VIII. CIRCUIT APPARATUS

A. CELLS

This section contains cells and simple batteries which may serve as suitable sources of electrical energy for typical classroom experiments.

B. CIRCUIT COMPONENTS

The apparatus described here is limited to such typical components as switches and bulb holders.

C. RESISTORS

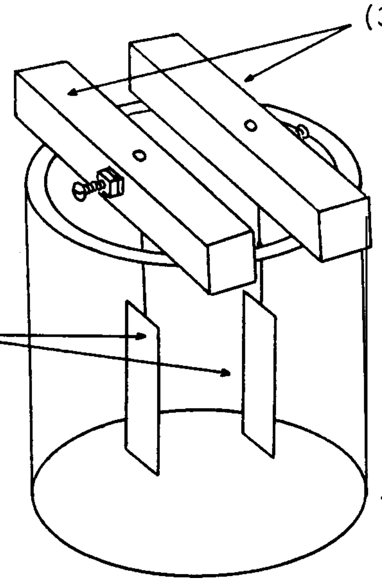
Fixed and variable resistors for typical classroom experiments are described in this section.

D. DYNAMO/MOTORS

This section contains two motors which may also be used as dynamos. The first is a very simple device which is capable of generating only a very minute current, whereas the second is a much more substantial item which generates sufficient current to light a bulb.

A. CELLS

Al. Chemical Cell ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Plastic Container (A)	Approximately 8 cm diameter, 8 cm deep
(2) Plates	1	Zinc Sheet (B)	5 cm x 2 cm x 0.05 cm
	1	Copper Sheet (C)	5 cm x 2 cm x 0.05 cm
	1	Steel Sheet (D)	5 cm x 2 cm x 0.05 cm
	1	Carbon Rod (E)	Extracted from dry cell
	4	Brass Wire (F)	2.5 cm long, 0.1 cm diameter
(3) Holders	2	Wood Holders (G)	10 cmxl cmxl cm
	1	Bolt (H)	0.3 cm diameter, 1.5 cm long
	2	Nuts (I)	0.3 cm internal diameter

c. Construction

(1) Container

Use a plastic or glass jar (A) as the electrolyte container. (A wide variety of electrolytes

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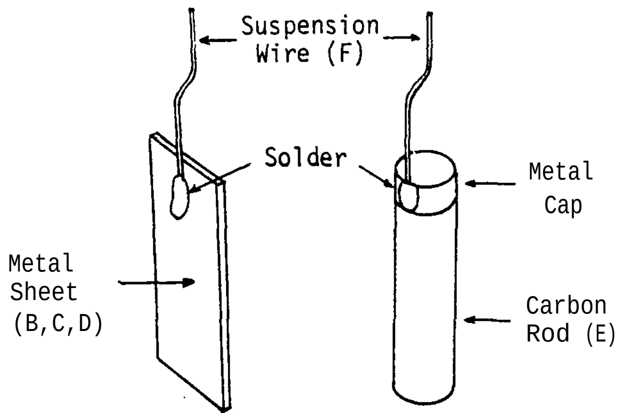
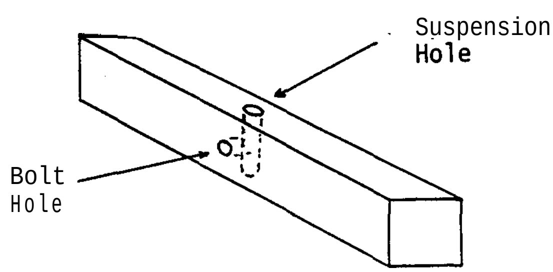
may be used, including commonly available vinegar and household salt solutions.)

(2) Plates

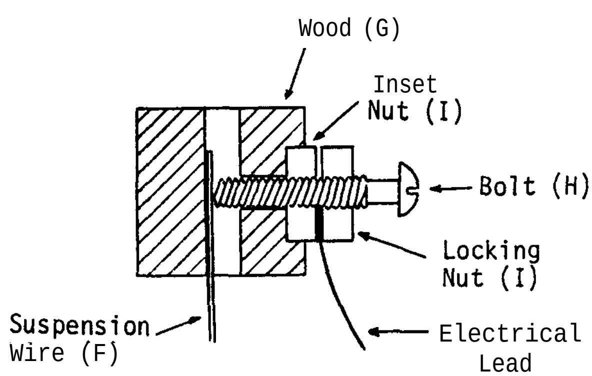


Solder a brass suspension wire (F) on to each of the metal sheets (B, C and D). Also solder a similar suspension wire (F) to the metal cap on a carbon rod (E) extracted from a dry cell.

(3) Holders



In each wood holder (G), drill a vertical suspension hole (0.2 cm diameter) and a horizontal bolt hole (0.3 cm diameter) to meet the vertical hole.



Cross Section

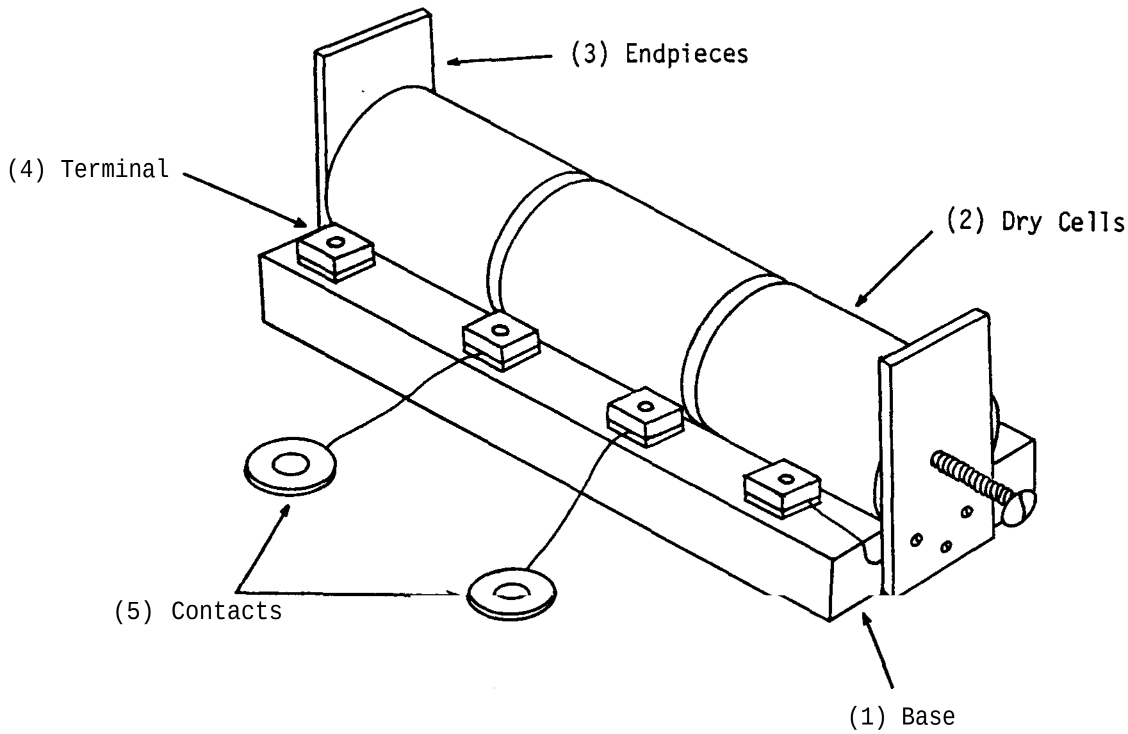
Inset one of the nuts (I) over the bolt hole with a sharp tap of the hammer (A little epoxy resin will hold the nut permanently in position.) Thread the second nut (I) on to the bolt (H) to serve as a locking nut, and then screw the bolt into the bolt hole. Insert a suspension wire in the vertical hole, and clamp it in position by tightening the bolt.

Electrical leads may be fastened under the locking nuts on the holders, and the cell connected into an electrical circuit.

C. Notes

(i) Any of the two plates in combination with one of the electrolytes mentioned above will produce an electric current. The latter may be detected by means of a simple galvanometer (e.g., X/Bl). It is recommended that students compare the magnitudes of currents that can be produced by the various plate and electrolyte combinations.

AZ. Dry Cell Holder with Cells ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	18.5 cm x 5.5 cm x 2 cm
(2) Cells	3	Dry Cells (B)	1.5 volts each
(3) Endpieces	2	Brass Sheets (C)	4.0 cm x 1.5 cm x 0.3 cm
	6	Screws (D)	Approximately 0.8 cm long
	1	Bolt (E)	0.4 cm diameter, 2 cm long
	1	Nut (F)	0.4 cm internal diameter
(4) Terminals	4	Brass Bolts (G)	0.3 cm diameter, 2.5 cm long
	8	Nuts (H)	0.3 cm internal diameter
	4	Magnet Wire (I)	#22, 15 cm long

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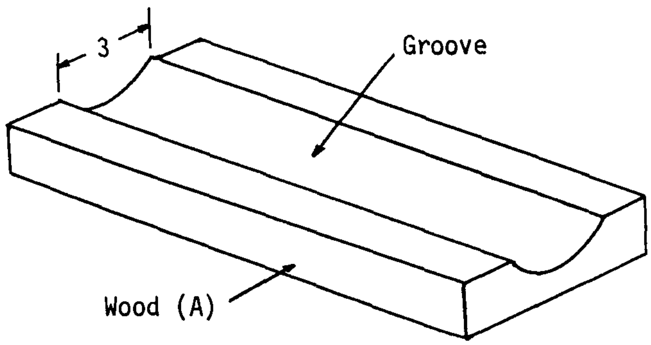
(5) Contact Plates	2	Circular Brass Sheets (J)	1.5 cm diameter, 0.05 cm thick

b. Construction

(1) Base

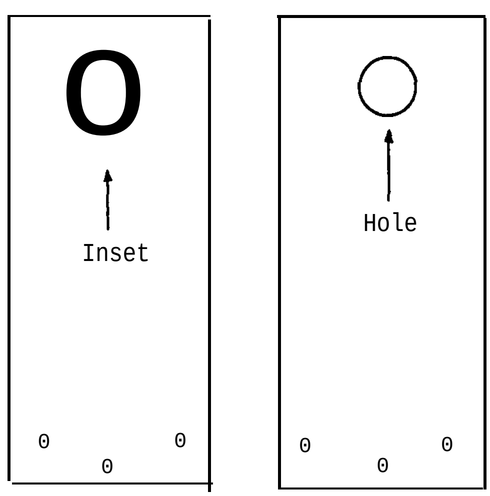


Cut the base out of the soft wood (A), and use a curved chisel to make a long groove (about 0.5 cm deep) in the surface to hold the dry cells in position.

(2) Cells

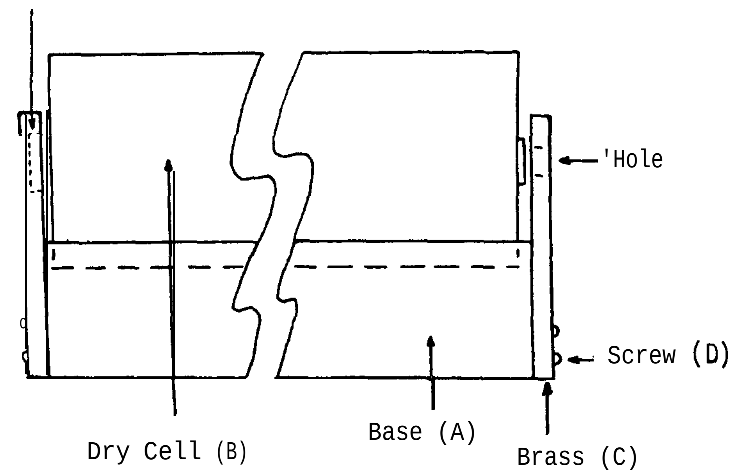
Place three dry cells (B) in series in the groove of the base. The groove should be from 1 to 1.5 cm longer than the three cells placed end to end, thus allowing room for the placing of contacts between the cells, and for adjustment of the screw in one of the end-pieces.

(3) Endpieces

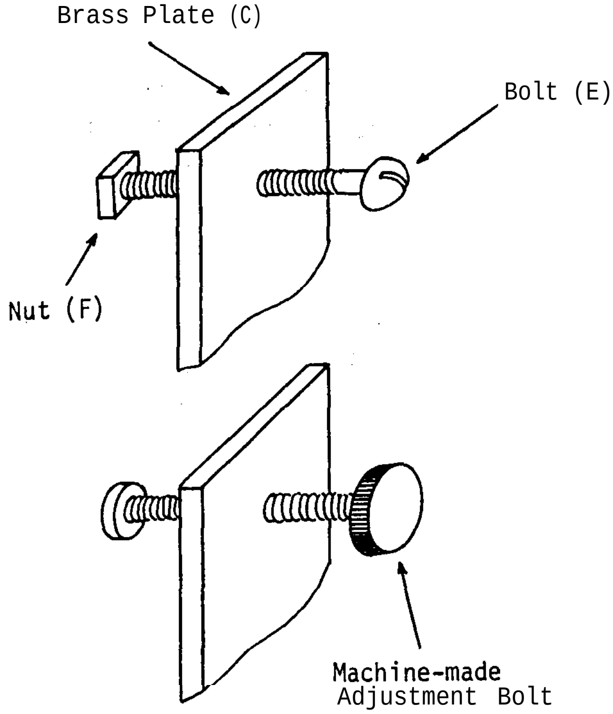


Brass Plates (C)

Use the brass sheets (C) for endpieces. Drill three small holes (0.2 cm diameter) at the base of each endpiece to facilitate attachment to the base with the screws (D). Place the dry cells on the base to determine the height of the mid-point of the dry cells, and then drill an inset (0.9 cm diameter, 0.15 cm deep) at this height in one endpiece, and a hole (0.4 cm diameter) at the same height through the other endpiece. Thread the newly drilled hole to take the adjustment bolt (E).

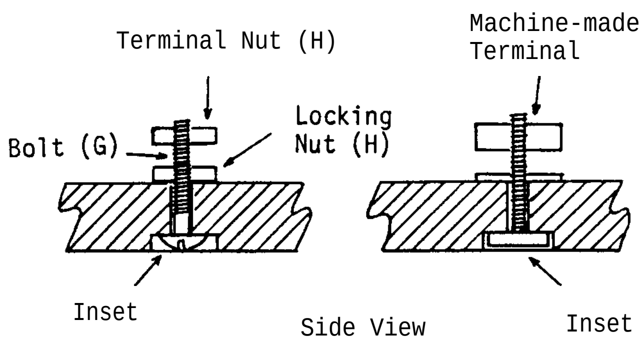


Side View



The latter bolt may have to be adjusted with the help of a coin, or some such device. A much more convenient adjustment bolt could be made by a technician, or anyone familiar with a metal lathe, cutting the head and bolt from a single piece of brass. The base in either case would be made from a separate nut (F), firmly attached to the bolt by damaging the threads at the end.

(4) Terminals

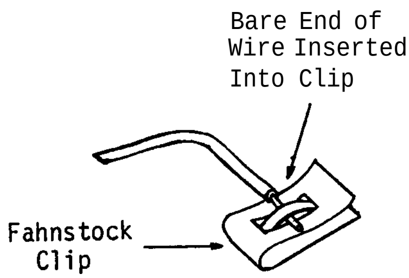


Side View

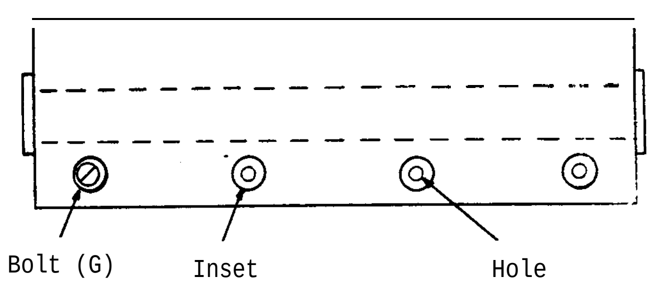
(Cross-section)

Make four terminals from the brass bolts (G) and nuts (H). Two nuts are required for each terminal, one to serve as a locking nut and one as a terminal nut.

Somewhat better nuts, which are more easily adjusted with the fingers, may be made with a metal lathe. The terminal nut should be 0.5 cm thick, while the locking nut should be much thinner (0.2 cm). The diameter of both should be 1.0 cm.

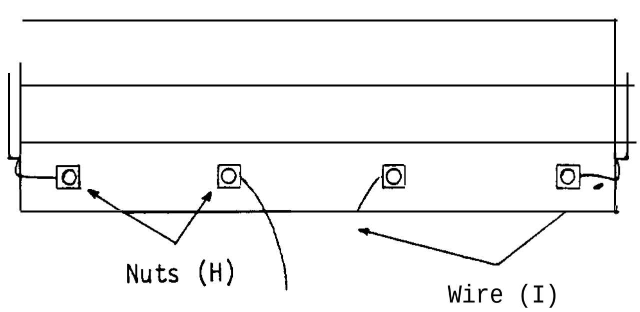


In some localities it is cheaper to purchase terminals on the local market. Check the availability of such items as Fahnstock clips which can replace the above.



Base, Bottom View

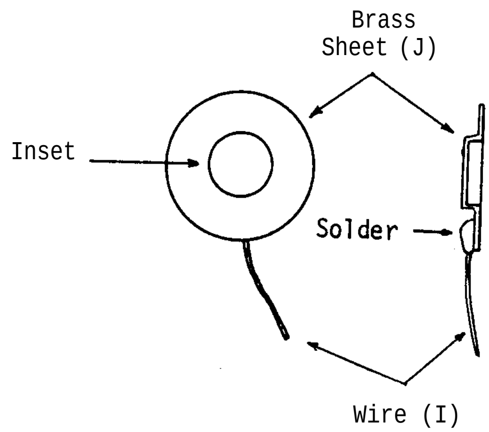
Make four insets (0.2 cm deep) at equal intervals underneath the front side of the base to take the boltheads of the terminals. Insert the four bolts (G) from below, through holes drilled through the base, and attach the locking nuts (H) and terminal nuts (H).



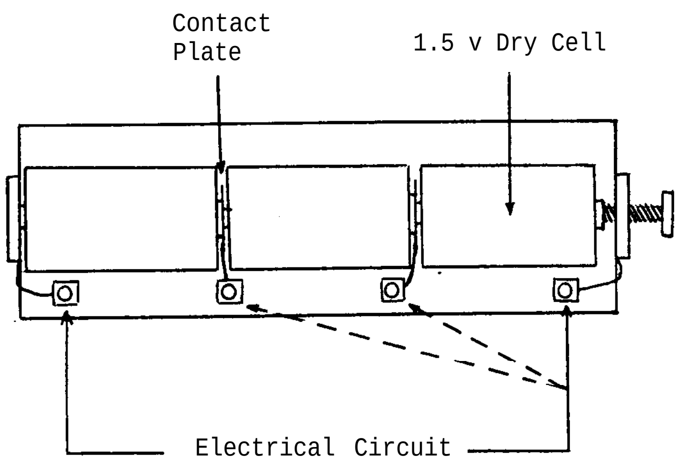
Base, Top View

Use copper wire (I) to attach the end terminals to the end-pieces, fastening the bare ends of the wire beneath the terminal locking nuts and brass endpieces. Similarly attach a length of copper wire (I) (15 cm long) to each of the middle terminals.

(5) Contact Plates

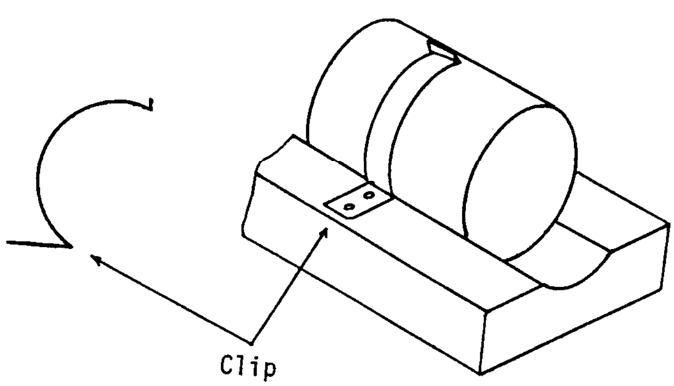


Use a nail head, or punch, to make a central inset (1 cm diameter, 0.2 cm deep) in the two brass sheets (J). Solder the two plates to the bare ends of the wire (I) attached to the two middle terminals. The contact plates are placed between the first and second, and second and third cells, thus enabling the apparatus to provide an external circuit with 1.5, 3.0 or 4.5 volts according to the terminals connected to the circuit.



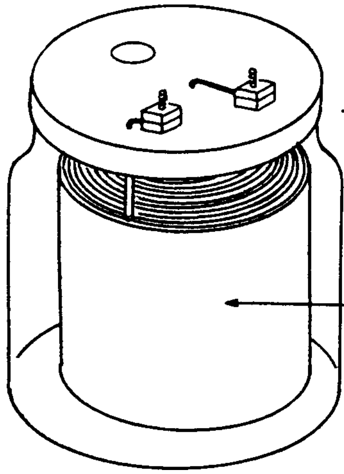
C. Notes

(i) So long as the adjustment bolt is not tightened too tightly, the cells will remain firmly in the base groove. However, should any problem occur (e.g., due to bad alignment of the adjustment screw) the cells could be held more firmly in place by means of clips made from packing case bands.



(ii) The dry cell holder serves as a variable source of potential providing from 1.5 to 4.5 volts, according to the terminals connected into the circuit.

AS. Simple Battery *



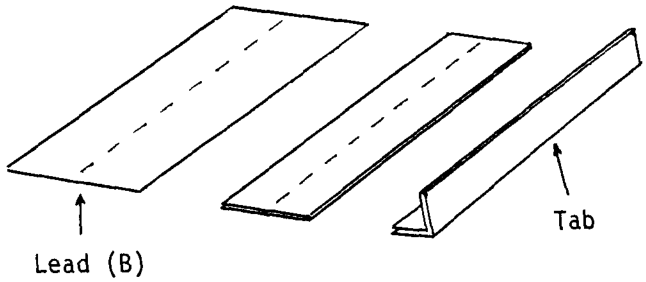
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Plates	2	Lead Sheets (A)	80 cm x 7.5 cm x 0.01 cm
	2	Lead Sheets (B)	15 cm x 6 cm x 0.01 cm
	2	Thick Blotting Paper (C)	85 cm x 10 cm
	2	Rubber Bands (D)	--
(2) Container	1	Jar (E)	Capacity 1 liter, approximately
	1	Plywood Lid (F)	10 cm diameter, 0.5 cm thick
	2	Terminals (G)	VIII/A2,Component (4)
	1	Sulphuric Acid (H) (Concentrated)	200 ml

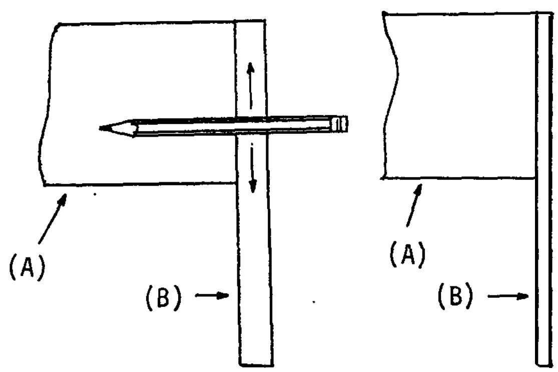
*Adapted from Intermediate Science Curriculum Study, Probing the Physical World, Volume 1, Experimental Edition, (Tallahassee, Florida: Florida State University, 1967), PP l-4.

b. Construction

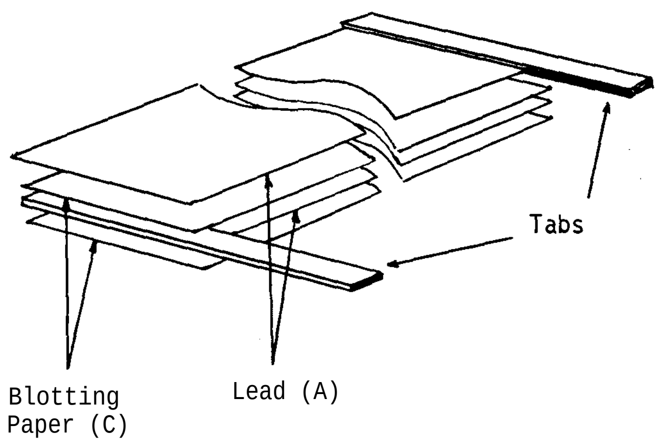
(1) Plates



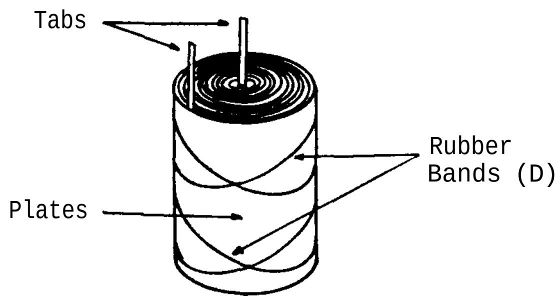
Fold one of the small lead sheets (B) down the middle. Repeat the process again, but this time leave the fold open. You now have a tab for attachment to one of the lead plates.



Fit the end of one of the large lead sheets (A) into one of the tabs (B), and fold the tab firmly down over the sheet using a pencil to flatten the tab down. With the lead sheet fully inserted into the tab, fold the tab once more, and smooth it again. You now have one lead plate complete with tab. Now make a second lead plate complete with tab in an identical manner, using the remaining lead sheets (A and B).

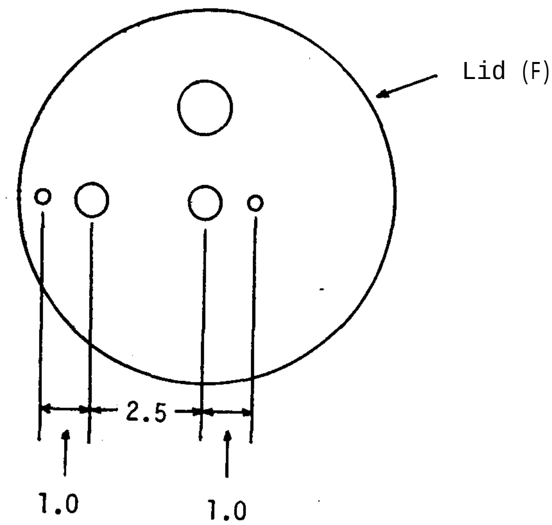


Make a plate "sandwich" by placing the blotting paper (C), lead plate, blotting paper (C), lead plate one on top of the other. The tabs should be at opposite ends of the sandwich, but emerging from the same side.

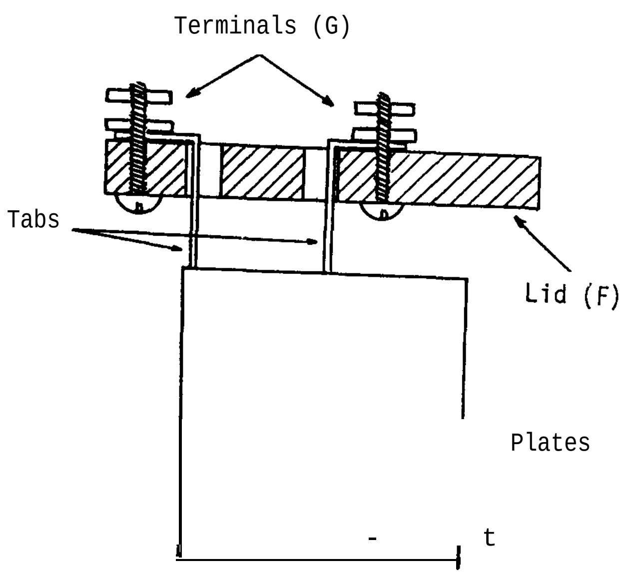


Roll the "sandwich" up into a tight cylinder. One tab will protrude from the center and one from the edge. Hold the plates in the form of a cylinder by wrapping the rubber bands (D) around the cylinder.

(2) Container



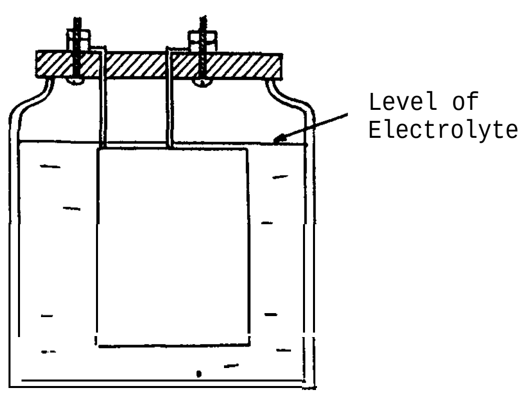
Obtain a one liter jar (E), and use the plywood lid (F) to cover the open end of the jar. Bore two holes (0.5 cm diameter) through the lid to accommodate the tabs, one hole being at the center of the lid and the other 2.5 cm away from the first hole. Drill two more holes (0.3 cm diameter), one on either side of the first two holes to accommodate the terminals. Drill a fifth hole (1 cm diameter) anywhere else in the lid to permit addition of the electrolyte.



Cross Section

Push the plate tabs through the two larger holes in the lid (the center tab through the center hole), and fold the top 1.5 cm of each tab over at right angles so that each overlaps the adjacent small hole in the lid. Fit two terminals (G) into the small holes in the lid, and lock a tab under each terminal. Make one liter of electrolyte in a separate container. This may be dilute sulphuric acid or sodium sulphate. Sulphuric acid is the better electrolyte, but from a student point of view it can be dangerous if it is not handled carefully. Many will prefer to use sodium sulphate for this reason.

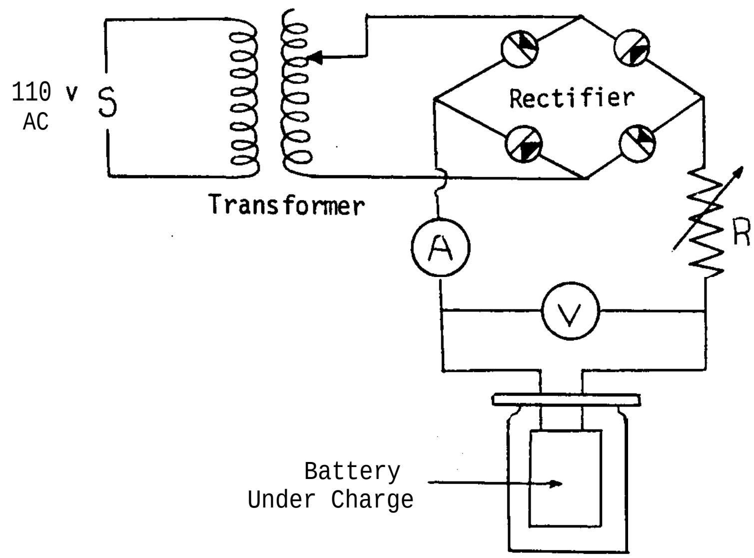
To make the sulphuric acid electrolyte pour 813 ml of water into a container. Then add 187 ml of concentrated sulphuric acid (H) to the water in very small quantities, letting the acid run down the sides of the container into the water. Much heat will be caused by the inter action. Stir the electrolyte, and allow it to cool before adding more concentrated acid. Before pouring the electrolyte into the battery it must be completely cool. (If a sodium sulphate electrolyte is preferred add 1.0 liter of water to 114 g of solid sodium sulphate and stir.)



Pour the electrolyte carefully through the appropriate hole in the lid until it just covers the plates. The battery is now ready for charging and use.

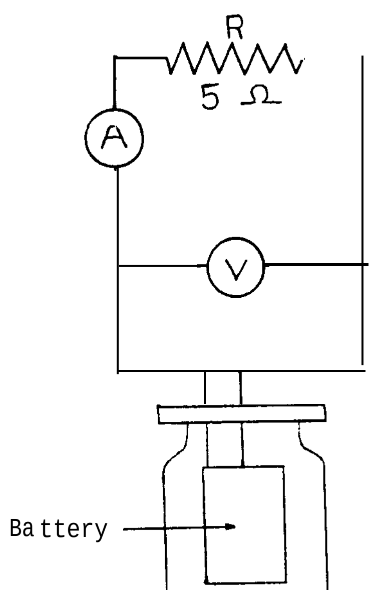
C. Notes

(i) To charge the battery a DC current of one amp at approximately 2.5 to 3.0 volts is required. This is best obtained with the help of a transformer (VII/A3) and rectifier (VII/B2). Connect the rectifier to the 10 volt taps on the transformer, and connect the battery across the rectifier as illustrated. A variable resistor (VIII/C2) should be connected into the circuit to control the current, and an ammeter and voltmeter connected as indicated to monitor the circuit.



Charge the battery for 30 minutes keeping the current-steady at one amp by adjusting the variable resistance. (The voltage will not remain constant throughout charge.)

(ii) Some idea of the strength of the battery may be obtained by discharging it through a five ohm resistor, and noting the current generated over a period of time, and the voltage of the battery output. The results of one such discharge are given below (for the battery with sulphuric acid electrolyte).



t Minutes	V Volts	I Amps
1	1.00	0.40
2	0.40	0.20
3	0.20	0.10
4	0.19	0.04
5	0.19	0.04

The voltage and current output fall off rapidly with time, indicating that the battery in its present state is not suitable for quantitative experimentation.

(iii) A good, strong battery may be produced simply by recharging the battery and discharging it several times over. This process is more successful if the direction of the current is changed for each recharge. The battery tested above was charged four more times (each time with reversed polarity) and discharged for five minutes through the five ohm resistor after each charge. After each discharge the battery terminals were shorted to remove any remaining charge. The results of the fifth discharge show that the battery, after repeated charging and discharging* is capable of maintaining a steady current output at a steady voltage, and as such is suitable for quantitative experimentation.

t Minutes	V Volts	I Amps
1	1.9	0.39
2	1.9	0.39
3	1.9	0.39
4	1.9	0.39
5	1.8	0.35

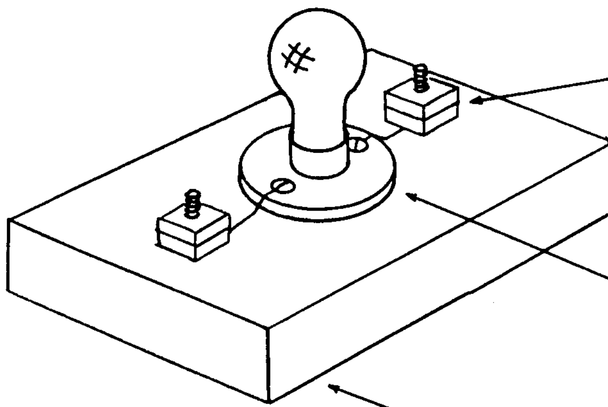
(iv) Some idea of the strength of the battery is obtained by comparing the discharge of a small dry cell (through a five ohm resistor) with the above observations. The results indicate that the dry cell is not as steady a source of current and voltage as the battery after successive recharging, but that it is much steadier than the battery after only one charge.

t Minutes	V Volts	I Amps
1	1.39	0.25
2	1.37	0.25
3	1.36	0.24
4	1.35	0.24
5	1.35	0.24

(v) Somewhat similar results are obtained if the battery is filled with sodium sulphate electrolyte and tested in the same way.

B. CIRCUIT COMPONENTS

Bl. Bulb Holder with Bulb



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	7 c m x 3 c m x l c m
(2) Bulb Holder	1	Bulb Holder (B)	To hold flashlight bulbs
	1	Bulb (C)	1.1, 2.5, or 6.2 volts
(3) Terminals	2	Brass Bolts (D)	0.3 cm diameter, 2.5 cm long
	4	Nuts (E)	0.3 cm internal diameter
	2	Magnet Wire (F)	4 cm long

b. Construction

(1) Base

Use the wood (A) to serve as the base of the bulb holder.

(2) Bulb Holder

Obtain a bulb holder (B) (porcelain or metal) from the local market, and screw it onto the base. The holder should take a variety of local bulbs (C) (e.g., 1.1 volts, 2.5 volts and 6.2 volts).

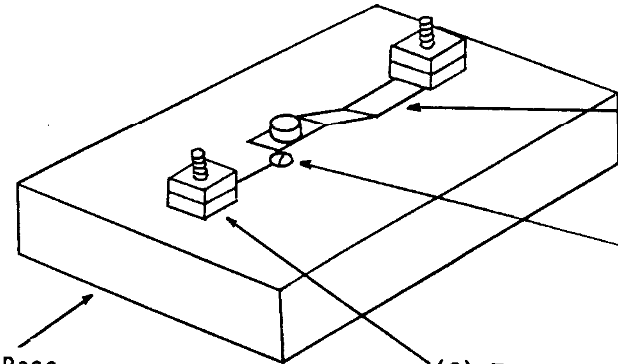
(3) Terminals

Make the terminals from the nuts (E) and bolts (D) as described in item VIII/A2, Component (4). Use the magnet wire (F) to connect the bulb and terminals, not forgetting to clean the ends of the wire.

C. Notes

(i) Bulbs may be used not only to investigate electrical phenomena in simple circuits, but also to serve as suitable resistances.

B2. Switch ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	7 c m x 3 c m x l c m
(2) Terminals	2	Brass Bolts (B)	0.3 cm diameter, 2.5 cm long
	4	Nuts (C)	0.3 cm internal diameter
(3) Contact Point	1	Brass Screw (D)	0.8 cm long
	1	Magnet Wire (E)	#22, 3 cm long
(4) Spring	1	Brass Sheet (F)	5 cm x 1 cm x 0.1 cm
	1	Wooden Dowel (G)	1 cm diameter, 0.5 cm long

b. Construction

(1) Base

Use the wood (A) to serve as the base of the switch.

(2) Terminals

Make the terminals from the nuts (C) and bolts (B) as described in item VIII/A2, Component (4).

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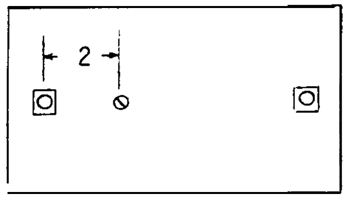
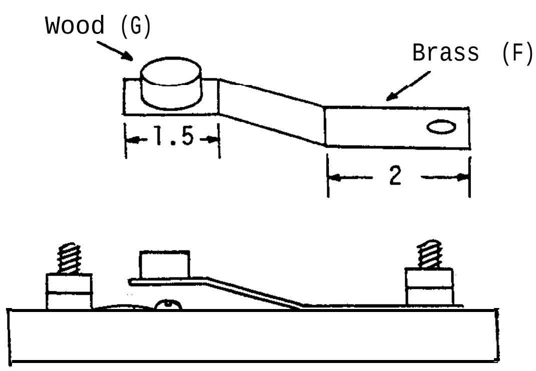
(3) Contact Point



Top View

Screw the brass screw (D) into the wood (2 cm from one terminal) and connect it to the terminal by means of the short length of copper wire (E).

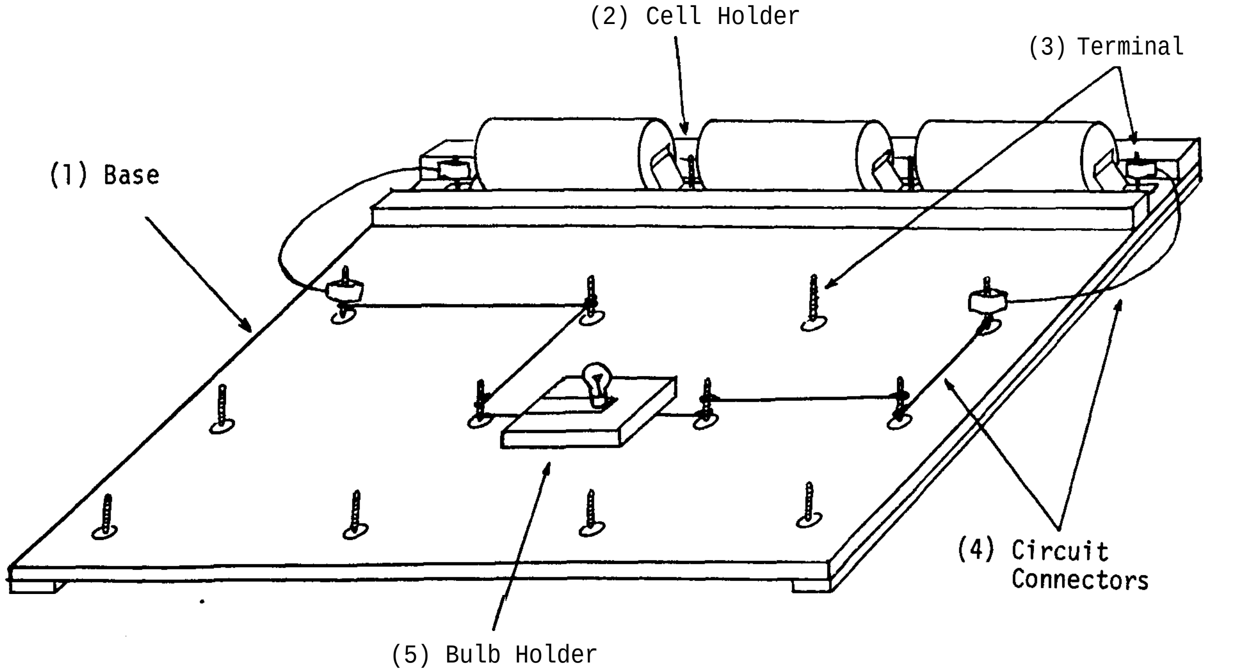
(4) Spring



Side View

Make the spring out of the piece of brass sheeting (F). Drill a small hole (0.3 cm diameter) in one end of the spring so that the terminal bolt will pass through it, and hold the spring in position by fastening the terminal locking nut. Cut the wooden head (G) and attach it to the free end of the spring with epoxy resin.

63. Circuit Board



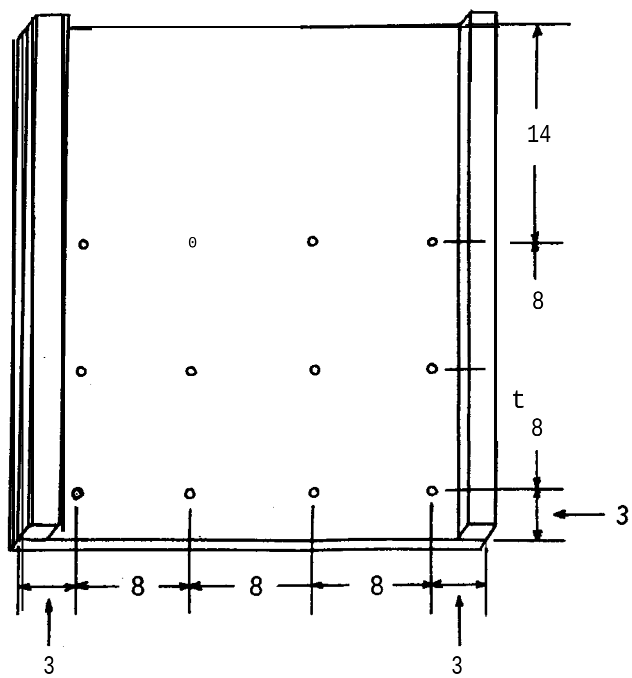
a. Materials Required

Components	Qu	Items Required	Dimensions
(1 Base	1	Plywood (A)	33 cm x 30 cm x 0.6 cm
	2	Wood (B)	33 cm x 2 cm x 0.5 cm
(2) Cell Holder	2	Wood (C)	30 cm x 2 cm x 2 cm
	3	Dry Cells (D)	1.5 volts each
	2	Metal Strips (E)	4 cm x 2 cm x 0.02 cm
	2	Metal Strips (F)	6 cm x 2 cm x 0.02 cm
	4	Bolts (G)	0.3 cm diameter, 4 cm long
	4	Nuts (H)	0.3 cm internal diameter
	8	Washers (I)	Approximately 1.2 cm external diameter
(3) Terminals	12	Bolts (J)	0.3 cm diameter, 4 cm long
	12	Nuts (K)	0.3 cm internal diameter
	24	Washers (L)	Approximately 1.2 cm external diameter
(4) Circuit Connectors	12	Coat Hanger Wire (M)	10 cm long
	10	Metal Strips (N)	6 cm x 1.5 cm x 0.02 cm

	5	Copper Wires (0)	#18, 25 cm long
(5) Bulb Holders	3	Wood (P)	5 cm x 3 cm x 2 cm
	3	Coat Hanger Wires (Q)	6 cm long
	3	Eye Screws (R)	Approximately 3 cm long
	6	Screws (S)	1 cm long, approximately
	3	Washers (T)	--
	3	Metal Sheets (U)	3 cm x 2 cm x 0.02 cm
	--	Assorted Flashlight Bulbs (V)	--

b. Construction

(1) Base

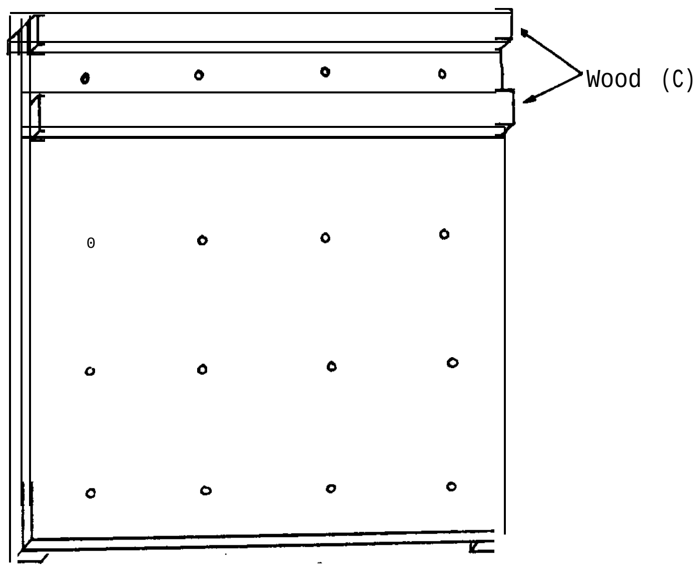


Botton View

Drill 12 holes (diameter 0.3 cm) through the plywood (A) in the positions indicated. If a piece of scrap wood is placed beneath the plywood during drilling the bottom edges of the hole will not splinter so readily.

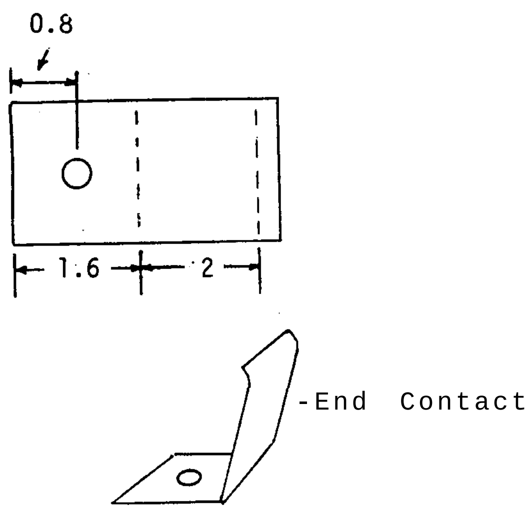
Glue the two strips of wood (B) along the bottom edges of the base, at right angles to the grain of the wood, so that bending or warping of the base is prevented.

(2) Cell Holder



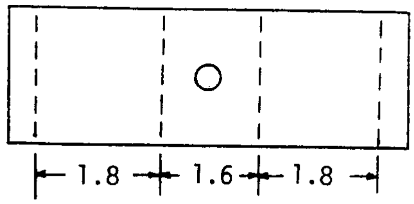
Use two pieces of wood (C) to serve as the cell holder strips. Using nails and glue attach one strip to the end of the base which has not yet been drilled with holes. Place the second strip parallel to, and about 3 cm away from, the first strip. Adjust the separation between the two strips so that they will hold three dry cells (D) snugly in position. Then glue and nail the second strip firmly in position.

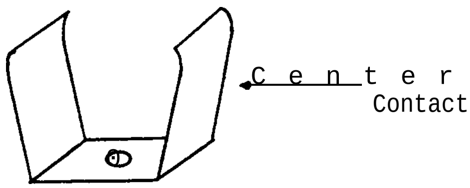
Drill four holes (diameter 0.3 cm) between the two strips as illustrated.



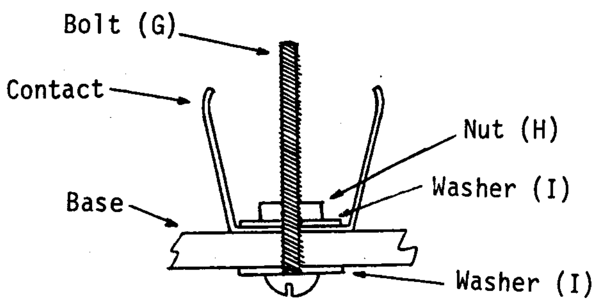
The two strips of flexible metal (E) may be cut from a tin can (or similar source). Drill a hole (0.3 cm diameter) in the end of each sheet, and then bend the sheet into the shape of an end contact, as indicated. Use sandpaper to remove any coating which might interfere with good electrical contact.

Two more metal strips (F) may be cut from the same source as before. Drill a hole (0.3 cm diameter) at the mid-point of each strip, and then bend each, as indicated, into the shape of a center contact. Use sand-paper to remove any coating which might interfere with good electrical contact.

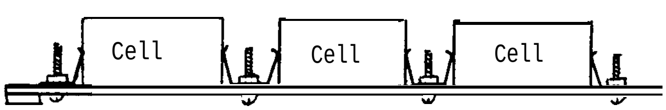




Mount the contacts in position on the circuit board base, in each instance using a bolt (G), a nut (H) and two washers (I). The purpose of the washers is to hold the bolts (which also serve as terminals) rigidly in a vertical position.



Side View
(Cross-section)

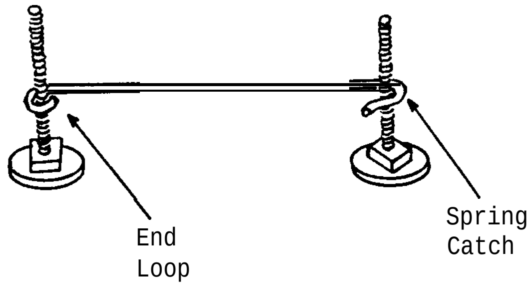


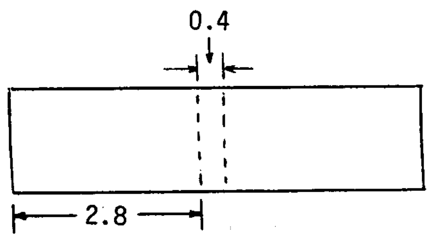
Side View

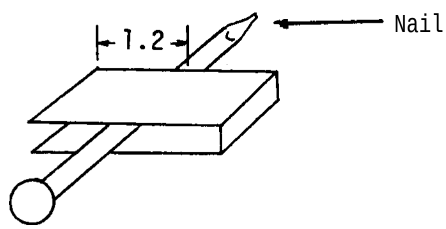
(3) Terminals

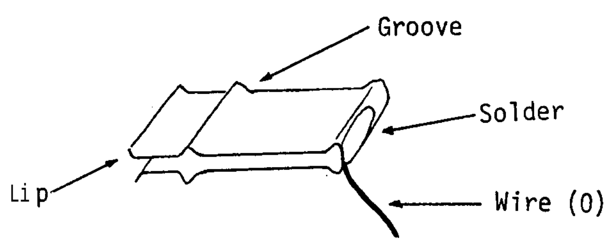
Fit 12 terminals in the remaining holes in the base. Each terminal is made in the same way as described above, each consisting of a bolt (J), a nut (K) and two washers (L).

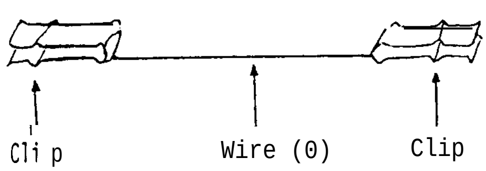
(4) Circuit Connectors







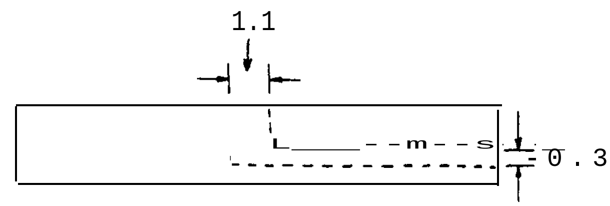




Remove any paint or coating from the wires (M) with sandpaper. Bend one end of each wire into a loop, and slip this onto one of the terminals. Bend the free end of the wire around an adjacent terminal so as to form a spring catch. Make a small lip on the end of the catch, thus permitting the catch to be readily attached to, or released from, an adjoining terminal.

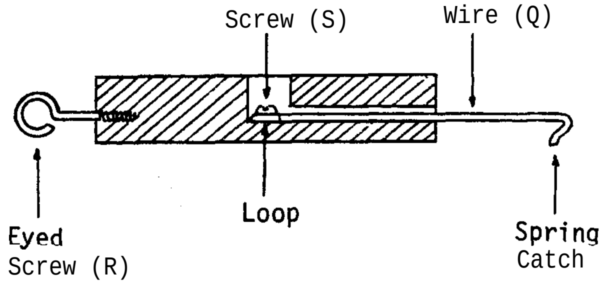
The ten strips of metal (N) may be cut from a tin can or similar source (brass sheet, etc.). Clean the surfaces with sandpaper. Bend each sheet into a "U" shape in which the sides are 0.4 cm apart. Then place a nail (0.2 cm diameter) between the sides of the "U" sheet, and squeeze the sheet on either side of the nail with pliers to form a small groove. Make small lips on the open ends of the "U" sheet to permit easy attachment to the terminal posts. Finally, attach each end of each copper wire (0) to one of the newly created clips with the help of solder. You should now have twelve coat hanger wire connections and five copper wire connections for completing circuits.

(5) Bulb Holders



Side View

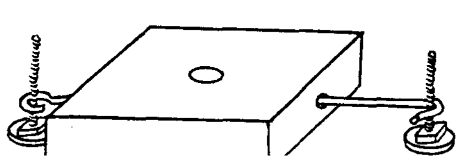
Drill a vertical hole (1.0 cm diameter, 1cm deep) into the middle of the top surface of the wood (P). Drill a horizontal hole (0.3 cm diameter) into the middle of one end of the block, so as to meet the first hole.

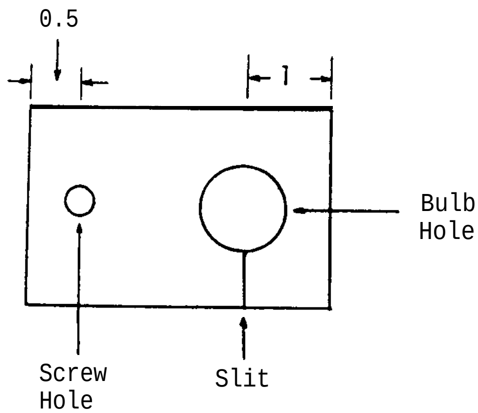


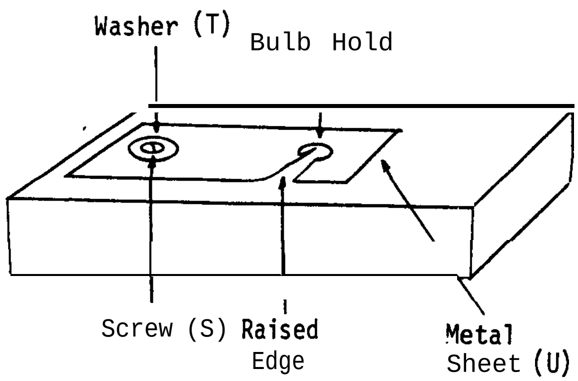
Cross Section

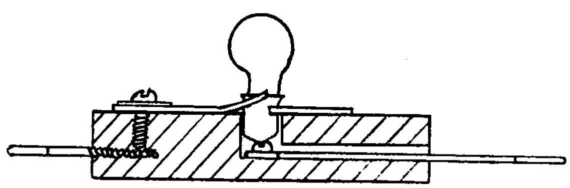
Clean the surface of the wire (Q) with sandpaper. Insert one end of the wire fully into the horizontal hole, and using a pair of dog-nosed pliers (inserted through the vertical hole) bend a loop into the inserted end of the wire. Insert a small screw (S) through the loop to attach the wire permanently within the block.

Fit an eye screw (R) into the middle of the other end of the block, and finally make a spring catch in the free end of the coat hanger wire (Q) (in just the same way as for the circuit connectors) so that the holder may be readily connected between adjacent terminals on the circuit board.









Cross Section

The flexible sheet of metal (U) may be cut from a tin can, or similar source (thin brass sheet). Drill a bulb hole (diameter 0.9 cm) and screw hole (diameter 0.3 cm) in the sheet as indicated. Make a cut in the sheet between one outer edge and the bulb hole. If one side of the slit is raised slightly higher than the other, the hole will serve as a screw socket for a bulb (V). Use a small screw (S) and washer (T) to attach the metal sheet to the top of the block so that the bulb hole in the sheet sits over the hole in the block.

The screw (S) should also be centered on the block so that it makes contact with the threads of the eye screw (R). (If this adjustment is found difficult, contact between the two screws may be made by soldering a short length of copper wire from one screw to the other.)

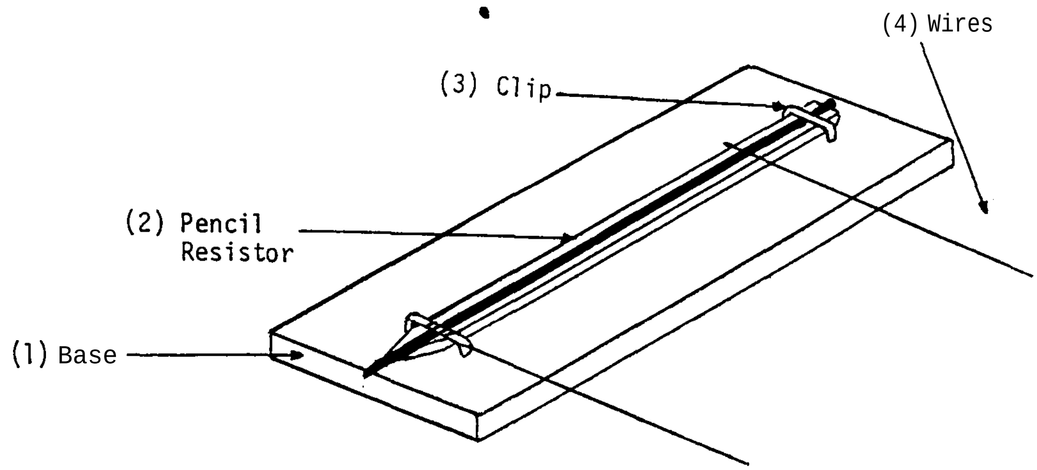
Three identical bulb holders should be made, each with a selection of bulbs (V) (e.g., 1.1 volts, 2.5 volts, 6.2 volts).

C. Notes

(i) The Circuit Board is a very convenient way of setting up electrical circuits. A typical series of experiments using such a circuit board will be found in Nuffield Foundation, Nuffield Physics, Guide to Experiments 2, (London: Longmans/ Penguin Books, 1967), pp 16-63.

C. RESISTORS

Cl. Variable Resistor (Carbon)



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	20 cm x 3 cm x 1 cm
(2) Pencil	1	Pencil (B)	20 cm long, approximately
(3) Clips	2	"U" Tacks (C)	--
(4) Wires	2	Copper Wires (Cotton or Plastic Covered) (D)	#22, 30 cm long

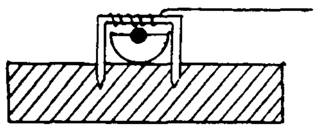
b. Construction

(1) Base — Use wood (A) as the base.

(2) Pencil Resistor — Split a soft lead pencil in half so that the lead (B) protrudes along its axis. It is important that the lead should not be broken or cracked by this process.

(3) Clips — Take two U-shaped tacks (C), normally used for securing electrical leads, and secure the pencil (B) to the base (A). One of the clips should be left relatively loose.

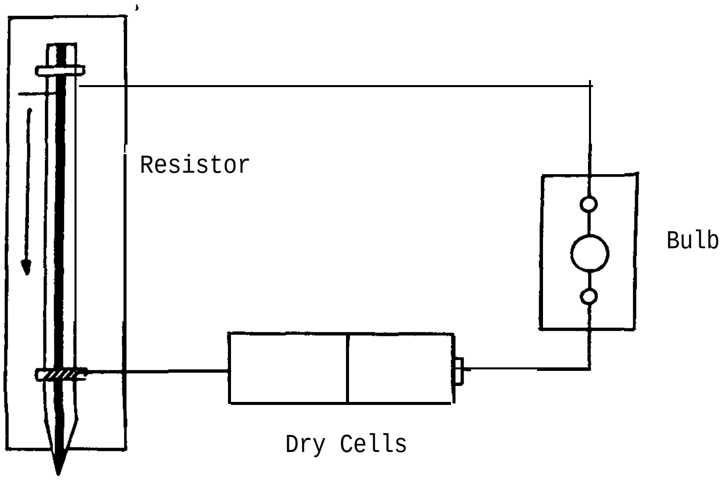
(4) Wires


Cross Section

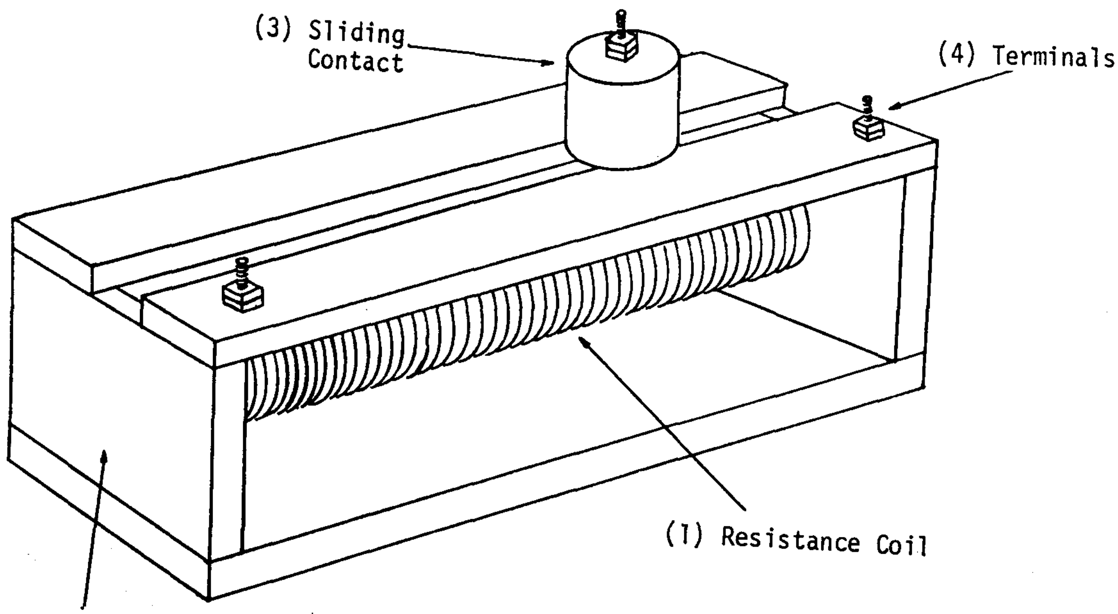
Take the bare end of a length of copper wire (D), and wrap it around the loose clip, so that when the latter is tapped securely into position the copper wire makes good contact with the pencil lead.

C. Notes

(i) If the resistor is connected into a circuit in series with two dry cells (1.5 volts each) and a flash-light bulb (approximately 1.5 volts), it will be found that increasing the length of pencil lead included in the circuit will diminish the brightness of the bulb, the **full length** of lead (approximately 20 cm of **#2B** lead) almost extinguishing the light altogether.



C2. Variable Resistor (Nichrome)



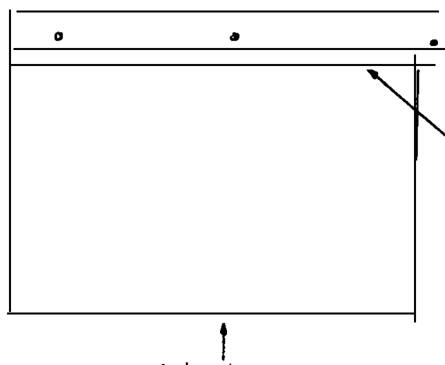
a. Materials Required

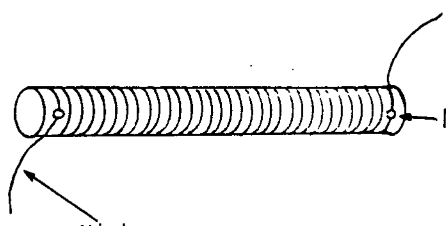
Components	Qu	Items Required	Dimensions
(1) Resistance Coil	1	Wooden Dowel (A)	26 cm long, 2.5 cm diameter
	1	Asbestos Paper (B)	40 cm x 26 cm
	1	Nichrome Wire (C)	#20, 450 cm long
(2) Coil Support	1	Wood (D)	30 cm x 7.5 cm x 2 cm
	2	Wood (E)	8 cm x 7.5 cm x 2 cm
	2	Plywood (F)	30 cm x 3 cm x 0.7 cm
(3) Sliding Contact	1	Wood Dowel (G)	3 cm diameter, 3 cm long
	1	Wood Dowel (H)	3 cm diameter, 1 cm long
	1	Brass Strip (I)	13 cm x 1 cm x 0.02 cm
	1	Bolt (J)	0.3 cm diameter, 6 cm long
	3	Nuts (K)	0.3 cm internal diameter
		Washers (L)	1.2 cm external diameter

(4) Terminals	2	Bolts (M)	0.3 cm diameter, 2.5 cm long
	4	Nuts (N)	0.3 cm internal diameter

b. Construction

(1) Resistance Coil



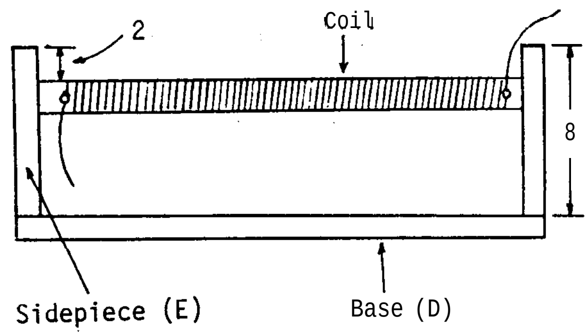


The dimensions of the apparatus depend very much on the resistance required. In this case a 25 ohm resistor, capable of carrying a current of up to 3 amps was required, and it was decided that this could be achieved by using some 400 cm of #20 nichrome wire which had a resistance of approximately 1 ohm per 16 cm length. This determined the dimensions of the coil and the resulting item of equipment.

Attach the asbestos paper (B) to the wooden dowel (A), as indicated, with two or three short nails, and then wrap the paper closely around the dowel. There should be enough paper to make about five layers. Attach the loose end of the asbestos paper to the dowel with two or three more short nails.

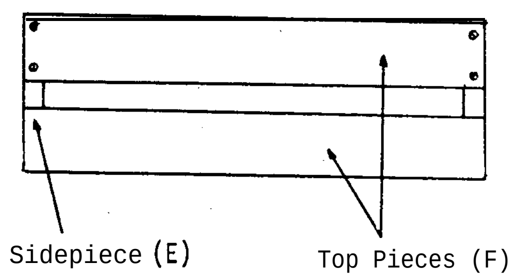
Attach the nichrome wire (C) to one end of the dowel by means of a nail, leaving about 7 cm of wire as a free end. Wrap the wire firmly around the dowel to make a coil with a regular 0.5 cm between turns. Do not allow the wire to touch any of the nail heads in the dowel, thus avoiding a "short" between adjacent turns. On reaching the end of the dowel, attach the wire once more to the dowel with a short nail. Cut off any unnecessary wire, leaving about 7 cm as a free end.

(2) Coil Support



Side View

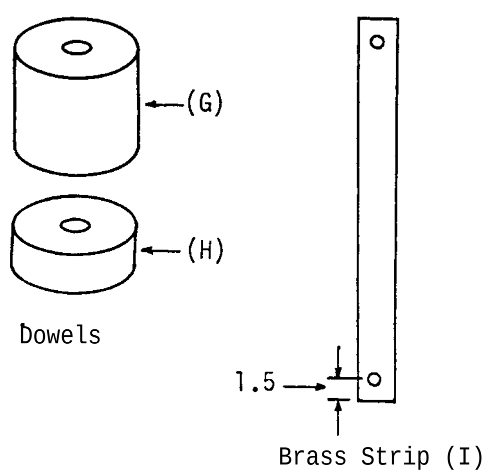
Make a support for the resistance coil from wood (D) for the base and wood (E) for the two side-pieces. Nail the resistance coil between the sidepieces (E) such that it is 2 cm from the top of, and on the median bisecting, each sidepiece.



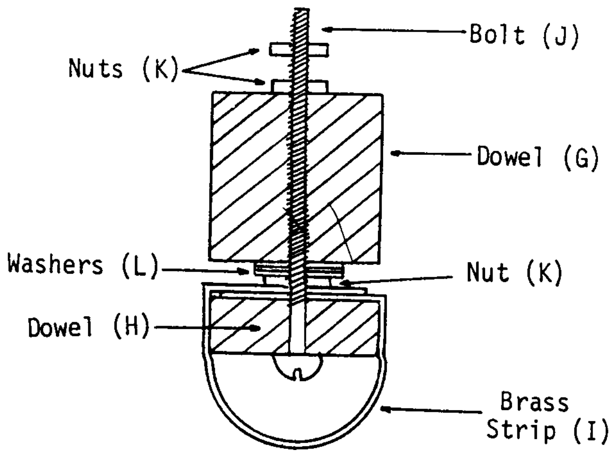
Top View

Set the two pieces of ply-wood (F) in position on top of the support as indicated, but only screw one piece in position for the moment.

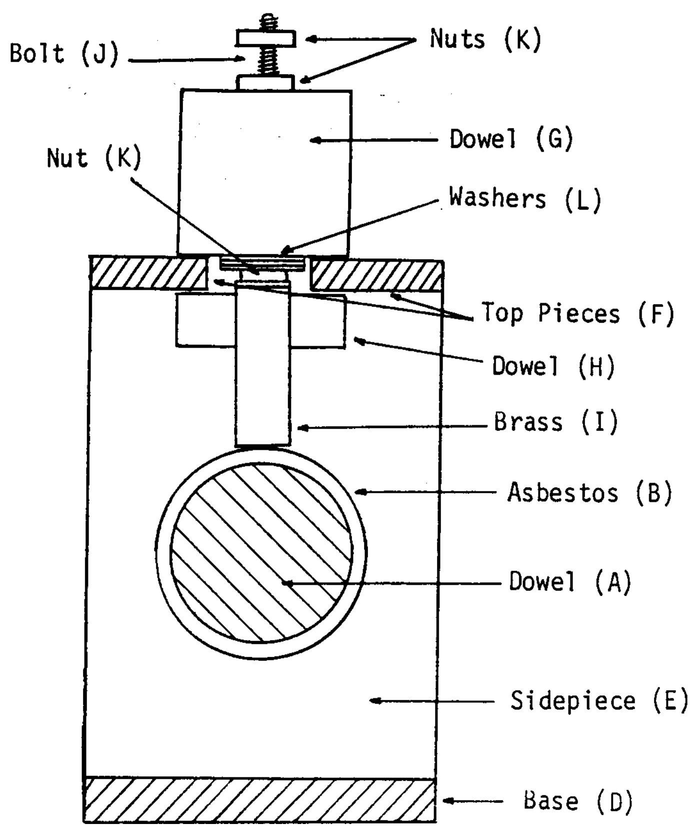
(3) Sliding Contact



Bore a hole (diameter 0.3 cm) along the axis of each dowel (G,H). Similarly, drill a ho (0.3 cm diameter) at a distance of 1.5 cm from either end of the brass strip (I).



Side View
(Cross-section)



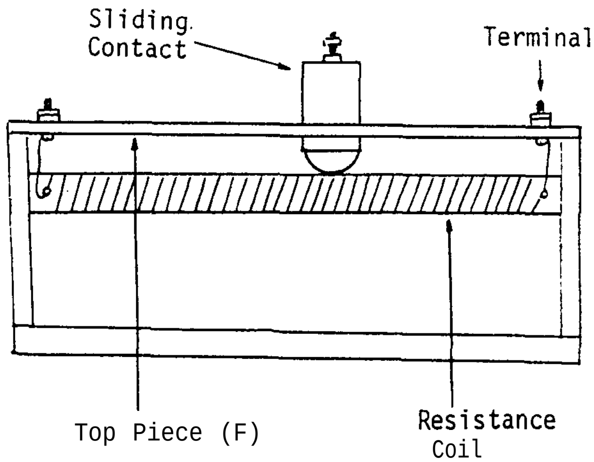
End View
(Cross-section)

Bend the brass strip (I) into a semicircular shape around the smaller dowel. Insert the bolt (J) through the lower dowel (H) and the end holes in the brass strip (I). Lock the strip in position with a nut (K), and then add washers (L) (no more than 1.2 cm in diameter) to create a spacer between the two dowels of 8.8 cm depth. Slide the larger dowel (G) onto the bolt, and fix it in position with a locking nut (K). Add another nut (K) to serve as a terminal.

Place the sliding contact above the resistance coil so that the fixed top piece of the support fits into the space between the dowels of the sliding contact. Take the second top piece (F) already cut, and set it in position on top of the support so that it holds the sliding contact in position in contact with the resistance coil. Screw the top piece in position on top of the endpieces. If necessary, adjust the position of the resistance coil to insure not only that there is good electrical contact between the sliding contact and the resistance coil, but also that the contact slides smoothly along the length of the coil.

(4) Terminals

Use the nuts (N) and bolts (M) to make two terminals [see VIII/AZ, Component (4)], one at either end of the support top piece, and fasten the free ends of the resistance coil to these terminals.



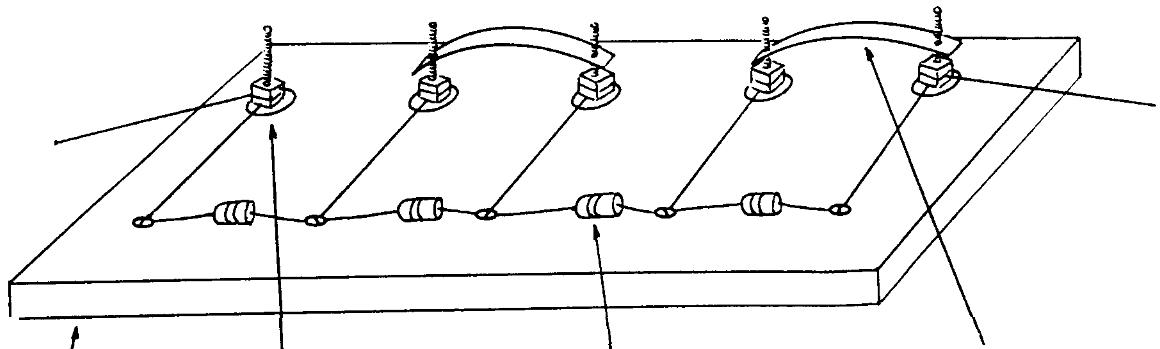
Side View

c. Notes

(i) If the resistor is connected into a circuit by means of the two fixed terminals, a fixed resistance of 25 ohms is added to the circuit. If the terminals used are one fixed terminal and the terminal on the sliding contact, then the resistance added to the circuit may be varied from 25 ohms to almost zero.

(ii) A current passing through the coil will tend to heat it up. A Z-amp current makes the coil fairly hot, and a 3-amp current makes it very hot, but the heating does not affect the performance of the resistor.

C3. Decade Resistor



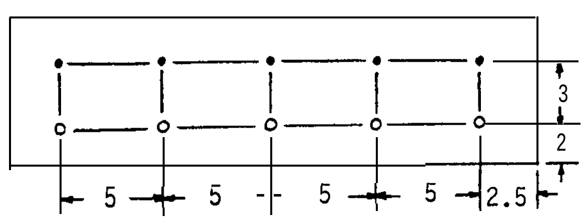
a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	25 cm x 7 cm x 2 cm
(2) Terminals	5	Bolts (B)	0.4 cm diameter, 5 cm long
	10	Nuts (C)	0.4 cm internal diameter
	20	Washers (D)	--
(3) Resistors	1	Resistor (E)	10 ohms, 2.5 watts
	1	Resistor (F)	20 ohms, 1.5 watts
	2	Resistors (G)	30 ohms, 1.0 watt
	1	Copper Wire (H)	#24, 30 cm long
	5	Screws (I)	1.5 cm long
(4) Connectors	4	Brass Strips (J)	7.5 cm x 1.5 cm x 0.05 cm

b. Construction

(1) Base

Use wood (A) for the base. Mark on the top surface the position of the terminals and screws as indicated.

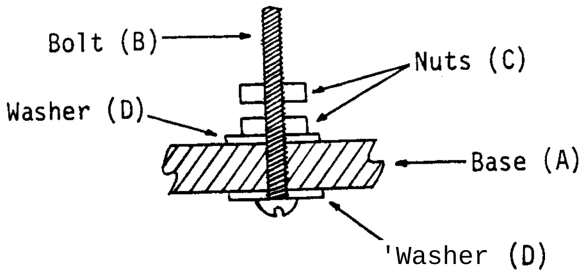


• Terminal Positions

0 Screw Positions

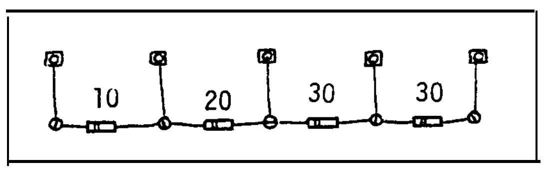
(2) Terminals

Drill holes (0.4 cm diameter) in the base (A) in the terminal positions, making sure that the holes are at right angles to the plane of the base. Use a bolt (B), two nuts (C), and two washers (D) to make each terminal.



(3) Resistors

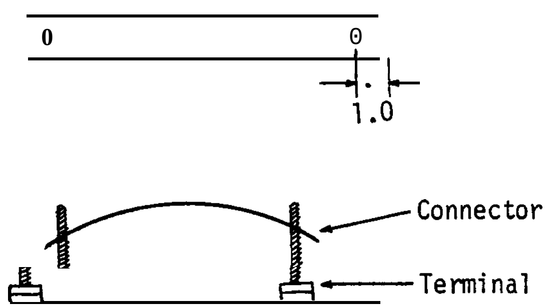
Insert five screws (I) into the base in the positions indicated. Connect each screw to the neares terminal with a short length of copper wire (H). Connect radio resistors (E, F, G) (see notes) of 10, 20, 30 and 30 ohms betwee successive pairs of screws (see notes).



Top View

(4) Connectors

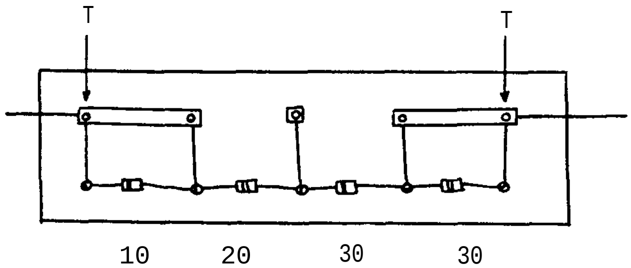
Make four connectors from the brass sheeting (J). Drill a hole (0.7 cm diameter) at a distance of 1.0 cm from each end. Squeezed gently into the shape of an arc, it should be possible to set the connector across two terminals, thus shorting one of the resistors out of the circuit.



Side View

C. Notes

(i) The resistance between the main terminals (T) may be any multiple of 10 ohms from 0 to 90, according to the way in which the connectors are placed across the terminals. In the case illustrated the resistance would be 50 ohms.



(ii) If the decade resistor is designed for use with a voltage supply of no more than 5 volts then the 10, 20, and 30 ohm resistors purchased should have ratings of 2.5, 1.5 and 1.0 watts respectively.

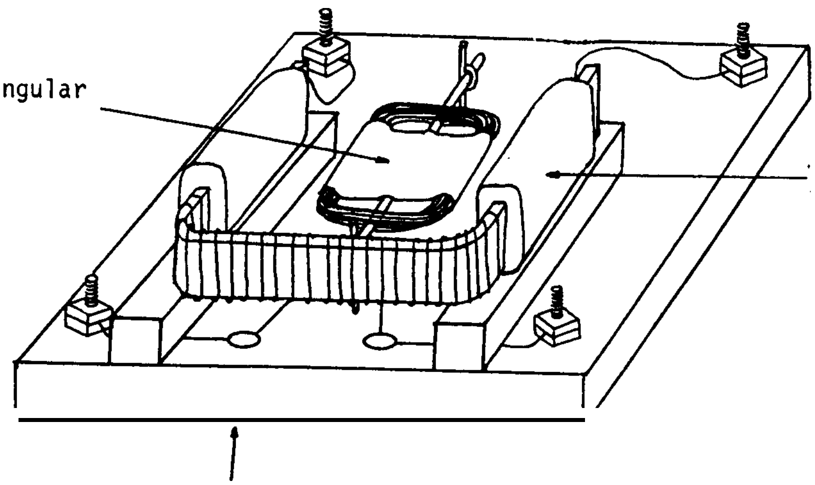
R Ohms	V Volts	I Amps	W Watts
10	5	0.50	2.50
20	5	0.25	1.25
30	5	0.17	0.83

Alternatively, if all the resistors purchased were rated at 1 watt, then the voltage placed across the 10, 20 and 30 ohm resistors should never exceed 3.0, 4.5 and 5.5 volts respectively.

R Ohms	W Watts	V = W.R Volts
10	1.0	3.2
20	1.0	4.5
30	1.0	5.5
40	1.0	6.3
50	1.0	7.1
60	1.0	7.6
70	1.0	8.4
80	1.0	8.9
90	1.0	9.5

D. DYNAMO/MOTORS

Dl. Simple Motor

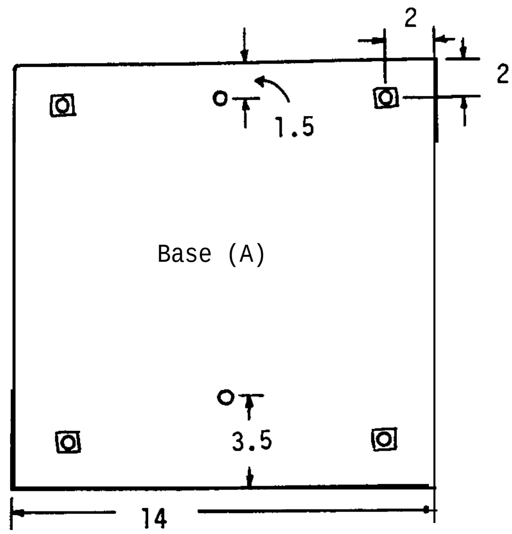


a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	14 cm x 13 cm x 1.5 cm
	4	Bolts (B)	0.3 cm diameter, 3.0 cm long
	a	Nuts (C)	0.3 cm internal diameter
	2	Coat Hanger Wire (D)	7 cm long, 0.2 cm diameter
(2) Rectangular Coil	1	Roll of Magnet Wire (E)	#26
	1	Coat Hanger Wire (F)	10 cm long, 0.2 cm diameter
	1	Insulating Tape (G)	--
	1	Masking Tape (H)	--
	2	Magnet Wire (I)	#26, 10 cm long
	4	Thumbtacks (J)	--
(3) Electromagnet	1	Soft Iron Bar (K)	17.5 cm x 2.0 cm x 0.3 cm
	1	Roll of Magnet Wire (L)	#26, approximately 100 g
	1	Masking Tape (M)	--
	2	Wood Strips (N)	a cm x 1.5 cm x 1.0 cm

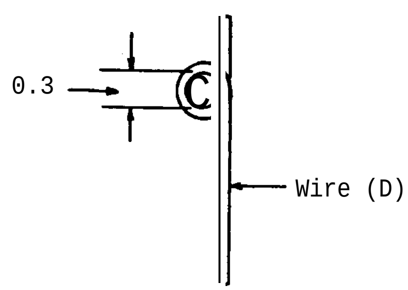
b. Construction

(1) Base



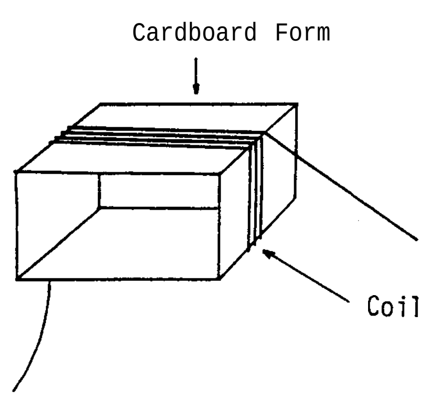
Top View

Use wood (A) as the base. Use the four bolts (B) and eight nuts (C) to make four terminals [see VIII/A2, Component (4)]. Attach a terminal at each corner of the base, making sure to inset the boltheads into the bottom of the base. Drill two holes (0.2 cm diameter, 1.0 cm deep) into the base to hold the vertical supports.

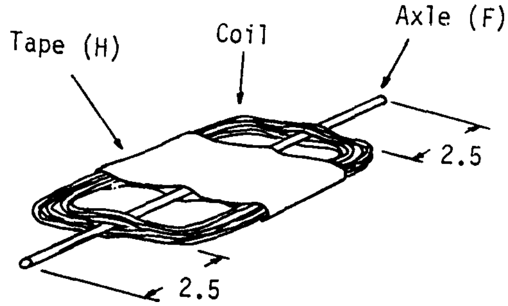


Make two vertical supports for the coil by twisting the coat hanger wire (D) into the shape indicated. Set the supports vertically upright in the newly drilled holes in the base.

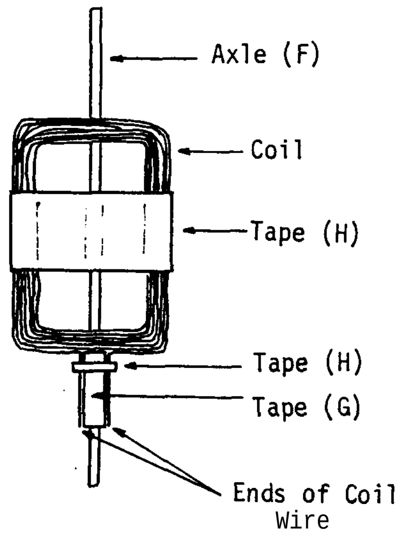
(2) Rectangular Coil



Wind 30 turns of magnet wire (E) around a cardboard form in order to make a coil of internal size 3.5 cm x 1.5 cm. Leave 10 cm of wire free at either end of the coil.

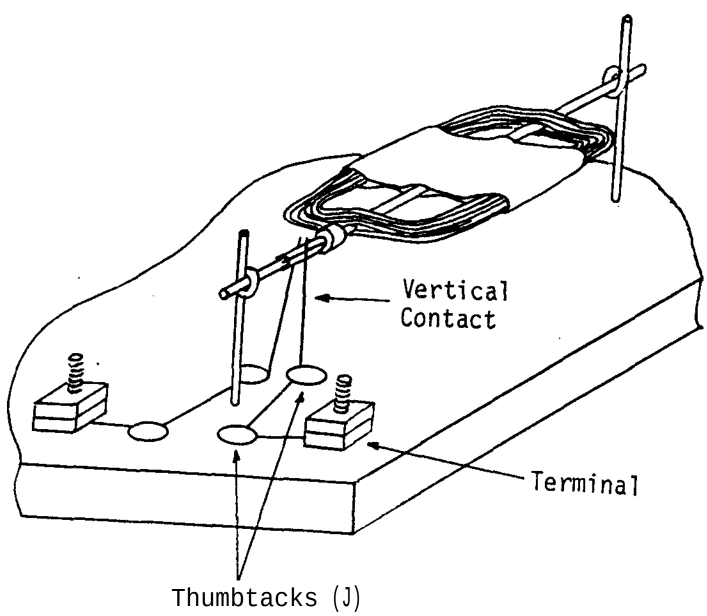


Take the length of straight coat hanger wire (F) and thread it through the middle of the coil to serve as the axle. W r a the masking tape (H) around the coil and axle to hold the coil firmly in position.



Wrap a length of insulating tape (G) around the axle, adjacent and external to the coil, to create a region of insulation, 1.5 cm long, on the axle (F).

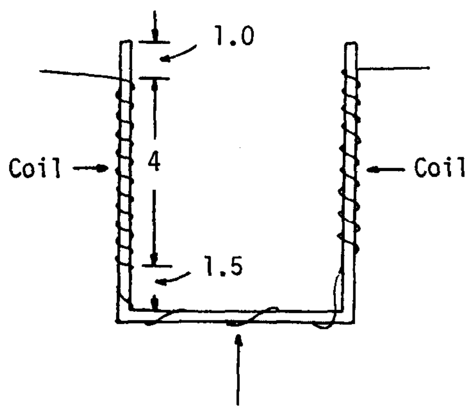
Adjust the ends of the coil wire so that they lie parallel to this insulated portion of the axle, and on either side of it. Cut the parallel wires so that they do not protrude beyond the insulation. Clean the enamel off the wire with sandpaper.



Fasten a thin piece of masking tape (H) around the ends of the coil wire and axle, thus keeping the ends of the coil wire in position. Fit the coil axle into the coil supports on the base. Take the two lengths of copper wire (I), and remove the varnish from the ends. Make one end of each wire into a vertical contact which just touches one of the wire ends from the coil. Hold each wire in position on the base with thumbtacks (J), and attach the free end of the wire to one of the front terminals as indicated.

(3) Electromagnet

A simple horseshoe magnet, with poles about 4 cm apart, will serve the purpose well. However, if a suitable horseshoe magnet is not available, an electromagnet may readily be made as follows.



Connecting Turns

Take a soft iron bar (K), and bend it into a horseshoe shape with parallel sides 4.5 cm apart. Take about 100 g of #26 magnet wire (L), and wind a coil on each side of the U-shaped bar. Each coil should be about 4 cm long, and should contain ten layers of wire. The coils should be connected in series to one another, simply by continuing the windings in the same direction around the bar from one coil to the other in a series of widely spaced connecting turns. Cover the final layer of turns with masking tape (M) to hold the coils in position. Connect the free ends of the coils to the rear terminals on the base.

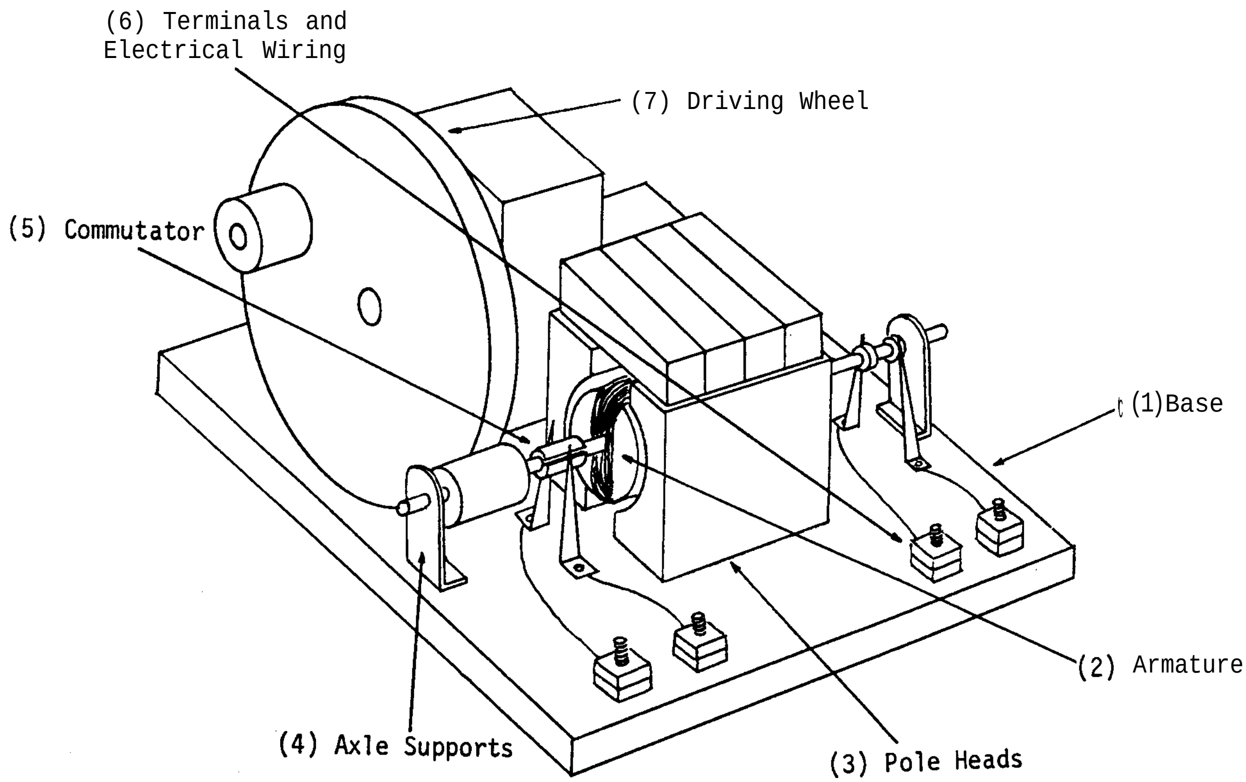
Place two wood strips (N) beneath the electromagnet such that the magnetic poles are either side of, and at the same height as, the middle of the rectangular coil.

c. Notes

(i) With a current of 1 amp through the electromagnet and about 0.7 amp through the rectangular coil, the latter will rotate quite rapidly, thus behaving as a motor. The current required may be readily provided by dry cells.

(ii) With a current of 1 amp through the electromagnet it is possible to generate a current in the rectangular coil by rotating it as rapidly as possible. However, the current generated is extremely small (of the order 0.1 milliamps).

D2. Dynamo/Motor ©



a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	2D cm x 15 cm x 2 cm
(2) Armature	1	Nail (B)	0.7 cm diameter, 15 cm long
	1	Box of Nails (C)	4 cm long
	1	Epoxy Resin (D)	--
	1	Roll of Magnet Wire (E)	#26
(3) Pole Heads	1	Box of Nails (F)	4 cm long
	1	Epoxy Resin (G)	--
	4	High Quality Steel (or Alnico) Bars (H)	7 cm x 1 cm x 1 cm

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide (London: Center for Educational Development Overseas, 1972), pp 61-/3

(4) Axle Supports	2	Brass Sheets (I)	5.5 cm x 2.0 cm x 0.2 cm
	1	Masking Tape (J)	--
(5) Commutators	1	Brass Tube (K)	1 cm long, 1 cm external diameter, 0.8 cm internal diameter
	1	Epoxy Resin (L)	--
	2	Brass Sheets (M)	5.0 cm x 1.0 cm x 0.1 cm
	1	Brass Tube (N)	1 cm long, 1 cm external diameter, 0.8 cm internal diameter
	2	Brass Sheets (O)	5.0 cm x 1.0 cm x 0.1 cm
	1	Magnet Wire (P)	#26, 15 cm long
(6) Terminals and Electric Wiring	4	Bolts (Q)	0.3 cm diameter, 3.5 cm long
	a	Nuts (R)	0.3 cm internal diameter
	1	Magnet Wire (S)	#26, 40 cm long
(7) Driving Wheel System	1	Wooden Spool (T)	2.5 cm long, 3 cm diameter
	1	Rubber Strip (U)	9.5 cm x 2.5 cm
	1	Wood (V)	12 cm x 5 cm x 4 cm
	1	Wood Disc (W)	15 cm diameter, 1.5 cm thick
	1	Nail (Y)	0.7 cm diameter, 6 cm long
	1	Wooden Spool (Z)	2.5 cm long, 2.5 cm diameter
	1	Screw (AA)	4 cm long
	4	Washers (BB)	0.8 cm internal diameter diameter, approximately

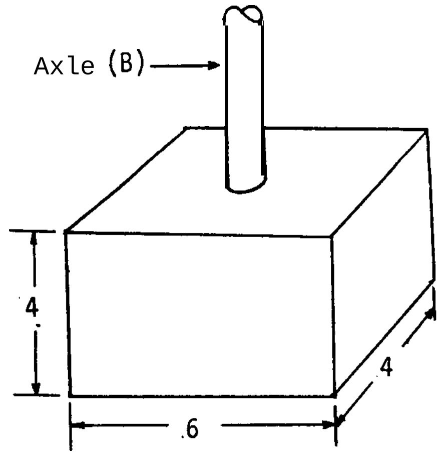
b. Construction

(1) Base

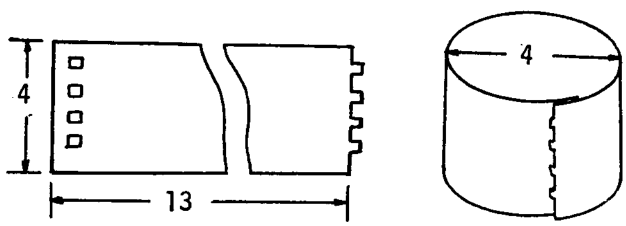
Use the wood (A) as the base.

(2) Armature

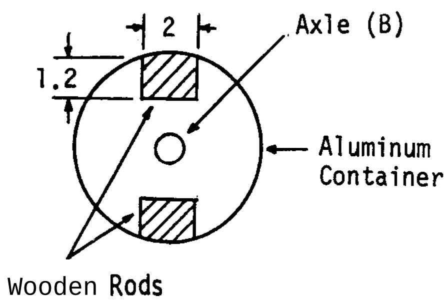
Take a wooden block, and drill a vertical hole (0.8 cm diameter) through its center so that it can support steel axle (B). The latter may be a very long nail with the head removed.



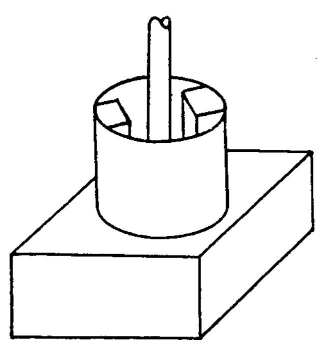
Take a sheet of aluminum (13 cm x 4 cm) and with the help of an appropriate series of end projections and holes make it into a cylindrical container (4 cm tall, 4 cm diameter).

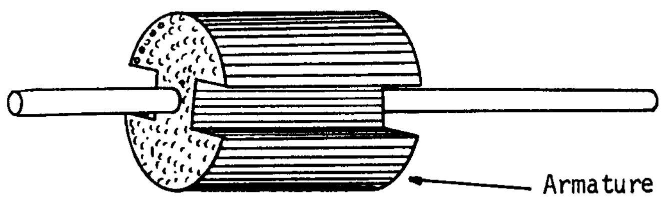


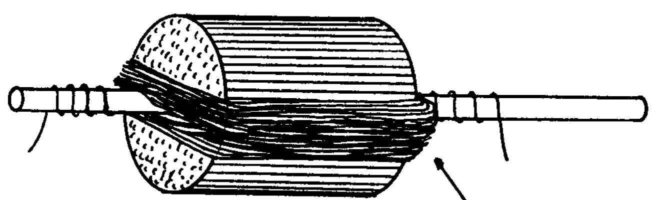
Place the container on the wooden block so that it encircles the axle. Take two wooden rods (4 cm x 2 cm x 1.2 cm) and stand these against opposite walls of the container. Now fill the remaining space in the container with the nails (C) (or similar soft iron material) packed closely side by side and parallel to the axle.



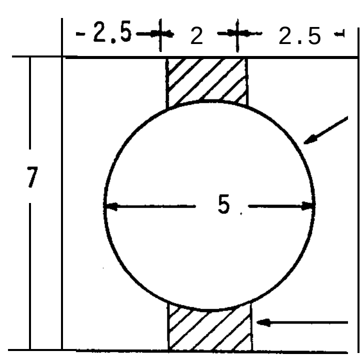
Top View







(3) Pole Heads

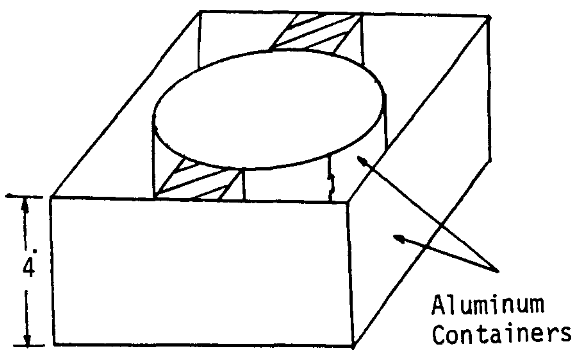


Top View

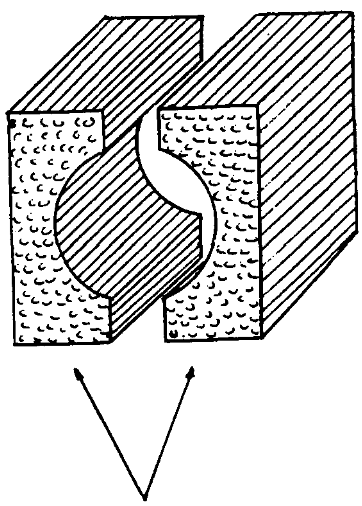
Cover the ends of the nails (not the wood) at both ends of the container with epoxy resin (D), so that when it dries the nails are welded together into a solid soft iron core, penetrated along its axis by the steel axle (B) protruding 4 cm at one end and 7 cm at the other. Remove the aluminum container and the wooden rods. You now have the core of your armature.

Wind as much magnet wire (E) as possible into a coil around the core, making sure that you have about 10 cm of both ends left free on completion of the coil. Temporarily twist the loose ends around the long end of the axle. The resistance of the coil will be approximately 5 ohms.

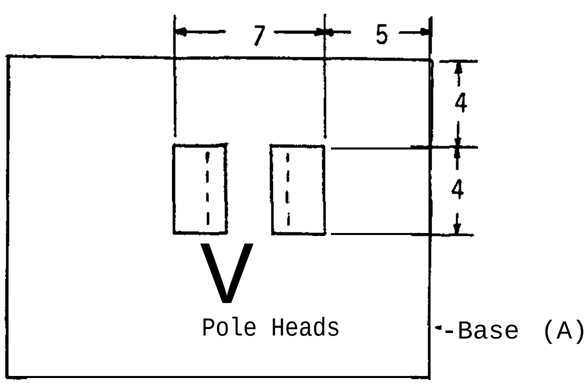
The pole heads are made in very much the same way as the armature core. Two open ended aluminum containers are required this time, one cylindrical (5 cm diameter, 4 cm long) and one a rectangular cube (7 cm x 7 cm x 4 cm). The cylindrical one is placed inside the rectangular one, and the two held apart by two wooden rods (2 cm x 1 cm x 4 cm). Just as when making the armature core, pack the space between the two containers with the nails (F) packed parallel to the axis of the cylindrical



container. Cover the nail ends at both extremities of the containers and the wooden rods. You will now have two pole heads.



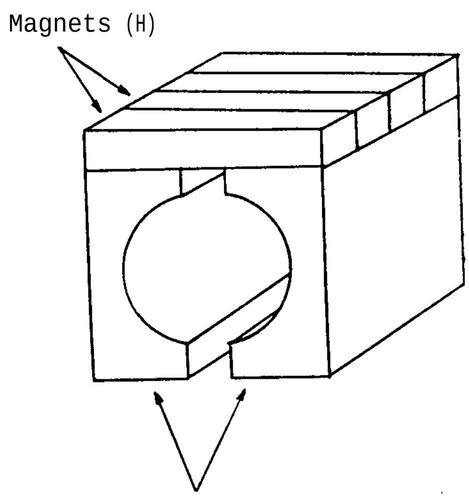
Pole Heads



Top View

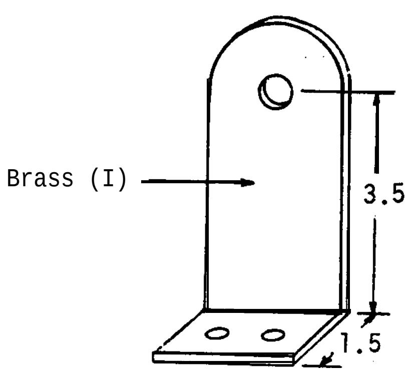
Place the pole heads on the base in the positions illustrated, and attach them firmly to the base with the help of epoxy resin.

Complete the system with four very strong magnets laid parallel to one another (North Pole touching North Pole) across the gap between

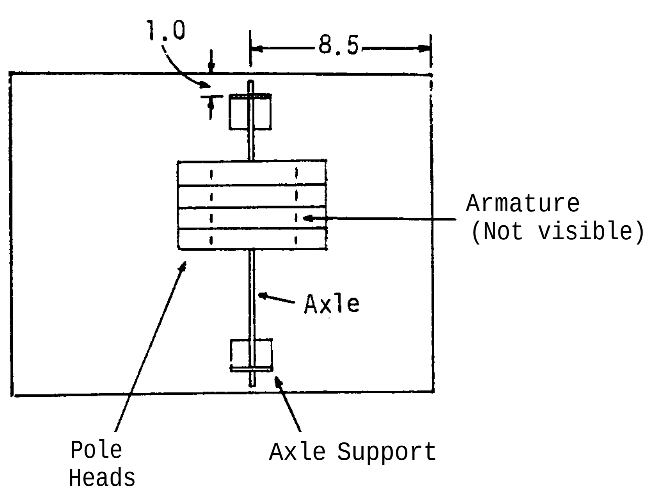


the pole heads. The magnet may be purchased, or made (as described under IX/Alfrom the steel bars (H).

(4) Axle Supporters

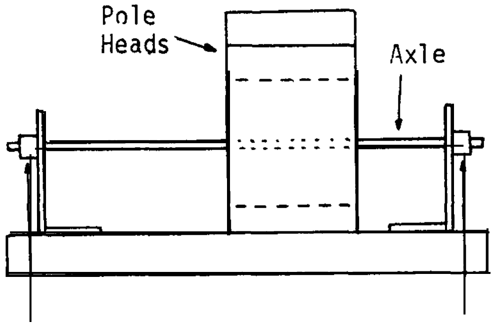


Make two axle supports out of the two brass sheets (I), drilling one hole (0.8 cm diameter) in the upright portion to take the axle, and two holes (0.3 cm diameter) in the base portion to take two screws.



Top View

Slide the supports on to either side of the axle (B), and attach them firmly to the base of the apparatus in the position shown.



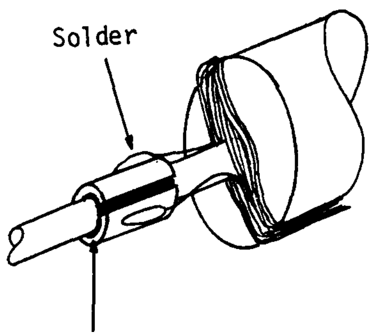
Side View

The axle may be held firmly in position by winding masking tape (J) (not scotch tape) around the axle next to, and just outside, the supports. Do this as a last step in constructing this item, however,

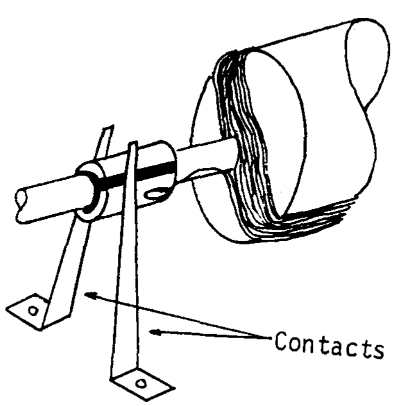
(5) Commutators

To make the DC commutator, take a piece of brass tubing (K), and cut it to make two halves.

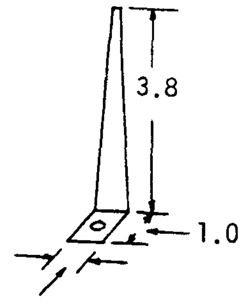
Take some epoxy resin (L), which is a good insulator, and coat all the inner surfaces of the two halves with resin about 0.1 cm thick.



Rotate the armature coil until it is in a vertical plane, and then attach the two split halves to the axle so that the split between the halves is in a horizontal plane. If the epoxy resin is thick enough, it will not only attach the split halves firmly to the axle, but will also insulate the two halves from one another, and from the axle itself.

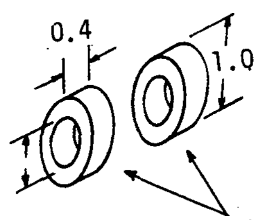


Take the two loose wires from the armature coil and, after cleaning the ends with sandpaper, solder one to one split half and the other to the other split half.

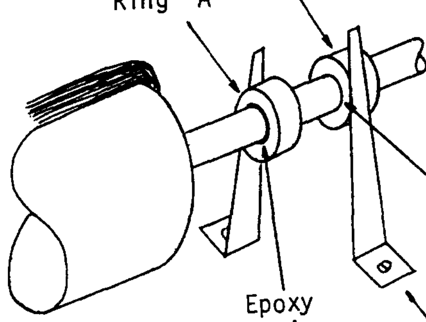


Cut two identical contacts out of the thin brass sheets (M) as shown. Attach these to the base of the apparatus with screws, so that they are in spring contact with opposite sides of the split halves.

The DC commutator is now complete.

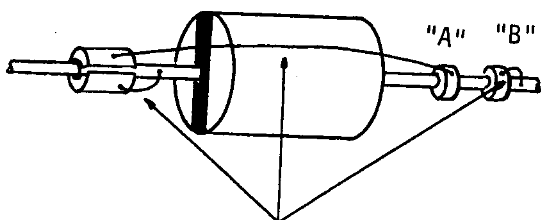


To make the AC commutator, cut two identical rings from the brass tubing (N).



Temporarily remove the axle support and slide the two rings onto the axle. Coat a length of axle (0.5 cm long) with epoxy resin about 0.1 cm thick and slide ring "A" into position over this. The epoxy resin should be such as to insulate the ring from the axle as well as to hold it firmly in position.

Ring "B" is soldered to the axle about 0.5 cm from ring A. Solder insures good electrical contact between the ring and axle. Two contacts, identical to those described above, should be cut from brass (O), and attached to the base so that each is in spring contact with one of the rings.

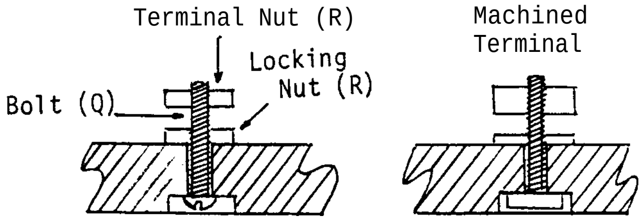


Connect ring "B" electrically to one of the split halves by soldering a very short length of magnet wire (P) from ring "B" to the axle and another piece from one split half to the axle. Don't forget to clean the ends of the magnet wire with sandpaper prior to soldering.

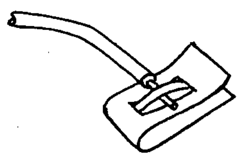
Connect ring "A" electrically to the other split half by soldering a length of magnet wire (P) from one to the other.

The AC commutator is now complete,

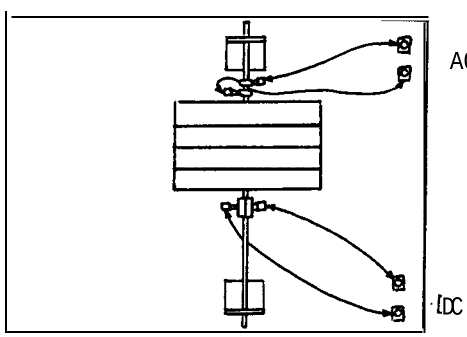
(6) Terminals and Electric Wiring



Side View
(Cross-section)



Fahnstock Clip



Top view

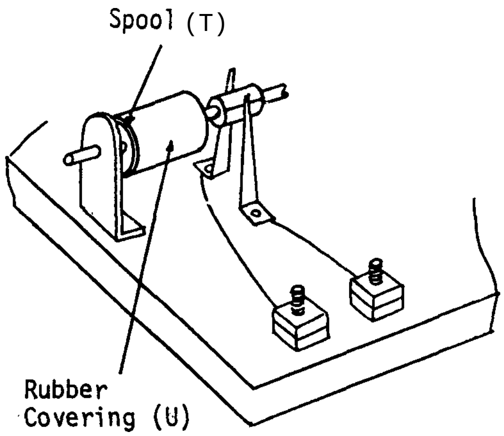
Drill four holes through the base to take four terminals, two to serve as an AC outlet and two as a DC outlet.

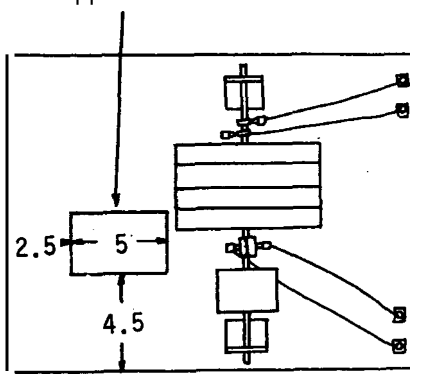
Make each terminal as described under VIII/A2, Component (4). Each terminal requires a bolt (Q), and two nuts (R).

It is of course very nice to have fairly large nuts which can be easily adjusted with the fingers. Such nuts are probably best made on a metal lathe. The nuts might both be 1 cm in diameter, with the thickness of the terminal nut being 0.5 cm and that of the locking nut 0.2 cm.

In some localities it is cheaper to purchase terminals on the local market. Check the availability of such items as Fahnstock clips which can replace the above. Take some magnet wire (S), clean the ends with sandpaper, and then connect the terminals to the contacts as illustrated, fastening the wire beneath the locking nut on the terminal.

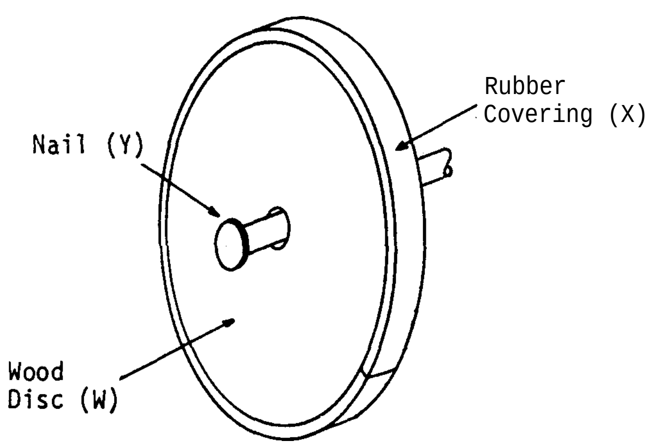
(7) Driving Wheel System



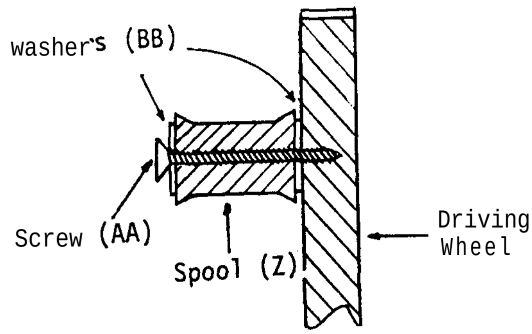


Top View

Take the wooden spool (T) and fill the central hole with wood putty. When the latter is perfectly dry, drill a new hole (0.7 cm diameter) along its axis so that it will just fit on the armature axle. A rubber strip (U) may be cut from an old car inner tube. Nail it around the perimeter of the spool. Temporarily remove the appropriate axle support, and attach the spool firmly to the axle with epoxy resin. Use wood (V) as a support for the driving wheel, locating it on the base in the position shown. Cut a slight inset (0.2 cm) into the base to hold the bottom of the support (V) firmly, and put some wood cement in the inset. Fasten the support firmly in position with the help of two wood screws passing through the base of the apparatus.



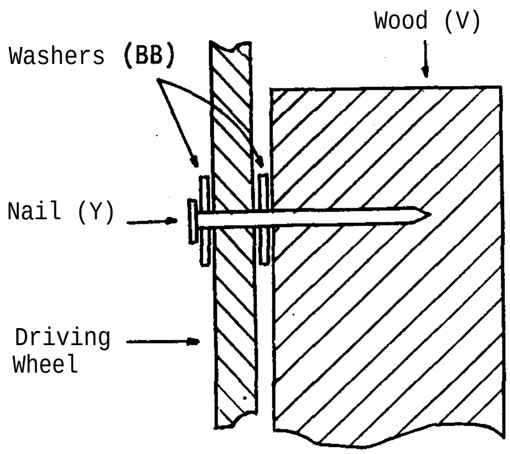
Use the wooden disc (W) to serve as the driving wheel. The rubber strip (X), cut from an old car inner tube, should be nailed around the perimeter of the disc. Drill a hole (0.8 cm diameter) through the center of the disc, and pass a nail (Y) through it to serve as a pivot.



Side View
(Cross-section)

Drill a hole along the axis of the spool (Z) so that the spool fits loosely on the screw (AA), but cannot slip over the screw-head. Screw the spool onto the driving wheel about 4 cm from the perimeter. Put washers (BB) either side of the spool to permit it freedom of motion. You now have a handle for the driving wheel.

Washers (BB) should be similarly placed on the pivot, either side of the driving wheel.



Side View
(Cross-section)

Finally, hold the driving wheel tight against the axle spool, and use the pivot (Y) to mark the best position to locate it permanently in the support. This will be at a height of approximately 10 cm on the support. Drill a horizontal hole (diameter 0.7 cm) into the support, and fix the pivot firmly in the hole with epoxy resin.

Your dynamo/motor is now ready for operation.

C. Notes

(i) The Dynamo/Motor was tested out with two Nuffield horseshoe magnets (Nuffield Physics Item 50/2) across the pole heads; these appear to produce a fairly standard field, whereas locally produced ones vary considerably in strength, depending on the quality of steel or alnico used. The driving wheel was turned at as rapid, but constant, a speed as possible, and was noted to be turned at

4.5 to 5.0 revolutions per second on the average. Under these conditions the following observations were made:

The dynamo was found to produce up to 1.1 volts DC and 1.2 volts AC on open circuit.

Connected in series with a small bulb (1.1 volts, 5 ohms) the dynamo produced a DC current of 0.11 amp at 0.25 volts, and an AC current of 0.13 amp at 0.5 volts. On both occasions the bulb was noted to flicker faintly.

(ii) With the driving wheel disconnected, it was noted that a voltage of 1.4 volts, producing 0.2 amp, was capable of driving the motor.