide switch
Resistors, moulded carbon, 10 per cent tolerance, $\frac{1}{2}$ W (see figure 9 for values)
4 mm insulated sockets *2*

1018 Capacitance substitution box *quantity* 4

The capitance substitution box is a box which enables capacitors covering the range roughly from 1000 pF or less to 0.22 μF or more to be brought into circuit. The circuit shown in figure 10 provides a satisfactory box, though fewer components can be used if more complex switching is employed.

In figure 10, the switch can be a simple one-pole multiway wafer switch. The capacitors can be of the 600 V working mixed-dielectric type.

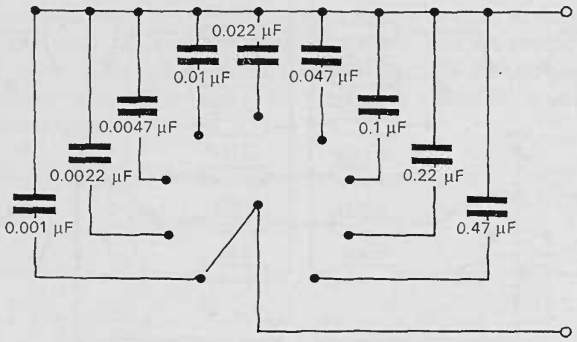


Figure 10
Item 1018. Capacitance substitution box circuit.

The insulating base to carry the switch and components may be cut from rectangular section plastic rainwater pipe, as shown in figure 5.

Special items required

From RS Components Limited

Mixed-dielectric capacitors (see figure 10 for values)
Miniature wafer switch, one-pole, 12-way
4 mm insulated sockets *2*

1022 Jig for making sodium chloride lattice model *quantity* 1

The jig, shown in figure 11, is a sheet of metal drilled with fifteen 43.5 mm diameter holes, intended to keep fifteen 50 mm diameter expanded polystyrene balls in place while smaller, 25 mm diameter balls are glued in place in their interstices. Constructional details for the model are given in Unit 1 Teachers' guide, *Materials and structure,* appendix B.

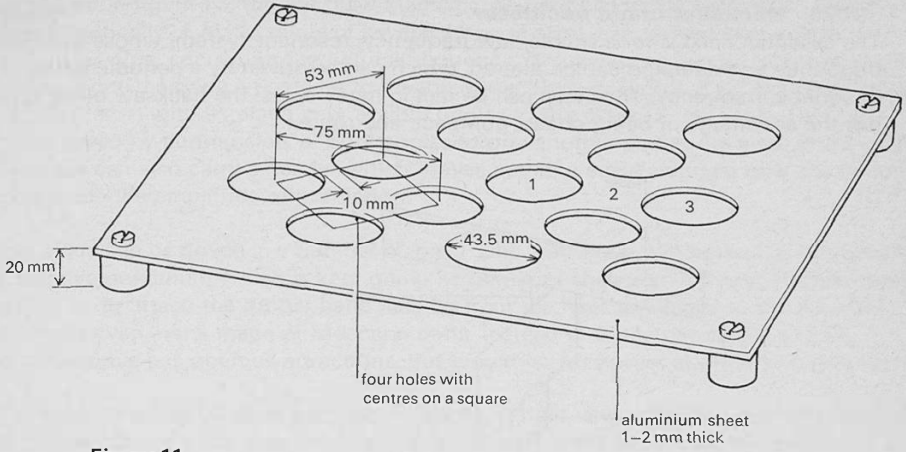


Figure 11
Item 1022. Jig for making sodium chloride lattice model.

The jig holds the 50 mm balls in a pattern of squares, 53 mm from centre to centre along a side of the square. The 25 mm balls fit between 50 mm balls along the diagonals of the squares, as shown in figure 12, so that the diagonals must be 75 mm, centre to centre. The hole diameter is such as to support the 50 mm balls with their centres a distance above the surface of the jig equal to the radius of the small, 25 mm balls, so that these small balls rest on the jig in position while the glue fixing them in place is drying.

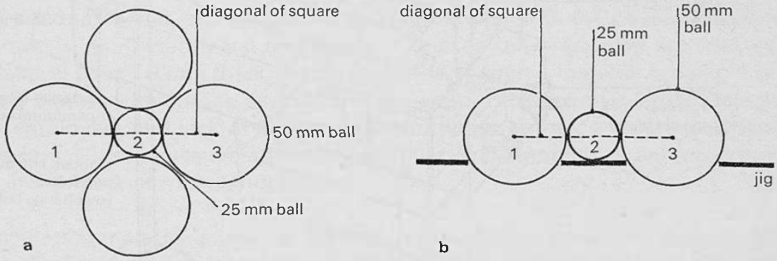


Figure 12
50 mm balls in a square pattern enclosing 25 mm balls.

Because the large balls project a little below the jig, it needs to be supported above the bench on feet about 20 mm high. Aluminium sheet about 1 to 2 mm thick is a suitable material for the jig, and holes can fairly easily be cut in it using a brace and a hole cutting tool.

1024 Hacksaw blade oscillator

quantity 8

The essential need is for a simple, low frequency, resonant system, whose natural frequency and damping can be altered, which can be driven by a periodic force of variable frequency. This need can be met in many ways: the hacksaw blade system has the advantage of being cheap, compact, and robust.

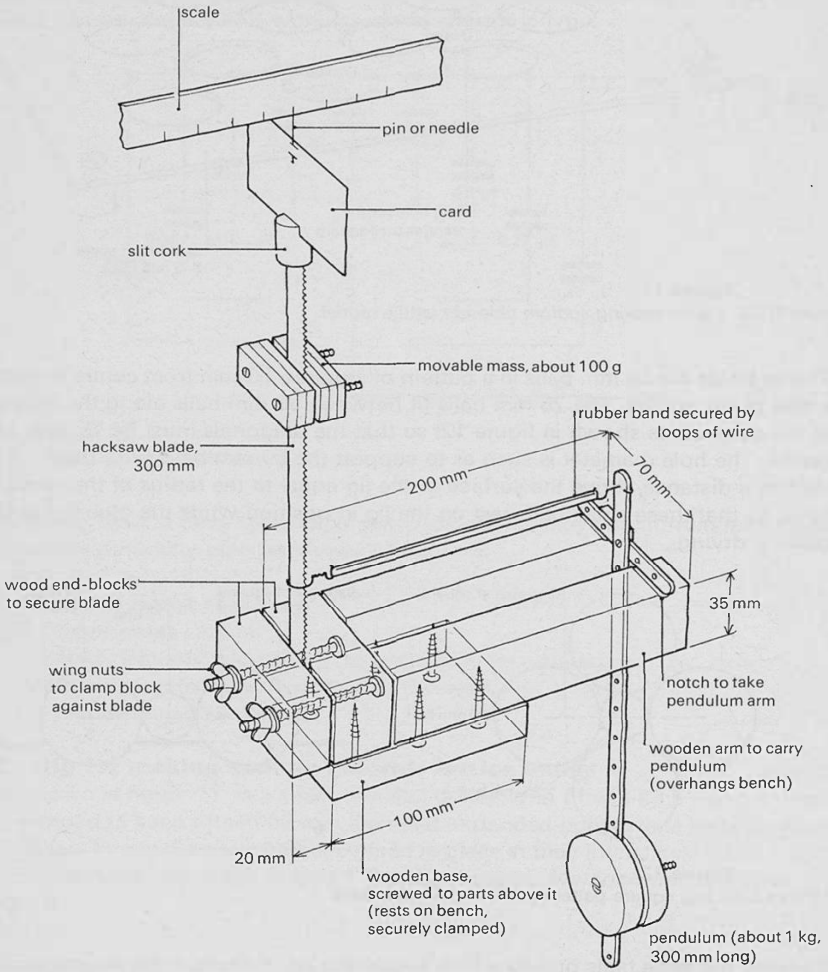


Figure 13
Item 1024. Hacksaw blade oscillator.

As shown in figure 13, the hacksaw blade can be clamped at the bottom, so that it stands vertically. A mass, made of several strips of steel, can be clamped to it at various heights, so varying the natural frequency. The damping can be changed by adding a cork carrying a postcard to the top of the blade in such a way that the postcard can be placed with its plane in or at right angles to the plane of vibration. This can be achieved by cutting slots at right angles to one another across the ends of the cork. The card can also carry a needle which moves across a scale clamped over the bench, to indicate the amplitude of oscillation.

The blade can be driven in a number of ways. One way, shown in figure 13, is to employ a massive pendulum which is kept going by gentle pushes from a finger. Another way would be to attach the rubber band leading from the hacksaw blade to the drive to a hand-driven crank made of Meccano parts, instead of to the pendulum shown. A motor drive has obvious attractions, but would be expensive to provide in quantity.

The base, to which all parts are fixed, needs to be rigid, and able to be clamped securely to the bench. If a pendulum drive is employed, part of the base must overhang the bench.

1025 Pair of capacitor plates *quantity* 2 pairs

The capacitor plates supplied by a manufacturer, as shown in figure 51, page 172, of the *Teachers' handbook,* are made of sheets of aluminium alloy, some 5 mm thick and 250 mm square. Such material is not easy to obtain, but if it can be obtained more cheaply than the ready-made plates, it is the best material to use. 4 mm holes to accept 4 mm plugs can be drilled in the edges of the plates, the thickness of which ensures that they will remain flat in normal use.

The difficulty of finding an alternative lies first in finding a material which will remain adequately flat, and second, in making contact with the conducting surfaces. Hardboard is insufficiently flat and stable. A thicker, but ungrained material, such as chipboard at least 10 mm thick, is more suitable. If such a material is used, it is best to have the plates rather larger, say 500 mm square or more, so that larger plate spacings can be employed, and lack of flatness or smoothness of the conducting surfaces matters less. Glass plates are admirably stiff, flat, and smooth but are too brittle for the rough and tumble of most laboratories.

If an insulating material is used as the basis of the plates, it requires a conducting surface. This can either be Aquadag painted on it, or a smooth layer of new aluminium cooking foil pasted carefully over the surface. In neither case is it easy to provide simple, robust, and reliable electrical connections which do not project into the space between the conducting surfaces. One solution is to carry part of the conducting surface onto the back of each plate, and to make contact with it via a metal strip fixed to the plate, which presses against the conductor, as in figure 14. The metal strip can be secured by and electrically connected to a 4 mm socket.

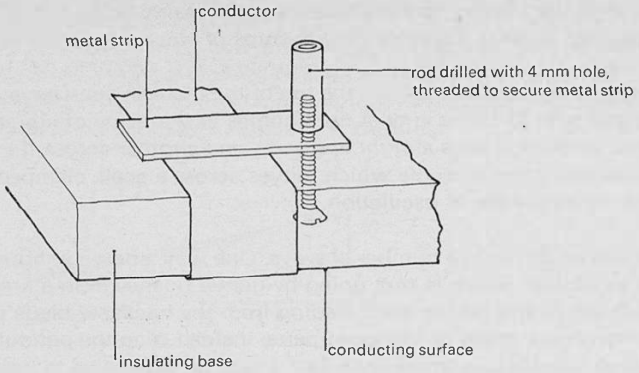


Figure 14
Detail of one method of making a connection to a conducting surface on an insulating base.

1029 Hall voltage apparatus for metals

quantity 1

Given suitable workshop facilities for accurate drilling and hole cutting, the apparatus is not hard to make. Figure 15 shows the main parts.

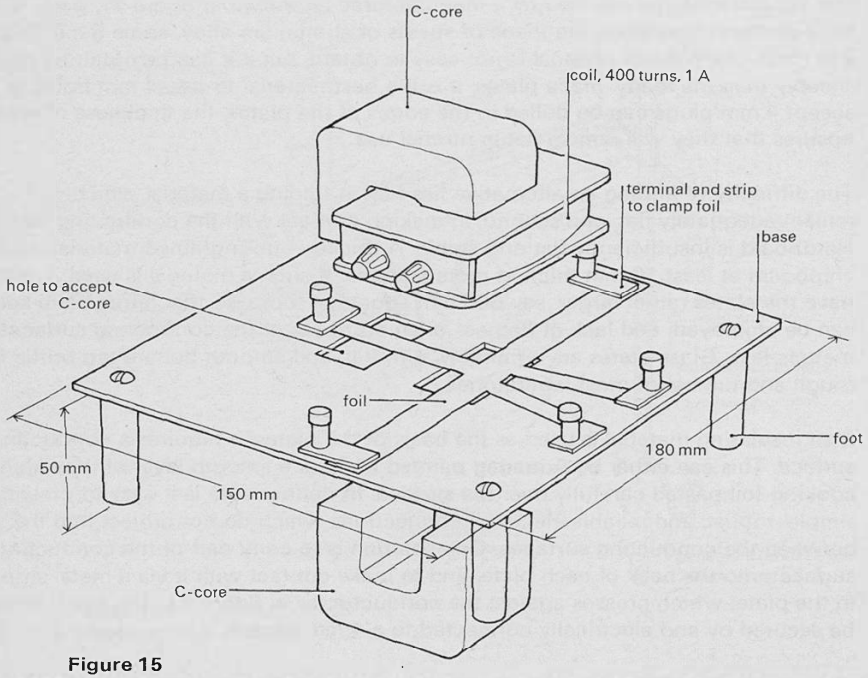


Figure 15
Item 1029. Hall voltage apparatus for metals. (*Not shown:* clip to hold C-cores in place; polythene sheets between which the foil strip is sandwiched.)

A strip of foil 10 mm wide passes between two faces of a pair of C-cores, around which there is a coil to provide magnetic flux across the foil. The foil carries about 5 A. Three narrower strips (these and the current-carrying strip are all cut in one piece from a sheet of foil) lead from the region of the foil strip between the C-cores, so that the Hall voltage across the specimen may be picked up. There are two such narrow strips on one side so that any misalignment of the strips on opposite sides of the current-carrying strip, leading to an ohmic potential difference as well as to a Hall voltage, can be compensated for. Fuller details of the procedure appear in the *Students' laboratory book*.

The foil can be laid out on a base about 150 mm by 180 mm, carrying metal strips which can be screwed down over the five ends of the foil strips, so securing and making electrical contact with them. It is convenient if the means of holding down the metal contacts incorporates 4 mm sockets so that leads may quickly be brought to each contact.

One of the C-cores goes above the base, and the other below, the base having apertures cut in it so that the C-cores are separated only by the foil going between them, and by two layers of thin polythene above and below the foil which insulate it from the cores. The base requires feet about 50 mm tall so that one core can fit under it, and a spring clip (not in figure 15) to press the upper core firmly onto the lower one.

1031 200 kHz pulse generator *quantity* 1

The circuit is shown in figure 16. It is easily constructed on a small piece of printed circuit board (Veroboard, 0.15 inch pitch), later to be mounted in a metal box such

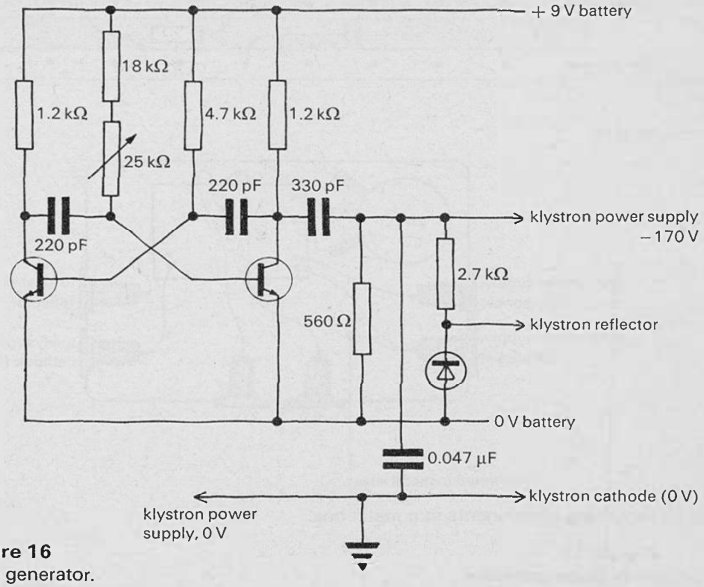
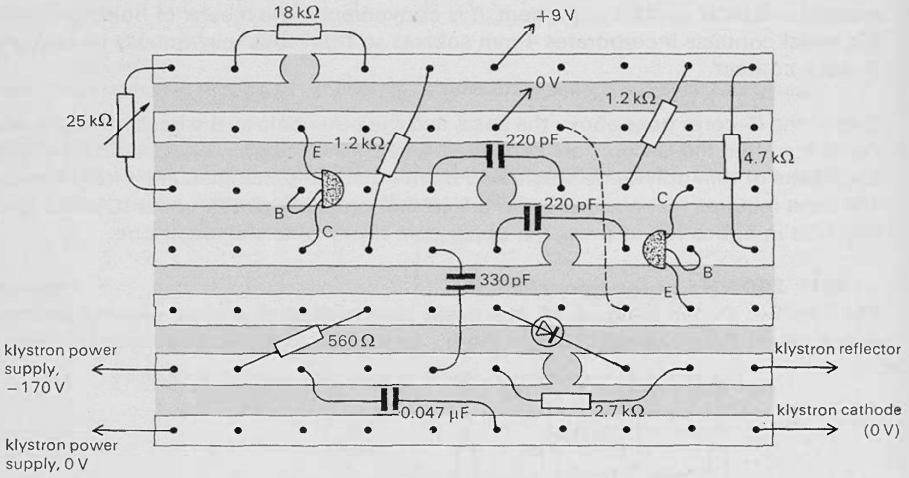


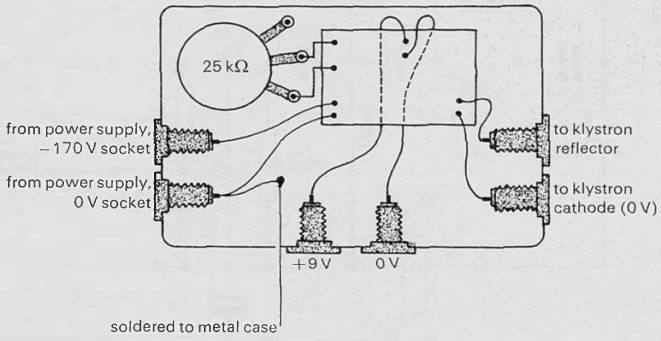
Figure 16
Circuit of pulse generator.

as a rectangular tobacco tin. Figure 17 *a* shows a plan for mounting the components on the copper-strip side of the Veroboard. The necessary gaps in the copper strips are made with the tip of a 3/16 inch drill.

All components except the 25 kΩ potentiometer should be soldered in, working systematically from left to right, or from back to front. When soldering a component in position, remember that others have to be mounted near it and that space must be left for them. The wire dotted in figure 17 *a* goes underneath the board (that is, on the plain side) and should be connected first. The battery connections and the leads to the klystron power supply and klystron transmitter are 100 mm lengths of insulated wire. Any silicon n-p-n transistor designed for high speed switching should be



a Veroboard plan.



b Plan for mounting components in a metal box.

Figure 17
Construction of pulse generator.

suitable. Those used in prototype versions of this circuit were type 2N3904. Figure 17 *b* shows how the printed circuit board is mounted in the tobacco tin. Holes are drilled in the sides of the tin in order to mount six insulated 4 mm sockets. A hole is required in the base of the tin for the 25 kΩ potentiometer, from which the Veroboard is supported by very short lengths of 20 s.w.g. copper wire forming the connections to the potentiometer. The insulated wires from the Veroboard are then trimmed to the correct length and soldered to the appropriate sockets. Note the connection to the klystron power supply 0 V outlet. The circuit requires a 9 V d.c. supply.

Special items required

From RS Components Limited

Resistors, moulded carbon, $\frac{1}{2}$ W: two of 1.2 kΩ, and one of each of 560 Ω, 2.7 kΩ, 4.7 kΩ, and 18 kΩ
Capacitors, silvered mica or polystyrene, two of 220 pF, and one of 330 pF
Capacitor, miniature polyester, 0.047 μF
Potentiometer, midget carbon, less switch, linear track, 25 kΩ
Round control knob for potentiometer
Diode, 1GP5 or IN914
Stripboard type A (0.15 inch pitch)
4 mm insulated sockets *6*

From suppliers advertising in Wireless world, Practical electronics, *etc.*

Transistor, n-p-n silicon, 2N3904 *2*

Local purchase

Small metal box, e.g. rectangular '2 ounce' tobacco tin

1033 Cell holder *quantity* 16

The cell holder is required to hold four U2 dry cells connected in series in such a way that connections can be made via 4 mm plugs to one, two, three, or four cells.

There are many ways of making such a holder, two of which are shown in figure 18. Both those shown have the cells in a shallow box, which can be constructed of hardboard with thicker wooden end-pieces. Connections to the cells may be made by metal contact plates, either connected to 4 mm sockets, or having tags rolled over to form 4 mm sockets, as in figure 18 *a*.

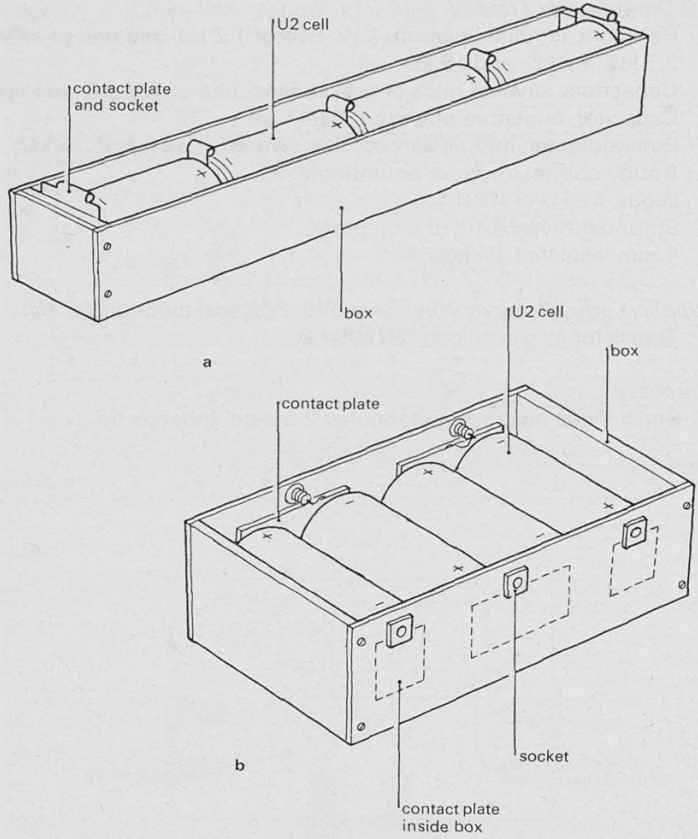


Figure 18
Item 1033. Cell holder: two possible forms.

Other possibilities include Terry clips mounted on a baseboard, separated by contact strips connected to 4 mm sockets. All methods require some means of holding the cells firmly in contact with each other and with the connections to them. One means of doing this is to pack foam plastic in the cell holder; another is to provide suitable springs in the holder.

1034 Large electrolytic capacitor

quantity 2

A substantial saving can be achieved by making up this item from a capacitor bought as a component. A single-ended can-type 10 000 μF capacitor is required, which is mounted with its contacts downwards on a suitable insulating base. Stiff wires soldered to the tags on the capacitor and taken through a hole cut in the base to a pair of 4 mm sockets mounted on the base, as in figure 19, may be adequate to secure the capacitor, but a fixing clip is recommended.

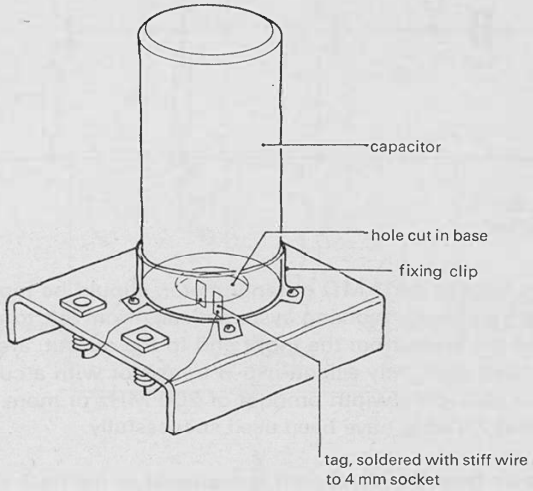


Figure 19
Item 1034. Large electrolytic capacitor, mounted on an insulating base.

The base can be cut from rectangular section plastic rainwater pipe, as shown in figure 5, page 8. For greater protection of the capacitor, it may be better still to mount it inside a length of the pipe, holding it in place with foam plastic.

Special items required

From RS Components Limited

Single-ended capacitor, can, 10 000 μF, 30 V
Fixing clip, 44.5 mm diameter, vertical
4 mm insulated sockets *2*

1035 Pre-amplifier *quantity* 2

A circuit which has been found suitable is shown in figure 20. It can be constructed on a small piece of printed circuit board (Veroboard, 0.15 inch pitch) later to be mounted in a metal box such as a rectangular tobacco tin. Figure 21 *a* shows a wiring plan for the printed circuit board. The necessary gaps in the copper strips are made with the tip of a 3/16 inch drill.

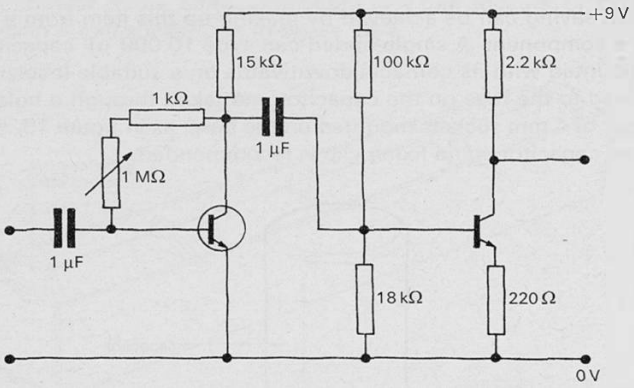
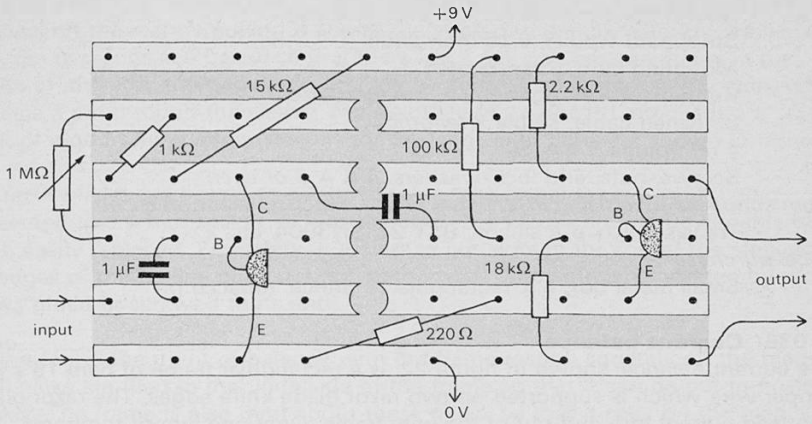


Figure 20
Circuit of pre-amplifier.

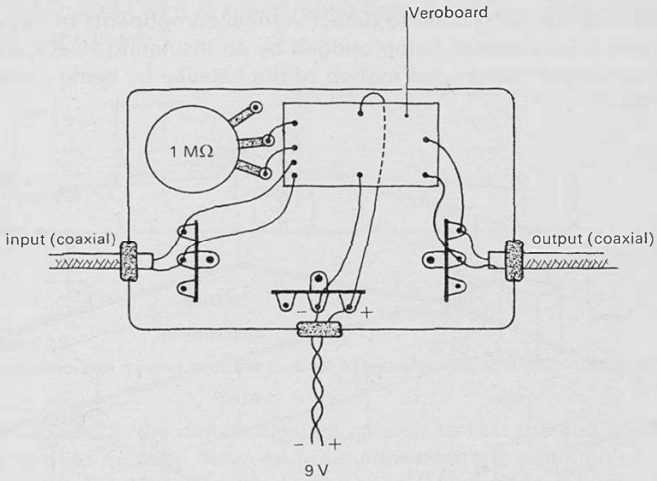
All components, except the 1 MΩ potentiometer, should be mounted on the copper-strip side of the Veroboard, working systematically from left to right. The battery connections and the leads from the input and to the output, are 100 mm lengths of insulated wire. Any silicon n-p-n transistor with a current gain of 50 or greater, and a gain–bandwidth product of 200 MHz or more, should be suitable. Types BSY 27 and 2N3904 have been used successfully.

Figure 21 *b* shows how the Veroboard is mounted in the base of the tobacco tin. Holes will have to be drilled in the sides of the tin to mount three small rubber grommets for the input, output, and battery leads. Holes in the base of the tin are needed for the 1 MΩ potentiometer and for three 4 B.A screws, each to secure a three-tagged mounting strip. The mounting strips should be screwed in place and then soldered to the base of the tin. It is advisable to use screened cable for the input and output leads, the screen being connected to the tag soldered to the tin. The inner conductors are connected to insulated tags on the appropriate mounting strip. The negative battery lead is also connected to the tin in this way, as shown in figure 21 *b*. All leads may be terminated at the free ends with 4 mm plugs.

Finally, the Veroboard is supported by very short lengths of 20 s.w.g. copper wire forming the connections to the 1 MΩ potentiometer, the insulated wires being trimmed to the correct length and soldered to the appropriate tags (see figure 21 *b*). A 9 V d.c. supply is required.



a Veroboard plan.



b Plan for mounting components in a small metal box.

Figure 21
Construction of pre-amplifier.

Special items required

From RS Components Limited

Resistors, moulded carbon, $\frac{1}{2}$ W, one of each of 220 Ω, 1 kΩ, 2.2 kΩ, 15 kΩ, 18 kΩ, and 100 kΩ
Capacitors, miniature moulded polyester, 230 V, 1 µF *2*
Potentiometer, midget carbon, less switch, linear track, 1 MΩ

Round control knob for the potentiometer
Stripboard type A, 0.15 inch pitch
Mounting strip, three-tagged *3*
Rubber (or PVC) grommets, smallest size *3*
Screened cable, single *2 lengths*
4 mm plugs *6*
Screws, nuts, and lock-washers, 4 B.A *3 of each*

From suppliers advertising in Wireless world, Practical electronics, *etc.*

Transistors, n-p-n silicon, BSY 27, 2N3904, etc. *2*

Local purchase

Small metal box, e.g. rectangular '2 ounce' tobacco tin

1036 Current balance *quantity* 2

The current balance, shown in figure 22, is a rectangular frame of bare 16 s.w.g. copper wire which is supported on two razor blade knife edges. The razor blades also lead current into and out of the wire frame. Only one arm of the frame parallel to the line joining the knife edges is electrically complete and carries current, the balance being used to detect vertical components of forces on this arm. The other arm is incomplete, being bridged by an insulating sleeve which carries a pin, this serving to restrain the motion of the balance by being passed through a slot in a stop.

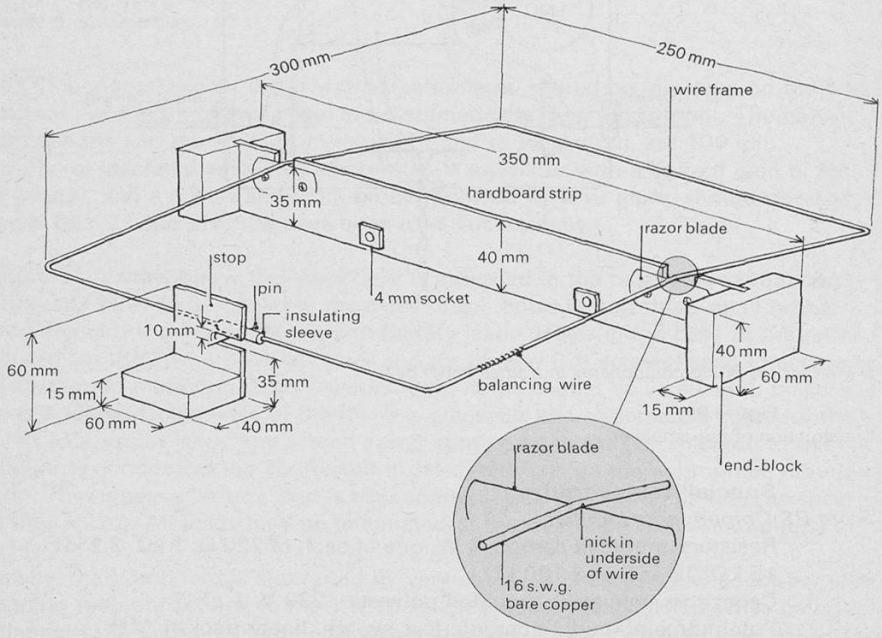


Figure 22
Item 1036. Current balance.

The frame itself is made from 16 s.w.g. copper wire which has been straightened as it comes off the reel by pulling it across the edge of a bench. After the frame is bent, the two ends can be cut so that there is a 5 mm gap between them in the middle of one arm, the gap being bridged by an insulating sleeve. The stop, which restrains a pin through the sleeve, can be made of hardboard attached to a small block of wood. Suitable dimensions for this and other parts are shown in figure 22.

The razor blades are bolted to a 40 mm wide strip of hardboard, each being connected to a 4 mm socket let into the strip. The blades should be capable of being easily replaced. For safety, it is best to cut slots in the top of the strip, so that the edges of the blades need not project above it. The strip is supported by wooden blocks glued or screwed to its ends.

Having found the point of balance with the frame resting squarely on the blades, small nicks are filed in the underside of the frame so that it can be put in position quickly. The frame is also bent about these nicks, so that it rests on the blades in stable equilibrium with its arms some 5 mm below the level of the blades. A small length of thinner copper wire wrapped round one of the larger arms of the beam can be used to balance the beam.

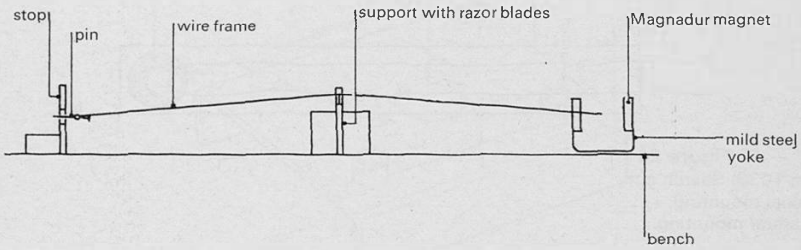


Figure 23
Balance supported so that its end is at the level of Magnadur magnets on a mild steel yoke.

As shown in figure 23, the dimensions are chosen so that the arm of the frame carrying current lies midway between Magnadur magnets mounted on mild steel yokes (items 92 B and 92 I) when these and the frame support rest on a flat bench.

1039 Search coil *quantity* 4 axial, 4 lateral

The 5000-turn search coils suggested in the *Teachers' handbook* for this item can be used for all the experiments suggested, often at a frequency of only 50 Hz, and without using a pre-amplifier in addition to an oscilloscope to detect the alternating p.d. across the coil. Such coils are not easy to make, though it might not be very difficult to wind many turns of 48 s.w.g. enamelled copper wire onto a plastic sewing machine bobbin, using the device provided on a sewing machine for winding thread onto the bobbins.

Small coils with fewer turns can be found ready-made as IF transformer coils for radio sets. A suitable coil would be 10 to 20 mm in diameter, and have several hundred turns. Such coils would serve for many of the experiments suggested, and would be suitable for all experiments if the field to be detected alternates at 10 kHz and a pre-amplifier is available.

Two coil mountings are desirable, as shown in figure 24 *a* and *b*. In one, the axial mounting, the coil is fixed with its axis along a rod which also carries leads to the coil. In the other, lateral mounting, the coil is let into a long strip so that its axis is perpendicular to the plane of the strip.

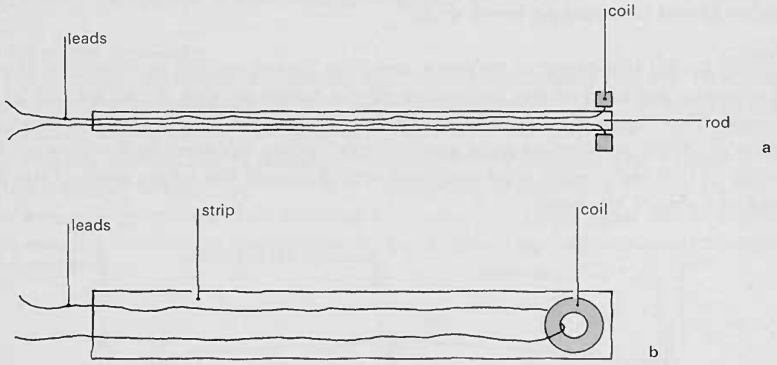


Figure 24
Item 1039. Search coil.
a Axial mounting.
b Lateral mounting.

1040 Clip component holder

quantity 8 or more

This holder makes it easy to connect wire-ended components into circuits which use 4 mm plug and socket connections elsewhere. Figure 25 shows a version of the holder.

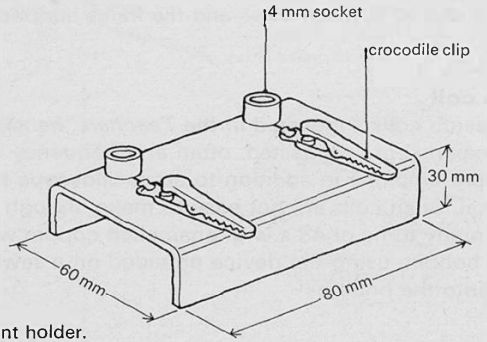


Figure 25
Item 1040. Clip component holder.

It can consist of a pair of crocodile clips bolted to the upper face of an insulating base, and connected to 4 mm insulated sockets let into the base. It is important to secure the clips very firmly. The base can be cut from rectangular section plastic rainwater pipe, as shown in figure 5, page 8.

1041 Potentiometer holder *quantity* 16

The holder is intended to take a radio component potentiometer. Where the right values are available, a preset control is the most convenient, but the most useful value, 5 kΩ, may not be available in this form, and it may be necessary to use a wire-wound control or a midget carbon track control. Consult the catalogue of RS Components Limited for up to date information.

The holder is simply a base, drilled to take the potentiometer, and provided with four 4 mm sockets. The base may be cut from rectangular section plastic rainwater pipe, as shown in figure 5, page 8. Figure 26 shows the base, less potentiometer, and figure 27 shows the circuit.

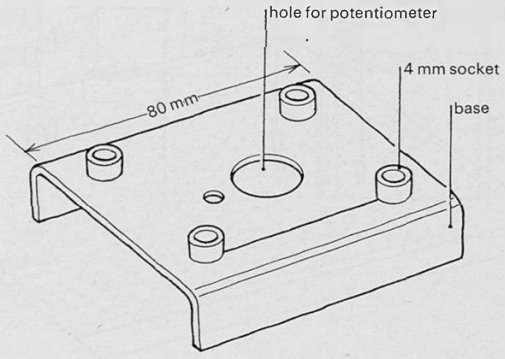


Figure 26
Item 1041. Potentiometer holder.

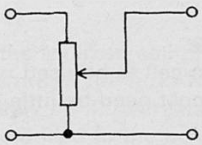


Figure 27
Circuit for potentiometer.

1042 Magnetic field board *quantity* 4

The magnetic field board is a board onto which coils of plastic covered wire (item 92X) can easily be wound in a variety of forms and with varying numbers of turns. This is most readily achieved by making the board of perforated hardboard (pegboard) or by using other similar perforated board such as that available for sound insulating panels. The wire is wound round pegs inserted into the holes. These may simply be dowels, golf tees, or other suitable pegs such as those sold for fixing notices to pegboard panels. About two dozen pegs are needed for each board.

The whole board, shown in figure 28, must be made of non-ferromagnetic material, including all screws. It should be 0.3 m to 0.5 m square. If pegboard is used, it will be necessary to provide a frame to lift the board off the bench, so that pegs can be inserted into the holes.

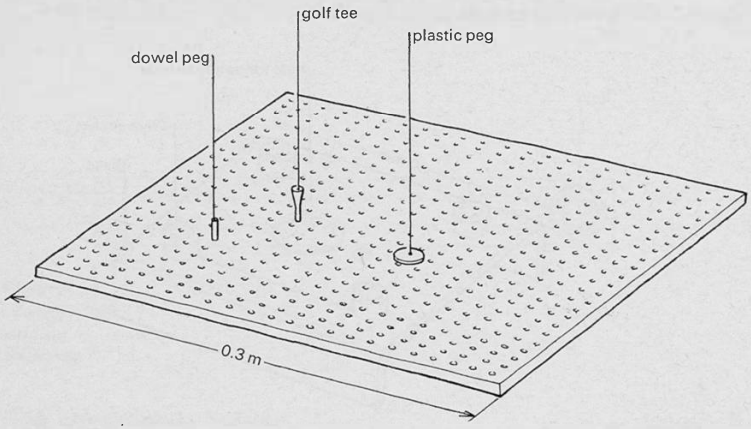


Figure 28
Item 1042. Magnetic field board. See also *Teachers' handbook*, figure 64, page 183.

1043 Millikan apparatus *quantity* 1

The construction of a Millikan cell to be used with an existing microscope is not particularly difficult, and the cost need be little greater than that of a suitable objective for the microscope.

The cell shown in figure 29 is in the form of a rectangular box made of insulating material, with its back resting on the microscope stage, which must be vertical. To achieve this with most microscopes, a support is needed to which the microscope is bolted. Such a support is shown in the *Teachers' handbook*, figure 65, page 184. To stop the cell slipping, it has a rough rubber backing (see figure 29 *b*) and is held onto the stage by stout rubber bands.

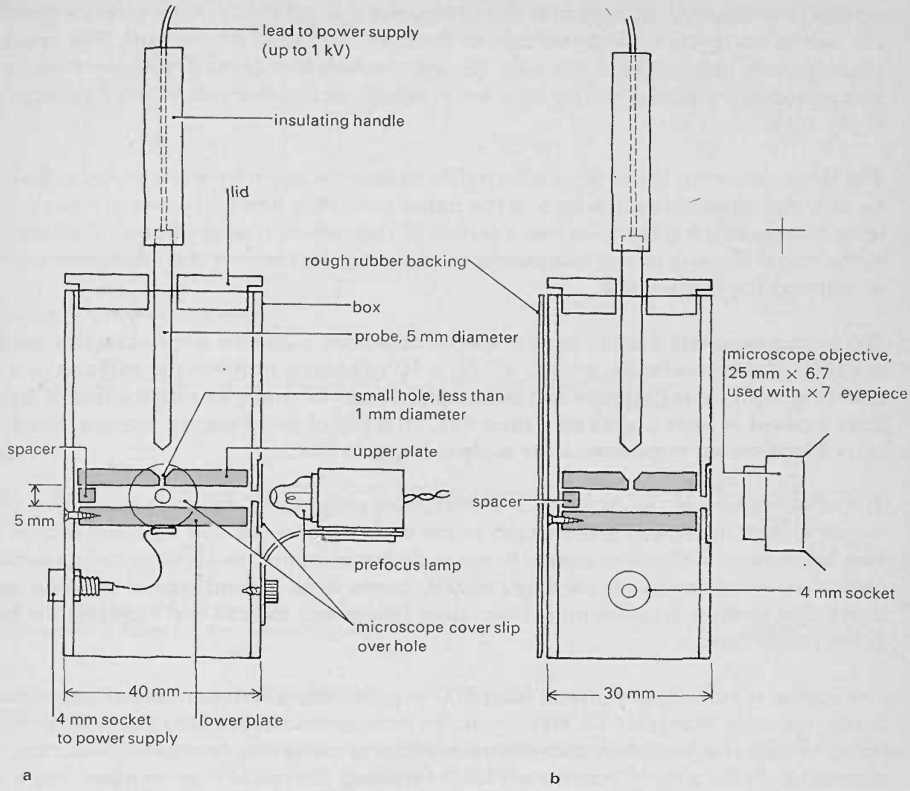


Figure 29
Item 1043. Millikan cell.
a Front view.
b Side view.

The two metal plates which form the Millikan cell proper, cut from metal plate about 5 mm thick, are mounted in the centre of the box. The lower plate is bolted into the box, while the upper plate rests freely on it, over spacers about 5 mm thick cut from Perspex. Two 4 mm holes are drilled in the box at the level of the space between the plates, at right angles to one another. Both are covered with microscope cover slips glued over them. A prefocus lamp shines through one hole, being mounted on an arm so that the lamp actually touches the glass slip over the hole. The microscope is directed at the other hole.

A fine hole (less than 1 mm diameter) is drilled in the upper plate, countersunk on the top surface. Contact with this plate is made by a metal probe with a bevelled tip which enters the cell through a hole in its lid. Lowering the probe at once pumps

oil drops, previously sprayed into the space over the top plate, into the space between the plates, connects the high voltage to the plate, and seals off the hole. The upper plate is made removable so it is easy to clear the hole in it of oil. The lower plate is connected to the power supply by a 4 mm socket let into the side of the box, as in figure 29 *a*.

The lamp mounting needs to be adjustable, so that the beam from the prefocus bulb can be shone directly below the hole in the upper plate. It is helpful to over-run the lamp somewhat. A needle, let into a length of rod, which passes through the hole in the upper plate, is useful as a means of adjusting the focus of the microscope, and of aligning the illumination.

The microscope will usually need a special objective, a 25 mm $\times$6.7 objective being suitable. The eyepiece, for which $\times$7 or $\times$10 will serve, requires the addition of a graticule. A suitable graticule can be bought, or can be made by ruling a pair of parallel lines crossed at right angles by a third line, on a slip of thin Perspex, using a sharp razor blade drawn once across the surface for each line.

The effectiveness of the oil spray is important. A good spray will emit a fine haze of droplets, with no drops large enough to see with the unaided eye. Apiezon A oil is very suitable. A metal tube some 10 mm in diameter and up to 100 mm long, bent if necessary and placed over the spray nozzle, seems to be a good way of trapping large drops that emerge, so preventing them from falling into the cell and clogging the hole in the upper plate.

The power supply should give at least 500 V, preferably 1 kV, and be well smoothed. Safety resistors of at least 10 MΩ should be included in the leads to the cell, to avoid risk of shock. It is important that the microscope is well away from any conductor connected to the supply, particularly bolts retaining the lower plate in place, lest a spark jumps from them to the microscope and thence to the eye.

1047 Kit of two-terminal boxes *quantity* 2 kits

Each kit consists of about eight boxes, each box having two 4 mm sockets, and some simple components concealed underneath.

The boxes may be made up in several ways. One way uses wooden terminal boxes sold for the mounting of mains fittings. Another way is to cut insulating bases from rectangular section plastic rainwater pipe, as shown in figure 5, page 8. The underside of the base can be covered with adhesive, opaque PVC tape, if required.

Figure 30 shows the boxes, while figure 31 gives some suitable circuits for their contents.

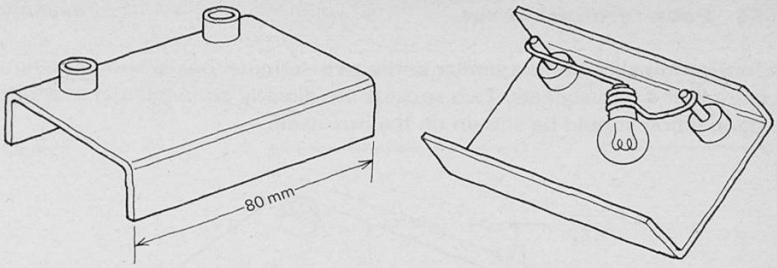


Figure 30
Item 1047. Two-terminal boxes.

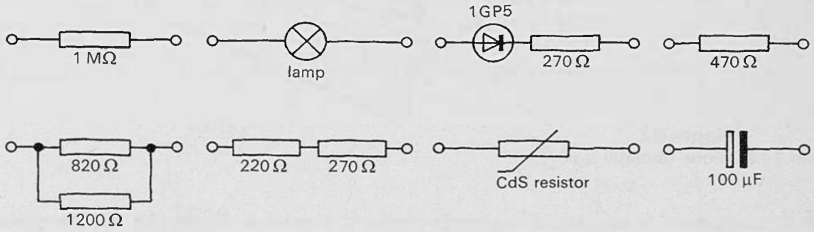


Figure 31
Suggested circuits for two-terminal boxes.

Special items required

From RS Components Limited

Resistors, moulded carbon, $\frac{1}{2}$ W, 10 per cent tolerance, two of 270 Ω and one of each of 220 Ω, 470 Ω, 820 Ω, 1.2 kΩ, and 1 MΩ
Diode, 1GP5
Round M.E.S. pilot lamp, 12 V, 0.1 A
Electrolytic capacitor, double-ended, 100 μF, 25 V
4 mm insulated sockets *16*

From suppliers advertising in Wireless world, Practical electronics, *etc.*

CdS resistor

1048 Four-terminal boxes *quantity* kit 1 2 kits
kit 2 2 kits

The four-terminal boxes are similar to the two-terminal boxes shown in figure 30, but carry four 4 mm sockets. Two sockets are directly connected in every box, and this connection should be shown on the box itself.

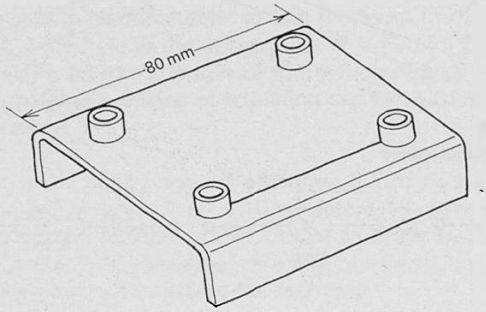


Figure 32
Item 1048. Four-terminal box.

Kit 1 consists of four relatively simple circuits, shown in figure 33. Kit 2 consists of more complex circuits, suggestions for which are given in figure 34.

It is very convenient if every box is labelled permanently with a code letter such as those given in figures 33 and 34. The contents of the boxes should not be visible, but it should be possible to remove whatever conceals the contents to inspect them.

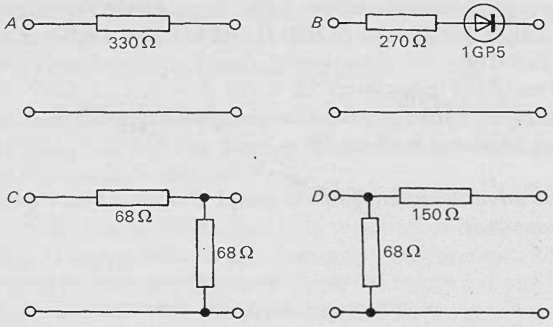


Figure 33
Four-terminal boxes, kit 1. Possible contents of boxes.

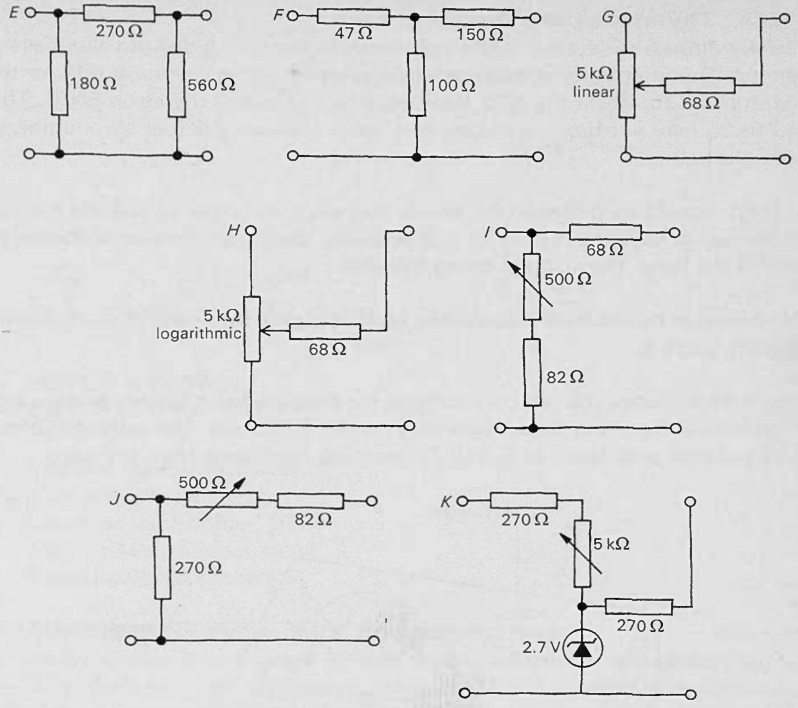


Figure 34
Four-terminal boxes, kit 2. Possible contents of boxes.

Special items required

From RS Components Limited

For kit 1, per kit:
Resistors, moulded carbon, $\frac{1}{2}$ W, 10 % tolerance, 150 Ω, 270 Ω, 330 Ω
Resistors, moulded carbon, 1 W, 10 % tolerance, 68 Ω *3*
Diode 1GP5
4 mm insulated sockets *16*

For kit 2, per kit:
Resistors, moulded carbon, $\frac{1}{2}$ W, 10% tolerance, 47 Ω, 82 Ω, 100 Ω, 150 Ω, 180 Ω, 270 Ω, and 560 Ω
Resistor, moulded carbon, 1 W, 10 % tolerance, 68 Ω *3*
Standard wirewound control, 500 Ω *2*
Midget carbon track control, linear, 5 kΩ *2*
Midget carbon track control, logarithmic 5 kΩ
Zener diode, BZY 88 series, 2.7 V
4 mm insulated sockets *28*

1049 Thyratrons and thyratron base *quantity* 2

The thyratron base carries 4 mm sockets wired to two types of valve base in parallel. The international octal base accepts the argon thyratron 884, or the helium thyratron 6K25, while the B7G base accepts the xenon thyratron EN91. The 884 and 6K25 may not be easy to get, and not a great deal is lost by omitting the octal base altogether.

Sockets should be provided for anode and grid, and pairs of sockets for cathode and for heater, as shown in figure 35 *a*. If possible, the circuit should be shown on the face of the base, the sockets being labelled.

The base can be cut from rectangular section plastic rainwater pipe, as shown in figure 5, page 8.

Figure 35 *b* shows the pin connections for the two valve bases, as seen from the underside of the valve base. Note that on the B7G base, the cathode connection goes to three pins (pins 2, 5, and 7, counting clockwise from the gap).

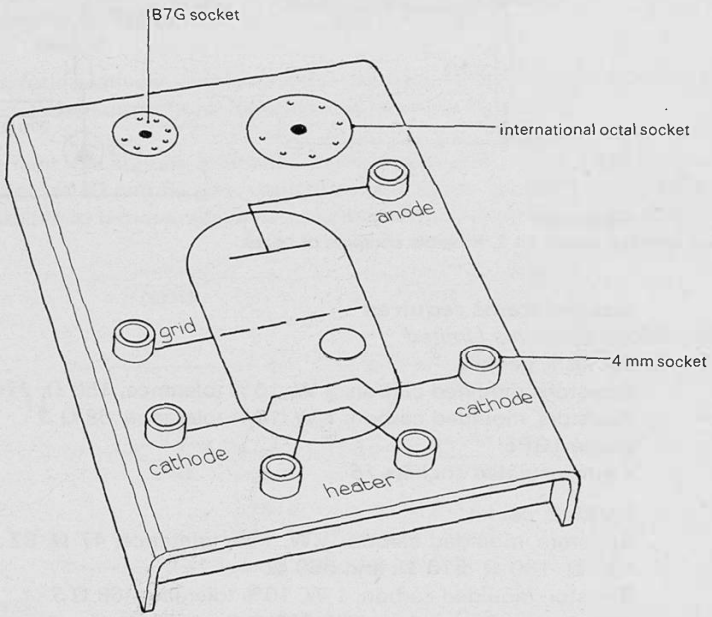


Figure 35
Item 1049. Thyratron base.
a Base and circuit.

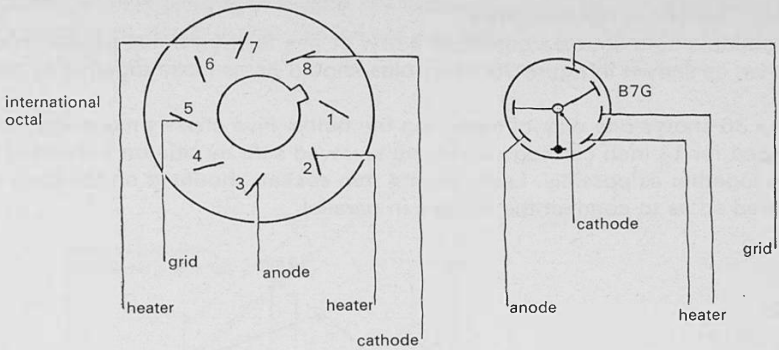


Figure 35 (*continued*)
b Connections to valve base pins, from below.

Special items required

From RS Components Limited

Low-loss valveholder, B7G
Moulded valveholder, octal
4 mm insulated sockets *6*

1052 Absorbers for alpha, beta, and gamma rays *quantity* 1 kit

The kit should consist of a range of 50 mm square samples of absorbing materials for use with radiations from radioactive substances. The following materials and thicknesses make a suitable range. The larger thicknesses could be provided for by having larger numbers of thinner samples.

Lead: 20 mm, 10 mm, 5 mm
Aluminium: 5 mm, 3 mm, 2 mm, 1 mm, kitchen foil, leaf (item 58 A)
Paper: card, writing paper, tissue paper, cigarette paper

The thinner materials could conveniently be mounted in cardboard 35 mm film slide mounts.

1063 Multiple light source *quantity* 1

The multiple light source consists of a row of five festoon bulbs parallel to one another, as shown in figure 36. The bulbs should be as close together as possible.

Figure 36 shows one way of mounting the bulbs. Five chassis mounting holders, intended for $1\frac{1}{4}$ inch cartridge fuses, are screwed side by side on a wooden base, as close together as possible. Leads from 4 mm sockets mounted on the base are soldered so as to connect the holders in parallel.

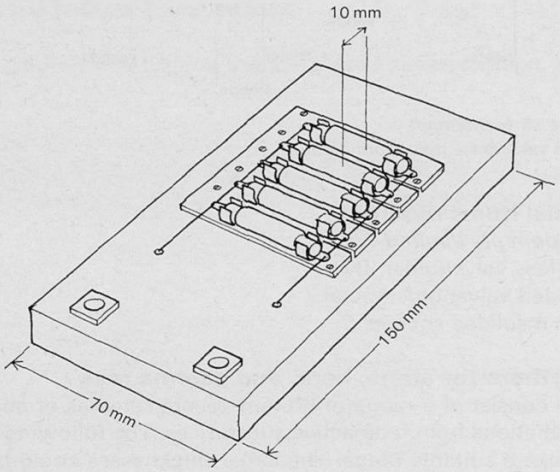


Figure 36
Item 1063. Multiple light source, using cartridge fuse holders.

Special items required

From RS Components Limited

Festoon bulbs, 12 V, 3 W *5*
Chassis mounting holders, single, $1\frac{1}{4}$ inch *5*
4 mm insulated sockets *2*

1065 Big mirror *quantity* 1

The mirror is intended for the reflection of 3 cm microwaves in sufficient quantity to be detected over a considerable distance, in a time of flight determination of the speed of the microwaves.

For this purpose it must be large, and flat. Figure 37 shows one form of construction. The mirror, at least 0.7 m by 1 m, is made of a sheet of plywood about 5 mm thick, coated on one face with conducting material. Metallized plastic film is a very suitable coating, the material sold as Melinex being very good. Aluminium foil of the sort sold as kitchen foil is adequate, but less good; great care must be taken

to stick it down very smoothly. Ideally, the surface should reflect visible light well enough to form an image which can be used in aligning the mirror. In any case, the mirror must not depart from flatness by more than a few millimetres.

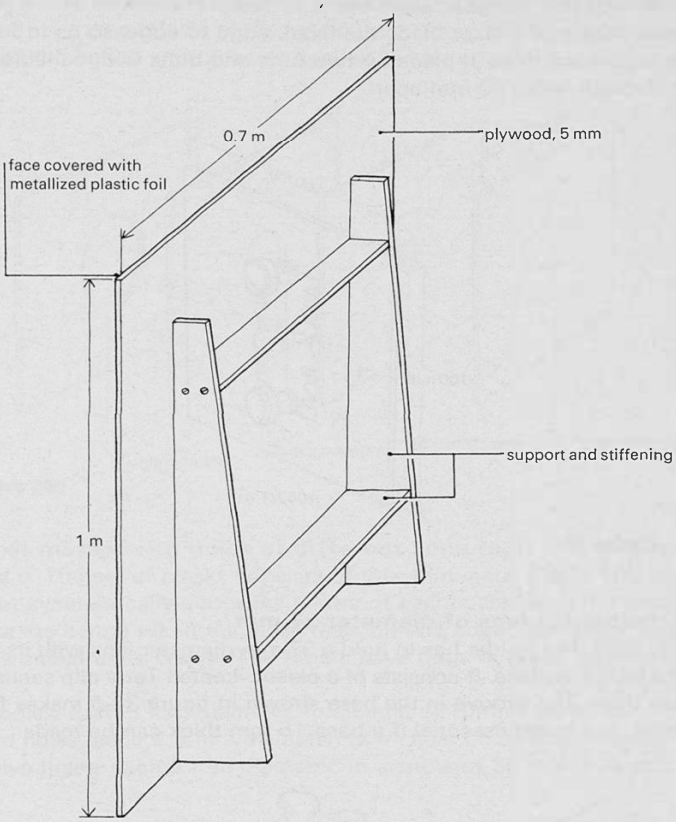


Figure 37
Item 1065. Big mirror.

The plywood sheet needs to be stiffened, as shown in figure 37, so that it remains flat over long periods of time. It is advisable to store it in a dry place.

1067 Physical optics kit *quantity* 1 kit

Some of the parts required for the physical optics kit can be made quite easily in a school, others, including lenses and eyepieces, will have to be bought. For a full list of all items, see the *Teachers' handbook,* pages 201 to 204. Only the parts which can be made or provided in a school are dealt with here.

1067/1 A **sheet with slit and holes** *quantity* 4

See figure 38 *a*. The sheet, 100 mm square, made of thin metal, has four holes drilled in a line across its middle with diameters of 2.0 mm, 1.5 mm, 1.0 mm, and 0.5 mm. A further 7 mm diameter hole is drilled at the centre of the plate, over which two halves of a razor blade are fixed, edge to edge, so as to form a narrow slit. The blades are fixed in place by two nuts and bolts with suitable washers passing through holes 40 mm apart.

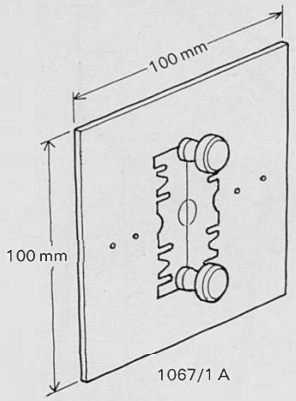


Figure 38a

1067/1 B **holder for lens of diameter 37 mm** *quantity* 8

See figure 38 *b*. The holder has to hold a 37 mm diameter lens with its centre 50 mm above the bench surface. It consists of a plastic-coated Terry clip secured to a wooden base. The groove in the base shown in figure 38 *b* makes for a more rigid fixture, but is not essential if a base 15 mm thick can be made.

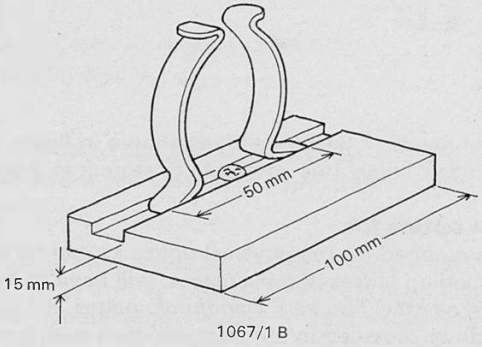


Figure 38b

1067/1 E **set of stops for lens in holder** *quantity* 1 of each

See figure 38 *c*. Four round holes, diameters 30 mm, 20 mm, 10 mm, and 5 mm, are cut at the centres of four thin metal plates, 100 mm square. Each hole should thus be centred on the middle of a 37 mm diameter lens held in the holder (item 1067/1 B) with the middle of the lens 50 mm above the bench, and the stop resting on the bench and propped against the lens.

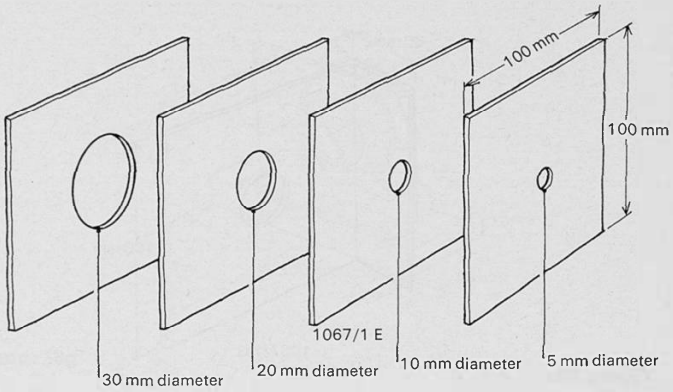


Figure 38c

1067/1 F **set of masks with holes at different zone radii** *quantity* 1 of each

See figure 38 *d*. The set of masks consists of four thin metal plates 100 mm square, with holes cut symmetrically about the centre of each mask, with the centre 50 mm above the bench when the mask rests on one edge. One plate has a 5 mm diameter hole drilled at its centre. The others have rings of holes, as follows:

six holes, each 3 mm diameter, in a circle of 10 mm diameter
eight holes, each 2.5 mm diameter, in a circle of 20 mm diameter
twelve holes, each 2 mm diameter, in a circle of 30 mm diameter.

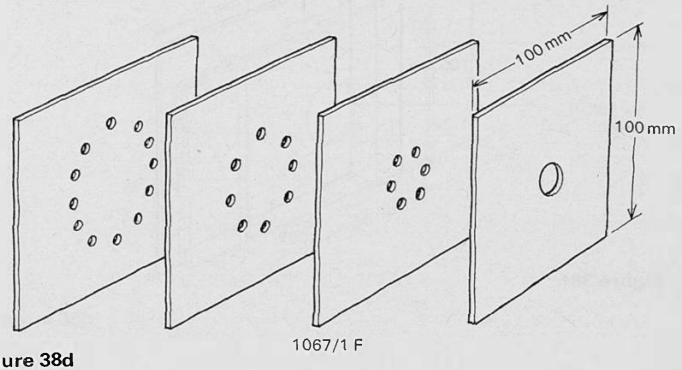


Figure 38d

1067/1 G **big stop to stand on bench** *quantity* 4

See figure 38 *e*. This stop is used to screen stray light which might otherwise enter eyepieces. It must stand freely on the bench, so a flat sheet with one edge bent through a right angle is suitable. The sheet should be 100 mm square, an edge or support 30 mm wide being adequate. The hole, drilled at the centre of the sheet, has a diameter of about 20 to 25 mm.

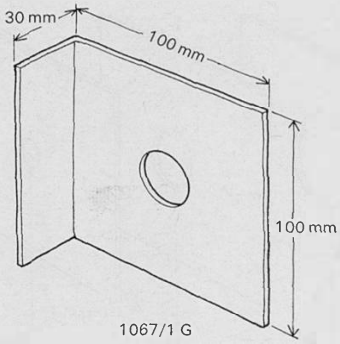


Figure 38e

1067/1 H **small translucent screen** *quantity* 6

See figure 38 *f*. The screen can be made from a 100 mm square sheet of 3 mm Perspex, glued into a groove cut in a wooden support 100 mm × 30 mm × 15 mm. One side of the Perspex should be well roughened by rubbing it with fine glasspaper. The screen can be used on its side as in figure 38 *f*, or resting on the wooden support.

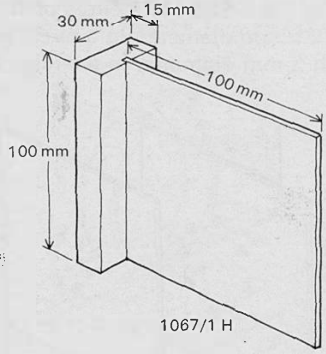


Figure 38f

1067/1 I **holder for eyepiece or adjustable slit** *quantity* 5

See figure 38 *g*. The holder is intended to hold an eyepiece or an adjustable slit (taken, for example, from a spectrometer) with its centre 50 mm above the bench. The eyepiece or slit assembly can be held in a Terry clip mounted at a height found by trial, on a wooden base. The base also carries a metal mask with a 20 mm diameter hole drilled so that its centre is 50 mm above the bench.

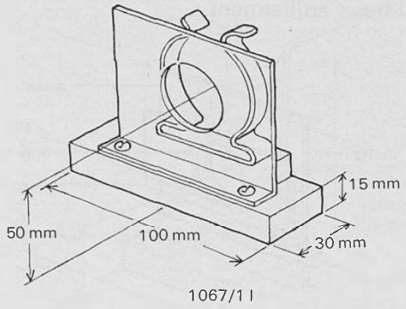


Figure 38g

1067/1 J **holder for two halves of a razor blade to be used as a single slit** *quantity* 16

See figure 38 *h*. This holder is used to keep two halves of a razor blade, edge to edge, so that they form an adjustable, narrow slit. The blades are sandwiched between sheets of stout cardboard or of metal, 35 mm × 70 mm, with holes 10 mm in diameter drilled or cut at their centres. The sheets, with blades in place, can be held together by pairs of rubber bands 25 mm × 3 mm × 1 mm.

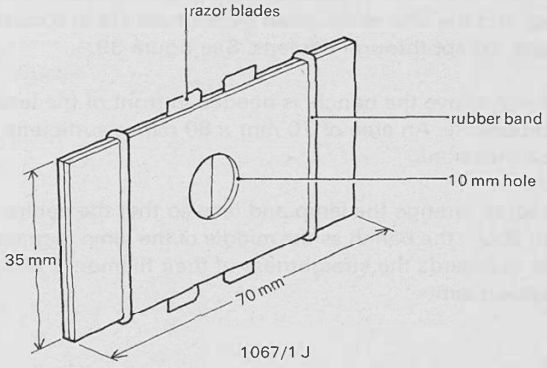
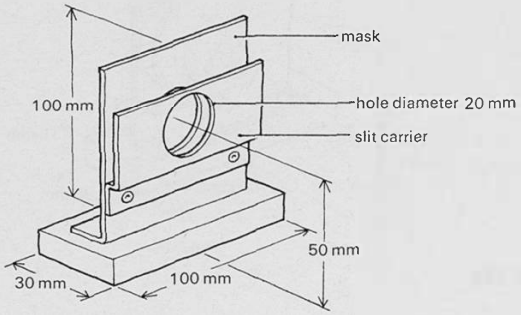


Figure 38h

1067/1K **support for a set of slits** *quantity* 1

See figure 38 *i*. This holder is used to support the slits, item 1067/2 O, or the gratings, item 1067/2 N, so that their centres are 50 mm above the bench, over a mask with a 20 mm diameter hole also with its centre 50 mm above the bench. If the slits or gratings are mounted in 35 mm slide mounts, the bottom of the slit carrier (see figure 38 *i*) should be 18 mm below the centre of the hole, that is, 32 mm above the bench. But if the slits are mounted in some other way, the height of the slit carrier will need adjustment.



1067/1 K

Figure 38i

1068 Parallel beam projector *quantity* 1

The parallel beam projector is much the same as a conventional 'ray box', and can be made by modifying one slightly. It employs a +7 dioptre plano-convex lens and a 12 V, 24 W, straight filament lamp, which can be moved towards or away from the lens so that the filament could be placed up to 200 mm from the lens. The lamp is in a light-tight casing, and the lens is mounted over a hole cut in a mask so that hardly any light emerges except through the lens. See figure 39.

A table, 50 mm above the bench, is needed in front of the lens, to carry a prism or other optical components. An area of 70 mm × 80 mm is sufficient. Figure 39 gives other significant dimensions.

It is important to arrange the lamp and lens so that the centre of the lens is at the same height above the bench as the middle of the lamp filament. Individual lamps vary a good deal as regards the straightness of their filaments, and it is well worth while selecting a good lamp.

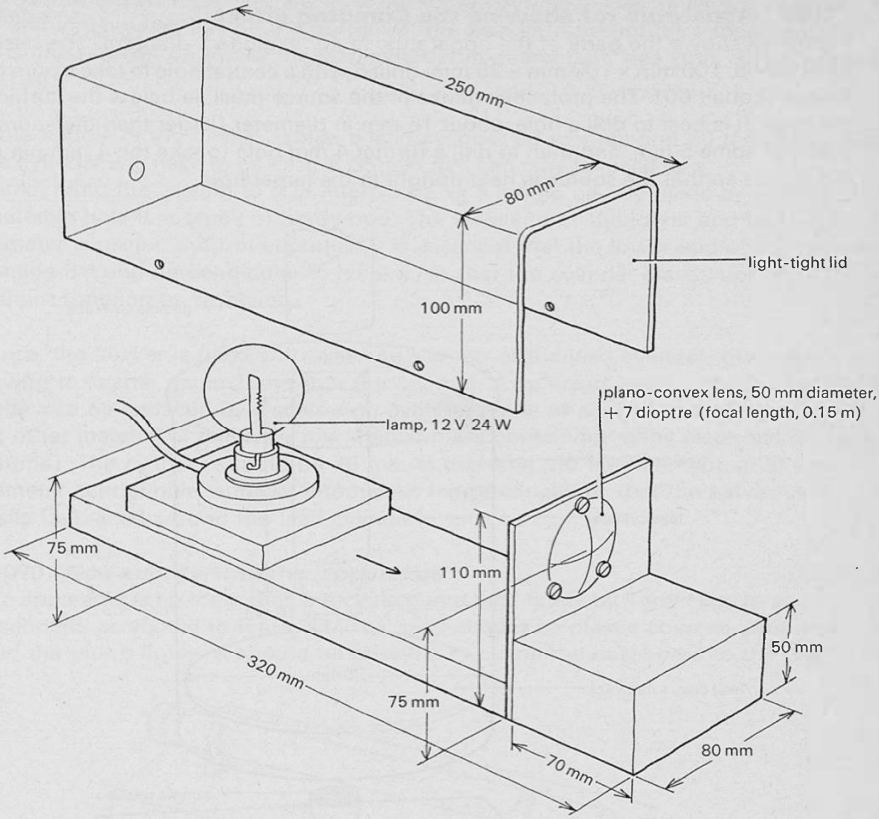


Figure 39
Item 1068. Parallel beam projector.

1069 Apparatus for showing the Compton effect *quantity* 1

Figure 40 shows the parts of the apparatus, in an 'exploded' diagram. The base may be of wood, 100 mm × 100 mm × 25 mm, drilled with a central hole to take a pure gamma source (cobalt 60). The protective gauze of the source must lie below the surface of the base. It is best to drill a hole, about 15 mm in diameter (larger than the source) to a depth of some 5 mm, and then to drill a further 4 mm hole to take the 4 mm pin on the source so that the source is held upright in the larger hole.

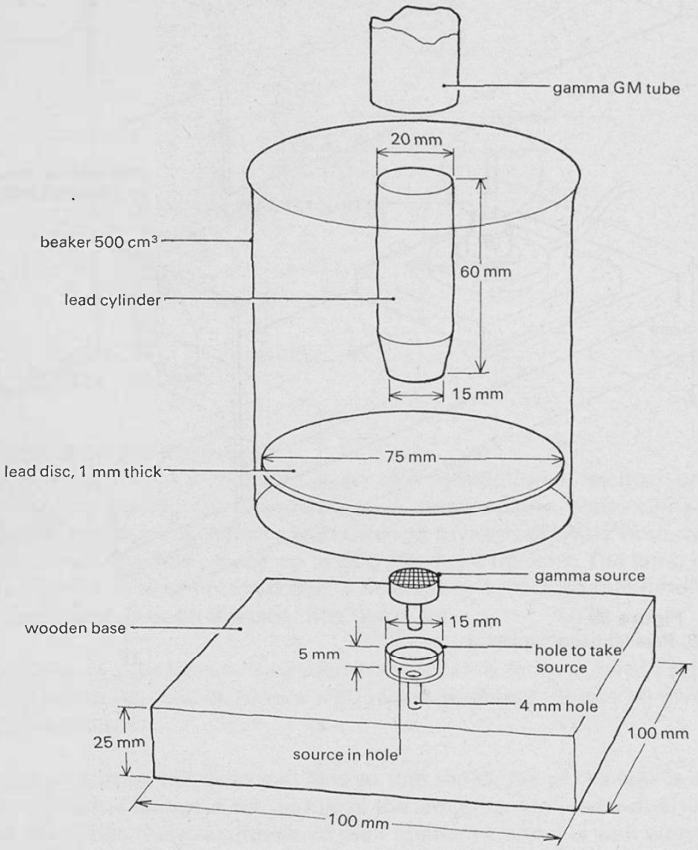


Figure 40
Item 1069. Apparatus for showing the Compton effect.

A 500 cm^3 beaker rests centrally over the source. A disc of lead sheet, 1 mm thick, 75 mm in diameter, lies on the bottom of the beaker in part of the experiment. (It is lifted to rest on top of the lead cylinder in a later part. See Unit 10, experiment 10.10.)

In the middle of the beaker stands a lead cylinder 60 mm tall and 20 mm in diameter. The cylinder will have to be cast. A 35 mm film can may be used as a mould, filing the casting to size afterwards, or a mould can be made by drilling a suitable hole in a block of hardwood. The bevelling of the lower end to 15 mm diameter is useful, but not essential. It is essential that the lower end of the cylinder is made flat and perpendicular to its axis, so that the cylinder stands upright without toppling or wobbling.

In use, the beaker is filled with water to the top of the lead cylinder, the water serving to scatter gamma rays into the counter. As a luxury option, the beaker and water can be replaced by a scattering cylinder made of aluminium or Perspex (or other material of relatively low atomic mass containing many electrons per unit volume). The cylinder should be 75 mm in diameter, 60 mm tall, with a 20 mm diameter central hole, and cut into halves longitudinally so that the halves can easily be placed around the lead cylinder.

1070 Gas energy transfer apparatus *quantity* 1

The apparatus is no more than a bicycle pump held firmly by Terry clips to a baseboard, as shown in figure 41. The clips should be plastic covered, and must hold the pump firmly. It should be possible to clamp the baseboard to the bench.

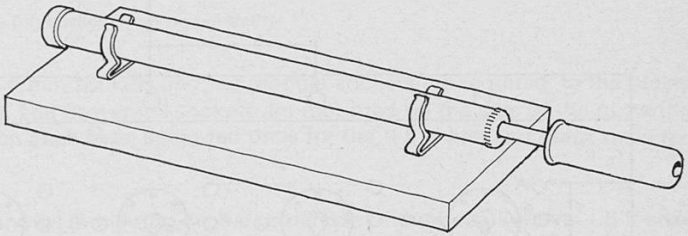


Figure 41
Item 1070. Gas energy transfer apparatus.

The pump must be a metal one, and should be as light as possible. The casing must have a heat capacity not exceeding 50 $J\ K^{-1}$; that is, if the casing is of aluminium, its mass should not exceed about 60 g.

It may be worth providing the pump with an insulating surround cut from expanded polystyrene.

1073 Concave reflection grating *quantity* 1

A cheap and fairly effective concave reflection grating can be made by cementing metallized replica grating material onto a concave mirror, or onto the concave face of a lens. A radius of curvature of 0.5 m is suitable. Care should be exercised to keep the replica grating surface smooth, using the minimum amount of cement. The grating material should have about 600 lines per millimetre. A piece of material about 30 mm by 30 mm is required. It is often possible to obtain metallized replica grating material from Proops Brothers Limited.

1075 Electronics kit *quantity* 8 kits

It is not difficult to make the electronics kit, and only cheap components are required, most of the manufacturer's cost being labour. To make a class kit is, however, a lengthy job, and may only be worth while if the school's workshop can undertake repetitive work, especially soldering. The form of the kit will depend on the boxes the school can obtain, within which the modules are to go. The notes below assume that the modules will be built either in 8-pin relay cases from RS Components Limited, or in 11-pin module cases from Lugton and Company Limited. The 11-pin cases are preferred. The cases containing modules then plug into 8-pin or 11-pin sockets mounted on baseboards.

The baseboard

The baseboards can be constructed from half metre lengths of Limpet plastic guttering, available from builders' merchants. Any other firm insulating base, about 0.1 m wide, raised about 20 mm off the bench by a suitable frame, will serve.

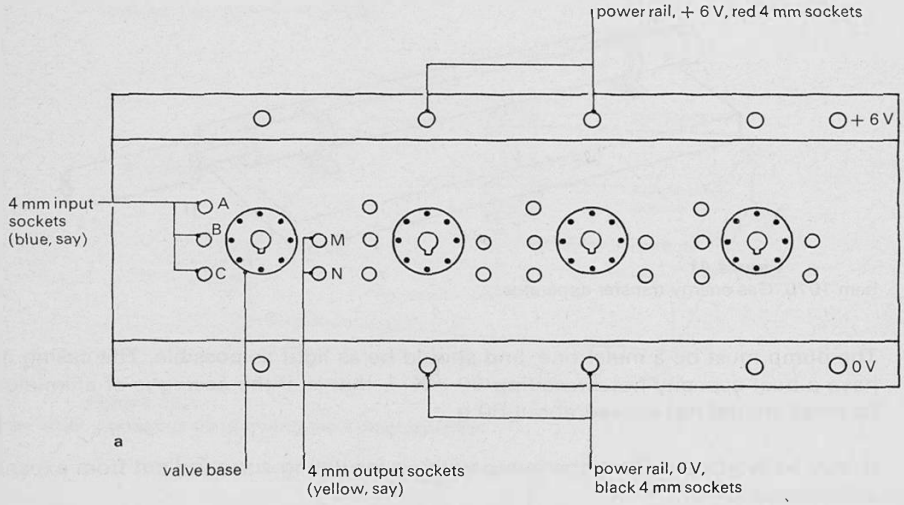


Figure 42
Baseboard.
a From above.

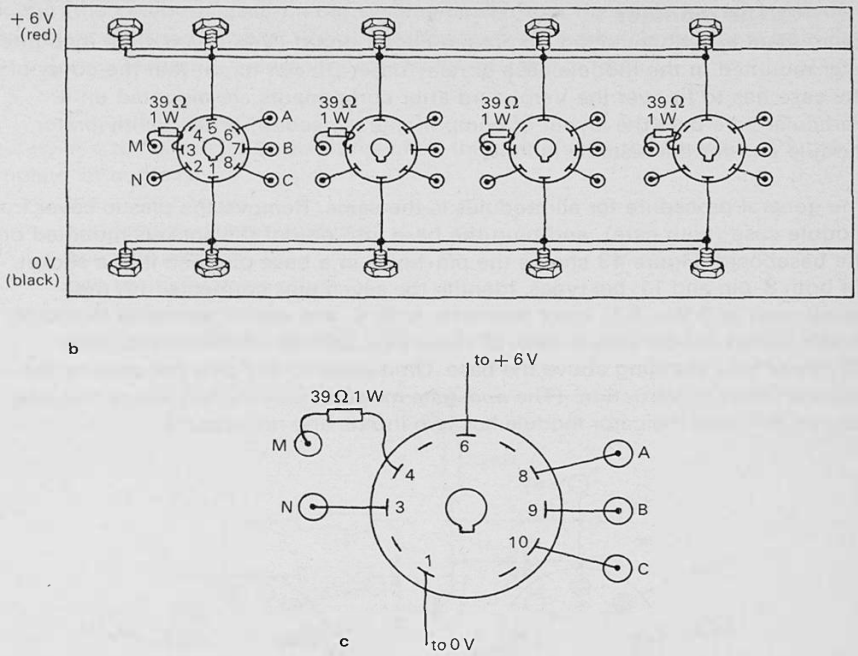


Figure 42 (*continued*)
b From below.
c Wiring for 11-pin socket (from underneath).

Holes for the 4 mm sockets and the module sockets are required, in the places shown in figure 42 *a*. The power rail sockets are mounted on the side of the guttering, with five sockets on each side, using red ones for the +6 V line and black ones for the 0 V line.

Figure 42 *b* shows the wiring on the underside of the base. All five +6 V sockets and then all five 0 V sockets, are wired together. Each module socket has one pin joined to the +6 V rail and one pin to the 0 V rail. Figure 42 *b* shows the pin connections for 8-pin sockets, while figure 42 *c* shows the corresponding connections for an 11-pin socket. The three input sockets and the two output sockets for each position on the base are wired to pins on the corresponding module socket. The connection to each uppermost output socket (socket M) includes a 39 Ω 1 W resistor. Note that the module sockets are shown mounted with the key-ways facing the 0 V line.

The modules

Every module is constructed on printed circuit board (Veroboard, 0.15 inch pitch), later mounted in the module case or relay case. Do not forget that the cover of the case has to fit over the Veroboard after components are mounted on it. Particular care over the layout of components is needed for the multivibrator module and for the bistable module.

The general procedure for all modules is the same. Remove the plastic cover from a module case (with care), and plug the base into one of the sockets mounted on the baseboard. Figure 43 shows the pin-holes in a base plugged into a socket, for both 8-pin and 11-pin types. Identify the seven pins connected (in the baseboard) to 0 V, +6 V, input terminals A, B, C, and output terminals M and N. Solder tinned copper wire in each of these pins, cutting off the wire to leave 40 mm of wire standing above the base. Omit wires to any pins not used by the module under construction. (The *and*-gate module has only two inputs and one output; the lamp indicator module has two inputs and no output.)

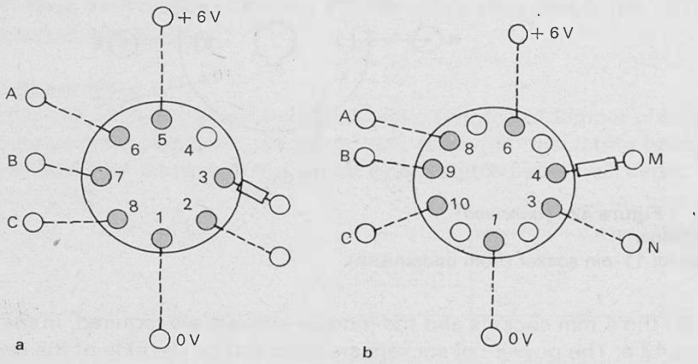


Figure 43
Connections made in the baseboard to pins in a module base standing in a socket (seen from above).
a 8-pin.
b 11-pin.

Complete any wiring, shown dotted on the plans, which is required on the plain underside of the Veroboard, having drilled gaps in the copper strips at the places indicated in the plans. Then pass the wires, soldered to the base, through the appropriate holes in the Veroboard, with the copper strips on the board uppermost and parallel to the length of the baseboard. The plans (figures 45 *a* to *f*) indicate the appropriate connections for each module. Solder the wires to the Veroboard, and trim off the ends. Check that the module case cover will fit over the Veroboard.

Solder in the components, working systematically from the back. No component may project outside the base. Check the positions of nearby components from the plan before soldering in a component. Finally, test the module.

Circuit diagrams

Figures 44 *a* to *f* give circuit diagrams of all the modules in the electronics kit. A complete kit contains:

three basic units
two lamp indicator modules
one *and*-gate module
one multivibrator module
one bistable module
one beam splitting module.

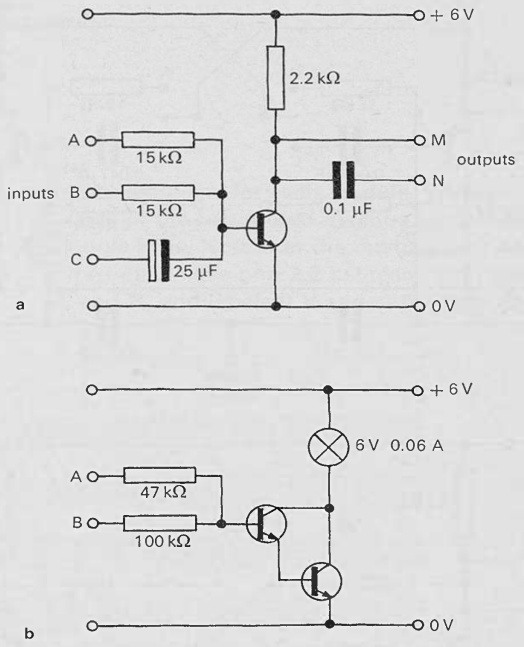
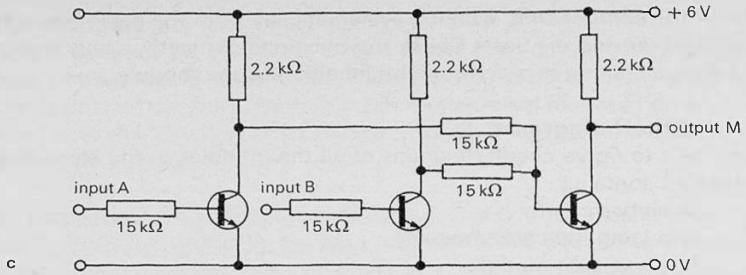
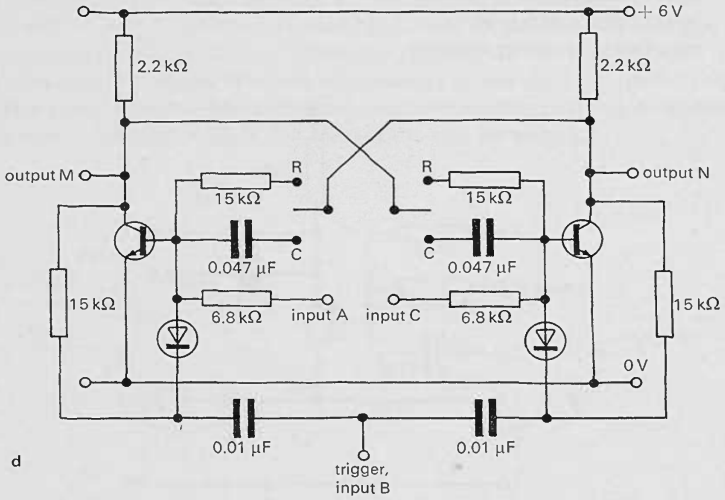


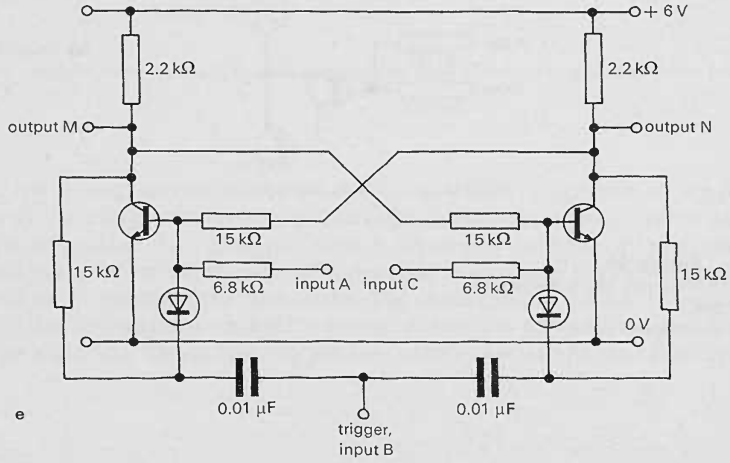
Figure 44
Circuits of modules in electronics kit.
a Basic unit.
b Lamp indicator module.


+ 6 V
2.2 kΩ
2.2 kΩ
2.2 kΩ
output M
15 kΩ
15 kΩ
input A
input B
15 kΩ
15 kΩ
0 V

c


+ 6 V
2.2 kΩ
2.2 kΩ
output M
output N
R
R
15 kΩ
15 kΩ
C
C
0.047 µF
0.047 µF
15 kΩ
15 kΩ
6.8 kΩ
input A
input C
6.8 kΩ
0 V
0.01 µF
0.01 µF
trigger,
input B

d


+ 6 V
2.2 kΩ
2.2 kΩ
output M
output N
15 kΩ
15 kΩ
15 kΩ
15 kΩ
6.8 kΩ
input A
input C
6.8 kΩ
0 V
0.01 µF
0.01 µF
trigger,
input B

e

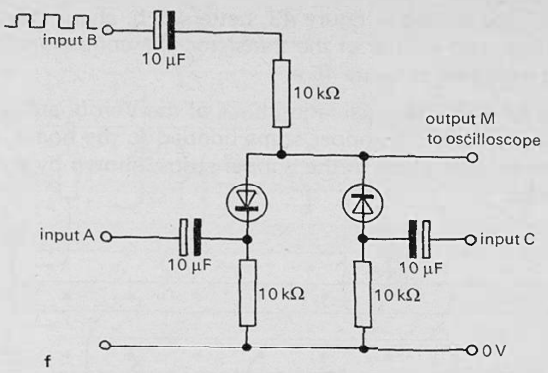


Figure 44 (*continued*)
c *And*-gate module.
d Multivibrator module.
e Bistable module.
f Beam splitting module.

Veroboard plans

Figures 45 *a* to *f* show Veroboard plans for each module. Wiring shown by broken lines is on the plain underside of the board, and *must* be completed before the board is soldered to its module base. Note that the multivibrator and bistable modules (figures 45 *d* and *e*) each have one 2.2 kΩ resistor on the underside of the board. Letters A, B, C, M, and N, and labels 0 V and +6 V refer to the connections

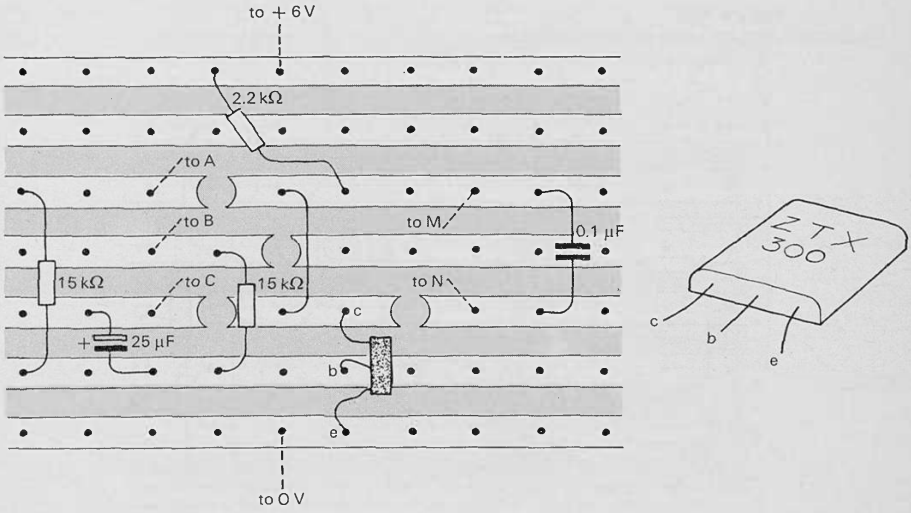


Figure 45a
Veroboard plan for basic unit.

to module base pins shown in figure 43. Letters c, b, and e indicate respectively the collector, base, and emitter of the transistor, the corresponding wires for the ZTX 300 being indicated in figure 45 *a*.

In all of figures 45 *a* to *f*, the insulating base of the Veroboard is shown darker than the white strips representing copper strips bonded to the board. Note that each plan involves some cuts made in the copper strips, shown by a darker region crossing the strip.

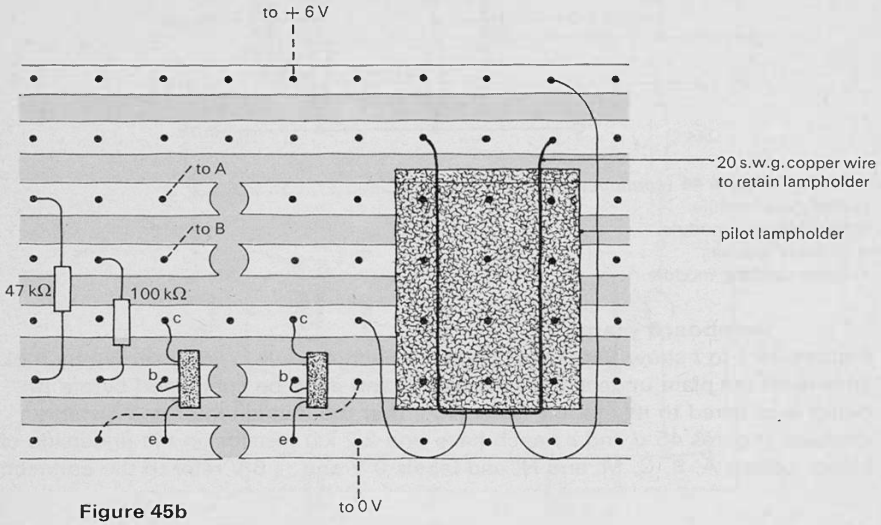


Figure 45b
Veroboard plan for lamp indicator module.

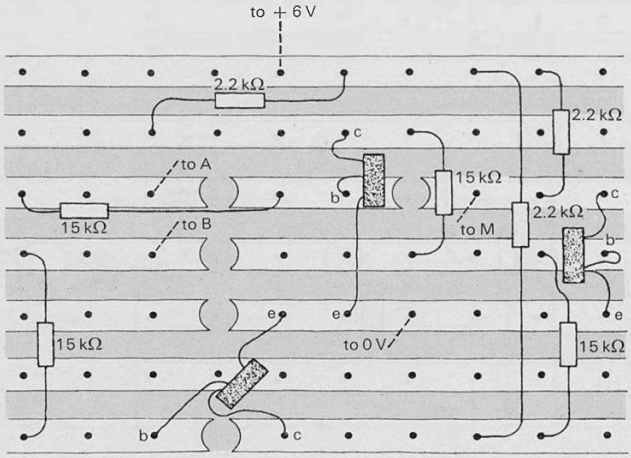


Figure 45c
Veroboard plan for *and*-gate module.

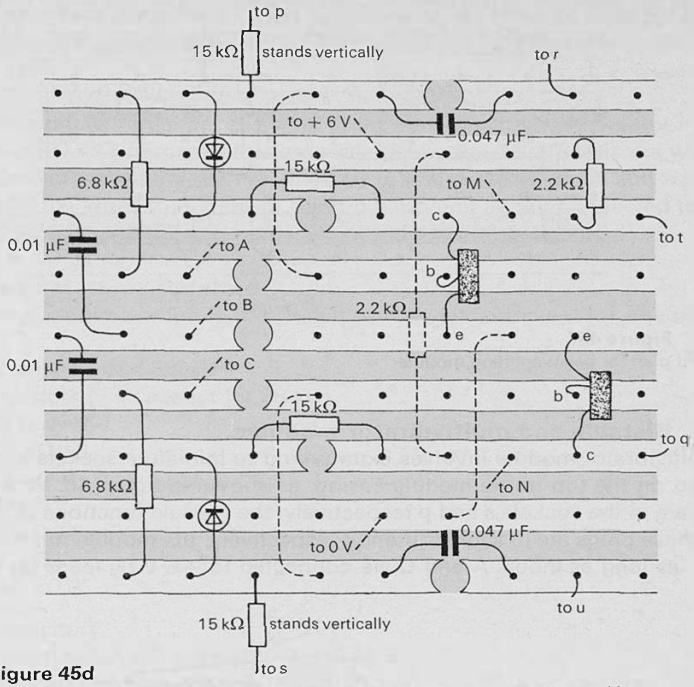


Figure 45d
Veroboard plan for multivibrator module (for symbols p, q, r, s, t, u, see figure 46).

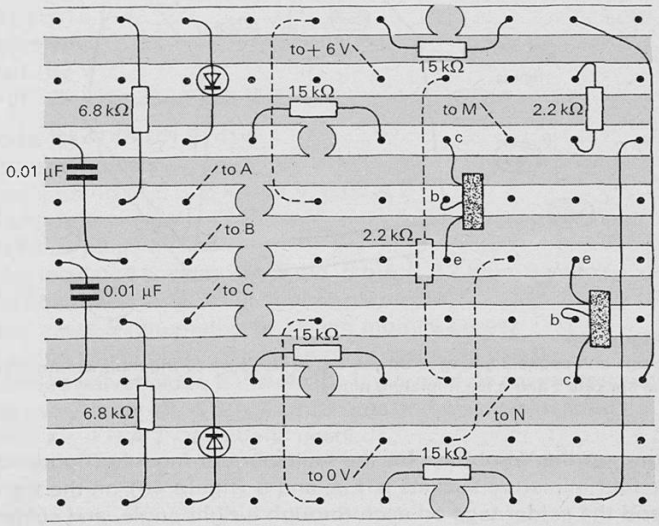


Figure 45e
Veroboard plan for bistable module.

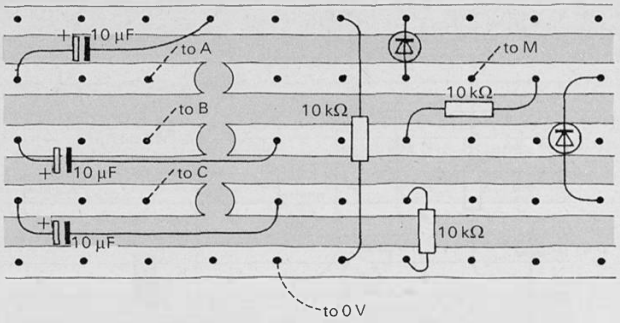


Figure 45f
Veroboard plan for beam splitting module.

Bistable and multivibrator modules

The multivibrator module involves extra wiring to miniature sockets and plugs mounted on the top of the module casing, as shown in figure 46. When the plugs t and q are in the sockets s and p respectively, the module functions as a bistable. When these plugs are in sockets u and r respectively, the module functions as an astable, as long as inputs A and C are connected to +6 V by leads on the baseboard.

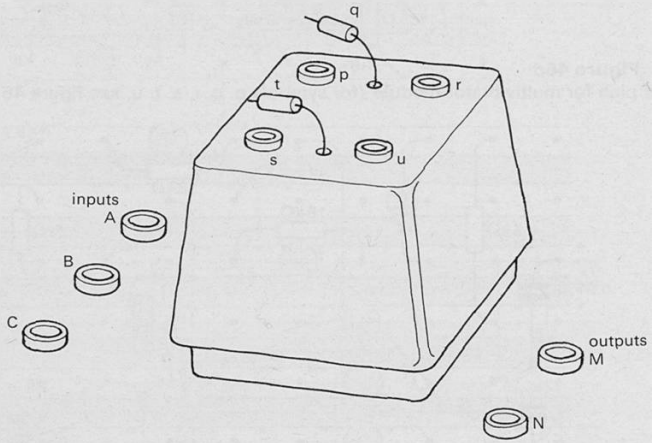


Figure 46
Miniature plugs and sockets arranged on the top of the case of the multivibrator module. p, r, s, u, are miniature sockets; t and q are miniature plugs.

When wiring up the Veroboard for the multivibrator module (figure 45 *d*), first mount the four miniature sockets p, r, s, and u (figure 46) on the top of the module casing, bend the solder tags on each through a right angle, and solder 80 mm of thin flexible insulated wire to each one. Then solder 100 mm of the same wire to

to the two miniature plugs t and q, and pass these wires through small holes in the cover. Solder the six leads to the points marked p, q, r, s, t, and u on the Veroboard plan.

The bistable module, figure 45 *e,* is almost the same as the multivibrator module, except that the 0.047 μF capacitors are replaced by the 15 kΩ resistors which, in the multivibrator module, were connected to p and s. The plugs and sockets are not used, and the wires that went to t and q are permanently connected to the places from which wires previously led to u and r respectively.

Special items required

The following are the components needed for one kit, sufficient for one pair of students.

From RS Components Limited

Resistors (½ W except for 39 Ω):
39 Ω, 1 W *4*
2.2 kΩ *10*
6.8 kΩ *4*
10 kΩ *3*
15 kΩ *18*
47 kΩ *2*
100 kΩ *2*

Capacitors:
miniature tubular polyester, 0.047 μF *2*
disc ceramic, low voltage:
0.1 μF, 30 V *3*
0.01 μF, 18 V *4*
electrolytic:
10 μF, 63 V *3*
25 μF, 25 V, or 22 μF, 63 V *3*

Diode, IN 4148 (IN 914) *6*
Pilot lampholders *2*
Lamps, round M.E.S. pilots, 6 V, 0.06 A *2*
Miniature sockets *4*
Miniature plugs *2*
4 mm insulated sockets *30* (5 red, 5 black, 12 blue, 8 yellow)
Stripboard type A (0.15 inch pitch) *9 pieces*
Relay cases *9* (alternative to 11-pin module cases)
Moulded valveholder, octal *4* (if relay cases are used)
Moulded valveholder, B11A *4* (if 11-pin module cases are used)
Nut and washer kit, 4 B.A *1 kit* (8 nuts and washers needed)
Screw kit, 4 B.A *1 kit* (8 bolts needed)

From Coventry Factors Limited

Transistors, ZTX 300 *14*
They can also supply electrolytic capacitors as below:
Mullard miniature electrolytic C426AR/F25, 25 μF, 25 V; *and*
Mullard miniature electrolytic C426AR/E10, 10 μF, 16 V

From Lugton and Company Limited

11-pin module cases, type MP4511 *9* (alternative to relay cases)
Moulded valveholder, type XP11/U *4* (for 11-pin module cases)

From builders' merchants

Limpet plastic guttering, 0.5 m length required

1076 Large ring *quantity* 1

A stout ring, about 0.3 m in diameter, is needed to support a rubber sheet stretched over it and held taut by a rubber band round the sides of the ring. It must be possible to support the ring rigidly about 150 mm above the bench.

Figure 47 shows one form of suitable ring, which will not be hard to make if good metalwork facilities are available. A metal bar, section 25 mm by 5 mm, about 1 m long, is bent into a circle. The Nuffield O-level telescope mount (item 115) could be used, or its fixtures copied.

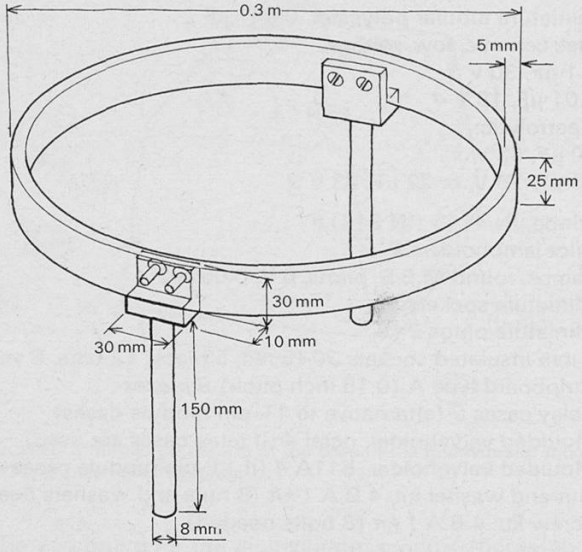


Figure 47
Item 1076. Large ring.

A pair of metal rods are used, in retort stand bases, to support the ring. The rods can be threaded into metal blocks 30 mm × 30 mm × 10 mm, into which a rebate has been cut as shown in figure 47. The ring goes into the rebate, and is secured by bolts threaded into the ring. One block can be placed where the ends of the ring meet, the other being on the same diameter.

1078 Gramophone motor *quantity* 2

A pair of mains voltage gramophone motors should be bought. Such motors, of the kind shown in figure 48 *a*, are usually available from surplus supplies dealers, such as Proops Brothers Limited. One motor is left unmodified. The other is modified so that the rotor can be removed for inspection, and so that the effect of making the shading ring circuit open can be seen.

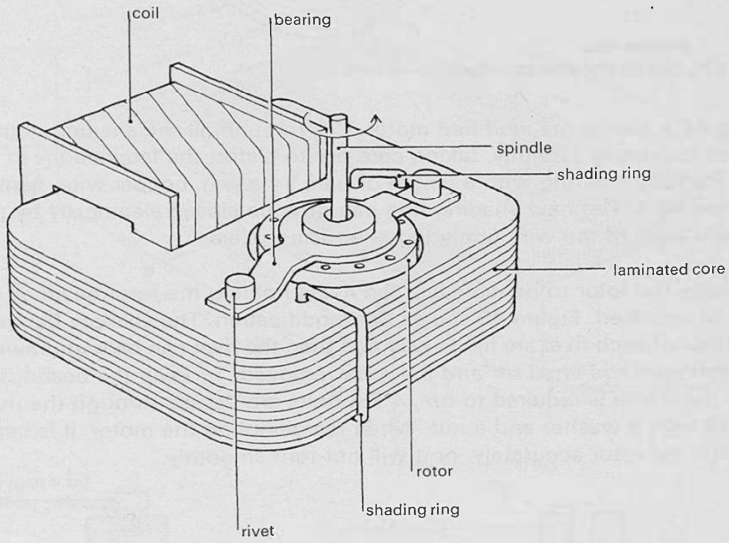


Figure 48
Item 1078. Gramophone motor.
a Unmodified.

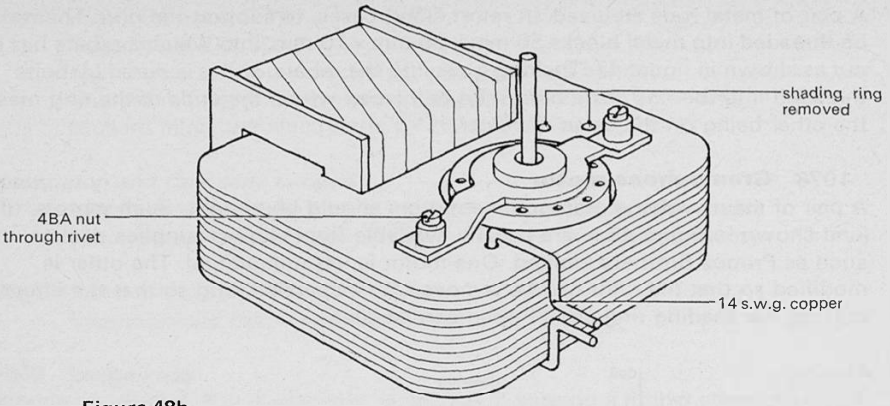


Figure 48b
Item 1078, gramophone motor. Modified version.

Figure 48 *b* shows the modified motor. Cut through all the shading rings, and remove them very carefully, taking care not to distort the laminations in the iron core. Replace one ring with a length of bare 14 s.w.g. copper wire, bent as shown in figure 48 *b*. The new shading ring can now be closed electrically by pinching the bent ends of the wire firmly together using pliers.

To enable the rotor to be removed, the rivets holding the rotor bearings to the core must be modified. Figure 49 shows the modification. The shallow flanges on the underside of each rivet are filed away and then the rivet can be withdrawn, allowing the bearings to be lifted off and the rotor removed. To keep the bearings in place when the motor is required to run, 4 BA bolts are passed through the rivets and secured with a washer and a nut. When reassembling the motor, it is important to centre the rotor accurately, or it will not turn smoothly.

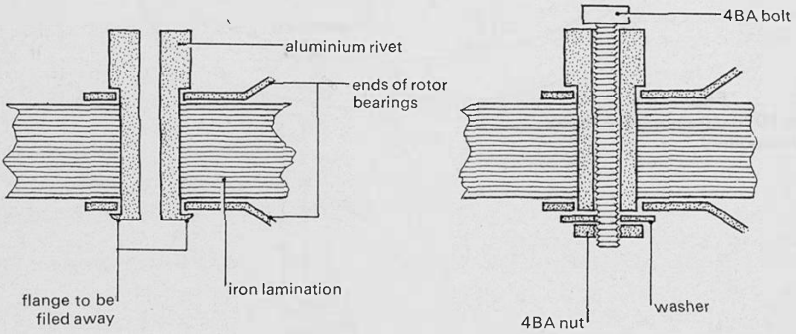


Figure 49
Modifications to rivets holding bearings.

1079 Flat solenoid *quantity* 1

The flat solenoid is a tedious item to make, and this is reflected in its cost from a manufacturer. A school may find it worth the effort, since only one is required. (*The set of solenoids, item 1037, presents a similar case, but several solenoids* are needed and the effort involved is likely to be less economic.)

Figure 50 shows the construction and dimensions of the solenoid. The solenoid is intended for use with the current balance, item 1036, so the centre of the space inside the windings must be the same height above the bench as the arm of the balance which carries current. A height of 35 mm is about right.

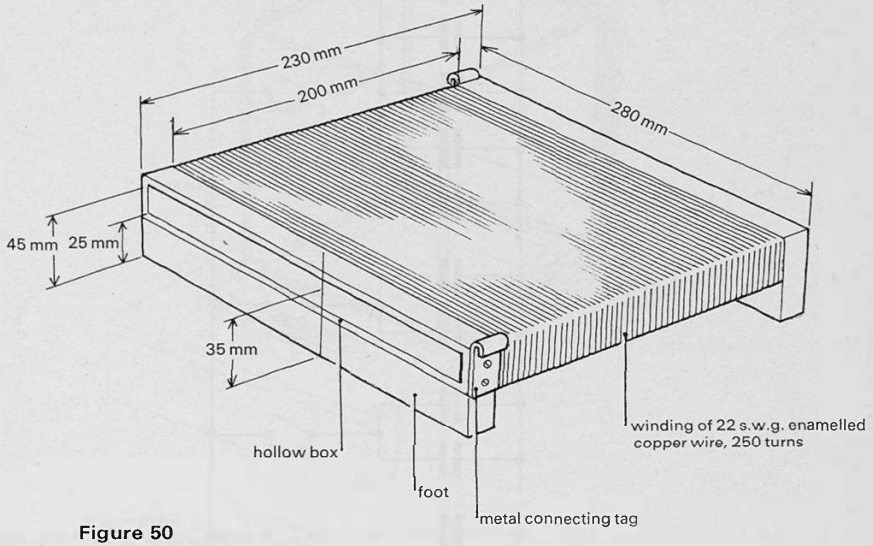


Figure 50
Item 1079. Flat solenoid.

The coil is wound on a flat shallow box 280 mm × 230 mm × 25 mm, the smallest dimension being whatever is needed for the space inside to be at least 20 mm, having regard for the thickness of the material employed. The box can be made from two sheets of hardboard glued and screwed (brass screws) to strips of wood 230 mm × 20 mm × 5 mm. Any stiff insulating material will serve. The box requires feet of such a height as to bring its centre to the correct level above the bench for use with the current balance.

The winding is one layer of enamelled 22 s.w.g. copper wire, the turns touching one another. There will be about 250 turns in a length of 200 mm to give the same turns density as the larger value for item 1037. The remainder of the length of the box is left free of windings, so that sockets can be attached. These may be of any form, so long as they do not project into the inside of the solenoid. Figure 50 shows a simple terminal made by turning over the end of a metal strip so as to form a 4 mm socket.

1081 Decade capacitance unit (1–10 μF) *quantity* 1

The decade capacitance unit is a box which enables capacitance of each integral value from 1 μF to 10 μF to be brought into circuit. Figure 51 shows one suitable circuit using ten 1 μF capacitors and four toggle switches, the capacitors being grouped in the values 1 μF, 2 μF, 2 μF, and 5 μF, so that all values are available from combinations of switches. Other circuits, which could employ rotary decade switches, can be equally suitable. The capacitors can be of the polyester type, 250 V working, tolerance 20 per cent.

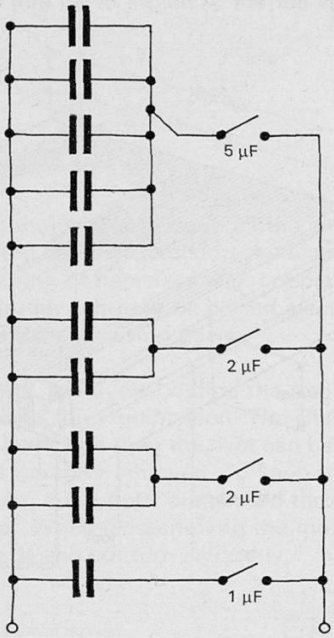


Figure 51
Item 1081. Decade capacitance unit (1–10 μF). All capacitors are 1 μF.

The insulating base to carry the switches and the capacitors may be cut from rectangular section plastic rainwater pipe, as shown in figure 5, page 8. The components are relatively bulky, and the cut shown in figure 5 *c* is likely to be most suitable.

Special items required

From RS Components Limited

Polyester moulded capacitors 1 μF, 250 V working *10*
Light-duty single-pole single-throw toggle switches *4*
4 mm insulated sockets *2*

1082 Coils surrounding a space *quantity* 1

Item 1082 is a box consisting of six ten-turn coils arranged on the faces of a 100 mm cube, as shown in figure 52. The pairs of leads from each coil are twisted and brought out to seven 4 mm sockets, the coils being connected in series as shown in figure 53. This figure shows only two turns in each coil, so as to make it clear that the windings are all connected in the same sense. Each coil in figure 53 is drawn as it appears looking at right angles to it, from the outside of the box.

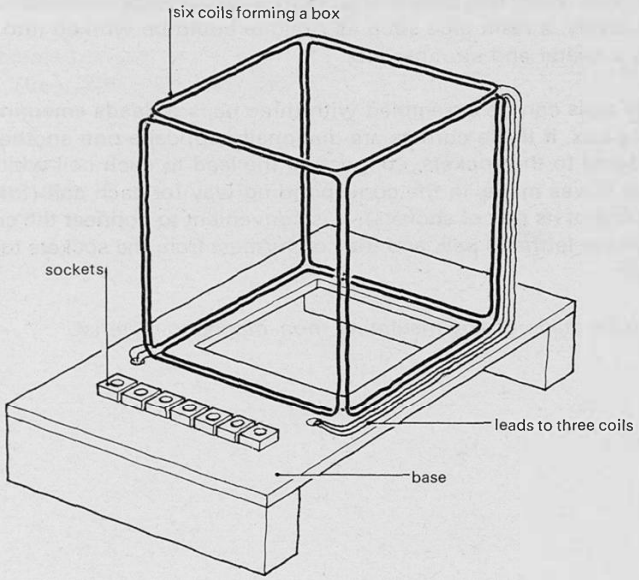


Figure 52
Item 1082. Coils surrounding a space.

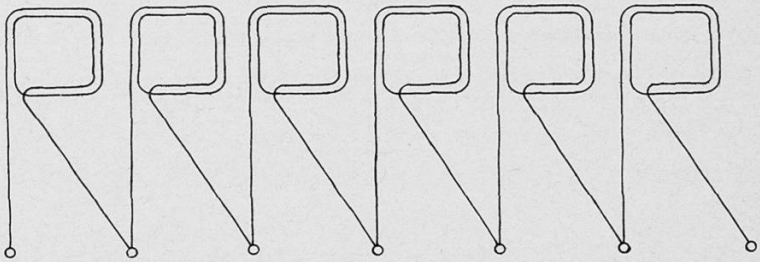


Figure 53
Connections to coils. The coils have been drawn in a row with the outward face lying uppermost. Each coil has ten turns, but only two are shown here, for clarity.

The coils can be wound as follows. Hammer four panel pins into a baseboard, at the corners of a 100 mm sided square. Wind ten turns of 32 s.w.g. enamelled copper wire on the pins, mark one lead (say, that leading into the coil clockwise) and the top of the coil, and twist the leads together. Hold the turns of the coil in place temporarily with cotton tied round at several places, or with wire wound round. Having made six such coils, assemble the coils into a box, the marked upper face of every coil facing consistently inwards or outwards. The box needs no other support if the coils are bound together with wire at the corners where three coils meet. It is also advisable to bind the coils in the middle of each edge. Alternatively, a resin glue such as Araldite could be worked into the turns, giving a neater and stronger job.

Note that the coils can be assembled with three pairs of leads emerging from two corners of the box, if these corners are diagonally opposite one another. The leads are now soldered to the sockets, connecting the lead to each coil which was marked when it was made, in the corresponding way for each coil (for example, to the lefthand one of its pair of sockets). It is convenient to connect the coil nearest the sockets to the lefthand pair, and the coil furthest from the sockets to the righthand pair.

The base can be made of any insulating, non-magnetic material.

Addresses of suppliers

RS Components Limited,
PO Box 427, 13–17 Epworth Street, London EC2P 2HA

Proops Brothers Limited,
52 Tottenham Court Road, London, W1P 0BA

Lugton and Company Limited,
209–212 Tottenham Court Road, London W1P 0BA

Coventry Factors Limited,
Upper Well Street, Coventry CV1 4AF

Osmor Limited,
540 Purley Way,
Croydon CR9 4DY

Editor **Jon Ogborn**

Contributors and members of the Nuffield Advanced Physics team
P.J.Black Jon Ogborn *Joint organizers*
W.Bolton R.W.Fairbrother G.E.Foxcroft Martin Harrap
John Harris A.L.Mansell A.W.Trotter

Many of the items of apparatus recommended for the Nuffield Advanced Physics course can be built in a school, with consequent substantial saving in cost. This book provides enough information for a teacher working with his laboratory assistant to make these items. For each piece of apparatus, drawings and dimensions are given, suitable materials suggested, and construction details outlined. In addition to the obvious advantages of making some of their own apparatus, teachers will find it a valuable way of getting to know the course itself.

Published by Penguin Education